

# **Deaf primary school children's achievement in mathematics**

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## Abstract

The present research aims to evaluate the extent of deaf children's delay in mathematics, identifying the moderators of this delay and determine the longitudinal predictors of their mathematical achievement.

For five decades, studies have reported that deaf children lag behind their hearing peers in mathematics (Gottardis, Nunes and Lunt, 2011). Background factors such as age, degree of hearing loss, presence of cochlear implant and types of educational provision were previously hypothesised to be moderators of the extent of this delay but, up to now, they have not been tested. Pagliaro (2010) argued that number knowledge, working memory and degree of hearing loss could be possible causes of deaf children's difficulties in mathematics but no clear conclusions were reached. The present investigation aims to provide insight into the causes of deaf children's delay in mathematics.

The survey study addressed the first aim of the present study. The maths test of the Performance Indicators for Primary School (PIPS) was used as outcome measure. Factors related to deaf children (degree of hearing loss, age, years in education, presence of cochlear implant, gender, causes of deafness) and background factors (highest maternal education, language used at home, type of educational provision) were assessed as possible predictors and moderators of the extent of deaf children's delay in mathematics. The overall extent of deaf children's delay in mathematics was of -1.76 SDs. The older the children get and the more years they spend in special schools for the deaf or in units for hearing impaired, the wider is their gap in mathematical achievement compared with their hearing peers. It is, therefore, necessary to intervene in their mathematical learning in the early years of schooling in order to create pathways for improvement.

The second aim of the present study was addressed through a longitudinal design. Logical-mathematical reasoning, working memory and counting ability were chosen as predictors of deaf children's mathematical attainment on the basis of theoretical framework, evidence from longitudinal studies and from the analysis of the difficulties that deaf children have in these factors compared with hearing peers. Hierarchical regression analyses were used to assess the independence of the contributions of logical-mathematical reasoning, working memory and counting ability to the prediction of deaf children's mathematical achievement measured through the PIPS. Age, years in education, degree of hearing loss, type of educational provision and non-verbal intelligence were used as controls. Counting ability and working memory did make independent contributions to the prediction of deaf children's mathematical success but logical mathematical reasoning was by far the strongest predictor.

This study makes several empirical contributions. First, it established age, years in education and types of educational provision as moderators of the extent of deaf children's delay in mathematics. Second, it determined the plausibility of a causal link between logical-mathematical reasoning, counting ability, working memory and deaf children's mathematical achievement. The implication is that schools must explicitly plan to improve deaf children's mathematical reasoning, counting ability and working memory when they are in kindergarten and in the first years of school in order to help the children's mathematical development.

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# Chapter 1

## Introduction

The aim of this thesis is to evaluate the extent of deaf children's delay in mathematics, identifying the factors that could affect it and to determine the longitudinal predictors of their mathematical achievement.

In the first section, this chapter presents the rationale for the study. The second section describes deaf children both in terms of their hearing impairment and as learners. Through the description of the population that is the focus of the present investigation, hypotheses on possible reasons for deaf children's lower mathematics performance in comparison to their hearing peers are defined. The third section briefly presents theories about how children learn mathematics in order to highlight different factors that could affect deaf children's low mathematical performance. Finally, the research strategy employed in the present study and the organisation of this thesis are described.

### 1.1. Rationale of the study

Studies over the past five decades have shown that, comparing the performance of hearing and deaf children's achievement in mathematics, on average, deaf children's performance is below that of their hearing peers (Swanwick, Oddy and Roper, 2005; Gottardis, Nunes and Lunt, 2011, see Appendix A). Although extensive analyses of deaf children's difficulties in mathematics have been conducted over this period, the extent of their delay in mathematics and the causes of this low mathematical attainment remain unclear.

In a recent analysis of the literature on the nature and extent of deaf children's delay in mathematics, Gottardis, Nunes and Lunt (2011) pointed out the difficulty of

reaching a clear quantitative conclusion in relation to the extent of deaf children's delay. This was due to the difficulty of analysing the effect of possible moderators on the extent of deaf children's delay in mathematics. Gottardis, Nunes and Lunt (2011) argued that factors related to deaf children's hearing loss and those related to their background characteristics could either predict or moderate the extent of their delay in mathematics. A predictor is a qualitative or quantitative variable that explains significant amounts of variance in a dependent variable. A moderator is a qualitative or quantitative variable that affects the direction or degree of the relation between an independent or predictor variable and a dependent or outcome variable (Baron and Kenny, 1986). In order to verify whether a factor is a moderator, the interaction between the moderator and the independent variable has to be significant (Baron and Kenny, 1986).

Gottardis, Nunes and Lunt (2011) hypothesised that factors such as degrees of hearing loss, age and type of educational provision could affect deaf children's delay in mathematics but they were not able to verify this hypothesis because of the differences among the studies examined. Thus, they pointed out the need to verify it in order to create a predictive model of risk and protective factors of deaf children's mathematical achievement. This will provide a better understanding of the factors that could increase or reduce the extent of deaf children's delay in mathematics.

The identification of the possible causes of deaf children's mathematical learning has to be based, firstly, on an examination of the theories of how children develop mathematical thinking and, secondly, on an analysis of longitudinal research and comparative studies between deaf and hearing children. In order for a cause of a delay to be identified, deaf children must lag behind their hearing peers on these factors and the same factors must predict deaf children's mathematics attainment (Moreno, 2000).

Geary and colleagues (2004; Geary et al., 2007) pointed out the crucial role of working memory in the general learning process. There is an extensive literature in hearing children that supports this assertion with the observation that working memory significantly influences children's mathematical achievement above and beyond the contribution of general intelligence (e.g. Bull, Epsy and Weibe, 2008; Passolunghi, Vercelloni and Schadee, 2007; Passolunghi, Mammarella and Altoé, 2008; Nunes et al., 2007; Nunes et al., 2012; Swanson, 2011; De Smedt et al., 2009; Alloway and Alloway, 2010; Gottardis, 2009; Mazzocco and Thompson, 2005; Fuchs et al., 2005). Also, when deaf children with mild and moderate hearing loss are considered, working memory is found to be a significant predictor of deaf children's mathematical attainment, after controlling for non-verbal intelligence (Gottardis, 2009). Comparative studies (e.g. Moreno, 2000; Gottardis, 2009) on deaf and hearing children's performances in working memory tasks showed that deaf individuals present lower working memory abilities than their hearing peers. Taken together, these findings support the hypothesis that working memory is a longitudinal predictor of deaf children's mathematical achievement. If this is verified, working memory could be considered a possible candidate for causes of deaf children's low mathematical abilities.

Nunes and Byrant (1996) argued that, in order to learn mathematics, children need to use logical-mathematical reasoning and to learn the systems of signs that are part of mathematics. Longitudinal studies (Nunes et al., 2007; Nunes et al., 2012) on hearing children reported that logical-mathematical reasoning contributes significantly to the prediction of children's mathematical attainment above and beyond the influence of general intelligence, working memory and arithmetic. When deaf children's abilities in logical-mathematical reasoning are compared with those of their hearing peers, hearing

children out-perform deaf children (e.g. Nunes et al., 2008; Nunes et al., 2009a; 2009b). Recently, Nunes and colleagues (Nunes and Moreno, 2002; Nunes et al., 2008; Nunes et al., 2009a; Nunes et al., 2009b) conducted intervention studies aimed at improving deaf children's abilities in some of the logic relations that are included in the concept of logical-mathematical reasoning. These are additive composition, inverse relations and one-to-many correspondence. After short intervention programmes conducted in schools, deaf children improved their mathematical skills in these logical relations, showing that it is possible to help to develop their logical-mathematical reasoning.

Nunes and Bryant (1996) highlighted that logic is not sufficient to successfully support children's mathematical learning but children need also to use a set of conventions. One of the first of these is counting ability. Recent studies (Aunola et al., 2004; Aubrey, Dahl and Godfrey; 2006) showed that counting ability is a predictor of hearing children's mathematical achievement after controlling for general intelligence. Comparisons between hearing and deaf children's performances in counting tasks demonstrated that hearing children out-performed deaf children in their counting skills (Secada, 1984; Leybaert and Van Cutsem 2002). In conclusion, the findings related to logical-mathematical reasoning and counting ability suggest that logical-mathematical reasoning and counting ability could be longitudinal predictors of deaf children's mathematical achievement. If this is verified, logical-mathematical reasoning and counting ability might be causes of deaf children's delay in mathematics.

To the best of my knowledge, Moreno (2000) has conducted the only longitudinal study that investigated different predictors of deaf children's mathematical attainment. The predictors in her study were demographic and medical background, intelligence, language, understanding of time, memory capacity, number processing speed and numerical skills

such as counting and additive composition. She found that, after controlling for age and non-verbal intelligence, only language assessments, additive composition and number processing speed were significant predictors. This study presents two main limitations. First, Moreno (2000) considered only one aspect of logical-mathematical reasoning that is additive composition. The second limitation relates to the small sample size of the study that included 42 deaf children attending eight schools located around London.

The current study proposes, both to evaluate the extent of deaf children's delay in mathematics, exploring the factors that moderate the extent of this delay, and to investigate whether logical-mathematical reasoning, working memory and counting ability are predictors of deaf children's mathematical achievement, after controlling for background factors and non-verbal intelligence. In order to address these two aims, the present research uses two research strategies: an extensive survey study and a longitudinal research strategy.

## **1.2. Characteristics of deaf children**

This section presents deaf children's characteristics in order to describe the population that is at the centre of this investigation and to raise hypotheses about the reasons for deaf children's delay in mathematics. First, the different terms used to describe deaf people are presented followed by a description of the aetiology of hearing loss, how deaf children are educated, their intellectual abilities and how they learn.

### **1.2.1. Definition of the terms related to deaf people**

Different terms have been used to describe deaf people. The terms "deaf" and "hearing impaired" can be used interchangeably and include all people with any degree of hearing loss (from mild to profound) (Action on Hearing Loss, 2012). A deaf person who is an active member of the Deaf community, and shares the same culture and language (sign language) with the other members of the community is called "Deaf". Lastly, "hard of hearing" can describe a person who lost his/her hearing later in life or people who have mild hearing loss (Stewart and Kluwin, 2001).

In the present study, the word "deaf" is used to refer to people who have moderate to profoundly hearing loss.

### **1.2.2. Aetiology**

The different causes of hearing loss result in different types and degrees of hearing loss. The degree of hearing loss describes the severity of the impairment. The type of hearing loss refers to the location of the dysfunction in the ear. In the following sections, types, causes and degrees of hearing loss are presented followed by a description of the hearing assistance that deaf children can adopt.

### *Types of hearing loss*

There are three types of hearing loss: conductive, sensori-neural and mixed (Glasgow, 2009).

Conductive hearing loss occurs when sounds are reduced or prevented from passing through the outer and middle ear to reach the inner ear normally (Maltby and Knight, 2000). Hearing losses arising from conductive problems are often caused by common and temporary illnesses such as congestions of the middle ear cavity with fluid (otitis media) that may even occur during a cold. Less common but more permanent causes of conductive hearing loss include perforated eardrums or abnormalities in the ossicular chain that vibrates to transport the sound into the inner ear (Gibbens, 1993).

This type of hearing loss is usually less severe than the other two types (sensori-neural and mixed) and is treatable by medication or surgery. According to McCormick (1995), 6% of all children will have an episode of significant hearing loss at some stage. Most incidents develop in children below the age of 4 years and rarely manifest themselves in children above 8 years.

Sensori-neural hearing loss occurs in and beyond the inner ear preventing, reducing and distorting the sounds reaching the auditory cortex (Maltby and Knight, 2000). It is generally a result of problems in the inner ear and can be caused by complications located in two areas, the cochlea and the auditory pathway. Abnormalities in the cochlea involve damages or abnormalities to the nerve in the inner ear (Northern and Downs, 1991). Damage in the auditory pathway can result either from a tumour in the brain stem or in any of the auditory cortex areas of the brain (Mason, 1993) or from malformations in the

nervous system. Damage in the auditory pathway can also be acquired later in childhood leading to a profound or total hearing loss (Maltby and Knight, 2000).

This type of hearing loss is permanent and not usually treatable. Gibbens (1993) states that sensori-neural hearing loss often results in a more severe or profound loss. This type of hearing loss is rarer than conductive hearing loss. It is estimated that severe to profound hearing loss only affects one to two babies per thousand births. This incidence is greater in babies born in special care units, who are ten times more likely to be affected than babies who have births with no complications (McCormick, 1995).

Mixed hearing loss is sensori-neural hearing loss with an additional conductive overlay (Maltby and Knight, 2000). It is caused by the same factors associated with both previous types of hearing loss. The mixed hearing loss is a permanent condition and can be treated with the use of a hearing assistance device. However, the presence of a conductive hearing loss typically complicates remediation of the sensori-neural impairment via amplification. This is because the conductive component of the loss may vary substantially from one day to the next making it extremely difficult to calibrate amplification to a comfortable and effective level (Braden, 1994; Maltby and Knight, 2000).

In the present study, only deaf children with a permanent hearing loss are included.

### *Severity of hearing loss*

There are four categories of hearing impairment that express the severity of hearing loss (NDCS, 2011): mild (20-40dB), moderate (41-70dB), severe (71-94dB) and profound (95+dB). The levels of severity of hearing loss are established by using a pure-tone audiogram. This involves the child wearing a set of headphones through which a range of pure tones are played in a range of pitch and loudness. The task is to acknowledge whether

the tone being played is heard. The audiogram test covers the frequency range of 125 Hertz (Hz) to 8000 Hz because these are the frequencies covered by speech. Table 1.1 shows the range of sounds that can be heard at different ranges of loudness. For example, a person with moderate hearing loss may be able to hear a dog barking and loud music but not hear normal conversation or bird-song without amplification.

Table 1.1 Range of sounds that can be heard at varying levels of decibels (adapted from McCracken and Sutherland, 1991).

<b>Decibel level (dB)</b>	<b>Sound heard at this level</b>
10	Leaves rustling on a branch
20	Bird singing
30	Whispering at one metre
40	
50	Bank of a stream
60	Normal conversation
70	Dog barking
80	Loud music
90	Lorry revving at 5 metres
100	
110	Pneumatic drill at 1 metre
120	Jet plane taking off
130	
140	Threshold of pain

### *Causes of hearing loss*

The identification of the causes of hearing loss is very difficult. As reported by Fortnum, Marshall and Summerfield (2002) in their epidemiological study conducted in England on deaf children born between 1980 and 1995, for almost half of deaf primary school children, it is not possible to determine the causes of their deafness.

When the causes of hearing loss can be identified, they can be divided into three main groups: congenital/hereditary, peri-natal and post-natal (Maltby and Knight, 2000). Children with congenital hearing loss are those born with a hearing impairment. They can

be caused by hereditary factors present in the parental chromosomes which may cause deafness alone or may be part of a combination of abnormalities. An example of a combination of abnormalities occurs with Usher's syndrome. This is an autosomal recessive disorder which includes sensori-neural hearing loss together with progressive blindness and speech impediment above and beyond that associated with deafness. Congenital hearing loss can also be caused by factors that act on the foetus while it is developing. Examples of this second type of factor is the virus of the maternal rubella or cytomegalovirus (Maltby and Knight, 2000).

The category of peri-natal causes includes difficulties either during the pregnancy that cause a premature birth or during the delivery of a child. One of these problems, for example, is that the mother and child have incompatible blood types. The most common is the presence of Rhesus protein in the blood of the mother but not the baby and vice versa.

Finally, the most common causes of post-natal hearing loss are serious illnesses such as meningitis, mumps or measles that may result in hearing loss in one or both ears. A severe accident, particularly to the head, may also cause post-natal hearing loss. These illnesses occur later in children's life often when the children have begun to acquire language (McCracken and Sutherland, 1991; Maltby and Knight, 2000).

### *Types of amplifications*

There are two main types of amplification: hearing aid and cochlear implant. The former is an external device that amplifies some pitches of sound more than others, depending on the shape of the hearing loss, and transmits them through an earhook (a plastic canal) to an earmould that is custom made for the child's ear (Maltby and Knight, 2000). The latter is an implantable device designed with the goal of providing sound detection and speech

recognition for people who receive little or no benefit from hearing aids. A cochlear implant has external and internal components. The external components consist of a microphone, that collects sounds converting them to the electrical signals, and a transmitter that rests on the skin behind the ear and transfers the signal from the external speech processor to the internal receiver. The internal portion, which is implanted surgically under the skin behind the ear, has a receiver and tiny electrodes. The receiver is embedded under the skin behind the ear and the electrodes are surgically inserted into the cochlea. The internal and external parts work together to change sound into electrical signals that are sent to the hearing nerve (Maltby and Knight, 2000).

Neither hearing aids nor cochlear implants are able to discriminate noise like the normal ear can, but are limited to amplification of sound. It is the work of the child and the people that are around him/her that makes this sensation of “hearing” meaningful and pleasurable (Maltby and Knight, 2000).

Very recently, the British Association for Teachers Of the Deaf (BATOD) (2011) conducted an extensive epidemiological survey in the U.K. and reported that the percentage of children having at least one cochlear implant increased from 4% in 1998 to more than 6% in 2011. This figure is probably an underestimation of the proportion of children implanted especially in view of the data provided by the Ear Foundation that estimates that 5,000 deaf children have received a cochlear implant since the procedure was introduced in 1989 (BATOD, 2011). This increase in the presence of cochlear implanted children makes relevant the evaluation of the benefit of this type of amplification in comparison to the use of other amplification devices.

### **1.2.3. How deaf children are educated**

As described in the National Deaf Children's Society (NDCS) report (2011a), there are three main different types of educational provision for deaf children: mainstream schools, 'units' or 'departments' for hearing impaired children and special schools for the deaf. They differ in the inclusion of hearing impaired children with hearing children. In mainstream schools, deaf children are included in regular classes and they may have some additional support from specialists. This support can be by a peripatetic teacher of the deaf who visits the children on a scheduled basis or a teaching assistant who helps them during class activities.

In schools with a unit or department for hearing impaired children, part of the school space and timetable is set aside for teaching deaf children (NDCS, 2011a). Usually, deaf children spend some time in classes with the hearing children but there is also the opportunity for one-to-one or small group tuition with a teacher of the deaf.

Special schools for the deaf teach deaf children only and offer specialist teaching and specific support where needed. There are residential and day schools for the deaf. Generally, families and local education authorities approach these schools when local schools cannot offer the necessary level of support for a deaf child (NDCS, 2011a). In this type of educational provision, children are not divided into year groups as in mainstream schools or units for hearing impaired but are grouped in different classes.

The type of school that the child is sent to is dependent upon the availability of schools and facilities within education authorities (NDCS, 2011a) and is often a consequence of the choice made about the mode of communication (Lynas, 2005). This can be either manual, oral or a combination of both. The languages a child in U.K. can be exposed to are English and British Sign Language (BSL). BSL is a manually signed

language with its own grammar and structure which is signed without speaking. Schools in the U.K. generally teach using oral methods or using Total Communication (TC) methods. TC involves teaching the children through a combination of signed and oral modes together with other visual cues to enable deaf children to get as much information as possible from a communication point of view (Swanwick and Watson, 2005; Lynas, 2005).

Lynas (2005) suggests that there is still a debate among researchers on which of these methods allows children to develop their language more effectively and acquire good levels of literacy. As pointed out by Lynas (2005) in her literature review on this issue, research evidence suggests that the use of signs and speech is quite helpful in the early stages of communication development improving children's acquisition of verbal language, whereas the oral communication approach seems to have some benefits in later stages. However, no clear conclusions have been reached and the choice of which communication methods to use with deaf children is often made by parents on the basis of their child's requirements (for example, whether there are additional learning disabilities or the severity of the hearing loss) and their personal preference (Lynas, 2005).

#### **1.2.4. Deaf children's intellectual ability**

The description of deaf children's educational environment presented in the previous section shows that their hearing impairment influences different aspects of their life. It is therefore possible that it could have a broader consequence on children's development, influencing academic achievement and cognitive development.

Pintner was one of the first psychologists who applied intelligence tests to the study of deaf children's intelligence, beginning the formal systematic measurement of the intellectual abilities of deaf children. In one study, he and his colleagues (Pintner and

Patterson, 1917) administered the Binet scale (Binet and Simon, 1905) to a sample of 22 deaf students, aged between 8 and 20 years, attending a school for the deaf. He reported that deaf children's intellectual ability was significantly behind their hearing peers. After this first study, other studies (see Vernon (2005) and Braden (1992) for references) compared deaf children's intelligence with that of hearing children reporting results similar to those obtained by Pintner.

Braden (1992; 1994) carried out the most extensive and systematic review of the literature on this issue considering both qualitative and quantitative studies. Through the analysis of the methods and characteristics of 208 studies, Braden (1994) highlighted that there was a significant association between the results on intelligence tests and the year of publication of the studies with a tendency for earlier studies to yield lower mean IQs than later studies. This was mainly due to the use of methods that do not depress IQ in the more recent studies compared with the first research which applied methods that reduced IQ results.

Intelligence tests are divided into verbal and nonverbal tests. The quantitative analysis of the studies that used verbal intelligence scales reported that the mean verbal IQ for deaf people was one standard deviation below the mean for normally developing individuals (Braden, 1994). Verbal tests are based on the assumption that the individual being tested has been exposed to the verbal content of the items in the verbal subtests approximately as often as the participants in the normative sample (Braden, 1994). Because deaf people's exposure to the language environment is often restricted, low scores of deaf persons on a verbal intelligence test could merely reflect that the deaf person has been denied the opportunity to acquire verbal knowledge due to the hearing loss.

Therefore, verbal intelligence tests are generally strongly discouraged with deaf people, whereas non-verbal tests are more widely used (Braden, 1994).

When intelligence was assessed with non-verbal intelligence tests, the mean IQ of deaf people was well within average limits and did not differ statistically from the means of normal-hearing people. This was true, not only for the centre, or mean, but also for the spread of the IQ (Braden, 1994). Braden (1994) argued that this result confirmed that deaf children do not show any difference regarding their intelligence in comparison to their hearing peers and that the differences observed in the verbal tests are due to the methods used to test them.

The absence of differences between deaf and hearing people in their intellectual abilities is also supported through the analysis of the demographic factors that generally influence intelligence in hearing children such as age, gender and race. Braden (1994) addressed this issue and stated that these factors appear to exhibit effects in the deaf population similar to those found in the normal hearing population with the exception that an increase in age is not as strongly related to an increase in verbal IQ in deaf as it is in normal hearing people. However, this is not a surprising result in light of the limited exposure that deaf individuals have to a language environment.

These results clearly demonstrate that deaf children's intellectual abilities do not differ quantitatively in comparison to their hearing peers when measured with methods that are "fair" for deaf children.

### **1.2.5. How deaf children learn**

The absence of quantitative differences between deaf and hearing children in terms of their intelligence shows that they are able to learn as well as hearing children. However, research has often reported that deaf children lag behind their hearing peers in their academic achievement (e.g. Traxler, 2000). The question then is: Why do deaf children show low performances in their attainment and in particular in mathematics? This section examines deaf children as learners in order to investigate whether there are some factors that could explain their difficulties. In particular, the focus is on the influence of language in terms of general learning and memory and deaf children's tendency to rely on visual-spatial information. Marschark and his colleagues (Marschark and Mayer, 1998; Marschark, 2003; Marschark et al., 2011; Marschark, Lang and Albertini, 2002; Marschark and Hauser, 2012) have carried out extensive investigations of this issue and the following paragraphs are a summary of their analysis.

Effective learning demands shared communication between instructors and students positioning communication at the centre of learning. Several studies (e.g. Padden and Ramsey, 1998; Singleton et al., 1998; DeVilliers et al., 1993; Pisoni et al., 2008) demonstrated the presence of a relationship between deaf children's early language fluency and their academic achievement. Higher levels of language skills (either sign language or spoken language) were significantly related to better reading abilities. These studies employed a correlational research strategy and therefore it is not possible to determine a causal link. Nevertheless, they report that deaf children need to develop good language skills in order to understand instructions and to be involved in classroom activities.

Deaf children often arrive at school lagging significantly behind their hearing peers in their language fluency (Marschark and Wauters, 2008). Marschark, Lang and Albertini

(2002) highlight the lack of incidental experience and difficulties in the interaction between deaf children and their parents as factors that affect early language fluency. Deaf children are likely to be exposed to fewer fluent language users than hearing children of the same age, and they could miss many of the opportunities for incidental learning that hearing children have by virtue of overhearing the conversation of others (Marschark and Hauser, 2012). 95% of deaf children are born to hearing parents (Marschark and Hauser, 2012). Compared with deaf parents, hearing parents can find it more difficult to interact with their deaf child because of their lack of experience (Jamieson, 1994; Marschark, Lang and Albertini, 2002; Swanwick and Watson, 2005; Marschark and Wauters, 2008). However, as pointed out by Marschark and Hauser (2012), having deaf or hearing parents is not the important issue. The crucial factor is that parents are able to provide their child with earlier and more fluent access to language, giving a greater support for their literacy and cognitive development.

From this evidence, it seems that deaf children's lack of language fluency and of early interactions could be one of the reasons for their difficulties in learning (Marschark and Wauters, 2008) but the situation is more complex. Deaf individuals are generally more sensitive to visual information than their hearing peers (Hauser et al., 2007). Pictures accompanying text, the spatial layout of objects, and visual characteristics of people and things are likely to be more readily noticed by and more important to deaf pupils than hearing pupils supporting their learning, whereas hearing pupils depend on hearing (Marschark and Hauser, 2012). These differences are not related to the more sensitive vision of deaf than hearing children but to their use of visual attention (Dye, Hauser and Bavelier, 2008). Recent research (Sladen et al., 2005; Bavelier et al., 2001; Proksch and Bavelier, 2002) has demonstrated that deaf individuals notice more quickly than hearing

individuals when something appears in their peripheral visual field or if it moves. They are faster at shifting their visual attention to the periphery and then shifting back. Such enhanced peripheral attention has been observed mainly in deaf signers but not in hearing individuals who are native signers. The lack of a similar effect in hearing native signers suggests that using signed language is not sufficient to induce changes in peripheral attention. Rather, as pointed out by Dye, Hauser and Bavelier (2008) deafness appears to be the leading factor in this reorganisation of the attentional system. Marschark and Hauser (2012), in their recent book on how deaf children learn, suggest that this reorganisation is a way of adapting to being deaf, allowing deaf individuals a way of being alerted to danger and to others trying to communicate with them. At the same time, this different use of visual attention also carries two potential disadvantages. Firstly, this can make deaf children more distractible in the classroom. Secondly, when deaf children and adults work on a problem together and the adult is saying something about an object, the deaf child has to look at the object being talked about and at the adult to establish what is being said. Both these issues could explain why deaf children generally often lag behind their hearing peers in their learning in the classroom.

The other aspect that is related to deaf children's learning is their memory. In relation to long-term memory tasks, deaf and hearing individuals are similar in how much information they recall, although deaf individuals may organise this information differently from their hearing peers (see Marschark and Mayer, 1998 for references). Regarding short-term memory and working memory, since the pioneering work of Conrad (1979) and Hermelin and O'Connor (O'Connor and Hermelin, 1972; Hermelin and O'Connor, 1975), it has become clear that there are differences between deaf and hearing people's coding strategies, which in turn affect what they remember. With lists of simple stimuli such as

words, pictures, or numbers, hearing individuals, by virtue of their dependence on spoken language, tend to rely on speech-based verbal coding, usually linked to the order of the information to be remembered (Baddeley, 1986; Marschark and Mayer, 1998). Deaf people, in contrast, by virtue of their relative lack of oral language experience and their use of visual-gestural language, rely more heavily on visual-spatial short-term memory codes such as remembering locations rather than the temporal sequence of objects presented (Marschark and Mayer, 1998; Marschark, Lang and Albertini, 2002). “This means that there are memory tasks where deaf individuals can perform better than hearing individuals and vice versa, depending on whether the information is presented sequentially or spatially and how it is to be recalled” (Nunes, 2004, p.25). Todman and Seedhouse (1994), for instance, compared deaf and hearing schoolchildren on a memory task in which they were asked to learn an action response to an arbitrary paired visual cue. Once the pairs are learned, their memory can be tested using either a spatial or sequential presentation. In the spatial presentation, they are shown a matrix with four figures; the matrix is then covered and they are required to perform the four actions that were paired with the figures. In the sequential presentation, they are shown the figures one at a time and after the series is completed they are required to perform the actions. In the sequential presentation, recall may be required in the same order as the figures appeared (serial recall) or in any order (free recall). Todman and Seedhouse (1994) observed that deaf children were superior to their hearing peers in the tasks where the figures were presented simultaneously in the spatial display. Thus, they were better able to encode the spatial information and then produce the associated actions. The sequential presentation produced different results for the serial and the free recall. The hearing children were better than the deaf children in the serial recall whereas no difference was found in the free recall. These results clearly

demonstrate that the way in which the items are presented and the way in which they have to be recalled affect deaf children's performance.

As for learning, deaf children's memory can be influenced by their language fluency. Early studies (Conrad, 1972; 1979) indicated that memory for letters and words by deaf children exposed only to spoken language was closely linked to their spoken language skills and inversely linked to their degree of hearing loss. Marschark and colleagues (Marschark and Mayer, 1998; Marschark, 2003; Marschark et al., 2011) pointed out that the use of printed word as elements to be recalled by deaf children can affect their performance as many people with congenital or early onset hearing losses depend on sign and have relatively poor reading abilities. Marschark and colleagues (Marschark and Mayer, 1998; Marschark, 2003; Marschark et al., 2011) reported that when less biased stimuli were used, deaf students with better speech skills tend to rely primarily on speech recoding as a strategy in memory tasks, whereas deaf children with low to moderate speech coding abilities tend to use both speech and sign strategies (Marschark, Lang and Albertini, 2002). Those students with better speech skills tend to remember more because working memory works better on the basis of speech recoding. Sign language fluency has also been found to be inversely related to memory span in deaf students, whereas spoken language fluency is directly related to memory span (Marschark and Mayer, 1998). It is important to point out that these studies are correlational studies and therefore they do not imply causality.

This brief description of deaf children as learners highlights two issues. Firstly, the strength of deaf children in visual-spatial and sequential memory and the fact that language influences memory as well as learning show that explaining pictures or diagrams with language could lead to better learning and memory than either one alone. This is not only

true for deaf children but also for hearing children. Secondly, the influence of language in the general process of learning and in memory ability suggests that it could have an effect on deaf children's mathematical performance. Gregory (1998) proposed that if deaf children lack the language necessary to understand and solve mathematical questions, they will find difficult to make progress in mathematics learning. She refers specifically to the development of a particular vocabulary for mathematics that it is necessary to acquire in order to be successful in mathematics. Nunes (2004) argues that, although this is certainly a reason for difficulties with mathematics, hearing children, as well as deaf children, have to learn this specific vocabulary, so it is unlikely that the existence of a technical mathematical vocabulary could explain the differences of attainment between deaf and hearing children, particularly in primary school where the specialised vocabulary is not yet used.

### **1.3. Theories on how children learn mathematics**

In order to identify the factors that could affect deaf children's mathematical performance, it is necessary to focus on how hearing children acquire mathematical skills.

There are three major theories on this issue that can be distinguished whether they refer specifically to mathematics learning and whether they are developmental approaches. The first theoretical approach is domain specific to mathematics and it focus on innate processes. The second approach refers to general learning process that can be applied also to mathematics. The third approach is specifically related to children's mathematical learning in a developmental context. In the present section, these three theoretical approaches are outlined briefly, looking at how these theoretical approaches can be applied in the context of deaf children's mathematical learning.

### **1.3.1. Domain specific approach**

The first theory is a nativist approach proposed by Gelman (Gelman and Gallistel, 1978; Gelman and Meck, 1983;1986; Gelman, 2000) and later on by Butterworth (2000; 2005) who argue that we are born with brain circuits specialised for identifying small numerosities. They claim that our numerical abilities depend on three aspects: an inner core of innate mathematical abilities, mathematical knowledge of the culture and the extent to which we have acquired this knowledge. On the basis of the analyses conducted on patients with brain damage and on functional neuroimaging, Butterworth and other colleagues (Dehaene et al., 2003; Cipolotti and van Harskamp, 2001; Piazza et al., 2002) located this “mathematical brain” in the left parietal lobe, especially in the left Intra Parietal Sulcus and the angular gyrus.

One piece of evidence supporting this theory comes from the findings of experiments of habituation and dishabituation paradigm on babies. Starkey, Spelke and Gelman (1990), for example, assessed the ability to perceive numerosity in babies aged from 6 to 8 months. As the habituation element, they showed the babies a series of cards where there were always two pictures but they varied in each card in terms of type of pictures, colour, shape and size. The dishabituation card also had new pictures on it but there were three of them now. Starkey, Spelke and Gelman (1990) found that babies looked significantly longer at the card with three pictures on it. Therefore, they concluded that infants seemed to be sensitive to the number of pictures on the cards. This means that they categorised what they saw in a way that was quite abstract separating the features of the pictures from the number of pictures.

Infants are not only able to perceive numerosities but they seem to be able to calculate the results of addition and subtractions (Wynn, 1992, 1998; McCrick and Wynn,

2004). This was shown in a series of experiments in which five-month-old infants were shown simple addition and subtraction operations on small sets of objects. One group of infants saw a “1+1 operation”: a doll was placed in a display stage, a screen then rotated upwards to temporarily hide it from view. A hand then entered the display stage with another identical doll, placed the object behind the screen along with the first and exited the stage empty. The screen then came down to reveal either two dolls (the correct answer) or one doll (the incorrect number). Another group of infants saw the “2-1 operation”. The only thing that changed in this second group compared with the first group was that the children saw two dolls on the stage at the beginning and then after the stage was covered, the hand removed one of the dolls. Infants in both groups showed significant differences in their looking patterns: those shown the addition operation looked longer at the outcome of one doll than two dolls, while those shown the subtraction showed the reverse pattern. These results have been replicated in different laboratories and also with bigger numerosities (8 versus 16 and 10 versus 5 objects) (see Xu and Spelke (2000) and McCrick and Wynn (2007)) showing that infants have a magnitude system that is innate.

The analysis of the difficulties of children with dyscalculia provides additional evidence to support Butterworth’s and Gelman’s theory. Dyscalculia is a condition that affects the ability to acquire arithmetical skills (Landerl, Bevan and Butterworth, 2004). Children affected may have difficulty understanding simple number concepts, lack an intuitive grasps of numbers, learning number facts and procedures (Geary, 1993). Butterworth (2005) argued that children with dyscalculia appear to have a specific problem with understanding basic numerical concepts, especially the concept of numerosity. This could affect performance in very simple tasks such as counting or comparing numerical magnitude (Butterworth, 2005). This claim was based on observations of small differences

between first grade dyscalculic children and controls age matched in magnitude comparisons (Geary, Hamson and Hoard, 2000; Landerl, Bevan and Butterworth, 2004) and on the fact that dyscalculic children appeared to be counting to three rather than subitising in a dot-matching task (Koontz and Berch, 1996). Butterworth (2005) argued that differences in number representation between normally developing children and those with difficulties in mathematics are the cause of the difficulties shown by children with dyscalculia.

In view of this theory, the reason for the difficulties of deaf children in mathematics could be due to specific differences in how deaf children represent numerical information compared with hearing children. In the next chapter, this issue is investigated through the analysis of the evidence that could support this theory.

### **1.3.2. Not domain specific approach**

The second theory on how children learn is proposed by Geary (2004; 2005; Geary et al., 2007). It focuses on more general cognitive abilities as fundamental aspects of children's learning. Geary et al. (2007) argue that the ability to learn new information results from two types of abilities and cognitive plasticity. The abilities are divided into primary and secondary. The first type is a base of biologically-primary modular system, some of which are modifiable during the developmental period, but within constraints. These are the core modular system that defines the human mind. The secondary type of abilities are those built on the first one based on cultural needs and practices such as schooling. The cognitive plasticity results from our ability to mentally represent and manipulate information in working memory which in turn creates mental experiences that can modify the primary system. In this theoretical framework, the central components of the working memory are at the centre of the learning process.

The evidence that supports this theory comes from an analysis of difficulties of children with mathematical learning disabilities. Geary (2004), in his review of the literature on children with mathematical learning disabilities, proposed that the counting and procedural errors and the use of immature strategies observed in these children are due to a deficit in the children's working memory abilities. This deficit appears to involve information representation, manipulation in the language system specifically the phonetic-articulatory system and the central executive function due to the inability to monitor and coordinate the sequence of problem-solving steps (Geary, 2004).

According to this theoretical approach, it is possible that deaf children's delay in mathematics could be caused by a deficit in their working memory ability. In the following chapter, this issue is examined investigating the findings presented in the literature.

### **1.3.3. Developmental domain specific approach**

The third theory on how children learn mathematics was suggested by Vergnaud (1997) and embraced by Nunes and Bryant (1996; Nunes et al. 2007). It is the only approach which focuses specifically on children's mathematical learning from a developmental point of view.

Nunes and Bryant (1996) argued that, in order for children to learn mathematics, they need to be logical and, therefore, use their mathematical thinking meaningfully and appropriately in different situations and learn the conventional system of symbols. The first two aspects (being logical and using the mathematical thinking in different situations) were included in the concept of logical-mathematical reasoning by Nunes et al. (2007). This is defined as "learning to reason about the underlying quantities and relations in different mathematical problems" (Nunes, et al., 2009c, p.3).

Piaget (1952) was the first researcher to highlight the central and crucial role of logic in children's mathematics learning. The most evident example of the necessity to be logical in order to learn mathematics is in relation to the principle of conservation. To understand conservation is to know that the number of a set of objects can only be changed by addition or subtraction: all other changes are irrelevant. When a child counts a bowl of oranges and decides that there are six oranges and then someone spreads the oranges around into an extended row, if the child thinks that there are more oranges than before, it follows that the child does not know what the word "six" means (Nunes and Bryant, 1996). This example clearly shows that although children are able to produce the number words in the right order and count the objects in the set, if they do not understand the principle of conservation they will not be able to understand the significance of number as expression of quantity.

Nunes and Bryant (1996) stated that the understanding of logical principles is not sufficient to develop successful mathematical thinking. Children need also to use it appropriately in different situations. This is based, for example, on the observation of an 8-year-old child using subtraction in a problem that should have been solved by division or of a 13-year old subtracting one number from the other when these should have been added in a problem that involves negative numbers. Nunes and Bryant (1996) highlighted that the meaning of mathematical symbols comes from the fact that they can be used in certain situations but not in others. In order to use mathematical techniques and tools appropriately, it is important to know whether the elements that are specifically related to them are the same in the situation at hand. It is the connection between the specific characteristics of the problem situation and those in the mathematical tool that define whether it will be a good tool for that situation (Nunes and Bryant, 1996).

Finally, the other important element in the process of learning mathematics is to use a set of conventions. These provide ways of representing concepts that allow people to think and talk about them. An example of conventions is the numeration system. This is a conventional way of referring to and thinking about the number of objects in a set. Nunes and Bryant (1996) pointed out that learning about these conventions may actually increase children's ability to respect logical principles. For example, in the case of counting, our conventional system is based on a decimal structure and when children try to remember and reproduce number words in the right order, if they try to remember as many number words as they can in a fixed order, there will be a strict limit to how many words they can commit to memory. But, if they take advantage of the base system, they do not have to remember all the words in rote fashion. They have only to remember all the numbers from zero to ten, the teen words, some of the decade words and the words for units of a new size (hundred, thousand, million) because they are hard to derive from the structure of the system but that is all. In this way they gain a powerful way of counting because they can generate numbers. The system will become a thinking tool, a means to solve problems which could not be solved without a numeration system as, for example, to compute sums or compare numbers (Nunes and Bryant, 1996; Nunes et al., 2007).

On the basis of this theory, one can hypothesise that deaf children are delayed in mathematics compared with their hearing peers because they could have difficulties learning either the system of signs or the logical principle applied to different situations or both. On the one hand, learning conventional systems such as the counting string involves learning and remembering words in a particular order. As reported in the section on deaf children as learners, this task is more difficult for deaf children than for hearing children. On the other hand, deaf children may have reduced opportunities for incidental learning

(Nunes and Moreno, 2002). This can create difficulties in the development of their logical-mathematical thinking. In the next chapter, evidence for this theoretical approach is examined extensively considering its possible application in relation to deaf children's mathematical performances.

#### **1.4. Present study: research strategies**

The present study aims to investigate the moderators of the extent of deaf children's delay in mathematics and the longitudinal predictors of deaf children's mathematical performance. Two research strategies were employed to address these two aims: a survey study and a longitudinal study.

The survey study aims to evaluate the moderators and predictors of the extent of deaf children's delay in mathematics and to determine the extent of this delay. By collecting extensive background information on a deaf sample as representative as possible of the deaf children's population, the survey study proposes to investigate the effects of moderators and predictors of the extent of deaf children's delay in mathematics compared with their hearing peers.

Once these relations are investigated, it is possible to control for those factors associated with children's mathematical skills while comparing deaf and hearing children's performance in mathematics in order to obtain a more accurate analysis of the extent of deaf children's delay in mathematics.

The identification of the factors related to deaf children's mathematical achievement provides evidence for considering risk and protective factors in models of prediction of deaf children's mathematical achievement. In relation to deaf children's difficulties in mathematics, a risk factor is an element that increases the chances for

children of being delayed in mathematics whereas a protective factor is an element that reduces the chances for children of having difficulties in mathematics (Nunes and Moreno, 1998). The risk and protective factor hypotheses suppose that it is possible to prevent a risk factor from leading to negative outcomes if the necessary steps are taken (Nunes and Moreno, 1998). These findings, together with the evaluation of the extent of deaf children's delay in mathematics, will have important implications for policy recommendations in terms of the focus for future interventions aimed to reduce deaf children's delay in mathematics.

The longitudinal research strategy aims to identify those factors that determine how well deaf children learn mathematics. In particular, whether logical-mathematical reasoning, working memory and counting ability are independent predictors of deaf children's mathematical achievement is investigated. In the predictive model, a series of control variables are inserted in order to be confident that, if a relation between predictor variables and deaf children's mathematical performance is found, this is not due to a third factor that affects both children's mathematical attainment and the predictor variables but it is a consequence of the specific relation between predictor variables and mathematical achievement. These control variables are those which were found to significantly influence deaf children's mathematical attainment in the survey study.

The use of a longitudinal research strategy allows us to address the first step of a programme of research designed according to the Bradley and Bryant (1983) paradigm. Bradley and Bryant (1983) argued that in order to establish a causal link between two variables both longitudinal and intervention studies are essential because neither method alone can support causal inferences without the contribution of the other. Longitudinal studies support causal inferences because, first, intervening variables are controlled and

ecological validity can be detected (Coolican, 2006) and, second, sample size can be very large and thus generalisations can be made. However, the weakness of this type of study is that there may be a third variable which could also be a factor influencing the causal connection that is not controlled for. On the one hand, when intervention studies are carried out in the laboratory, they are regarded as effective in specifying the relation between cause and effect (Reiss and Judd, 2000) because it is possible to control for confounding variables but their weakness is in the lack of ecological validity. On the other hand, when intervention studies are conducted outside the laboratory, although it is possible to achieve good ecological validity, it is harder to determine a causal relation because conditions in the real world setting outside the laboratory are completely different (Gorard, 2001) and confounding variables are more difficult to control.

Intervention studies on the logic relations that are included in the concept of logical-mathematical reasoning have already been conducted in previous research (Nunes and Moreno, 2002; Nunes et al., 2008; 2009a;2009b). These studies reported that, after employing short intervention programmes based in school, deaf children's performance in these aspects improved significantly. To the best of my knowledge, no longitudinal studies have investigated whether logical-mathematical reasoning, working memory and counting ability predict deaf children's mathematical attainment. If strong connections between the variables within the longitudinal design are found, together with the results of the intervention studies, it would be possible to propose factors that could cause deaf children's low mathematical performances. The combination of both methods, the longitudinal design and the intervention study, would compensate for the weaknesses of the other thus successfully ensuring causal conclusions.

## **1.5. Outline of the thesis**

This thesis is divided into five chapters. The next chapter, Chapter 2, reviews literature on the factors that influence how well children learn mathematics in order to provide support for examining logical-mathematical reasoning, counting ability and working memory as possible predictors of deaf children's mathematical achievement. This analysis is based on evidence from the investigation of theoretical frameworks and from the findings of comparative, intervention and longitudinal studies that examined these factors in relation to children's mathematical achievement. The chapter then continues with an overview of the present research. In particular, the necessity for controlling for other factors such as background factors and intelligence, when the specific relation between working memory, logical-mathematical reasoning and counting ability and deaf children's mathematical achievement is evaluated. This is followed by a description of the design of the two studies carried out and of the ethical issues raised in this project.

In Chapter 3, the results of the survey study are presented and discussed. First a detailed description of the participants (deaf and hearing children) is presented comparing the deaf sample with wider survey studies in order to determine the representativeness of the present sample in relation to the population of deaf primary school children in the U.K. The chapter goes on to describe the results about the presence of a relation between deaf children's mathematical achievement and their background factors. Next, the mathematical performances of the two samples are compared in order to obtain a quantification of deaf children's delay in mathematics. Finally, the hypothesis that the factors that relate to deaf children's mathematical achievement are also moderators of the extent of deaf children's delay is investigated.

Chapter 4 addresses the hypothesis of the independent and longitudinal relation between logical-mathematical reasoning, counting ability and working memory and deaf children's mathematical achievement after controlling for background factors and non-verbal intelligence. A description of the participants and measures used is followed by an analysis of the results of this study.

In Chapter 5, the results of the current project are summarised and discussed. In addition, the empirical and theoretical contributions of this study are considered and its strengths and limitations analysed. Suggestions for future research are also presented.

## Chapter 2

### **Factors that influence deaf children's mathematical learning**

The previous chapter described deaf children as a very heterogeneous population in terms of their hearing impairment and of the consequences that this has on their life. Although they have the same cognitive learning ability as their hearing peers, they are delayed in learning mathematics in comparison to hearing children. The theoretical frameworks on how hearing children learn mathematics highlighted different factors that could be responsible for this delay. The focus of the current chapter is to investigate the literature concerning the contribution of these factors in predicting, longitudinally, children's mathematical attainment. This will provide additional reasons to investigate whether these factors could be predictors of deaf children's mathematical achievement.

The focus of this review is on comparative, longitudinal and intervention studies. Comparative studies provide information on whether there is a difference between deaf and hearing children's performances on particular tasks. Longitudinal designs offer strong evidence for the link between the predictor and outcome variables and offer certain advantages over intervention studies. For instance, in longitudinal studies, researchers can control for confounding variables statistically; performance data may be collected in school settings thus ensuring ecological validity, and findings can be generalised because large sample sizes can be used. A further advantage of longitudinal designs is that they are useful in testing connections between the variables because they can present evidence on whether early skills are responsible for children's later success in mathematics. Finally, intervention studies produce evidence on whether it is possible to improve a specific

mathematical skill and whether this improvement has consequences on children's mathematical progress.

The first section of this chapter examines the factors highlighted in the theories on how children learn mathematics in order to determine whether these could be plausible predictors and possible causes of deaf children's delay in mathematics. The second section outlines the strategy of the current research, pointing out, also, the variables that need to be controlled when the relations between the predictors and deaf children's mathematical achievement is evaluated. These control variables are children's intelligence and demographic characteristics. Intelligent children might have high performance scores on any of the predictor variables analysed here because of their intelligence, so, the argument that these factors predict mathematics is stronger when this connection exists after intelligence is taken into account. Children's demographic characteristics are also taken into account because it is possible that the presence of a relation between the predictor variables and deaf children's mathematical achievement is due to these factors and not to the presence of the relation in itself. Finally, the study design and the ethical issues that this project raises are described.

## **2.1. Deaf children and mathematics: strengths and weaknesses**

This section aims to report and discuss the literature on deaf individuals' mathematical abilities in view of the three theoretical frameworks (domain specific approach, not domain specific approach and developmental domain specific approach) briefly described in the previous chapter. For each of these three theoretical approaches, the evidence that supports their predictions is investigated in order to highlight the reasons that bring us to consider these factors as possible predictors of deaf children's mathematical attainment.

### **2.1.1. Domain specific approach: number representation processes**

As reported in the previous chapter, Gelman and Gallistel (1978) and later on Butterworth (2000) argued that “the foundation of human numerical competence lies in the preverbal mechanism for counting and arithmetic reasoning that we share with genera at least as distant as rodents and birds” (Gallistel and Gelman, 1992, p.44). This innate number-relevant mental structure includes principles for counting, for generating cardinal values and for adding and subtracting the resulting cardinalities (Gelman, 2000). The evidence that supports this claim comes from studies on animals (see Deheane, 1992), infants (McCrick and Wynn, 2004; Xu and Spelke, 2000; Wynn, 1992;1998) and patients with brain lesions (Butterworth, 2000). The evidence of the importance of the number processes in learning number and arithmetic comes from the studies on developmental or acquired dyscalculia (e.g. Butterworth, Cipollotti and Warrington, 1996; Landerl, Bevan and Butterworth, 2004; Butterworth, 2005). These studies reported that dyscalculic children have difficulties in accessing verbal and semantic information, counting dots, reciting number sequences and writing numbers. All these difficulties are associated with a general deficit in number processing. Therefore, Butterworth (2005) claims that number representation processing is one of the causes of dyscalculic difficulties in arithmetic.

If this theory is applied to deaf children, it would be necessary to test whether deaf children’s difficulties in mathematics are due to differences in how deaf children represent numerical information in comparison to hearing children. For instance, deaf children should present lower abilities in magnitude comparison, subitising processes and number-size congruity in comparison to their hearing peers. In turn, these difficulties could affect also their mathematical development in comparison to hearing individuals.

In the following paragraphs, deaf children's mathematical abilities are investigated focusing on number representation processes. This analysis aims to examine whether the hypotheses suggested by the nativist theory could be supported in view of deaf individuals' difficulties in mathematics.

#### **2.1.1.1. Number representation processes in deaf individuals**

Deaf individuals' number representation processes have been analysed in both children and in adults. Three studies (Zarfaty, Nunes and Bryant, 2004; Barbosa, in press; Arfè et al., 2011) investigated whether deaf children differ in their number processing abilities compared with hearing children: the first study examined kindergarten children, the second considered primary school children and the third focused only on deaf primary school children with cochlear implants. The first research was conducted by Zarfaty, Nunes and Bryant (2004) who analysed whether deaf children at kindergarten were delayed in number representation tasks that could be accomplished without counting. They hypothesised that deaf children have a preference for processing information that is displayed simultaneously and can be represented using the visuo-spatial sketch pad in working memory (Gathercole et al., 2004), whereas they are at a disadvantage when the information is presented successively and is more easily represented using the phonological loop. Deaf children showed better performance in the number representation task than their hearing peers when the items were displayed simultaneously and did not differ from hearing children when the items were presented successively. Barbosa (in press) carried out a similar study with Brazilian deaf children aged 5-6 years. Her results supported the previous findings by Zarfaty, Nunes and Bryant (2004): the young deaf children's number representation ability was as good as that of hearing children when

counting was not required. Both these studies confirmed that deaf children present the same abilities in numerical representations as their hearing peers.

The third study was carried out by Arfè et al. (2011) who investigated number comparison in hearing and deaf primary school children with cochlear implants. They used a digit comparison task and an analogic comparison task. In the first task, children were asked to choose the larger number between two digits (from 1 to 9) presented on cards, whereas the second task involved comparing sets of dots by asking children to select which of two dot patterns presented on cards has the greater numerosity. No difference was found between deaf and hearing children's performances on the digit comparison task, whereas in the analogic task, deaf children performed significantly better than their hearing peers.

These three studies clearly provide evidence of the absence of differences between deaf and hearing children in their number representation processes. They also highlight that deaf children have similar mathematical abilities to their hearing peers when the tasks required little or no counting skills.

Research (Epstein, Hillegeist and Grafman, 1995; Bull, Marschark and Blatto-Vallee, 2005; Bull, Blatto-Vallee and Fabich, 2006; Korvorst, Nuerk and Willmes, 2007; Bull, Marschark and Covertino, 2011) on deaf adults' number representation processes examined their abilities on more complex aspects such as magnitude comparison, subitizing, parity and knowledge of multiplication facts. The participants of all these studies were in an age range between 17 and 25 years old and they usually attended colleges or some form of higher education. Epstein, Hillegeist and Grafman (1995), for example, tested deaf students on a magnitude comparison task in which they were asked to determine which of two numbers presented (ranging from 1-99) was the largest and press a spatially appropriate key to indicate their choice of number. Although accuracy of both

deaf and hearing participants was very high, deaf adults were found to have slower response times overall compared to hearing participants. Bull, Marschark and Blatto-Vallee (2005) also investigated deaf adults' performance on a magnitude comparison task, but they used single-digit numbers in their task. Whereas deaf participants were found to be slower than hearing participants in making comparative judgments, their basic number processing capacity did not substantially differ from age-matched hearing peers. This study confirmed the results observed previously by Epstein, Hillegeist and Grafman (1995) showing that, after controlling for speed of response times, deaf adults perform as well as their hearing peers in magnitude comparison.

Bull, Blatto-Vallee and Fabich (2006) examined subitising, automaticity and magnitude representation in hearing and deaf adults. They used two types of task: one task in which participants were instructed to make judgments about the physical size of the numerals and a subitising task where participants were asked to enumerate rapidly small sets. The first task was based on the stroop paradigm that assessed interference from irrelevant aspects of the stimuli and on the Spatial Numerical Association of Responses Codes (SNARC) effect that refers to the concept that magnitude information is represented conceptually in the form of a visual number line. Both these tasks were presented in the communication mode most appropriate to the participants (either sign language or English). Bull, Blatto-Vallee and Fabich (2006) found that the performance of deaf and hearing adults did not differ from each other. Both groups showed distance effects taken to indicate the use of a visual-spatial analog number line representing approximate quantity. They also showed similar patterns of performance on the subitising tasks and similar amounts of interference in an analysis of congruity effects. Bull, Blatto-Vallee and Fabich (2006) argued that these results provide evidence against the notion that there are

differences in basic number processing between deaf and hearing individuals that account for deaf individuals' mathematical difficulties.

Korvorst, Nuerk and Willmes (2007) analysed a more complex process of number representation using a verification version of the number bisection task. In this task, participants were presented with number triplets for which they have to determine whether the middle number in the sequence is the exact numerical mean of the two outer numbers. This task was either presented using sign language through a video or with Arabic digits modes. The number triplets differed for multiplicativity (whether a triplet was part of a multiplication table or not) and range (small versus wide difference between the two outer numbers). When the task was presented in sign language, no difference was observed between deaf and hearing students' performances. Some discrepancies were observed in the Arabic digit mode: opposite to hearing adults' performance, deaf adults were faster to reject a bisection than to accept one. Korvorst, Nuerk and Willmes (2007) concluded that, although a slight better performance was observed when the task was presented in sign language, deaf adults make use of the equivalent number representations in bisecting numbers tasks.

Finally, very recently, Bull, Marschark and Covertino (2011) examined estimation skills in deaf and hearing students. According to Bull, Marschark and Covertino (2011), estimation skills provide a clear physical measure of one's mental representations of distance between numbers on a number line. They showed a number line to the participants with end-points labeled 0-100, 1-1000 or 0-10,000. For each line, deaf and hearing students were shown a number and asked to make a mark on the line where they thought that number would come. In all three types of number line, a significant difference between groups (deaf and hearing) was observed, with deaf students presenting a higher mean

absolute error compared with their hearing peers. Bull, Marschark and Covertino (2011) also analysed the format of the numerical representations obtained by deaf and hearing students. In both groups, numerical representations for all the number lines were best fit by linear functions. Bull, Marschark and Covertino (2011) pointed out that, although deaf students are less accurate in their estimation skills, they showed no qualitative differences with their hearing peers. It is important to highlight that deaf children have difficulties in learning the number string showing a delay of two and half years in their learning to count compared with their hearing peers (Nunes, 2004). It is therefore possible that this difficulty affects the results of this study explaining the low level of accuracy in estimating numbers.

The results of the studies examined provide clear evidence against the hypothesis that deaf people process numerical information differently from hearing people. It was demonstrated that deaf individuals use similar numerical representation processes to those employed by hearing people. The only differences found were related to speed of response time and accuracy in number line estimation tasks between deaf and hearing adults. The adult participants recruited in the studies were all good signers and almost all of them had graduated high school or finished some kind of higher education. Therefore, it is possible that their sample is not representative of the general deaf adult population. Future research should investigate this issue further with a wider population.

In conclusion, due to the lack of differences between deaf and hearing individuals in their number representation processes, it is not possible to apply the nativist theory to deaf children's mathematical delay. Thus, number representation processes cannot be considered to be a plausible factor that influences deaf children's mathematical attainment.

### 2.1.2. Not domain specific approach: working memory

The cognitive approach focuses on general cognitive abilities as fundamental aspects of children's learning. Geary (2004), in his theory on how children learn, argued that competencies in any given area of mathematics depends on a conceptual understanding of the domain and a procedural knowledge that supports actual problem solving. Conceptual and procedural knowledge are subsequently supported by working memory.

“The term working memory is used to refer to a mental workplace in which information can be temporarily stored and manipulated in order to support ongoing complex activities” (Gathercole and Pickering, 2000, p.178). Baddeley and Hitch (1974) proposed a model of working memory as a result of comprehensive research on the abilities and errors made by hearing adults and children when recalling information under a number of different conditions (see also Chalifoux (1990) for a review of the research with hearing participants on which the model is based). They stated that working memory comprises an attentional control system (called central executive), aided by two subsidiary “slave” systems: the *phonological loop*, which holds and manipulates acoustical and speech-based information, and the *visuo-spatial sketchpad*, which performs a similar function for visual information.

Using this model, Geary and colleagues (Geary, 2004; Geary et al., 2007) argued that working memory is involved in supporting conceptual and procedural knowledge. The central executive controls the attentional and inhibitory processes needed to use procedures during problem solving and much of the information supporting the conceptual and procedural competencies is likely to be represented in the phonological loop or in the

visuo-spatial sketchpad. Thus, working memory is a core component of the learning process.

There is a massive amount of evidence regarding the crucial role played by working memory in processes involved in the mathematical development of normal developing children (Adams and Hitch, 1997; Gathercole and Pickering, 2000; Bull and Sherif, 2001; Holmes and Adams, 2006; Andersson, 2008) and of those with learning difficulties (Hitch and McAuley, 1991; McLean and Hitch, 1999; Siegel and Linder, 1984; Barrouillet and Lepine, 2005; Swanson and Beebe-Frankenberger, 2004).

These studies have focused mainly on the influence of working memory on children's arithmetic performance or on problem solving. For the former, for example, deficits in arithmetic achievement were linked to poor performance on measures of the visual-spatial working memory and of the central executive (Gathercole and Pickering, 2000; Geary, Hoard and Hamson, 1999; McLean and Hitch, 1999) but not on phonological working memory tasks (McLean and Hitch, 1999). In the case of problem solving, children with poor problem solving abilities have significant difficulties with central executive tests of working memory (Passolunghi and Siegel, 2004) and with working memory tasks where irrelevant information must be inhibited (Passolunghi, Cornoldi, and De Liberto, 1999). In the case of children with learning disabilities, measures of visual-spatial and phonological working memory predict accuracy in mathematics problem solving (Swanson and Sachse-Lee, 2001).

One limitation of these studies is that there are no controls for general intelligence. It is reasonable to assume that general intelligence is related both to working memory and children's mathematical achievement. Thus, the connection between working memory and mathematical achievement could result from this relation to general intelligence.

Longitudinal studies that measure children's general intelligence reported that working memory continues to predict children's mathematical abilities above and beyond the influence of children's general intelligence (Alloway and Alloway, 2010; Fuchs et al., 2005; Gottardis 2009; Nunes et al., 2007; Nunes et al., 2012; Passolunghi, Vercelli and Schadee, 2007; Passolunghi, Mammarella and Altoè, 2008; De Smedt et al., 2009). Working memory also predicts children's arithmetical skills and problem solving beyond the contribution of reading and age (Andersson, 2008; Bull and Sherif, 2001; Keeler and Swanson, 2001; Swanson and Beebe-Frankenberger, 2004; Gottardis, 2009).

If this cognitive approach is applied to deaf children's difficulties in mathematics, it is possible that deaf children's low mathematical performances could be caused by differences in working memory between deaf and hearing children. To verify this hypothesis, deaf children should present difficulties in working memory in comparison to their hearing peers and this factor should affect their mathematical performance. In the following paragraphs, the possibility of applying this cognitive approach is analysed.

#### **2.1.2.1. Working memory and deaf children's mathematical abilities**

In the previous chapter, when deaf children were considered from the point of view of learners, it was highlighted that they seem to have a different way of encoding information in memory, relying more heavily on visual-spatial information such as remembering locations rather than the temporal sequence of objects presented (Marschark and Mayer, 1998; Marschark, Lang and Albertini, 2002). When compared to hearing children, deaf children would perform better or worse according to the working memory task used. Due to the observation of differences between deaf and hearing individuals on working memory tasks, researchers investigating deaf children's mathematical skills explained their low performances in terms of working memory difficulties. For instance,

Epstein, Hillegeist and Grafman (1994) examined deaf and hearing adults' calculation verification skills with all four basic operations (addition, subtraction, multiplication and division). They expected that deaf college students would demonstrate a firm grasp of basic number knowledge and they would not differ from hearing students. The participants, aged from 18 to 25 years, were asked to determine whether the solution presented for each of the basic computational problems (with one digit operands greater than 0) was correct. Both deaf and hearing participants were very accurate: deaf adults' percentage of correct response was 97% compared to the 95% of correct responses of hearing students. These results were in line with the predictions hypothesised by Epstein, Hillegeist and Grafman (1994). In terms of reaction times, deaf and hearing participants presented similar reaction times for addition and multiplication calculations whereas a decrease of the reaction times in both groups was observed in subtraction and division problems. This reduction was much greater in deaf than in hearing adults resulting in a significant interaction between problem type and hearing status. Epstein, Hillegeist and Grafman (1994) noted that although deaf students' pattern of reaction times across tasks generally followed those of hearing students, they were always slower than those of hearing students and as tasks involved larger numbers, more difficult computations or increased memory loads, the difference in the performance between deaf and hearing participants increased. Epstein, Hillegeist and Grafman (1994) suggested that one of the reasons for these differences between deaf and hearing students was their working memory skills. They proposed that the less efficient use of working memory in deaf students would have a significant impact on their number processing skills, resulting in slower reaction times in calculation verification.

Later on, Davis and Kelly (2003) also investigated deaf adults' calculation verification tasks focusing only on multiplication and addition problems. They presented these two arithmetic operations under two interference conditions: tapping and voicing. The assumption was that the students (aged from 18 to 25 years) would primarily be using a memory-based retrieval model. Davis and Kelly (2003) aimed to verify whether the interference conditions would affect deaf and hearing students' performances in calculation verification in the same way, both for addition and multiplication. In the vocal interference condition, the participants were given the simple phonological interference task of repeating the word "the" while verifying the calculations. In the manual interference condition, the students were required to continuously tap the table with their nonresponsive hand as they verified the accuracy of the calculations. Because David and Kelly (2003) aimed also to investigate whether deaf students' reading skills influenced their ability to verify mental calculations, deaf participants were also divided into lower and higher readers. In addition and multiplication problems, higher deaf readers obtained similar results to those presented by hearing students in terms of reaction times and accuracy. Lower deaf readers showed greater reaction times and poorer accuracy compared with their hearing peers. In addition tasks, performances of both higher deaf readers and hearing children were affected by the voicing interference mode whereas in multiplication tasks, the tapping interference mode clearly affected the performance of both groups. Lower deaf readers did not show any interference effect in either addition or multiplication tasks. With the exception of deaf lower readers, these results showed that deaf adults present similar arithmetical abilities to hearing children also in relation to the effect of interference mode on arithmetic tasks. Davis and Kelly (2003) suggested that the low performances of deaf lower readers could be due either to their low reading skills or to a less efficient use of working memory and internal processing codes.

Due to the observation of differences between deaf and hearing individuals in their working memory skills and of low mathematical skills when the tasks rely heavily on working memory abilities, it is possible that working memory could be a cause of deaf children's delay in mathematics. Two studies investigated this issue: one was carried out by Moreno (2000) and the other was conducted by Gottardis (2009). Both studies worked with deaf and hearing children with an age range between 7 and 9 years.

In order for a cause of a delay to be identified, deaf children must lag behind their hearing peers on this factor and the same factor must predict deaf children's mathematics attainment. Therefore, firstly, Moreno (2000) compared deaf and hearing children's performance on a memory task. The children were shown digits on a computer screen and then were asked to indicate whether a particular digit, presented by itself on the screen, had been part of the series of numbers that they had just seen. Different numbers of digits were presented varying between 1 and 10. The children's score was the number of digits in the longest series for which recognition was accurate. She reported that hearing children performed significantly better than deaf children on this task: on average the hearing children were able to deal with information that held a longer list of numbers than the deaf children.

Secondly, Moreno (2000) investigated whether deaf children's working memory ability was a good predictor of deaf children's mathematical achievement measured through a standardised mathematical assessment (NFER-Nelson) seven months later. She reported that, after controlling for age and non-verbal intelligence, working memory performance was not related to deaf children's mathematical performance. Therefore, she argued that her results did not support the hypothesis that deaf children's mathematical difficulties can be explained by their working memory restrictions. The sample size of this

study was quite small therefore it is necessary to replicate this research with a larger sample size.

Gottardis (2009) investigated whether working memory could be a cause of deaf children's delay in mathematics through a secondary data analysis. She used data from the Avon Longitudinal Study of Parents And Children (ALSPAC) project, an epidemiological study of a large number of children born in Avon in 1991-92 and has continued since. The sample consisted of 86 deaf children with a hearing loss ranging from mild to moderate and 5973 hearing children of the same age range (between 7 and 9 years old). Children's mathematical achievement was measured through a mathematical reasoning task, the arithmetic task from the Wechsler Intelligence Scale for Children third edition (WISC-III) and the Key Stage 1 (KS1) mathematics achievement test. Three measures of working memory were used in the study: the backward digit span, the forward digit span from the WISC-III and the non-word repetition. The first one was a measure of working memory capacity whereas the other two tasks assessed short-term memory. Finally, children's general intelligence was then assessed through the WISC-III. Through the comparisons between deaf and hearing children's performance in these tasks, it was observed that only on the WISC-III backward digit span task that measures working memory ability did deaf children have a shorter working memory ability compared with their hearing peers, also when age and non-verbal intelligence were included as covariates. No difference was observed between the two groups in the other two measures when non-verbal intelligence was included as a covariate. Gottardis (2009) argued that this could be due to the limited range of level of hearing loss considered in this study. Although for only one measure, these results confirmed that deaf children have smaller working memory capacity.

In order to determine whether working memory was a significant predictor of deaf children's mathematical abilities, Gottardis (2009) carried out three regression models, one for each of the mathematical measures used in this study. They were carried out both for deaf and hearing children. In all three models, non-verbal intelligence was entered as the first factor because hearing and deaf children differed in this element and it had a significant effect on the outcome measures used in this study. In each regression model, a measure of working memory was used based on a factor extracted from the three working memory measures employed.

The results obtained by the regression models considering only hearing children confirmed that working memory is a significant predictor of mathematical achievement independent of intelligence. In the models, the contribution of working memory to the prediction of children's school achievement was smaller than that of non-verbal intelligence. In the case of the models for deaf children, differences were observed in relation to the types of outcome measure used. When the outcome measure was either KS1-mathematics or WISC-III arithmetic task, working memory continued to be a significant predictor of mathematical achievement after controlling for non-verbal intelligence. Its contribution was lower than that of non-verbal intelligence, confirming the results observed in the case of hearing children. This was not the case when a mathematical reasoning task was the outcome measure: working memory was not a significant predictor of mathematical reasoning after controlling for non-verbal intelligence. Gottardis (2009) argued that this discrepancy in the results could have been due to the small number of children (37 included in this last analysis).

These two studies clearly show that deaf children have difficulties in working memory ability compared with their hearing peers and provide evidence for considering

this factor a predictor of deaf children's difficulties in mathematics. There is a discrepancy in the results obtained in these two studies in relation to the influence of working memory on children's mathematical achievement. Moreno (2000) did not find a significant relation above and beyond age and intelligence between working memory and deaf children's mathematical achievement whereas Gottardis (2009) reported significant findings in relation to this issue. This discrepancy in the results could be due to the type of measures used to assess children's working memory ability. Future research should investigate this issue further including also other predictors of deaf children's mathematical achievement in order to have a more comprehensive predictive model.

In conclusion, the cognitive approach posed working memory as a crucial element in hearing children's learning process. The literature on deaf individuals was examined in order to verify whether it was possible to apply this theoretical approach to deaf individuals' difficulties in mathematics. The findings reported that deaf and hearing individuals differ in their working memory skills and that this factor seems to be associated with their mathematical achievement. Therefore, the results seem to support the cognitive approach and it is plausible that working memory is a predictor of deaf children's mathematical achievement.

### **2.1.3. Developmental domain specific approach**

Nunes and Bryant (1996) argued that there are two main aspects which play a fundamental role in children's mathematical development: logical-mathematical reasoning and learning the numbers and the system of signs used to represent numerical information. Evidence that supports this theoretical approach comes from observations in Piaget's work, Vergnaud's (1979) studies and from longitudinal studies that showed that these factors are

longitudinal and independent predictors of children's mathematical attainment, above and beyond the influence of general intelligence (Nunes et al., 2007; Nunes et al., 2012; Aunola et al., 2004; Aubrey, Dahl and Godfrey, 2006).

If this theoretical approach is considered in relation to deaf children's low mathematical performance, deaf children's delay in mathematics could be explained by difficulties in learning either the numbers and procedures or the logical principle applied to different situations or both. Learning numbers, procedures and systems of signs, such as the counting string, involves learning and remembering words in a particular order. As observed in the previous chapter in relation to deaf children as learners, this task is more difficult for deaf children than for hearing children. Deaf children may have reduced opportunities for incidental learning (Nunes and Moreno, 2002). This can create difficulties in the development of their logical-mathematical thinking.

The next two sections aim to determine whether there is enough evidence to support these hypotheses considering first logical-mathematical reasoning followed by the learning of numbers and procedures. Whether deaf children have difficulties compared with their hearing peers is analysed for each of these factors, as well as if there are any findings about the effect of these on deaf children's mathematical attainment.

#### **2.1.3.1. Logical-mathematical reasoning**

##### ***Comparison between deaf and hearing children in logical-mathematical reasoning***

The investigation on the performance of deaf children in logical-mathematical reasoning has focused only on three of the logical relations that are part of this concept. These are: 1) one-to-many correspondence, 2) inversion and 3) additive composition.

### 1. *One-to-many correspondence*

The relation of one-to-many correspondence means that an item of set A corresponds to several items in set B but items of set B can relate only to one item of set A. Nunes, Bryant and Watson (2007) argued that one-to-many correspondence is involved in the understanding of multiplication in the sense that children can solve multiplication problems using the schema of one-to-many correspondence even before multiplication is taught in school.

Nunes (2004) examined deaf children's performance in solving multiplicative problems comparing it with that of hearing children before they had received formal teaching on multiplicative reasoning. 82 children were recruited for this study attending from Year 2 to Year 5 classes. She gave the children both relational problems developed by Kornilaki (1999) where a numerical answer was not required to solve the problems and the same type of problem but asking them a quantification question. The children were presented with cut-out drawings of two lorries and warehouses and they were told that the green and blue lorries were going to unload the bags into the warehouse of the same colour, respectively. Then, the children were asked to indicate the number of bags of sugar inside each lorry using their preferred language (British Sign Language or English). After acting out the unloading process by moving the lorries over the warehouse and turning them upside down, the children needed to say if the number of bags of sugar inside the warehouse was the same or different. If the answer given was "different", they were asked to indicate which warehouse had more bags. Finally, the children were asked to provide a numerical answer to the question "how many bags of sugar would be in each of the warehouses" (Nunes, 2004).

In the relational problems, deaf children performed as well as hearing children showing a percentage of correct responses between 75% and 100% according to the different year group that they were enrolled in. When the numerical answer was necessary, the percentage of correct responses dropped drastically between 26% and 42% showing that, although a considerable number of deaf children demonstrated a good understanding of one-to-many correspondence, they were not able to use it when a number was required.

This low performance was replicated in a more recent study carried out by Nunes et al. (2009a) who compared young deaf children's performance on multiplicative reasoning with a hearing cohort. 28 deaf children and 78 hearing children in grades 1 and 2 (from 6 to 8 years old) were asked to solve 12 word problems requiring multiplicative reasoning. All problems were presented with the support of drawings on a computer screen in order to help the children to understand the problems better. The children were also given the Matrices sub-test of the British Abilities Scale, Second Edition (BAS-II) as a measure of nonverbal cognitive ability. Nunes et al. (2009a) found that deaf children's performance was weaker than that of hearing children, even after controlling for differences in general cognitive ability.

From these findings, it is possible to conclude that deaf children have difficulties in mastering one-to-many correspondence compared with their hearing peers but it is not clear whether this difference in performance between deaf and hearing is due to a lack of competence or to a delay in the development of this ability.

Nunes et al. (2009a) also conducted a brief intervention study in order to determine whether deaf children can learn how to use correspondence reasoning to solve multiplicative problems. They hypothesised that, if a brief intervention is effective in promoting deaf children's performance in multiplicative reasoning tasks, the difference

observed in the previous studies could be interpreted as a performance difference. The deaf and hearing children participating in the study were randomly assigned to either the intervention group or the control groups. The intervention group received instruction on multiplicative reasoning whereas the control group received instructions on visual analysis. In the intervention, at first, children were prompted to represent the situation described in the problems using the materials given and to check their counting. Later on, after the children created a full representation of the situation, the researcher hid some items before the children answered. The quantity which was unknown was varied throughout the training sessions so that the children always needed to reflect upon their actions and could not establish correspondences and answer mechanically. All the problems were presented in the preferred mode of communication (English or sign language) and with the support of pictures on a computer screen. Nunes et al. (2009a) assessed the children on three occasions: pre-test, immediate post-test and delayed post-test (2 weeks after the intervention). The testing consists of 12 multiplicative reasoning problems and 6 addition and subtraction problems used to make sure that children were not simply repeating correspondence actions. No significant differences were observed at the beginning of the intervention in both groups (intervention and control group). At post-test, a significant effect of intervention and no significant overall difference between hearing and deaf children were observed. At delayed post-test, there was a significant difference between deaf and hearing children and for the deaf, the difference between the intervention and the control groups was no longer significant.

These results clearly showed that the intervention was effective supporting the hypothesis that the differences between deaf and hearing children are related to a performance difference and not to competence discrepancy.

## *2. Inversion between addition and subtraction*

Piaget (1952), and more recently Nunes and colleagues (Nunes et al., 2007; Nunes et al., 2009d), highlighted that inversion is another crucial logic relation that children need to understand in order to be mathematical. For example, in relation to the operation of addition and subtraction, children not only need to understand that adding increases and subtracting decreases but also that one cancels the other out. If children do not grasp this logic, they may learn how to carry out simple additions and subtractions but they cannot understand what they are doing unless they understand the logical relation (Nunes and Bryant, 1996).

This logical principle is crucial not only for the understanding of addition and subtraction but also in relation to the decomposition of the number (if  $a+b$  equal  $c$ , then  $c-a$  must equal  $b$ ) and the understanding of algebra (Stern, 2006).

Nunes et al. (2008) investigated whether deaf children attending the first year of school present difficulties in understanding inverse relations in comparison to hearing children. In this research, 23 deaf and 130 hearing children attending their first year of school were involved. The mean age of the children in the deaf group was 6.7 whereas the hearing children's mean age was 5.8. Nunes et al. (2008) compared the performances of the deaf children's group with those of the hearing children's group in solving 6 inversion problems. Three of these problems were presented in the context of a concrete situation (they showed the children concrete materials) whereas the other three were part of a story problem presented along with drawings. In the concrete situation, the children were shown a row of bricks and were asked to count them. The experimenter partially hid the row leaving the end of the row visible so that the additions and subtractions would be seen. Then, the experimenter added some bricks to one side of the row and subtracted the same

number from the other side. The children were asked how many bricks were at the end of these operations (Nunes et al., 2008). In the story problems, the experimenter talked to the children about some objects put in a box and showed them the picture of the box marked with the number of objects put in the box. Then, the experimenter told them that a teacher came and put other objects in the box and after that some children came and took the same number of items out. The children were asked how many objects were in the box at the end (Nunes et al., 2008).

Even after controlling and adjusting for age differences, the mean number of correct responses in the inversion problems (out of 6) was 2.05 for hearing children and 1.87 for deaf children. Nunes et al. (2008) reported that the effect size of this delay is a large one. These results showed that deaf children were behind in understanding the inverse relation between addition and subtraction, despite the fact that the form of presentation of the problems had been shown to be helpful in a previous study (see Nunes, Bryant and Pretzlik, 2006).

This difficulty of understanding the inverse relation between addition and subtraction can also have an effect on deaf children's problem solving performance when this logic relation needs to be applied to solve story problems. Inverse problems belong to the category of change problems which are described as dynamic situations in which some event changes the value of a quantity (Nunes, 2004). The change problems involve three quantities, any of which can be unknown, resulting in six different types of problems (Frostd and Ahlberg, 1999). Inverse problems are those in which the start of the problem is unknown. These problems are in direct comparison with direct problems where the end is unknown. Three studies (Frostd and Ahlberg, 1999; Nunes and Moreno, 1998; Hyde, Zevenbergen and Powers, 2003) analysed deaf primary school children's performances on

these two types of problems. Frostad and Ahlberg (1999) worked with children aged between 6 and 10 years presenting them with a series of inverse and direct problems through graphical representations in a computer program and using children's own communication mode in order to make sure that they were able to understand the problems. They reported that 70% of the children were able to solve the direct problems correctly whereas only 52% succeeded in solving the inverse problems. These results were confirmed also by Hyde, Zevenbergen and Powers (2003) who examined deaf Australian children's ability to solve direct and inverse problems from the first to the seventh year of primary school. When children were in Year 3, 86% of the deaf answered the direct problems correctly whereas the rate of correct responses was 29% for the deaf in the case of inverse problems. Both Frostad and Ahlberg (1999) and Hyde, Zevenbergen and Powers (2003) did not recruit a control group of hearing children in their study but compared deaf children's performances with findings in the literature. Previous studies (Riley, Greeno and Heller, 1983; Lean, Clements and Del Campo, 1990) that used the same type of problems with hearing children showed that as for deaf children, hearing children also found solving direct problems quite easy. For instance, 90% of hearing children in Year 3 were able to solve direct problems presented by Hyde, Zevenbergen and Powers (2003) in comparison to the 86% of deaf children in their study. In the case of inverse problems, hearing children's performance was lower than that in direct problems, but within year groups, hearing children had higher response rates than deaf children. For example, in Year 3, 66% of hearing children were able to solve indirect problems compared with 29% of the deaf children (Hyde, Zevenbergen and Powers, 2003).

Nunes and Moreno (1998) also considered deaf children's ability to solve direct and inverse problems comparing them with a sample of hearing children. The children

recruited in this research were aged from 8 to 11 years. The children were asked to solve direct and inverse problems presented either with cut-out drawings of objects or with blocks, irrespective of what was mentioned in the problem. The children were tested individually in the communication mode most appropriate for the children (English or sign). They reported that deaf children performed similarly to hearing children in direct problems but showed a significant delay in inverse problems. Nunes and Moreno (1998) observed also that deaf children's performance was better when they were able to use cut-out objects than when they used blocks. They suggested that cut-out objects were better because, through them, children were able to imagine the situation and they could manipulate them in order to implement their informal strategies.

From these studies, it is clear that deaf children have difficulties in understanding and applying the logic relation of inversion but it is not clear whether this is due to a performance difference or a competence difference. Frostad and Ahlberg (1999), in their study previously described, provided detailed descriptions of deaf children's attempt to solve inverse problems. They reported that deaf children used similar solving strategies to those observed in hearing children, but deaf pupils employed informal procedures or they tended to approach the problems as number and procedures without reflecting on the semantic relations between parts.

Nunes et al. (2008), in the research described before, also carried out a very brief intervention study (2 intervention sessions) aiming to analyse whether it was possible to improve deaf children's understanding of inversion. They hypothesised that if this was the case, deaf children's difficulties were related to a performance rather than a competence difficulty. The children participating in the intervention study were those whose inversion abilities had been previously tested. The children were randomly assigned to an

intervention and a control group. The intervention group worked on inversion problems and the children in the control group were taught how to compose sums of money using coins of different denominations (for more details about the intervention sessions refer to Nunes et al. 2008). Deaf children were tested at pre-test, at immediate post-test and at a delayed post-test (2-4 weeks after the intervention). In the pre-test and immediate post-test, children were asked to solve the inversion problems described before and several control items that they could solve only by computation and not through applying the inversion principle. In the delayed post-test, only the inversion problems were used. The intervention group significantly out-performed the control group in the inversion items both at the immediate and at the delayed post-test. In particular, this significant difference was observed only when the inversion problems were considered, whereas no significant group difference was found in relation to the control problems. Nunes et al. (2008) argued that this pattern established that the improvement observed in the intervention group was specifically related to the understanding of inversion and not to a general improvement of computational skills. The findings supported the hypothesis that deaf children's difficulties in mathematics can be interpreted as a performance difference rather than a competence discrepancy.

### 3. *Additive composition*

Additive composition means that any number can be formed by the addition of two numbers. It is a basic concept that underlies any counting system with a base, oral or written. It is also the root of our ability to count money using coins and notes of different denominations (Nunes and Bryant, 1996).

Nunes and Moreno (1998) and, later on Nunes et al. (2009b), investigated whether deaf primary school children present difficulties with the logic principle of additive

composition compared with their hearing peers. These two studies considered this issue with two different age ranges: Nunes and Moreno (1998) assessed children from Year 2 through 5, whereas Nunes et al. (2009b) focused on children in the first year of primary school. Both studies used the Shop Task where children were invited to play a pretend-shop game and assessed children's non-verbal intelligence through the BAS-II.

In both studies, deaf children's performance on this task was lower than that of their hearing peers in both age ranges. In Nunes and Moreno (1998), for example, half of the children in Year 2 and 3 did not pass any of the eight additive composition tasks and only 25% obtained a full score. Their performance improved significantly in Year 4 and 5 when, respectively, 60% and 70% of the children obtained a full score on the additive composition task and only 10% were not able to complete the task. This difference in performance between deaf and hearing children remained when non-verbal intelligence was controlled (Nunes et al., 2009b).

From these findings, it is clear that deaf children began school without a good grasp of additive composition and they have a considerable delay on this aspect compared with hearing children, who do not have any difficulty in this task from the age of 7 (Nunes and Bryant, 1996).

Nunes et al. (2009b) carried out a brief intervention to evaluate the possibility of improving deaf children's understanding of additive composition. The participants were 22 children in the first two years of school recruited from mainstream schools and special schools for the deaf. The children were randomly assigned to either the intervention or the control group. The intervention group solved a series of problems in the Shop Task whereas the control group worked on a set of mathematical tasks focused on the inverse relation between addition and subtraction. The study included a pre-test, immediate post-

test and a delayed post-test (2-4 weeks after the immediate post-test). The testing involved the Shop Task and a Transfer Task adapted from Miura et al. (1988). At immediate post-test, significant differences between the groups in both measures were observed whereas in the delayed post-test, a significant group difference was found only in the Shop Task. The results of this study clearly demonstrate that a brief period of teaching can be effective in improving deaf children's performance in additive composition.

The analysis of deaf children's performance on these three logic relations tasks lead to the conclusion that deaf children find mastering these logic relations more difficult than their hearing peers. These differences between deaf and hearing are not due to competence discrepancy but to differences in performance as demonstrated by the short intervention studies conducted for each of the three logical relations examined. The intervention studies presented, however, did not consider whether the improvement observed in deaf children's understanding of logical relations was translated to an improvement in their mathematical abilities. Nunes and Moreno (2002) examined this issue conducting another intervention study which was implemented by teachers. This research aimed to improve deaf children's understanding of additive composition, additive and multiplicative reasoning and fractions. The children participating had an age range between 7 and 11 years and were divided into an intervention group (23 children) and a control group (65 children). Before the intervention, deaf children's mathematical ability was assessed through an age-appropriate, standardised academic test (NFER-Nelson). The same test was then re-assessed at the end of the intervention (a year after). The details of the intervention sessions are not reported here because they are not crucial for the present argument (for more references, refer to Nunes and Moreno (2002)). Nunes and Moreno (2002) reported that, at pre-test, comparison between intervention and control groups did not show any significant

difference, whereas the intervention group out-performed the control group in the post-test. They investigated also whether the intervention group's performances in the post-test were better than those expected from the children on the basis of their pre-test performance. They reported that 31% of the children made less progress than predicted and 68.2% had higher observed than predicted scores. A significant difference indicated that the observed scores were significantly higher than the predicted scores. Nunes and Moreno (2002) argued that the intervention was successful and it was possible to increase deaf children's success in mathematics by improving their understanding of logical relations.

### ***Logical-mathematical reasoning as a predictor of children's mathematical achievement***

These results provide further evidence that logical-mathematical reasoning is a crucial element in deaf children's mathematical attainment. It is therefore plausible to suppose that logical-mathematical reasoning could affect, longitudinally, deaf children's mathematical achievement.

To the best of my knowledge, there is no research on deaf children that has investigated whether logical-mathematical reasoning is a significant independent contributor to the prediction of children's mathematical achievement, but two studies have examined this issue in hearing children. The first research was conducted by Nunes et al. (2007) and examined whether children's logical-mathematical reasoning measured at school entry was a significant predictor of children's mathematical achievement 16 months later, assessed through the school-administered Standardised Achievement Tasks, Mathematics Section (SATs-Maths). The logical-mathematical reasoning task measured four logical relations: inversion between addition and subtraction, additive composition, one-to-one and one-to-many correspondence and seriation. At school entry, the children were also given the BAS-II as an assessment of their general cognitive ability and a

working memory test, Counting Recall. Through regression analyses, Nunes et al. (2007) reported that logical-mathematical reasoning was a significant and specific longitudinal predictor of children's mathematical achievement. It was specific in the sense that it could not be explained by general intelligence or working memory because these were controlled for in the regression. In the article, Nunes et al. (2007) did not report analysis on the specific connection of each of the logical relation measures by the logical-mathematical reasoning task and children's mathematical achievement. However, Nunes, Bryant and Watson (2007) described this analysis in relation to two of these logical relations: inversion between addition and subtraction and one-to-many correspondence. Using fixed-order regression analyses, they found that both the inversion task and one-to-many correspondence remained significant longitudinal predictors of children's mathematical achievement above and beyond the influence of children's age, general cognitive ability and working memory. The inversion task explained 12% additional variance of children's mathematical achievement whereas one-to-many correspondence at school entry explained a further 6% of the variance, after controlling for the other factors inserted in the equations. These results confirm further the important role that logic relations play in relation to children's learning mathematics, especially in the first year of school.

The second longitudinal study carried out by Nunes et al. (2012) analysed whether logical-mathematical reasoning and arithmetic skills are independent and specific predictors of children's mathematical achievement. They employed a wider longitudinal design compared with the previous study in terms of number of participants and of time elapsed between the testing occasions, adding further credit to the generalisability of their results. Nunes et al. (2012) used the data obtained from the ALSPAC database. Two logical-mathematical reasoning tasks were employed: one was administered when children

were 8 years old and the second when they were 11 and 12 years old. The arithmetic task used was derived from the WISC-III and it was administered when children were 8 years old. Through the use of hierarchical regression analyses, they assessed the independence and specificity of the contribution of logical-mathematical reasoning to the prediction of achievement in KS2 (at 11 years of age) and KS3 (at 14 years of age) mathematics, science and English. Age, intelligence and working memory were used as controls in these analyses. Nunes et al. (2012) found that logical-mathematical reasoning contributes to the prediction of children's mathematical achievement at 11 and 14 years above and beyond the influence of general intelligence, working memory and arithmetical skills. After taking into account all the other factors, logical-mathematical reasoning explained 8% of the variance and its beta value was .34. Also, arithmetic ability was found to be a significant and independent predictor of children's mathematical achievement at 11 and 14 years, after taking into account all the other factors inserted in the equation. Arithmetic ability explained an additional 3% of the variance of children's mathematical attainment and its beta value was .21. Nunes et al. (2012) pointed out that, from the analysis of the additional variance explained by these two predictors and from their beta values, it is clear that logical-mathematical reasoning was by far the strongest predictor compared with the other measures included.

Nunes et al. (2012) reported also that logical-mathematical reasoning and arithmetic skills were specific because these measures were more strongly correlated with mathematics than to science or English achievement. It is important to point out that intelligence and working memory were not specific predictors because intelligence contributed more to the prediction of science than maths and working memory influenced maths and English equally well.

The results of these two studies clearly show that logical-mathematical reasoning plays a crucial role in children's mathematical development. It is therefore expected that similar results will be observed in deaf children.

### *Summary of the findings*

Nunes and Bryant (1996) proposed that logical-mathematical reasoning was a crucial element for a successful mathematical development in hearing children. The literature on deaf children's mathematical abilities was examined in order to verify whether this statement can be applied also to deaf children's mathematical achievement. In order to test this, it was necessary to find that deaf children's understanding of logical relations should differ from that of their hearing peers and that logical-mathematical reasoning influences their mathematical attainment. Three logical relations were examined: one-to-many correspondence, inversion between addition and subtraction and additive composition. For each of these logic relations, deaf children had difficulties compared with hearing children (e.g. Nunes et al., 2009a; 2009b; Nunes et al., 2008). These differences were not due to competence discrepancy but to performance differences. This was demonstrated through the use of very brief intervention programmes aimed to improve deaf children's abilities in each of these logical relations. After this intervention, deaf children's understanding of these logical relations increased compared with that of the control group (Nunes et al., 2008; Nunes et al., 2009a; 2009b). An improvement in deaf children's logical-mathematical reasoning also had an effect on their mathematical achievement (Nunes and Moreno, 2002).

All of these findings support Nunes and Bryant's theory and the hypothesis that logical-mathematical reasoning could influence deaf children's mathematical development. Research (Nunes et al., 2007; Nunes et al., 2012) examined whether logical-mathematical

reasoning is an independent predictor of deaf children's mathematical achievement only on hearing children. These studies reported that logical-mathematical reasoning contributed to the prediction of children's mathematical attainment above and beyond the influence of age, general intelligence, working memory and arithmetic abilities and it was the strongest predictor among the other factors considered. Future research is needed to verify whether similar results are found when deaf children's mathematical achievement is considered.

### **2.1.3.2. Learn the numbers: counting ability**

According to Nunes and Bryant (1996), the other crucial specific factor that is at the base of children's mathematical learning is the learning of numbers and procedures. They used counting ability and the forms of measurement as examples in which the use of logic is not sufficient for a successful solution to a problem. To solve an arithmetic problem, for instance, children need not only to understand the logic involved in the problems but also to use signs for numbers to be able to find the numerical answer. Thus, it is necessary to know a number system, understand the conventions for number representation it involves and how to manipulate it. For instance, in the case of forms of measurement, in order to compare the length of two objects by measuring them, it is necessary not only to understand the logic of transitivity (if  $A = B$  and  $B = C$ , then  $A = C$ ) but also the use of arbitrary units that are standards which we use all the time.

If this theoretical approach is applied to deaf children's delay in mathematics, it should be observed that deaf children have difficulties in learning the numbers and procedures. Learning to count is one of the first mathematical abilities that children need to learn at the beginning of school. If deaf children's ability to count is delayed in comparison to that of their hearing peers, this difficulty can then have an effect on their mathematical achievement. An initial struggle with learning to count could lower adults' expectations

about what deaf children can learn in mathematics, resulting in less stimulation on mathematical tasks, and it could also interfere with the children's own discoveries in the domain of mathematical reasoning (Nunes et al., 2012). In the following paragraphs, the literature is examined in order to determine whether there is evidence that supports these predictions, considering first whether the deaf children have difficulties in counting ability compared with their hearing peers, followed by an analysis of how this delay in learning to count affects their arithmetic and problem solving skills.

#### **2.1.3.2.1. Counting ability**

Two studies (Secada, 1984; Leybeart and Van Cutsem, 2002) analysed deaf preschool children's performance in producing a counting string in comparison to their hearing peers. In both studies, deaf children used sign language as the mode of communication and their degree of hearing loss ranged from moderate to profound. The children were asked to count as high as they could and, if necessary, they were encouraged to continue by two prompts either asking "what comes after x?" or repeating the last three numbers ending on a rising tone. Both studies observed that deaf children have counting strings shorter than those of hearing children in the same grade and age level. This means that deaf children stopped earlier than their hearing peers in their production of the counting string. The analysis of where the children stopped counting showed that deaf children would stop more frequently at the numbers where there is a change of rules. This means that, although deaf children do show a delay in learning the counting string, this delay is not explained by a difficulty in learning rules but is a consequence of the serial recall nature of the task or is due to lack of experience.

If learning to count is an important element for the development of children's mathematical skills, as pointed out by Nunes and Bryant (1996), this initial difficulty in

learning to count could have three main consequences. Firstly, when mathematical tasks rely heavily on counting skills, deaf children's mathematical performance will be significantly affected. Tymms et al. (2003) compared deaf and hearing children's performances on a school-entry numeracy test, which includes tasks that require counting (e.g. "show me 5 blocks"; "tell me which number is bigger"). They recruited nearly 1000 deaf children aged between four and five with a range of hearing loss between mild to profound. With the exception of deaf children with a mild degree of hearing loss, deaf children performed significantly lower than their hearing peers on this test. These results confirmed the influence of the difficulties of counting skills on deaf children's mathematical achievement.

Secondly, this delay in development of counting skills can impede the construction of conceptual understanding that is typically developed through the use of modeling strategies (Frostdad, 1999). Ansell and Pagliaro (2006) analysed deaf children's difficulties of arithmetic story problems and its relation to strategy use. The problems used were change problems (direct and change unknown problems), combine problems (end unknown and part unknown) and compare problems (difference was unknown). Change problems have already been defined in relation to inverse problems described in the previous section. Combine problems are those in which in order to solve the problems two sets need to be combined. Compare problems involve two wholes and the question is which part of one whole cannot be set in correspondence with the other whole (Nunes, 2004). Ansell and Pagliaro (2006) recruited 233 children aged 5 to 9 years. The children were presented 6 story problems signed in American Sign Language. Deaf children's difficulty in solving these problems was based not on the story within the problem but on the canonical operation typically used to solve the problem. The split in difficulty was

based on whether the problem solution involved the sum or the difference between two sets. Ansell and Pagliaro (2006) observed that, in the literature, in comparison to what was reported for hearing children, deaf children participating in their study tended to use more counting strategies. They argued that this could have contributed to the presence of a different pattern of problem difficulty observed in their study.

Thirdly, it could be that, once deaf children learn to count or when they are compared with hearing children with similar counting skills, their mathematical performance is as good as that of hearing children. Hitch, Arnold and Philips (1983), for instance, were some of the first researchers to examine deaf children's arithmetic skills. The 10 profoundly deaf children age 6 years participating in the study were matched with 10 hearing children for arithmetic achievement. The researchers employed a chronometric technique measuring the time required by both deaf and hearing children to verify whether addition problems such as  $x + y = z$  were correct or incorrect. They found that deaf and hearing participants produced remarkably similar patterns of response times. Both groups conducted the sum beginning from the larger digit and incrementing it a number of times equal to the smaller. Mulhern and Budge (1993) decided to replicate this study with prelingually profoundly deaf children being educated in sign language. They worked with children aged 13 years. In order to investigate their arithmetical abilities on basic addition, the children were asked to produce answers to addition combinations of the form  $x + y = ?$ . The numbers responses used ranged from 0 to 18. Although deaf children's answers were slower than their hearing peers, both groups showed very similar patterns of response relying on similar counting models. It is important to point out that Mulhern and Budge (1993) used stimuli that were very simple in comparison to the age of the participants and

it is possible that a ceiling effect could have occurred. Therefore, the results need to be taken with caution.

Both the findings of these two studies add evidence to the hypothesis that, once deaf children learn to count, their arithmetic abilities are as good as those of hearing children. Therefore, the differences observed in their arithmetic performances could be due to a general slower development of their mathematical skills in comparison to their hearing peers rather than a different path of development. Chien (1993), for example, focused on deaf children's counting strategy choices in simple addition problems (the number range was between 1-10) considering younger children: from kindergarten to second grade. He aimed to investigate whether they differ from those of hearing children. The strategy choice was analysed across age and hearing status. Chien (1993) reported that both groups of children (deaf and hearing) used qualitatively similar strategies and they had a similar strategy development (for instance the strategies seemed to form the same conceptual hierarchy in the two groups) but deaf children lagged behind their hearing counterparts in the development using more immature strategies. Deaf kindergarten children more often used counting with concrete visible representations than their hearing peers, whereas they less often showed count-on and retrieval strategies. Deaf second graders showed more count-on strategies than the hearing children. Chien (1993) argued that the development of deaf children's strategy use was very similar to the development that mathematically less able hearing children go through. Frostad (1999), later on, carried out a similar study investigating Norwegian deaf pupils' strategies in solving addition and subtraction calculations. His results converged with those found by Chien (1993): deaf children presented the same strategies observed in hearing children, although they seem to use more count all strategies than hearing children of the same age.

Finally, Masataka (2006) investigated deaf adults' capacity of non-symbolic arithmetic performance in subtraction tasks. They aimed to examine whether deaf children's difficulties in mathematics begin before school and are shown also in non-symbolic arithmetic or whether they are a consequence of their difficulty in learning in the classroom. The participants performed subtraction in formal mathematics and numerical subtraction of large sets of elements presented as visual arrays of dots. In this last task, the participants were asked to subtract the second array from the first array and to compare this difference with the numbers of elements in the third array. Approximate answers were also considered correct. Deaf adults were as able as their hearing peers to conduct non-symbolic subtractions whereas they performed significantly lower than their hearing counterparts in subtractions in formal mathematics. These results lead to the conclusion that the delayed development of counting skills seems to be part of the problem of deaf children's mathematical difficulties.

From the analysis of all these studies, it is clear that deaf children have difficulties in learning to count compared with their hearing peers. When the tasks require little counting skill or when deaf children have acquired this ability, no difference is observed between deaf and hearing children's performance. These findings support the hypothesis that learning to count is an important factor in deaf children's mathematical development. It is therefore possible that counting ability is a predictor of deaf children's mathematical achievement. To the best of my knowledge, counting ability was examined as a predictor only in studies with hearing children but not with deaf children. These studies employed a longitudinal research design over multiple time points (Aunola et al., 2004; Aubrey, Dahl and Godfrey, 2006). Aunola et al. (2004), for example, examined the mathematics development of normally developing children during their transition from preschool (5-6

years old) to Grade 2 (7-8 years old) and the cognitive antecedents of this development. They examined the mathematical performance of 194 Finnish children twice during each year across a 3-year period. Counting ability, visual attention, meta-cognitive knowledge and listening comprehension were assessed at the first testing occasion. Counting ability was assessed using three subtests: counting numbers (counting as far as they could), counting forward (counting forward from a given number) and counting backward (counting backward from a given number). Children's mathematical performance was evaluated through the Diagnostic Test for Basic Mathematical concepts which consists of five subtests: knowledge of ordinal numbers, knowledge of cardinal numbers, number identification, word problems and basic arithmetic. After controlling for visual attention, listening comprehension and meta-cognitive knowledge, the level of counting ability at the beginning of preschool predicted both children's mathematics performance level and their growth rate: the higher the level of counting ability children showed at the beginning of the preschool year, the higher was their level of mathematical performance and the faster the rate of growth they showed in their subsequent skill development. These results confirm that counting ability plays an important role in predicting children's mathematical achievement.

In the U.K, Aubrey, Dahl and Godfrey (2006) investigated the influence of children's early mathematical experiences on children's results on the national standardised assessment tests at KS1 and KS2. A cohort of 300 English children took part in the study. They were assessed in three cycles at mid point and at the end of their reception year and mid-point of Year 1. Aubrey, Dahl and Godfrey (2006) used the Utrecht Early Mathematical Competence Test (van Luit, Van Rijt and Penning, 1994) as a measure of children's early mathematical competencies. This test is comprised of 8 subtests

including comparison, classification, correspondence, seriation, counting, calculation and practical problem solving. Results showed that children who bring into school early mathematical knowledge do appear to be at an advantage in terms of their mathematical progress through primary school. Discriminant analysis determined that a combination of counting, understanding of relations in shape, size and general number knowledge was the best predictor of children's mathematical results in KS1 and KS2. After taking into account the other factors, counting still explained 10% of variance of children's mathematical achievement.

Although both the studies described here confirm that the knowledge of counting influences children's learning of mathematics, they do not control for other factors such as children's background factors, intelligence and other cognitive components. Once these factors are inserted into the model, it is possible that the predictive power of counting ability could be modified. For example, in the previous section, it was demonstrated that logical-mathematical reasoning influences children's mathematical achievement above and beyond the influence of intelligence, working memory and arithmetic, suggesting that logical-mathematical reasoning is the strongest predictor of children's mathematical achievement. Thus, if logical-mathematical reasoning and counting ability are inserted in a predictive model of children's mathematical achievement, it is possible that the predictive power of counting ability would be reduced, after controlling for the influence of logical-mathematical reasoning on children's learning mathematics. Future research should examine whether counting ability predicts children's mathematical achievement above and beyond the influence of logical-mathematical reasoning, intelligence and working memory when deaf children's mathematical attainment is considered.

In conclusion, deaf children are behind their hearing peers in their counting skills and counting skills significantly affect children's mathematical abilities, although the strength of this relation is not clear when other factors are taken into account. Regarding deaf children, it is plausible that counting abilities influence their mathematical attainment.

## **2.2. Summary and future possibilities of research**

In order to understand which are the factors that could influence deaf children's low mathematical performance, the theories on children's mathematical learning were analysed. There are three main theoretical approaches. The first is a domain specific approach (Gelman and Gallistel, 1978) according to which number representation processes are innate aspects that are at the base of children's mathematical learning. Butterworth and Gelman did not extend their theory in relation to deaf children's delay in mathematics but, if their theory was applied, it would be necessary to test whether deaf children have difficulties in number representation processes in comparison to their hearing peers. All the research (e.g. Zarfaty, Nunes and Bryant, 2004; Epstein, Hillegeist and Grafman, 1995; Bull, Blatto-Vallee and Fabich, 2006) that examined this issue confirmed that deaf individuals have the same number representation processes as those presented by hearing children. Therefore, the nativist theory cannot be applied in the case of deaf children's mathematical difficulties and factors other than number representation processes need to be taken into consideration as possible explanations of deaf children's low mathematical performance.

The second theory is a not domain specific theoretical framework (Geary, 2004) that refers to the general learning process that could be applied to mathematics. In particular, it puts working memory at the core of children's mathematical learning. If this theory is considered in relation to deaf children's delay in mathematics, deaf children's

mathematical difficulties should be related to their low working memory abilities compared with their hearing peers. Different studies (Marschark and Mayer, 1998; Marschark, Lang and Albertini, 2002; Gottardis, 2009; Moreno, 2000) compared deaf and hearing children's working memory skills reporting that deaf children performed lower than their hearing peers in working memory tasks, also when age and non-verbal intelligence are taken into account. The presence of a less efficient working memory could also explain low abilities in calculation verification of the four basic operations (Epstein, Hillegeist and Grafman, 1995; Davis and Kelly, 2003).

The presence of a difference between deaf and hearing children in working memory tasks provides evidence for the hypothesis that working memory could be a predictor of deaf children's mathematical attainment. Two studies (Moreno, 2000; Gottardis, 2009) investigated whether working memory affects deaf children's mathematical achievement above and beyond the influence of general intelligence. These two studies reported contrasting results according to the measures employed. Thus, it is still necessary to investigate this issue further, also inserting in the predictive equation other factors that could affect deaf children's mathematical performance.

The third and final theoretical approach is a developmental and specific theory on children's mathematical learning (Nunes and Bryant, 1996) that proposes logical-mathematical reasoning and the learning of numbers and procedure as fundamental elements for the successful development of children's mathematical abilities. A few studies (Nunes et al., 2009a; Nunes et al., 2009b; Nunes et al., 2008) compared deaf and hearing children's performances on some logical relations such as additive composition, one-to-many correspondence and inversion. In all these studies, deaf children found it more difficult to master these logical relations compared with their hearing peers, after

controlling for general intelligence. The differences between deaf and hearing children are not due to competence discrepancy but to differences in performance, as demonstrated by the positive effect obtained on deaf children's performance by short intervention studies (Nunes et al., 2008; Nunes et al., 2009a; Nunes et al., 2009b). The improvement of deaf children's performance on these logical relations had a positive effect not only on the development of these logical relations but also on their mathematical attainment: the observed scores obtained in a standardised mathematical achievement test were higher than the scores predicted before the intervention (Nunes and Moreno, 2002). All these results seem to suggest that logical mathematical reasoning could be a significant predictor of deaf children's mathematical achievement. This issue was only investigated in two longitudinal studies that considered hearing children (Nunes et al., 2007; Nunes et al., 2012). These two studies demonstrated that logical-mathematical reasoning was the strongest significant independent contributor to the prediction of children's mathematical attainment above and beyond the influence of general intelligence, working memory and arithmetic abilities. This was true not only in the first year of school (Nunes et al., 2007) but also when children were 11 and 14 years old (Nunes et al., 2012). These results provide even stronger evidence of the crucial role played by logical-mathematical reasoning in children's mathematical development. There is now the need to investigate whether similar findings could be observed also in relation to deaf children.

Regarding the learning of numbers and procedures, learning to count is one of the first skills that children need to master at school. A lack of development of this ability can have consequences in the acquisition of other more complex skills. Therefore, the analysis of literature on deaf children has focused on counting ability. In order to test whether counting ability could be considered a crucial element of deaf children's mathematical

development, it is necessary to confirm that deaf children have difficulties in learning to count, and, to show that when the task does not rely heavily on counting, deaf children's abilities should be comparable to those of hearing children. Two main studies (Secada, 1984; Leybeart and Van Cutsem, 2002) compared deaf and hearing children's ability to learn the counting string. In both studies, deaf children presented lower performances than their hearing peers. This delay in learning is due, perhaps, to the nature of the task or to the lack of experience rather than a difficulty in learning the rules of counting or the counting string. This statement is supported by analysis of the mistakes during counting (Secada, 1984; Leybeart and Van Cutsem, 2002) and comparison of the development of counting strategies between deaf and hearing children (Chien, 1993; Frostad, 1999).

The presence of an effect of counting abilities on deaf children's mathematical achievement is also suggested by the presence of deaf children's lower mathematical performances compared with hearing children in school-entry testing that involves counting (Tymms et al. 2003) and by the absence of difference between deaf and hearing children's performances in arithmetical tasks, when counting was learned (Hitch, Arnold and Philips, 1983; Mulhen and Budge, 1993). Finally, research on hearing children (Aunola et al., 2004; Aubrey, Dahl and Godfrey, 2006) demonstrated that counting ability is a significant and quite strong predictor of hearing children's mathematical attainment but these studies did not take into account other confounding factors that could influence children's mathematical performance. Thus, when factors such as intelligence and working memory are considered, the power of the relation between counting ability and children's mathematical achievement could be reduced. These results lead to the conclusion that also in the case of deaf children, counting ability could affect mathematical achievement, but this hypothesis has still not been verified.

In conclusion, the evidence examined so far supports the cognitive approach and the developmental mathematical theory. It is therefore plausible to hypothesise that working memory, logical-mathematical reasoning and counting ability could influence deaf children's mathematical development. However, it is still not clear whether these factors are longitudinal predictors of deaf children's mathematical attainment. Future research should address this issue in order to help the understanding of deaf children's difficulties in mathematics.

### **2.3. Present study**

The current study aims to determine the moderators of the extent of deaf children's delay in mathematics and the factors that influence deaf children's mathematical attainment. In particular, it is investigating whether working memory, counting ability and logical-mathematical reasoning predict, independently and longitudinally, deaf children's mathematical achievement after six months, having controlled for background factors and non-verbal intelligence.

In order to determine the presence of an independent contribution of these predictor factors, it is necessary to determine whether there are other factors that need to be controlled when the specific relation between the predictors and deaf children's mathematical achievement is analysed. Although a significant relation could be found between the predictor variables that have been examined up to now and deaf children's mathematical achievement, it is still possible that a third factor could affect both children's mathematical achievement, the predictor variables and their relation with deaf children's mathematical achievement. Thus, the presence of a relation between the predictor variables and children's mathematical achievement could be due not to the influence of the predictors on children's mathematical achievement, but because of differences in this third

variable. This is the reason why, in the present research, intelligence and deaf children's characteristics are inserted as control variables. In this way, it is possible to be more confident that the predictor variables that are the centre of the present research contribute to the prediction of deaf children's mathematical achievement independently of the influence of these control variables.

In the following sections, the role of intelligence and deaf children's characteristics in relation to children's mathematical achievement is examined. This is followed by a description of the design and of the ethical issues of the present study.

### **2.3.1. Control variables: intelligence and background factors**

#### **2.3.1.1. Intelligence**

Measures of children's intelligence assess a verbal and a non-verbal component. Both these aspects of intelligence have been considered in relation to academic achievement reporting that general intelligence correlates significantly with children's academic achievement (e.g. Jencks, 1979; Jensen, 1998; Bartels et al., 2002; Sternberg, Grigorenko and Bundy, 2001; Jordan Hanich and Kaplan, 2003; Aswal, 2001). Recently, Deary et al. (2007) conducted an extensive longitudinal study investigating the relation between children's general intelligence assessed at 11 years through the Cognitive Ability Test (CAT) and their national school examinations (GCSE) taken at 16 years. The participants were more than 70,000 English children attending 973 secondary schools in the Local Education Authorities. Deary et al. (2007) reported a correlation of 0.81 between children's general intelligence and their results in academic achievement. In particular, general intelligence correlated significantly ( $r = 0.77$ ;  $p < .001$ ) with children's performance in mathematics and explained 58.6% of the variance of mathematics achievement.

This research presents two main limitations. First, Deary et al. (2007) did not consider any other factors other than general intelligence as possible explanations of children's academic attainment. Second, as observed in previous research, general intelligence is influenced by learning at school. Deary et al. (2007) measured intelligence when children were 11 years old giving more time for school learning to have influenced the results on the IQ test. Therefore, it is possible that, if intelligence was measured at an earlier stage and other factors were to be inserted in the model as additional predictors of children's mathematical learning, the strength of the relation between general intelligence and children's mathematical achievement could be modified. The study conducted by Nunes et al. (2012) using the ALSPAC database overcame these limitations. This study was described in the previous sections in relation to logical-mathematical reasoning. Here, the focus is on the results found in relation to general intelligence. This was measured when children were 8 years old using the WISC-III. In the model for the prediction of children's mathematical achievement at 11 years and 14 years, in addition to children's general intelligence, logical-mathematical reasoning, working memory and arithmetic were included. The correlation coefficient between intelligence and children's mathematical achievement was around 0.65. Through hierarchical regression analyses, general intelligence was found to be a significant predictor of children's mathematical achievement at 11 years and 14 years, explaining 37% of the variance of their mathematical achievement. This result confirms that general intelligence significantly influences children's mathematical learning, but its power is lower than that reported by Deary et al. (2007). It is also crucial to highlight that, although intelligence correlates significantly with both logical-mathematical reasoning and mathematical achievement, logical-mathematical reasoning explained additional variance of children's mathematical achievement above and beyond the influence of general intelligence. Thus, intelligence does not explain the entire

amount of variance of children's mathematical achievement but there are other factors that contribute more strongly to the prediction of children's mathematical development.

In relation to deaf children, Moreno (2000) included non-verbal intelligence in their regression models of deaf children's mathematical achievement. The methodology used in this study was explained in the previous section on working memory. Here, only the results in relation to non-verbal intelligence are considered. For deaf children aged 8 and 9 years, Moreno (2000) found a correlation of 0.38 (Spearman's rho) between the performance scale of the WISC-III and the NFER-Nelson Age Graded Mathematics Test. When inserted in a regression model, non-verbal intelligence explained an additional 15% of the variance of mathematical performance after controlling for differences in children's age. The findings of this research are in line with those reported in the case of hearing children, leading to the conclusion that intelligence influences deaf and hearing children's learning and especially their mathematical attainment. Therefore, general intelligence needs to be considered as a control variable in order to be able to investigate the presence of a specific connection between mathematical achievement and the predictor variables.

#### **2.3.1.2. Deaf children's characteristics**

As noted in the description of the deaf children population in the previous chapter, deaf children are a very heterogeneous group, as their hearing loss (such as degree of hearing loss, causes of hearing loss and type of amplification) as well as more general background factors vary. In the following paragraphs, for each deaf children's characteristics, their role in relation to children's mathematical attainment is examined in order to investigate whether they can have an effect (either predictor or moderator or both) on deaf children's delay in mathematics compared to their hearing peers.

### **2.3.1.2.1. Characteristics related to hearing loss**

#### *Degree of hearing loss*

Researchers (Nunes and Moreno, 1998; Wood et al., 1983) found no significant effect or a very low correlation between degree of hearing loss and mathematical achievement.

Through the analyses of the studies that considered the influence of degree of hearing loss and deaf children's mathematical attainment, Gottardis, Nunes and Lunt (2011)

hypothesised that this was due to the range of degrees of hearing loss considered in the different studies. A significant difference was mainly observed when more severe levels of hearing loss were considered, whereas milder levels of hearing loss did not show any significant difference (Tymms et al., 2003). These results lead to the hypothesis that degree of hearing loss could be a predictor of deaf children's mathematical achievement. Because of its role in predicting deaf children's mathematical achievement, degree of hearing loss could also affect the extent of deaf children's delay.

#### *Causes of hearing loss*

Through an epidemiological study on deaf children conducted in England, Fortnum, Marshall and Summerfield (2002) compared the aetiology of hearing loss with children's degree of hearing loss in order to investigate whether there was a relation between these two factors of hearing loss. They observed that moderately deaf children were more likely than children in the other two categories of hearing loss (severe and profound) to have unknown causes, whereas children with severe hearing loss more often presented with causes related to pregnancy. In the case of profoundly deaf children, genetic or post-natal causes were often reported. Fortnum, Marshall and Summerfield (2002) suggested the presence of a relation between causes of hearing loss and children's degree of hearing loss.

Jensema's study (1975) is the only research that investigated the relation between causes of hearing loss and students' academic achievement measured through the Stanford Achievement Test, Special Edition for Hearing Impaired Students (SAT-HI). This test evaluates both reading and mathematical abilities. It was administered to 6,873 deaf students in an age range between 8 and 18 years and extensive demographic information was collected. He found that those students reported as having an inherited loss clearly had academic achievement which was superior to those with other reported causes with the exception of mumps and otitis media. These are both diseases which tend to strike at a later age when the children have already experienced substantial language development giving them an advantage over the other children. Although Jensema (1975) did find a relation between causes of hearing loss and students' academic achievement, he did not analyse this relation after controlling for the relation between causes of hearing loss and degree of hearing loss. Therefore, it is possible that, when children's degree of hearing loss is taken into account, no significant association will be found between causes of hearing loss and children's mathematical achievement.

#### *Type of amplification*

Gottardis, Nunes and Lunt (2011) analysed the relation between the presence of cochlear implants and deaf children's mathematical achievement. On the basis of the few studies conducted on the mathematical performance of cochlear implanted children and on the wider literature carried out on reading tasks (see review conducted by Marschark, Rothen and Fabich (2007)), they argued that the presence of cochlear implants may predict deaf children's mathematical abilities and facilitate their mathematical learning. However, because of the small number of studies found and of the discrepancies observed in these studies, it was not possible to reach any clear conclusion (see Gottardis, Nunes and Lunt,

2011). Further research addressing this issue is needed in order to clarify whether there is any association between the type of amplification and children's mathematical performance.

Fortnum et al. (2002), in their epidemiological study, compared the type of amplification in relation to children's degree of hearing loss. They highlighted that the majority of the children implanted presented either a severe or profound degree of hearing loss whereas the majority of the children with moderate degrees of hearing loss used hearing aids. These results give credit to the hypothesis that there is a relation between the type of amplification and children's degree of hearing loss. Thus, when the relation between type of amplification and children's mathematical achievement is evaluated, it would be necessary to investigate the presence of this relation and if it is verified, control for it.

Cochlear implantation benefits deaf children by giving them the sensation of "hearing" (Maltby and Knight, 2000). For this hearing to become meaningful and pleasurable, a large and ongoing commitment on the part of the child, the family and others working with the child is required. Thus, when the outcome of the cochlear implant is evaluated, it is important to consider not only the presence of cochlear implant per se but also the benefit that this device has on a child's life. Nunes, Pretzlik and Ilicak (2004) hypothesised that it may not be the presence of a cochlear implant per se, but rather how much the child is benefitting from it that is the crucial issue. To the best of my knowledge, whether the use of cochlear implants predicts deaf children's mathematical achievement has still not been investigated.

### **2.3.1.2.2. Background factors**

#### *Chronological age*

In hearing children, in many studies (e.g. Nunes et al., 2012; Nunes et al., 2007; Jordan et al., 2007) age has been considered to be a predictor of children's mathematical achievement because the older children get, the more mathematical knowledge they acquire. It is very likely that a similar trend will be observed in deaf children. Gottardis, Nunes and Lunt (2011) highlighted also that when children begin primary school, deaf children's mathematical delay is quite small but it increases overtime. For this reason, it could be hypothesised that children's age not only predicts but also moderates the extent of deaf children's delay in mathematics.

#### *Years in education*

The term "years in education" refers to the number of years that deaf children attend school. This factor is used in the present study instead of year group for two reasons. First, in special schools for the deaf, children are not organised in year groups. In this way, it is possible to compare them with other deaf children and hearing children. Second, as observed by Nunes et al. (2008), deaf children's entry into primary school is often delayed by their teachers and parents for a variety of reasons (e.g. to allow them to develop language and communication further). Therefore, the number of years that children spend in education could have an effect on their mathematical achievement that cannot be explained by their chronological age.

Pollard and Oakland (1985) examined different factors that could be related to deaf students' academic achievement. These factors included not only psychological and cognitive factors (such as family support and general intelligence) but also demographic

characteristics. Among those, the number of years which the children spent in school was considered. They worked with 689 deaf children with an age range between 8 and 15 years. All children attended special schools for the deaf. Achievement was assessed by the Stanford Achievement Test: Hearing Impaired version. Pollard and Oakland (1985) carried out different multiple regression analysis taking into consideration the entire sample or only some subgroups created by dividing the students according to the causes of hearing loss (hereditary vs rubella) and degree of hearing loss (severe vs profound). In each of these regression models, number of years of education was significantly related to deaf students' mathematical attainment and it accounted for an additional 4% of the variance in mathematical achievement, after controlling for the other factors entered into the model. The results of this study support the hypothesis that number of years in education could be a predictor of deaf children's mathematical achievement.

Similarly to age, this factor can also be considered a moderator of the extent of deaf children's delay in mathematics because the more education the children receive, the more knowledge and learning skills they should develop and acquire. Because of the strong connection between age and years spent in education and the possible relation between these factors and deaf children's mathematical achievement, it is necessary to investigate whether either they both provide an independent contribution to deaf children's mathematical achievement or one of these factors is more strongly correlated with deaf children's mathematical achievement.

### *Gender*

Mitchell and Karchmer (2011) reviewed recent reports on the demographics of deaf and hard-of-hearing children in various educational settings carried out in the United States and in the U.K. They pointed out that, although the gender gap for hearing students is no longer statistically reliable for mathematics achievement, with girls catching up with boys (e.g. Leahey and Guo, 2001; Nunes et al., 2012), for deaf children, there is still mixed evidence on whether gender is associated with children's mathematical attainment. Some studies (Allen, 1986; Kluwin and Stinson, 1993) observed that males performed better than females, whereas others (Wood et al., 1983; Epstein, Hillegeist and Grafman, 1994; Powers, 2003) did not find any difference in deaf children's achievement. Thus, there is still the need for future research to examine whether this factor explains any variance in deaf children's mathematical achievement.

### *Type of educational provision*

The researchers (Allen and Karchmer, 1990; Allen and Osborn, 1984; Holt, 1994; Reich, Hambleton and Hound, 1977) who investigated the relation between type of educational provision and children's academic achievement agreed in observing that the degree of hearing loss predicts type of educational provision with a general trend for students with less severe hearing losses to attend mainstream schools. Powers, Gregory and Thoutenhoofd (1998), in their extensive literature review of U.K. studies carried out between 1980 and 1998, and Stinson and Kluwin (2011) reported that children attending mainstream schools perform better than those attending special schools for the deaf. Most of these studies did not control for other factors such as intelligence and degree of hearing loss when the performance of deaf children was compared between the different types of educational provisions. Only the study conducted by Wood et al. (1983) analysed this issue

taking into consideration children's degree of hearing loss. They evaluated the mathematical performance of moderately to profoundly deaf school leavers (aged 15-16 years) attending either special schools for the deaf, mainstream schools with hearing impaired units or integrated mainstream schools. They observed a low correlation between children's performance and educational provision. However, when degree of hearing loss was controlled for, the relation between the type of educational provision and deaf children's mathematical achievement was no longer significant (Wood et al., 1983).

It is therefore still unclear whether type of educational provision affects deaf children's mathematical attainment due to the possible presence of a relation between type of education provision and degree of hearing loss. Nevertheless, these results lead to the hypothesis that type of education provision could be a predictor and a moderator of deaf children's mathematical achievement as pointed out by Gottardis, Nunes and Lunt (2011).

#### *Language used at home*

Previous studies (Marschark, Lang and Albertini, 2002; Mayberry, 2002; Schick et al., 2007) evaluated the effect of language on deaf children's academic achievement. They observed that deaf children who have early and complete access to a true language, such as a signed language, perform better academically than those for whom language acquisition has been delayed or is not fully accessible. Herman et al. (2004) developed two measures that evaluate receptive skills and sign's output for children aged from 4 to 11 years using British Sign Language (BSL) as their first language, but neither of these measures is standardised so they cannot be used to compare deaf children with an oral language and those with sign language. Thus, in the current study, only the type of language used at home is recorded.

As highlighted by Mitchell and Karchmer (2011) through their extensive analysis of the literature, the majority of the studies that analysed the presence of a relation between language used at home and children's academic achievement focused on proficiency in reading comprehension. They found that deaf children who sign or use English as their first language performed better in language comprehension than those who use another language at home (Marschark et al., 2011; Mitchell and Karchmer, 2011). The only study that investigated this factor in relation to mathematical achievement is that carried out by Powers (2003). He examined whether there was an association between language used at home and the educational outcome of 16-year-old moderately, severely and profoundly deaf students in mainstream programmes. He reported a significant positive association between better examination GCSE results and English used at home, but when this factor was inserted in a multiple regression analysis, it did not explain any additional variance of students' GCSE results. It is important to note that this study analyses only those deaf students attending mainstream schools or mainstream with a unit for hearing impaired and does not consider the performance of deaf students in special schools for the deaf. Therefore, there is still the need to verify these results with children attending a wider range of educational provision.

On the basis of these results, it is possible to hypothesise that children who use a language other than English at home would be at a disadvantage in mathematics compared with those who have English as a first language or who use BSL.

#### *Highest maternal education*

Maternal level of education is one of the typically assigned indicators of children socio-economic background. Karchmer and Mitchell (2003) analysed the U.S. studies that investigated the relation between socio-economic status and children's academic

achievement. They reported that deaf students from higher socio-economic status families and with higher levels of education perform better on standardised tests of academic achievement, on average, than students from lower socio-economic families and with lower levels of education. In the U.K., Powers (2003), in the study previously described, investigated the relation between socio-economic status and children's academic achievement measured through GCSE results. He found a statistical association between better examinations results in mathematics and socio-economic status. Through regression analysis, he also observed that this factor was a significant predictor of deaf children's mathematical achievement, although its explanatory power was never more than 5%. In view of these findings, it is possible to hypothesise that the level of maternal education is a predictor of deaf children's mathematical achievement.

### **Summary**

The relation between intelligence, demographic factors and deaf children's mathematical achievement was analysed in order to identify the control factors that need to be considered when the specific relation between working memory, logical-mathematical reasoning and counting ability and deaf children's mathematical achievement is examined.

Intelligence was found to be significantly and quite strongly related to deaf children's mathematical performance (Moreno, 2000). This means that non-verbal intelligence needs to be taken into account in the creation of a predictive model of deaf children's mathematical achievement.

Very few studies examined the influence of demographic factors on mathematical performance and they often did not reach clear conclusions (as in the case of degree of hearing loss) or did not consider inter-effects between variables. This is the case, for

example, for type of educational provision. The degree of hearing loss can influence the type of educational provision that deaf children attend. The presence of this relation between degree of hearing loss and type of educational provision can confound the relation between type of educational provision and deaf children's mathematical achievement. Thus, in order to have a better understanding of the role of type of educational provision on deaf children's mathematical achievement, it is necessary also to take into account a possible effect of the degree of hearing loss on this factor. The same can be said in relation to causes of hearing loss and type of amplification. In both these cases, the degree of hearing loss can also influence their relation with deaf children's mathematical achievement.

Gottardis, Nunes and Lunt (2011) hypothesised that age, degree of hearing loss and type of educational provision are not only predictors but also moderators of deaf children's mathematical achievement. Due to the lack of data, they were not able to verify this hypothesis.

In light of all these findings, there is, therefore, the need to investigate the relation between all these background factors and deaf children's mathematical achievement. This will help to evaluate the extent of deaf children's delay in mathematics and to determine which are the background factors that need to be included as control factors in the predictive model of deaf children's mathematical achievement.

### **2.3.2. Aims and hypotheses of the present study**

The current study presents two aims: 1) to evaluate the extent of deaf children's delay in mathematics in the U.K. compared with their hearing peers and investigate the predictors and moderators of the extent of this delay; 2) to analyse whether working memory, counting ability and logical-mathematical reasoning predict, independently and longitudinally, deaf children's mathematical achievement after six months, having controlled for background factors and non-verbal intelligence.

On the basis of the literature described in this chapter, these are the hypotheses proposed for this research project:

1. age, years in education, type of educational provision and degree of hearing loss are moderators and predictors of the extent of deaf children's delay in mathematics.
2. causes of hearing loss, type of amplification, gender, language used at home and highest level of maternal education are predictors of deaf children's mathematical achievement.
3. counting ability, working memory and logical-mathematical reasoning are longitudinal and independent predictors of deaf children's mathematical achievement after controlling for background factors and non-verbal intelligence.
4. logical-mathematical reasoning will make the strongest contribution in the prediction of deaf children's mathematical achievement.

In order to address these hypotheses, two studies were carried out: a survey and a longitudinal study.

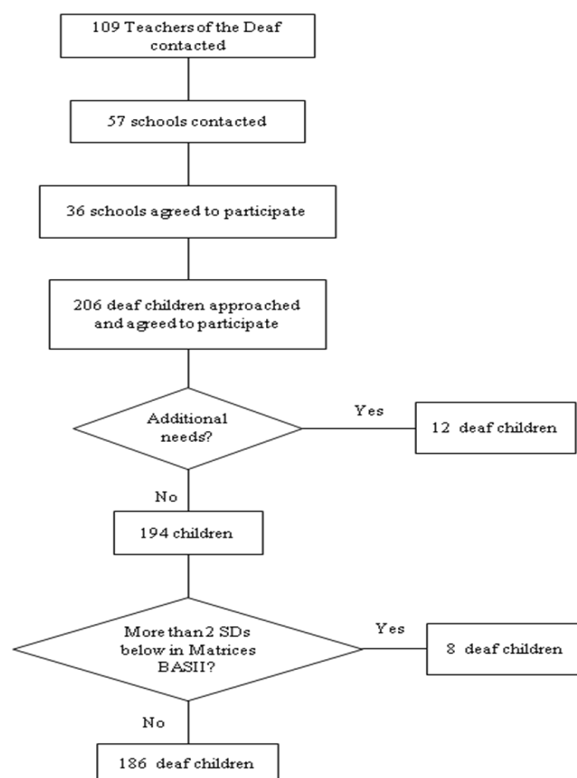
### **2.3.3. Study design**

#### *Survey study*

The survey study evaluates the extent of deaf primary school children's delay in mathematics and the presence of predictors and moderators of the extent of this delay. In order to determine how far behind deaf children are compared with hearing children in their mathematical skills, a deaf and a hearing children sample were recruited. The age range of the children for both samples was between 6 and 11 years. A particular attention was paid in order to obtain a sample of deaf children as representative as possible of different parts of the country. This is crucial in order to be able to be confident to generalise the findings of the present study to the population of deaf primary school children.

Figure 2.1 describes how the children were selected to take part in the study, beginning with the number of Teachers of the Deaf and the schools contacted followed by the number of children who agreed to take part in the study and the selective criteria employed in the study. More details about the recruitment are presented in Chapter 3 section 3.3.1.1.

Figure 2.1. Flowchart describing the recruitment of the deaf sample.



The second focus of the survey study is to determine the influence of factors on deaf children’s mathematical achievement. Thus, for each child, characteristics related to hearing loss and background factors were collected. A more detailed description of the design of the survey study is presented in the following chapter.

### *Longitudinal study*

The longitudinal design allows for an investigation of the presence of a specific connection between logical-mathematical reasoning, working memory and counting ability and deaf children’s mathematical performance after controlling for children’s background factors and non-verbal intelligence. A subgroup of children aged 6-8 years who participated in the survey study are the participants of this second study. This age range was chosen because early identification of the factors that influence how well deaf children learn mathematics

could reduce their difficulties at earlier stages of their education and therefore improve their future mathematical attainment.

The longitudinal study adopted a simple panel design with two phases of data collection. On the first testing occasion, measures of the predictor variables (logical-mathematical reasoning, working memory and counting ability) were administered together with a measure of non-verbal intelligence.

The second testing occasion comprises the outcome measure, the mathematical reasoning test of the Performance Indicators in Primary School (PIPS) that is used as a measure of their mathematical achievement. The interval between the first data collection and the second data collection was six months. Chapter 4 reports a more comprehensive explanation of the design with particular reference to the measures used in the longitudinal study.

#### **2.3.4. Ethical issues**

This project was designed in accordance with the Ethical Principles of the British Educational Research Association (2004) and approved by the Central University Research Ethics Committee (CUREC) and the Inter-Divisional Research Ethics Committee (IDREC), University of Oxford (see Appendix B1 for research approval and Appendices B2 and B3 for CUREC application forms).

The recruitment of the participants was achieved by sending a letter to the Head Teacher of the schools and contacting the Teachers of the Deaf who had responded to an invitation to participate in the research published in the British Association of Teachers of the Deaf (BATOD) magazine explaining the purpose of the research. The BATOD magazine deals with general issues of interest to Teachers of the Deaf. It is published five

times annually and includes reports on the work of the National Executive Council and items of immediate interest. Once the Head Teacher and the teachers agreed to participate to the research, a consent form was sent to the parents asking for permission for the participation of their children in this project, and to obtain information on the demographic variables. In this letter, it was indicated clearly that the child was also given the opportunity to say whether she/he wants to participate.

Head teachers, teachers and parents received all the necessary information concerning the research before giving their consent. Parents, teachers and Heads were assured that all the data would remain anonymous and confidential and that the participants' personal data would not be revealed.

The children's consent to participate was asked directly at the time of the testing, when each child was approached individually, explaining what they were about to do, and giving them the opportunity to decide. Asking the children's consent at the immediate time of the testing could raise doubt as to whether they had been given sufficient time to answer freely. However, this approach seemed the most appropriate for two reasons. Firstly, literacy is a challenge for deaf children and they cannot be asked for consent by letter. Secondly, many deaf children have difficulty in understanding conditional clauses and time intervals, so adding a delay in allowing time for them to think would not help, but would instead confuse them.

During the process for ethical approval, an ethical issue concerning the unequal relationship between the children and the researcher was raised. This asymmetry of the relationship could influence the children's freedom to decline. This was taken into account in the way in which the researcher interacts with the children. The researcher tried to put the children at ease by approaching them in a friendly manner, engaging with them in a

relationship that seeks to create a sense of mutual trust, and assuring them that they can ask questions about anything, if explanations are not clear enough. Throughout the assessment, the researcher checked with the children whether they want to carry on with the next task. In order to obtain this, the researcher was trained by experienced teachers and researchers who worked with and administer similar types of tasks to deaf children on a regular basis.

## **Chapter 3**

### **Survey study**

The purpose of this chapter is to evaluate the extent of deaf children's delay in mathematics in comparison to their hearing peers and investigate moderators and predictors of the extent of this delay. This will provide a better understanding of risk and protective factors in relation to the lower mathematical performances observed in the deaf population compared with their hearing peers. It will give the basis for creating a predictive model of deaf children's mathematical achievement, identifying the background factors that could influence deaf children's mathematical development.

As reported in the previous chapter, Gottardis, Nunes and Lunt (2011) investigated the nature and the extent of deaf children's delay in mathematics compared with hearing children through a systematic search of studies conducted since 1965. They argued that it was very difficult to reach any clear quantitative conclusion about the extent of deaf children's delay because of the presence of factors that could either predict, moderate, or both, the extent of deaf children's delay in mathematics. These factors were degree of hearing loss, type of amplification, chronological age and type of educational provision. Gottardis, Nunes and Lunt (2011) observed, for example, that a significant difference between deaf and hearing children's performance in mathematics was mainly observed when severe levels of hearing loss were considered, whereas milder levels of hearing loss did not show any significant difference. This leads to the hypothesis that degree of hearing loss could be a predictor of deaf children's mathematical achievement.

Through the examination of those few studies that considered whether there is a relation between type of amplification and children's academic attainment, Gottardis, Nunes and Lunt (2011) reported that the presence of cochlear implant seems to influence children's mathematical achievement. This finding needs to be treated with caution due to the small number of studies considered. In none of these studies, the possible relation between degree of hearing loss and presence of cochlear implant was taken into consideration. As reported by Fortnum et al. (2002) in their epidemiological research, severely and profoundly deaf children were more likely to use cochlear implants than moderately deaf children who use hearing aids as type of amplification. In the current research, whether this relation is significant will be investigated and if it is the case, it will be considered a control variable when the relation between type of amplification and children's mathematical achievement is examined. As highlighted by Nunes, Pretzlik and Ilicak (2004), it is also possible that not only the presence of cochlear implant in itself influences deaf children's mathematical achievement but also how much the children are benefitting from the use of cochlear implant. In the present study, a questionnaire on the use of cochlear implant is used in order to obtain information on children's use of their cochlear implants. The presence of variability in the scores on this questionnaire will justify the conclusion that it is also important to consider this factor in relation to deaf children's mathematical achievement.

Gottardis, Nunes and Lunt (2011) investigated also the influence of children's age on their mathematical attainment. They observed that the older the children get, the more knowledge they acquire. The extent of the delay in mathematics seems small when deaf children begin school, but it increases over time. Thus, it is possible that age is not

only a predictor of deaf children's mathematical development but also a moderator of the extent of their delay.

Finally, Gottardis, Nunes and Lunt (2011) examined a possible relation between type of educational provision and deaf children's academic attainment. As described previously, those studies that investigated this relation showed that, generally, children with moderate degrees of hearing loss attended mainstream schools, whereas children with more profound deafness tended to be enrolled in special schools for the deaf. Powers, Gregory and Thoutenhoofd (1998) and Stinson and Kluwin (2011) reported also that children in mainstream schools performed better academically than those in special schools for the deaf. Wood et al. (1983) investigated whether type of educational provision influences deaf students' mathematical attainment. They observed that, after controlling for degree of hearing loss, the relation between type of educational provision and mathematical achievement was no longer significant. In view of this evidence, it seems that type of educational provision could be a predictor of deaf children's mathematical performance but it is not clear if this is the case after also controlling for degree of hearing loss. Gottardis, Nunes and Lunt (2011) hypothesised also that type of educational provision could be a moderator of the extent of deaf children's delay in mathematics.

In conclusion, according to Gottardis, Nunes and Lunt (2011), age and type of educational provision are predictors and moderators of the extent of deaf children's delay in mathematics, whereas degree of hearing loss and type of amplification can be considered predictors of deaf children's mathematical development.

The analysis of the literature described in the previous chapter highlighted that, in addition to these factors, also causes of degree of hearing loss, gender, language used at

home and highest level of maternal education could influence deaf children's mathematical attainment. For instance, in relation to the causes of hearing loss, Jensema (1975) observed that children with a genetic cause of hearing loss obtained higher scores in academic tests than children with other types of causes of hearing loss. Causes of hearing loss are also related to the degree of hearing loss (Fortnum, Marshall and Summerfield, 2002). Moderately deaf are more likely than severely and profoundly deaf to have unknown causes (Fortnum, Marshall and Summerfield, 2002). Thus, in order to determine whether cause of hearing loss is related to deaf children's mathematical achievement, the relation between causes of hearing loss and degree of hearing loss needs to be verified. If it is significant, degree of hearing loss will be considered as a covariate when the relation between causes of hearing loss and mathematical attainment is examined.

Pollard and Oakland (1985) reported that number of years in education was significantly related to children's mathematical achievement leading to the hypothesis that this factor predicts deaf children's mathematical skills. In the present study, if a variability in the numbers of years in education is found, it could justify the conclusion that the relation between this factor and deaf children's mathematical achievement needs to be investigated. Pollard and Oakland (1985) did not include age in their predictive model for mathematical attainment. Therefore, it is not clear whether number of years in education influences deaf children's mathematical skills independently from the contribution of age. In the current research, this issue will be examined. As for chronological age, it is also possible that years in education is not only a predictor but also a moderator of the extent of deaf children's delay in mathematics.

Whereas in hearing children, it has been observed that there is no difference between male and female in their mathematical performance, in deaf children, the debate is still open. Some studies (Allen, 1986; Kluwin and Stinson, 1993) observed that males performed better than females, whereas others (Wood et al., 1983; Epstein, Hillegeist and Grafman, 1994; Powers, 2003) did not find any difference in deaf children's achievement. Thus, there is still the need to investigate this factor in relation to deaf children's mathematical development.

In the previous chapter, Marschark, Lang and Albertini (2002) investigated the influence of language used at home and deaf children's academic achievement and pointed out that deaf children who have early and complete access to a true language such as sign language perform better academically than those with a delayed language development. In the UK, Powers (2003) investigated whether there is a relation between the language used at home and students' academic achievement. He found that speaking English was related to deaf students' academic achievement at GCSE. These findings seem to lead to the hypothesis that children who speak English at home or sign are at an advantage compared with those who speak another language at home.

Finally, maternal level of education is one of the typically assigned indicators of children's socio-economic background. Powers (2003) examined whether there is a relation between socio-economic status and deaf students' academic achievement. He reported that this factor was significantly associated with students' attainment although it did not explain more than 5% of the variance in their academic achievement. It is therefore possible that highest level of maternal education is also related to deaf children's mathematical achievement.

The present research aims to investigate whether both the factors highlighted by Gottardis, Nunes and Lunt (2011) and those analysed in the literature influence deaf primary school children's mathematical achievement. Once the presence or absence of these relations has been verified, it will be possible to take these factors into consideration when deaf children's performance in mathematics is compared with that of hearing children. In this way, a more accurate analysis of the extent of deaf children's delay in mathematics is obtained.

Gottardis, Nunes and Lunt (2011) argued also for the necessity to control for children's non-verbal intelligence when deaf and hearing children were compared because deaf children's performance in mathematics might be lower as a consequence of a lower estimated cognitive ability. If this factor is controlled, the comparison between deaf and hearing children will be fairer. Therefore, a measure of children's non-verbal intelligence was administered to screen children whose levels of non-verbal intelligence were too low for inclusion in the study.

In the following sections, the hypotheses and predictions of the study are presented followed by a description of the design, methods and findings of the present research.

### **3.1. Hypotheses and predictions**

These are the hypotheses and predictions that will be tested in the present study:

1. Deaf children's performance in mathematics will be lower than that of hearing peers throughout each year of primary school.

2. Degree of hearing loss will be a predictor of deaf children's mathematical achievement. It will be tested whether children with mild levels of hearing loss will perform better than those with more profound levels of hearing loss.
3. Children whose cause of deafness is due to genetic factors will perform better in mathematics than those with other types of causes. Moderately deaf will be more likely than severely deaf to have unknown causes of hearing loss.
4. The older the children are, the better their mathematical skills are but, at the same time, compared with hearing children's mathematical achievement, it is possible that the older the children get, the wider will be their delay in mathematics.
5. The more years deaf children spend in education, the more knowledge they will acquire and, throughout the years spent in school, the difference between deaf and hearing children in mathematics performance will get wider.
6. Gender will not influence deaf children's mathematical achievement.
7. Children with more severe levels of hearing loss will be more likely to use cochlear implant than those with milder degrees of hearing loss. After controlling for degree of hearing loss, it could be that the presence of cochlear implant will affect deaf children's mathematical achievement. It is also expected that a better use of the cochlear implant is positively related with better performances in mathematics.
8. Children with milder levels of hearing loss will attend mostly mainstream schools whereas children with more profound levels of hearing loss will be enrolled in schools for the deaf. After controlling for degree of hearing loss, type of educational provision will predict a significant amount of variance in deaf

children's mathematical achievement. It is also expected that type of educational provision is a moderator of the extent of deaf children's delay in mathematics.

9. Language used at home will contribute significantly to the prediction of deaf children's mathematical achievement: children who speak English at home or sign perform better than those speaking another language at home.
10. Children whose mothers obtained higher levels of education achieve better results in mathematics than those whose mothers are school leavers or who obtained lower levels of education.

### **3.2. Design of the study**

In order to evaluate deaf children's delay in mathematics and verify these hypotheses and predictions, an extensive survey was carried out focusing on primary school children in the UK. A sample of hearing and of deaf children was recruited in order to be able to compare their mathematical skills. The hearing sample was recruited from some of the schools with a unit for the hearing impaired attended by deaf children. As reported previously, particular attention was paid to obtain a representative sample of deaf children in order to be able to generalise the results to the population of deaf primary school children.

For both samples, background factors (such as age, years in education, gender, language used at home and highest maternal education) were collected from school records. In the case of the deaf sample, for each child, factors related to their hearing loss (for example degree and causes of hearing loss, type of amplification and type of educational provision) were also obtained from their school records. Through the teachers involved in the project, the parent outcome questionnaire from pediatric cochlear implantation (Archbold et al., 2002) was sent to those parents whose children have

cochlear implants. This questionnaire was used to obtain an evaluation of deaf children's use of this type of amplification.

The matrices subtest of the British Ability Scale was used as the measure of deaf children's non-verbal intelligence. This was employed to screen deaf children whose levels of non-verbal intelligence were too low for inclusion in the study. In this way, the children whose mathematical difficulties could be due to the presence of additional needs were excluded.

The mathematical test from the Performance Indicator for Primary School (PIPS) was administered to both samples as the measure of their mathematical achievement.

### **3.3. Participants**

In the present study, a deaf and a hearing sample were recruited. Before beginning the recruitment, a power calculation was conducted in order to determine the sample size that will allow having a power of .90 to yield a statistically significant result. To calculate it, the smallest effect size ( $d=.20$ ) found in previous studies reported by Gottardis, Nunes and Lunt (2011) in their systematic review of the literature on the extent of deaf children's delay in mathematics was used. The calculation showed that the total sample required for this effect size and desired power should be 360 children, 180 deaf children and 180 hearing children (Howell, 1997). This number of deaf children recruited was approximately this; as it was possible to recruit a much larger hearing sample by testing all the hearing children in some of the schools attended by the deaf children in the study, the sample of hearing was increased.

Table 3.1 summarises the final sample size, gender, age and numbers of years spent in education of the current sample of deaf and hearing children taking part in the study. The characteristics of these two groups are presented in details in the following sections.

Table 3.1. Sample size, gender, age (range, mean, SD) and number of years in education (range, mean and SD) of deaf and hearing children.

Sample	Final sample size	Gender (boys)	Age			Numbers of years in education		
			Range	Mean	SD	Range	Mean	SD
<b>Deaf</b>	186	95	6-11 years	8.72	1.56	2-7 years	4.40	1.49
<b>Hearing</b>	798	428	6-11 years	8.91	1.30	2-7 years	5.16	1.28

### 3.3.1. Deaf children

This section firstly focuses on how the deaf sample was recruited followed by the description of the exclusion and inclusion criteria adopted and the presentation of the characteristics of the present sample.

#### 3.3.1.1. Recruitment

The aim of the recruitment was to obtain a sample that would be as representative as possible of different parts of the country. Deaf children can attend three different types of educational provision: mainstream schools, units for the hearing impaired in mainstream schools and schools for the deaf. In mainstream schools and units for the hearing impaired, there are very few deaf children in each school. It is possible, for example, that in one mainstream school there is only one deaf child. Deaf children are therefore spread around the country in this type of provision and it is very difficult to locate and recruit deaf children enrolled in mainstream schools. Although presently a higher proportion of deaf children attend mainstream schools (59%), this study includes only 25% of children in mainstream schools.

The researcher worked with a sample of Teachers of the Deaf who had responded to an invitation to participate in a research published in the British Association of Teachers of the Deaf (BATOD) magazine. This research project was supported by the National Deaf Children Society (NDCS). Through their cooperation, it was possible to reach a wider sample of deaf children.

109 Teachers of the Deaf replied to the advertisement presented in the BATOD magazine. Through these teachers, in September 2009, 57 schools were contacted requesting permission to work with deaf children aged from 6 to 11 years with a degree of hearing loss ranging from moderate to profound. 33 schools agreed to participate in the current research and 3 more schools became involved in September 2010.

### **3.3.1.2. Exclusion and inclusion criteria**

If the schools agreed to participate, the parents of the eligible children were contacted and permission for their children's inclusion in the study was requested. Only those children whose parents gave permission were included. 206 children were approached and took part in the study during September 2009 and October 2010. Of these children, 108 also took part in the other research study whereas the rest of the children (98) were involved only in the present research. The children with mild hearing loss were excluded from the recruitment because previous studies (Tymms et al. 2003; Gottardis, 2009; Gottardis, Nunes and Lunt, 2011) demonstrated that the mathematical performance of these children is very similar to that of hearing children. 12 children were excluded because they had a statement of additional special educational needs.

The matrices subtest of the British Ability Scales II (BAS-II) (Elliott, 1996) was used as screening measure of deaf children's non-verbal intelligence in order to exclude those children whose scores on non-verbal intelligence abilities were 1 or 2 SDs below the

mean. In this way, it was possible to identify children with possible additional cognitive difficulties that could affect their mathematical skills. The BAS-II is a measure of cognitive functioning over a wide age range (from 2.6 years to 17.11 years) and consists of two separate, but co-normed batteries: the Early Years and the School Age scales. The Early Years Battery is composed entirely of cognitive scales, whereas the School Age Battery comprises both cognitive and achievement scales. The BAS-II was chosen, firstly, because it is a quick, economical and objective measure of children's abilities that has been used with the deaf population in other studies (e.g. Nunes et al., 2008; Nunes et al., 2009a). Secondly, its individual scales are sufficiently reliable and measure sufficiently distinctive cognitive functions to make them individually interpretable (Elliot, 1996).

The matrices subtest is part of the School Age Battery and measures non-verbal cognitive ability. In previous studies (Nunes et al., 2009a), it was found to be significantly correlated with mathematical achievement. The matrices subtest presents high reliability (alpha coefficient .80) and a moderate test-retest correlation ( $r = .64$ ) (Elliot, 1996). It requires the identification and application of rules governing relationships among abstract figures. The test was administered individually using the children's usual communication mode in school, oral language or sign language. The researcher has obtained the British Sign Language level 2 qualification, which is the level required for the teachers in primary school.

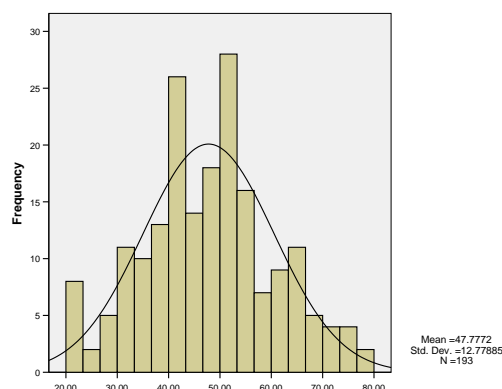
If the child found the instructions of the task difficult to understand, sign language was used as an additional support to communication. The extent to which sign was provided depended on the instructions given by the child's teachers before testing. The subtest was scored according to the published instructions (Elliot, 1996). The raw score is converted to an ability score which is the estimate of a child's level on the ability being

measured by the scale. The ability score reflects both the raw score and the difficulty of the items being administered. From an ability score, a t-score is obtained with mean 50 and standard deviation 10.

In the present sample, the mean of the t-scores obtained from this subtest was 47.77 (SD= 12.77). The scores ranged from 20 to 78. Although this mean score was lower than the published norm, the difference between the mean of deaf children and that of the published norm is less than one standard error of measurement (SEM) (SEM= 3.92). Therefore, the present sample can be considered a fluctuation of the population on which the test was normalised and it does not differ from the general population.

In the literature, two exclusion criteria have been used to screen children on the basis of their cognitive abilities in order to obtain a fairer comparison with hearing children: either exclude those who perform 1SD below the mean or exclude those who perform 2 SDs below the mean. This first criterion is very strict and excludes around 17% of the present sample but allows us to be certain that the difference in performance between deaf and hearing children is attributed to the difficulties that deaf children have in mathematics and not to a delay in their cognitive abilities. The exclusion of those who perform 2 SDs below the mean allows identification of those children with more severe cognitive problems. In the present chapter, it was decided to present the analysis using this second criterion whereas, in the Appendix C2, the analyses conducted applying the first criterion are described.

Figure 3.1. Distribution of t-score of Matrices sub-test of BAS-II.



In the present sample, eight children performed lower than 2 SDs below the mean (see Figure 3.1). These eight children were examined as individual cases in order to determine whether they share a set of characteristics. They are aged from 8 to 10 years and obtained t-scores of 20. They had a degree of hearing loss that ranged between severe and profound caused by either a genetic malformation, post-birth or pregnancy problems. Half of these children have cochlear implants and half of them use hearing aids. They are also equally distributed in terms of years in education (between 4 and 6 years spent in school). They attended either mainstream schools or special schools for the deaf. They were equally divided between those who have English as their first language and those who used another language at home. Their parents were either school leavers or had obtained GCSE qualifications. From this analysis, these eight children seem not to share any pattern. They were excluded from the subsequent analyses.

### 3.3.1.3. Description of the sample

The final sample consisted of 186 deaf children, 95 boys and 91 girls. Table 3.2 displays the location of the 36 different schools around the UK from which these children were recruited.

Table 3.2. Counties, town and cities in which the children were recruited and number of children.

<b>Counties</b>	<b>Towns and Cities</b>	<b>Number of children</b>
East Ayrshire	Crosshouse	9
Yorkshire and Humberside	Huddersfield, Sheffield, Rotherham, Pontefract, Scunthrope	23
Greater Manchester	Manchester	2
Lancashire	Rochdale	3
Staffordshire	Stafford	11
Derbyshire	Derby	10
West Midlands	Solihull	2
Northamptonshire	Northampton	4
Nottinghamshire	Nottingham	4
South Glamorgan	Neath, Cardiff	3
Buckinghamshire	Stoke Mandeville, High Wycombe	4
Hertfordshire	St Albans	13
Cambridgeshire,	Cambridgeshire, Peterborough	7
Oxfordshire	Abingdon	3
Berkshire	Newbury, Wokingham, Reading	27
Greater London	London, Southall, Twickenham, Croydon,	32
Kent	Strood	4
Sussex	Littlehampton	4
Hertfordshire	Potters Bar	1
Avon	Bath	7
Devonshire	Exeter	10

In the following paragraphs, the *child factors* (degree of hearing loss, causes of hearing loss, type of amplification, use of cochlear implant and years in education) and *background factors* (type of educational provision, language used at home and highest level of maternal education) are described. Where the information is available, the sample in the present study is compared to larger data sets of deaf children in order to assess whether this sample is biased.

## *Child factors*

### 1. Degree of hearing loss

The present sample had hearing loss ranging from moderate to profound, the exact number of children is shown in Table 3.3. For children with cochlear implants, the degree of hearing loss reported refers to that measured after the implant was fitted. The majority of the children are profoundly deaf whereas for the other degrees of hearing loss there is an almost equal proportion.

In order to evaluate the representativeness of the sample, the sample was compared to data obtained from the BATOD survey in 2011. This survey collected information about deaf children's degree of hearing loss from 562 different establishments in the 2010/11 financial year. They obtained information about 34,927 deaf children from preschool age (3 to 4 years old) to older than 16 years who were still in school or were still in education but did not attend a school. In order to compare these data with the present sample, only the 6 to 11 year old deaf children were considered. This subsample comprises 13,996 deaf children. All the children in this age range attended either schools for the deaf, mainstream schools or units for hearing impaired. The percentages of children with each degree of hearing loss observed in the BATOD survey and in this study's sample are presented in Table 3.3.

Table 3.3. Number and percentage of children by degree of hearing loss for the present sample and percentage from the BATOD survey (2011).

<b>Degree of hearing loss</b>	<b>Number of children</b>	<b>Percentage in this sample</b>	<b>Percentage from the BATOD survey (2011)</b>
Moderate	47	25.3	23.21
Severe	45	24.2	23.21
Profound	94	50.5	46.79

As in the present study, also in the BATOD survey (2011), the majority of the children are profoundly deaf whereas for the other two categories there is an equal proportion. The presence of the same pattern in both surveys suggests that the present sample is representative of the general population of deaf children regarding this aspect.

## 2. Causes of hearing loss

The cause of hearing loss was known for 114 (61.3%) children, 72 (38.7%) had unknown causes of hearing loss (see Table 3.4). When the causes were known, the most common was genetic followed by pregnancy and post-birth diseases.

In order to evaluate the representativeness of the present sample in terms of causes of hearing loss, the data from the present sample was compared to that of Fortnum et al. in 2002. They conducted an extensive survey of deaf children with permanent, moderate to profound bi-lateral hearing loss. The 17160 children in the Fortnum et al. (2002) sample were born between 1980 and 1995 in the UK. Through the use of questionnaires, they obtained information on the causes of deafness in their sample. In Table 3.4, the percentages of children by causes of hearing loss are reported.

Table 3.4. Number and percentage of children by cause of hearing loss for the present study and percentage from the survey conducted by Fortnum et al. (2002).

<b>Causes of hearing loss</b>	<b>Number of children</b>	<b>Percentage in this sample</b>	<b>Percentage from Fortnum et al. (2002)</b>
Genetic/hereditary	53	28.5	29.5
Pregnancy	36	19.4	12.1
Post-birth disease	25	13.4	8.8

Similar to what was noted in the present sample, in the Fortnum et al. (2002) study, the etiology of the hearing impairment was unknown for almost half of the sample (49.4%). The most common causes, when known, were genetic or hereditary, followed by those

related to pregnancy and post-birth disease. These results confirm that, regarding the causes of hearing loss, the present sample is in line with the general population.

### 3. Type of amplification

In the present sample, all the children used some forms of amplification: hearing aids or cochlear implants. For this reason, the sample was divided between those who did not use cochlear implants but used a hearing aid and those who used cochlear implants. In this last category, the children who had two cochlear implants or one cochlear implant in one ear and a hearing aid in the other have been included.

Table 3.5. Number and percentage of children by presence or absence of cochlear implant for the present study and percentage from the survey carried out by BATOD (2011).

<b>Amplification</b>	<b>Number of children</b>	<b>Percentage in this sample</b>	<b>Percentage from BATOD survey (2011)</b>
Absence of cochlear implant	108	58.1	92.0
Cochlear implant	78	41.9	8.0

From Table 3.5 it is possible to observe that although the majority of the children (58.1%) used hearing aids as type of amplification, a large proportion of children had cochlear implants (41.9%) (see Table 3.5). These proportions are very different to those reported in the survey study conducted by BATOD (2011) where only around the 8% of the children had cochlear implants compared with the 92% who used hearing aids as type of amplification. As pointed out in the BATOD survey (2011), this figure appears to be an underestimation of the number of children implanted, especially in view of the data provided by the Ear Foundation that reports that 5,000 deaf children have received a cochlear implant since the procedure was introduced in 1989.

#### 4. Use of cochlear implant

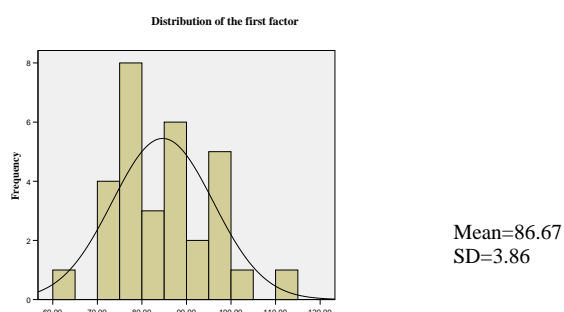
As pointed out previously in Chapter 2, it is possible that the presence of a cochlear implant is not as crucial in influencing deaf children's educational outcome as how much the child is benefitting from it. In order to evaluate whether it is important to look at the use of cochlear implant, variability between the children's use of cochlear implant needs to be observed.

The Parent outcome questionnaire from pediatric cochlear implantation (Archbold et al., 2002) (see Appendix B6) has been used to assess the children's use of cochlear implant from the parents' point of view in order to investigate whether all the children were using their cochlear implants to the same extent according to their parents. This questionnaire is the only one that yields information on the child's use of the cochlear implant from the parents' point of view, looking at the use of the cochlear implant in different aspects of the child's life.

The questionnaire consists of 74 statements, developed on the basis of open interviews conducted with parents of deaf children. These items cover ten themes: communication, self-reliance, well-being and happiness, education, process of implantation, decision to implant, social relationships, supporting the child, effects of implant and general functioning. The scale that considers the decision to implant is excluded in the present study because it is not directly relevant to determine the children's use of cochlear implants. The parents were asked to read each of the statements and indicate whether they 'strongly agree', 'agree', 'neither agree nor disagree', 'disagree', or 'strongly disagree'. The responses were coded in ascending order (1 for "strongly agree" to 5 for "strongly disagree"). The alpha reliability of the questionnaire varied between .50 and .83.

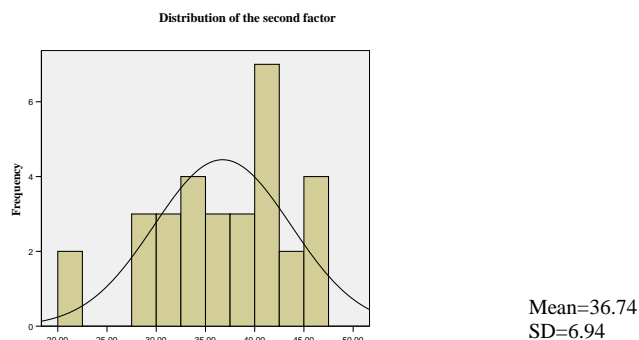
The questionnaire was sent to the 78 parents of children with cochlear implants through the school. 43.7% of the parents returned the questionnaire. Previous analyses of the questionnaire (Nunes, Pretzlik and Ilicak, 2004) identified four factors underlying the ten scales. The first factor score summarises the communication, well-being and happiness, social relationships and education scales. This represents the impact of the implant on the children's functioning in social settings. It was possible to obtain a minimum score of 24 to a maximum of 120 on this factor. In the present sample, the mean was 86.67 (SD= 11.35) (see Figure 3.2). From Figure 3.2, it is possible to observe a variability in the scores obtained on this factor.

Figure 3.2. Distribution of the first factor score of the Parent outcome questionnaire from pediatric cochlear implantation.



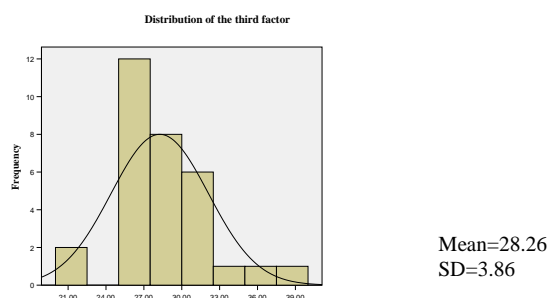
The second factor includes the self-reliance and attitudes to the process of implantation. The more independent the child is after the implant, the more positive the parents feel about the process and the less anxious they are about having made the decision to proceed with the implantation. The scores ranged from a minimum of 13 to a maximum of 65. In the present sample, the mean of this factor is of 36.74 (SD= 6.94) (see Figure 3.3). Also in this case, variability in the scores is observed.

Figure 3.3. Distribution of the second factor of the Parent outcome questionnaire from pediatric cochlear implantation.



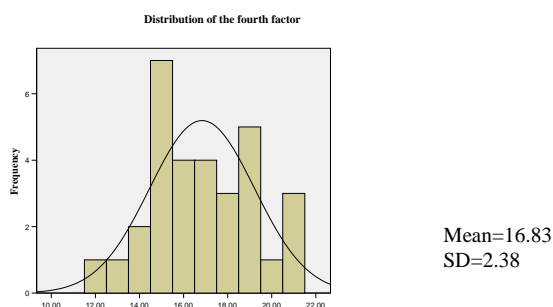
The third factor includes the use of implantation and the parental support scales and confirms that the parents seem to distinguish between their initial adaptation to the implant and long-term consequences. The third factor can have a minimum score of 9 to a maximum of 45. In this sample, the mean of this factor is 28.26 (SD= 3.86) (see Figure 3.4). Variability in the scores for this factor is observed.

Figure 3.4. Distribution of the third factor score of the Parent outcome questionnaire from pediatric cochlear implantation.



The fourth factor considers the use of implant and functioning before implant scales. The more negatively the child’s functioning before the implant is perceived, the more positively the use of the implant is judged. The scores for this factor can range from 5 to 25. In the present study, the mean of this factor is 16.83 (SD= 2.38) (see Figure 3.5). As for all the other factors, variability in the scores obtained on this factor is observed.

Figure 3.5. Distribution of the fourth factor of the Parent outcome questionnaire from pediatric cochlear implantation.



### 5. Years in education

The chronological age of the children recruited in this research was between 6 and 11 years. The term “years in education” refers to the number of years that deaf children attended school. Table 3.5 presents the number of years in education by chronological age. This factor was used instead of year group because, in special schools for the deaf, children are not grouped in year group. In this way, it was possible to compare them with the other deaf children and the hearing sample. As can be observed in Table 3.6, there is an association between age and years in education but there is considerable variation across children.

Table 3.6. Number and percentage of children by the number of years in education.

Age	Years in education					
	2	3	4	5	6	7
6 years old	13 (40.6%)	14 (43.8%)	5 (15.6%)			
7 years old		7 (24.1%)	16 (55.2%)	6 (20.7%)		
8 years old	2 (4.2%)	11 (22.9%)	12 (25%)	22 (46.8%)		
9 years old	4 (10.8%)	1 (2.7%)	7 (18.9%)	9 (24.3%)	16 (43.2%)	
10 years old			3 (13%)	6 (26.1%)	4 (17.4%)	9 (39.1%)
11 years old				9 (52.9%)	2 (11.8%)	6 (35.3%)

## ***Background factors***

### 1. Type of educational provision

As described previously in the section on deaf children in the Introduction chapter, there are three types of educational provision for deaf children: mainstream schools, ‘units’ or ‘departments’ for hearing impaired children in mainstream schools and special schools for the deaf.

In the present study, children are almost equally distributed between special schools for the deaf and units for hearing impaired whereas a smaller number of children attend mainstream schools (see Table 3.7).

Table 3.7. Number and percentage of children by types of educational provisions of the present sample and percentage from the BATOD survey (2011).

<b>Type of educational provision</b>	<b>Number of children</b>	<b>Percentage in this study</b>	<b>Percentage from the BATOD survey (2011)</b>
Special school	64	34.4	18.0
Unit for hearing impaired	75	40.3	24.0
Mainstream	47	25.3	58.0

In order to evaluate the representativeness of this sample, it was compared with that obtained by the BATOD survey in 2011 (see Table 3.7). In the BATOD survey, the majority of the children (58.0%) attended mainstream schools followed by those who attended mainstream schools with a unit for hearing impaired (24.0%). Only 18% of the BATOD sample attended special schools for the deaf. These results are in contrast with those found in the present research where there are fewer children attending mainstream schools than mainstream with a unit for hearing impaired and special schools for the deaf. There could be different explanations for the difference observed between the data reported in the present research and those obtained in the BATOD survey (2011). This difference

could be due to the exclusion of children with a mild loss from the present study or to a different rate of response between the BATOD survey and the present research. In the BATOD survey, the rate of response of mainstream schools with a unit for hearing impaired (61.5%) and mainstream (56.0%) was higher compared with that of school for the deaf (46.0%) whereas, in the present sample, fewer mainstream schools took part in the research compared with those that had a unit for the deaf and special schools for the deaf. A discrepancy in the results of the two surveys could also have resulted from the recruitment method used in the present study. In order to recruit as many deaf children as possible in as many areas as possible, Teachers of the Deaf were contacted, but these teachers only work in mainstream schools if they are peripatetic teachers. For this reason, only in the cases where the peripatetic teachers agreed to participate to the study would the school have been included.

## 2. Language used at home

It was not possible to obtain information about the language used at home for 7 of the children and they were considered as missing data. For the rest of the sample, the majority of the children speak English as their first language; 3.8% (7 children) used British Sign Language at home and 16.7% used another language that was not English (see Table 3.8). These languages were Russian, Punjabi, Urdu, Malaysian, Bengali, Farsi, Slovakian, Albanian, Arabic, Hindi, Edurati, Igala, Somali, Polish, Tamail, Turkish and Sylheti. Although these are very different languages, they were grouped in the same category because the aim of collecting this information was to investigate whether or not using English at home could affect deaf children's performance in mathematics.

The BATOD survey (2011) also reported data on the language used at home by deaf children. The percentages of children speaking English as their first language or of

those who used another language at home reported in the present sample are quite similar to those presented in the BATOD survey (2011) (Table 3.8). In both survey studies, more than 70% of the sample was English native speakers whereas around 17% used a language other than English at home. A difference in the results between the present study and the BATOD survey is found when children who use sign language at home is analysed. In the present research, only 3.8% of the children used sign language at home whereas, in the BATOD survey (2011), 9.0% of the deaf children signed at home. Although there is a difference between the two surveys in terms of children using sign language, it is possible to conclude that the sample is representative of deaf primary school population.

Table 3.8. Number and percentage of children by language used at home.

<b>Language used at home</b>	<b>Number of children</b>	<b>Percentage in this sample</b>	<b>Data from the BATOD survey (2011)</b>
English	148	79.6	73.0
Not English	31	16.7	18.0
BSL	7	3.7	9.0

### 3. Highest level of maternal education

Table 3.9 shows the highest level of educational qualification obtained by the mothers of the deaf children in this sample. The term “school leaver” refers to those parents who did not obtain any type of qualification. For 50 (26.9%) cases it was not possible to obtain information about this aspect. This data was considered as missing data. For the remaining cases, the majority (33.9%) left school before achieving GCSE followed by those who obtained any GCSEs (15.1%), A-levels (8.6%) or a degree (15.6%). It is important to note that there is variability in maternal education and all the levels are presented in the sample; this sort of variability was associated with moderate and significant correlations with outcomes in mathematics for hearing children (Nunes et al., 2009d).

In order to compare the present sample with another sample of deaf children, the data analysed by Gottardis (2009) was considered. She considered the data of maternal educational qualification of 86 deaf children obtained from the ALSPAC database. In this sample, the majority of the mothers of these children obtained GCSE levels (48.8%) followed by A-levels (30.2%), degrees (10.5%) and 5.8% were school leavers. These results are in contrast with those found in the present sample where the majority of the mothers are school leavers. This discrepancy in the results could be due to the difference in the cohorts considered. In the ALSPAC database, degree of hearing loss of the children ranged between mild and moderate excluding all the children with more profound levels of hearing loss. It is also possible that the response rates of children of deaf parents may be under-representative

Table 3.9. Number and percentage of children by highest level of maternal education in the present study and percentage from the ALSPAC database.

<b>Highest level of maternal education</b>	<b>Number of children (N=136)</b>	<b>Percentage in this sample</b>	<b>Percentage from the ALSPAC database</b>
School leavers	63	33.9	5.8
GCSE	28	15.1	48.8
A-level	16	8.6	30.2
degree	29	15.6	10.5

In conclusion, the present deaf sample can be considered to be representative of the deaf population of primary school children although few discrepancies were observed due to differences in the different cohorts considered.

### 3.3.2. Hearing children

The hearing sample is composed of 798 hearing children, 428 boys and 370 girls, classmates of children attending a hearing impaired unit based in a mainstream school. In the case of this sample, only data on number of years in education, language used at home and highest level of maternal education were collected.

#### 1. Years in education

The hearing sample attended 7 different schools around the UK (Northampton, Southall, Reading, Stoke Mandeville, Stafford, Scunthorpe, Littlehampton), which also included some of the deaf children in this sample. The age range of the sample was between 6 and 11 years. The means of number of years spent in education by children's age is presented in Table 3.10.

Table 3.10. Means and standard deviations of the number of years that children spent in school by chronological age for deaf and hearing children.

<b>Age</b>	<b>Group membership</b>	<b>Means</b>	<b>Standard deviations</b>
6 years	Hearing	2.70	.09
	Deaf	2.63	.11
7 years	Hearing	3.95	.05
	Deaf	3.97	.11
8 years	Hearing	4.73	.04
	Deaf	4.27	.08
9 years	Hearing	5.73	.05
	Deaf	5.00	.09
10 years	Hearing	6.68	.05
	Deaf	5.86	.13
11 years	Hearing	7.00	.09
	Deaf	5.82	.15

The hearing children's means of number of years spent in education are higher than those of deaf children (see Table 3.10). In order to verify whether this difference is significant, an analysis of variance was conducted considering age as a between subjects factor. There was a significant effect of age on the number of years in education ( $F_{(5,996)} = 421.31, p < .001$ ) and a significant effect of group membership on the number of years in education ( $F_{(1,996)} = 102.96, p < .001$ ). A significant effect of the interaction factor between age and group membership on the number of years in education was observed ( $F_{(5,996)} = 11.01, p < .001$ ). These results mean that there is a significant difference between deaf and hearing children in terms of years in education. For this reason, when the comparison between these two samples is carried out, years in education was taken into account as covariate.

## 2. Language used at home

It was not possible to obtain information about the language used at home for 39 children and they were considered as missing data. For the remainder of the sample (N=759), similarly to the deaf sample, the majority of children speaks English as a first language and only 19% use another language (see Table 3.11).

Table 3.11. Number and percentage of children by language used at home for hearing and deaf children.

<b>Language used at home</b>	<b>Hearing children</b>	<b>Deaf children</b>
English	606 (75.9%)	152 (78.8%)
Not English	152 (19%)	34 (17.6%)

### 3. Highest level of maternal education

For 21.2% of the hearing sample it was not possible to obtain information on the highest level of maternal education and it was considered as missing data. Table 3.12 summarises this information for the remainder of the sample (N=629). Half of the hearing mothers achieved GCSE level of education, 27% were school leavers, 9.6% obtained an A-levels or a vocational qualification and only 3.4% of them had a degree. In comparison to deaf children, in the hearing sample, fewer mothers were school leavers and the majority achieved GCSEs, but at the same time, there were fewer mothers with higher qualification levels such as A-levels or a degree.

An ordinal value was attributed to the different levels of maternal education: 1 to absence of qualification (school leavers) to 5 for the highest level of qualification (degree). In order to verify whether there is an association between this variable and the group membership (deaf or hearing), a non-parametric correlation using the Kendall's tau<sub>b</sub> was carried out. No significant correlation was observed between group membership (deaf or hearing) and highest level of maternal education ( $r = .007$ ,  $p = .79$ ). For this reason, highest level of maternal education was not taken in consideration as a covariate when the two samples are compared in terms of their mathematical achievement.

Table 3.12. Number and percentage of children by highest level of maternal education for hearing and deaf children.

Highest level of maternal education	Hearing children	Deaf children
School leavers	170 (27.0%)	65 (46.4%)
GCSE	315 (50.0%)	30 (21.4%)
Vocational	61 (9.6%)	----
A-level	61 (9.6%)	16 (11.4%)
degree	22 (3.5%)	29 (20.7%)

In conclusion, compared with the deaf sample, the hearing sample differs only in regard to years in education whereas significant differences were not observed in relation to language used at home and highest level of maternal education. Years in education was taken into account as a covariate when the two samples are compared.

### **3.4. Outcome measure: Performance Indicators in Primary**

#### **School (PIPS)**

This measure was used to assess children's mathematical achievement. It is designed by the Centre for Evaluation and Monitoring (CEM) at Durham University to monitor the pupils' achievement, and their progress throughout primary school (Tymms et al., 2003).

Its assessments include curriculum-based tests in mathematics, reading and science, along with an ability assessment which consists of a vocabulary and non-verbal ability test. This measure was chosen for three main reasons. First, all the assessments take the form of paper and pencil tests, which are quick and easy to administer and yet provide reliable measures. Second, the CEM center has adapted this assessment for children with special educational needs. In particular, they have developed instructions for children with hearing impairment and for children using British Sign Language. Third, it has been successfully used in previous research with deaf children (e.g. Tymms et al., 2003). The reliability of the test is .93 (Cronbach's alpha).

In this research, the mathematics test was used. There are three different versions of the tests for children from Year 1 to Year 6: one was designed to assess children's mathematical abilities in Year 2, another one for children in Year 4 and one for children in Year 6. In the Year 2 assessment, the questions use only two-digit numbers and require addition and subtraction, simple multiplications and fractions, solving problems with one

step, reading graphs and geometry (such as recognition of geometrical figures and simple symmetry). The other assessments involve the same types of mathematical aspects covered by the test for Year 2 but at a more demanding level. For example, they require calculation and reasoning with three digit numbers, decimals and solving problems with two or more steps. If the test for Year 2 was used, a ceiling effect would be likely to be found in hearing children above Year 2, whereas a floor effect would be observed if the age-appropriate test was used with deaf children. Previous research (Traxler, 2000) with deaf children has excluded from the study those children whose teachers expected them to be frustrated by the age appropriate test; this has resulted in biased sampling of deaf children. Because the focus of the current project was to evaluate deaf children's mathematical abilities, a test considered appropriate for the deaf children was used to compare deaf children's performance with that of hearing children on the same test. Thus, this study employed the Year 2 assessment as the initial estimate of deaf children's mathematical ability for all age levels. This assessment had also already been adopted for presentation to deaf children. The reliability of the maths test for Year 2 is of .90 (Cronbach's alpha).

In order to overcome the problems related to a ceiling effect, an analysis of the distribution of the PIPS maths total score for hearing and deaf children was carried out. In the case of the presence of a non-normalised distribution, the scores were transformed in order to obtain a normalised distribution, as suggested by Field (2009).

## **Procedure**

As pointed out before, the instructions for this assessment were adapted for deaf children who sign by a deaf researcher from CEM. In order to avoid unnecessary frustration among deaf children, and because the items are ordered by level of difficulty, administration to deaf children was in two sessions, the first of which covered 22 items. Children who

attained a score of at least 19 on the first set of items, which corresponds to 50% of the items in the total test, completed the assessment for Year 2. The test was administered individually and in the communication mode most appropriate for the child, either signed supported or oral English.

The hearing children of all age levels took the same test as a class. The researcher read out each item of the test following the same procedures used with deaf children. It is possible that deaf children may have had an advantage in having one-to-one administration compared with hearing children. However, there were two reasons for using individual administration with deaf children. The first pertained to uniformity: in some schools, there is only one deaf child and consequently administration would have to be individual. The second reason was that it was considered appropriate to aim at attaining the best performance from the deaf children by giving each child sufficient time to think about the question. If a difference were to be found between hearing and deaf children, it would be less likely that it could be explained by administration procedure.

For the purpose of comparing deaf and hearing children, hearing children's scoring was paralleled to the system used with deaf children: children who attained a score of at least 19 in the first set of items were awarded further points on the basis of their performance in the second set of items. This maneuver is equivalent to the use of a stopping rule in a graded test: the test was discontinued if the children's score was less than 19.

The test was marked according to the published instructions scoring 1 for a correct answer and 0 for a wrong answer.

### **3.5. Results**

The results are presented in four main sections. The first section presents a preliminary analysis on the distribution of the total scores of the PIPS in order to verify whether the scores are distributed normally. The second section presents the analysis of the predictors of deaf children's mathematical achievement in order to identify those factors that need to be controlled for when deaf and hearing children's performance in mathematics is compared. The third section aims to determine the extent of deaf children's delay in mathematics comparing their mathematical performance with that of hearing children after controlling for those factors that have been found to be significant predictors of deaf children's mathematical achievement. The fourth section aims to verify whether age, years in education and types of educational provision are moderators of the extent of deaf children's delay in mathematics.

#### **3.5.1. Preliminary analysis on the PIPS maths test distribution**

In this section, the distribution of the total scores of the PIPS maths test is examined in order to verify whether it is normalised. The distribution of the deaf children's performance on the PIPS maths test showed a positive skewness (the raw data are reported in the Appendix C1). In order to normalise the data, as suggested in Field (2009), a square root transformation was carried out. This transformation brings any larger scores closer to the centre. After this transformation, the distribution was normalised as it is possible to observe from the z values obtained dividing the skewness results with the standard error and the z values obtained dividing the Kurtosis value with the standard errors of Kurtosis in Table 3.13. The following analyses were carried out using these transformed data.

Table 3.13. Skewness values, standard error, z scores, Kurtosis value, standard error of Kurtosis and z scores of the distribution of scores of the PIPS maths test by age.

Age	Skewness value	Standard error	z	Kurtosis	Standard error	z
6 years	.21	.41	.51	.84	.81	1.03
7 years	.56	.43	1.35	-.23	.84	-.27
8 years	.47	.34	1.23	.23	.67	.34
9 years	.47	.38	1.23	.95	.71	1.33
10 years	.49	.48	1.02	-1.13	.93	-1.21
11 years	.03	.55	.05	-1.87	1.06	-1.76

### 3.5.2. Analysis of the predictors of deaf children's mathematical achievement

In the introduction section, nine factors were hypothesised to be predictors of deaf children's mathematical achievement. These were age, years in education, gender, causes of hearing loss, type of amplification, use of cochlear implant, type of educational provision, language used at home, highest level of maternal education and degree of hearing loss.

In this section, these hypotheses were tested in order to determine the factors that need to be considered when deaf children's performance in mathematics is compared to that of hearing children. Some of these factors (e.g. age) pertain to both samples (deaf and hearing children) whereas others (e.g. causes of hearing loss) are related only to the deaf sample. In the first case, if the factor significantly relates to deaf children's mathematical achievement, it will be considered as a covariate. In the second case, the factor will be used as a between-subjects factor.

The type of analyses used differs according to the nature of the variable considered. If the independent variable was continuous (e.g. age and years in education), a correlation

analysis was carried out followed by a regression analysis. Highest level of maternal education has been considered in previous research as a continuous variable (Tymms et al., 2003) and will therefore be analysed through a correlation between this factor and deaf children's mathematical achievement. Previous studies (Wood et al., 1983) have also treated degree of hearing loss as a continuous variable (from the less to more severe levels of hearing loss). For this reason, a correlation analysis between degree of hearing loss and deaf children's mathematical achievement was carried out followed by a regression analysis.

If the independent variable was categorical with two levels (e.g. gender, type of amplification, causes of hearing loss and language used at home), an analysis of covariance was used instead of a simple t-test because it was necessary to control for other variables that were observed to be significant in previous analyses (age and years in education).

If the independent variable was a categorical variable with three levels (type of educational provision), analyses of covariance were carried out comparing two levels at a time after controlling for age and degree of hearing loss. This approach was used because it was the only one that allows us to carry out all the comparisons when the categories in the independent variable cannot be treated as ordered.

In the following sections, the results of these analyses are presented, reporting first the results for the variables that relate to children factors followed by those related to background factors. The analyses conducted on degree of hearing loss are reported as the last factor because in order to determine whether degree of hearing loss is an independent contributor to deaf children's mathematical achievement, it was necessary, first, to determine whether there are other factors that predict deaf children's mathematical achievement and, then, control for them in the regression analysis that considered degree

of hearing loss as predictor and deaf children’s mathematical achievement as the outcome measure.

1. Age and years in education

It was hypothesised that there is a significant and positive correlation between age and deaf children’s mathematical achievement. A similar result was expected to be seen in the case of years in education.

Table 3.14 reports the correlation between age and years in education and deaf children’s mathematical achievement. Both age and years in education were significantly positively related to deaf children’s mathematical achievement.

Table 3.14. Correlation between age, years in education and deaf children’s mathematical achievement.

<b>Outcome measure</b>	<b>Age</b>	<b>Years in education</b>
PIPS maths test	.53**	.49**

\*\*p<.01.

Because these two factors are related to each other and they measure similar aspects, it is important to understand whether they explain a significant and independent amount of variance in deaf children’s mathematical achievement. For this reason, two regression analyses were carried out. Both these analyses have as dependent variable PIPS maths score. In the first regression, age was entered as the first factor and years in education as the second factor, whereas in the second regression, the steps were inverted. The technique of the regression analysis implemented was that of a fixed order regression equations that allows the researcher to partial out the effects of the variables that must be controlled for because they have a significant association with mathematics. The assumptions of normality, linearity and heteroscedasticity were satisfied by the model (see Appendix C1). The results demonstrated that no perfect multicollinearity (strong correlation between two

or more predictors) existed within the data because the value of the variance inflation factor (VIF) was not greater than 10 and the value of tolerance statistic was not below .1. The residual terms were uncorrelated: the value of Durbin-Watson test was quite close to 2 (Field, 2009).

Table 3.15 and Table 3.16 report the standardised and non-standardised coefficients for the first regression and the second regression respectively.

Table 3.15. The non-standardised and standardised regressions coefficients for age and years in education; PIPS maths test as outcome measure.

Steps	R <sup>2</sup>	Adjusted R <sup>2</sup>	R <sup>2</sup> change	B	SEB	β
Age	.21**	.20**	.21**	.23	.07	.31***
Years in education	.23**	.23**	.02**	.17	.07	.22**

\*\* .p<.01; \*\*\* .p<.001.

Table 3.16. The non-standardised and standardised regressions coefficients for age and years in education; PIPS maths test as outcome measure.

Steps	R <sup>2</sup>	Adjusted R <sup>2</sup>	R <sup>2</sup> change	B	SEB	β
Years in education	.18**	.18**	.18**	.17	.07	.22**
Age	.22**	.22**	.05**	.23	.07	.31***

\*\* .p<.01; \*\*\* .p<.001.

From these tables, it is possible to observe that age and years in education are independent contributors of deaf children's mathematical achievement. It is important to point out that years in education explains only 2% of the variance after controlling for age whereas age explains 5% of the variance after controlling for years in education. For these reasons, age and years in education are both entered as covariates factors in the following analyses.

## 2. Gender

An examination of the results in the PIPS mathematics test by gender in the present study can investigate whether there is a relation between gender and deaf children's mathematical achievement.

Table 3.17. Adjusted means and standard errors of the PIPS maths test by gender, after controlling for age and years in education.

<b>Gender</b>	<b>N</b>	<b>Adjusted Means</b>	<b>Standard errors</b>
Male	94	3.56	.10
Female	90	3.55	.10

Analysis of covariance comparing gender and mathematical achievement with age and years in education as covariates showed that the covariates were significantly related to mathematical achievement (age:  $F_{(1,184)} = 11.71$ ,  $p < .01$ ; years in education:  $F_{(1,184)} = 5.74$ ,  $p < .05$ ). There was no significant effect of gender on mathematical achievement after controlling for age and years in education ( $F_{(1,184)} = 0.01$ ;  $p = .91$ ). Therefore, gender is not included as a covariate in the following analyses.

## 3. Causes of hearing loss

There are three main causes: genetics, related to pregnancy and post-birth diseases. It is important to point out that for almost half of the sample, no causes of the hearing loss were identified. These cases were treated as missing values. As suggested by Jensema (1975), the causes of hearing loss are grouped in two categories: those induced by hereditary factors and those caused by illness or trauma. This last category refers mainly to events that happened during the pregnancy or the post-birth period.

In the present study, it was hypothesised that, first, there is a relation between the degree of hearing loss and the causes of deafness and, second, causes of hearing loss is a predictor of deaf children's mathematical achievement: children whose deafness is due to

hereditary causes perform better than those whose deafness was caused by other factors. A chi-square analysis was conducted between the degree of hearing loss and the causes of hearing loss. Table 3.18 reports the number and percentage of children with hereditary causes of hearing loss or with other causes by degree of hearing loss. The distribution of the number of children by degree of hearing loss is very similar between those having a hereditary cause of hearing loss and those whose deafness is caused by other factors.

Table 3.18. Number and percentage of children with or without hereditary causes of hearing loss by degree of hearing loss.

<b>Type of causes</b>	<b>Moderate</b>	<b>Severe</b>	<b>Profound</b>
Hereditary	11 (20.8%)	9 (17.0%)	33 (62.3%)
Non hereditary	15 (24.6%)	12 (19.7%)	36 (55.7%)

The chi-square analysis did not show a significant association between the degree of hearing loss and the causes of hearing loss ( $\chi^2_{(1,2)} = 500$ ;  $p = .78$ ). This result did not confirm that reported by Fortnum, Marshall and Summerfield (2002). In their study, Fortnum, Marshall and Summerfield (2002) grouped the causes of hearing loss in genetic, syndromal, prenatal, perinatal and postnatal. In the present study, it was not possible to follow this categorization due to the small number of cases in each category. It is therefore possible that the different categorisation of the causes of hearing loss used in the two studies is the reason why of the discrepancy in the results between the two studies. Although this difference is observed, it does not affect the main investigation on whether causes of hearing loss and deaf children's mathematical attainment are related.

Second an analysis of covariance was conducted including as covariates age and years in education. Table 3.19 reports the adjusted means and standard errors of the PIPS maths test after controlling for age and years in education by the causes of deafness.

Table 3.19. Adjusted means and standard error in the PIPS maths test by causes of hearing loss, after controlling for age and years in education.

<b>Causes of hearing loss</b>	<b>N</b>	<b>Adjusted Mean</b>	<b>Standard error</b>
Hereditary	53	3.50	.14
Non hereditary	61	3.25	.13

Both the covariates were significantly related to deaf children's mathematical achievement (age:  $F_{(1,114)} = 6.68$ ;  $p < .01$ ; years in education:  $F_{(1,114)} = 8.51$ ;  $p < .01$ ). No significant effect was observed between the causes of hearing loss and deaf children's mathematical achievement ( $F_{(1,114)} = 1.63$ ;  $p = .20$ ). Therefore, causes of hearing loss cannot be considered a predictor of deaf children's mathematical achievement and it was not taken into account in the following analyses.

#### 4. Type of amplification

It was hypothesised that the presence of cochlear implants is related to the degree of hearing loss and that the type of amplification is a predictor of deaf children's mathematical achievement. It was also expected that children with cochlear implants would perform better than those with other types of amplification.

Primarily, the first hypothesis regarding the presence of a relation between the presence of cochlear implant and the degree of hearing loss was verified. It is possible that children who have a cochlear implant have more severe degrees of hearing loss whereas those who do not use cochlear implants present milder degrees of hearing loss. The degree of hearing loss reported in the current study refers to the amount of hearing that children have after the implant. If there is a relation between degree of hearing loss and cochlear implant, this could confound the relation between the presence of cochlear implant and deaf children's mathematical achievement. Table 3.20 reports the degree of hearing loss by

the presence or absence of cochlear implant. For the children with cochlear implants, almost three quarters of them are profoundly deaf and only 14% are moderate or severe. Those who used another type of amplification are almost equally distributed between the different levels of hearing loss.

Table 3.20. Presence or absence of cochlear implant by degree of hearing loss.

<b>Degree of hearing loss</b>	<b>Absence of cochlear implant</b>	<b>Presence of cochlear implant</b>
Moderate	36 (33.3%)	11 (14.1%)
Severe	34 (31.4%)	11 (14.1%)
Profound	38 (35.1%)	56 (71.8%)

A chi-square test was carried out to investigate whether there is a relationship between degree of hearing loss and presence or absence of cochlear implant. This analysis showed a significant relation between these two variables ( $\chi^2_{(4)} = 26.62, p < .01$ ). For this reason, the degree of hearing loss was considered as a covariate in analysis that investigates the effect of cochlear implant.

Table 3.21 reports the adjusted means and standard errors of the PIPS maths test by the type of amplification after controlling for age, years in education and degree of hearing loss.

Table 3.21. Adjusted means and standard errors in the PIPS maths test by type of amplification, after controlling for age, years in education and degree of hearing loss.

<b>Type of amplification</b>	<b>N</b>	<b>Adjusted means</b>	<b>Standard errors</b>
Cochlear Implant	77	3.34	.10
Absence of cochlear implant	107	3.58	.12

An analysis of covariance between the presence or absence of cochlear implant and the scores on the mathematics subtest of the PIPS was carried out controlling for age, years in education and degree of hearing loss. The analysis showed that all the covariates (age:

$F_{(1,184)}= 13.85$ ;  $p < .01$ ; years in education:  $F_{(1,184)}= 8.34$ ;  $p < .01$ ; degree of hearing loss:  $F_{(1,184)}= 4.72$ ;  $p < .01$ ) were significantly related to deaf children's mathematical achievement. There was no significant effect of the presence or absence of cochlear implant ( $F_{(1,184)}= 2.12$ ;  $p = .15$ ) on the scores of the PIPS maths test.

This analysis suggests that the presence or absence of cochlear implant per se does not affect deaf children's performance in mathematics after controlling for age, years in education and degree of hearing loss. For this reason, this variable is not taken into account in the following analyses.

#### 5. Use of cochlear implant

As pointed out by Nunes, Pretzlik and Ilicak (2004), it is possible that the presence of a cochlear implant per se may not be what matters but how much the child is benefitting from it.

A Pearson's correlation analysis was conducted in order to investigate whether the factor's total scores were correlated with children's mathematical performance. A positive significant correlation was observed only between the children's results on the PIPS and the first factor ( $r = .37$ ,  $N = 31$ ;  $p < .05$ ). This means that the more the children are independent and the better they use the cochlear implants, the higher are the scores in the PIPS mathematics test. This result confirms further the necessity to analyse not only the presence or absence of cochlear implant but also the way in which the cochlear implant is used by the child. Thus, it is possible that the use of cochlear implants moderates the extent of delay that deaf children show in mathematics in comparison with hearing children. Because of the low rate of responses obtained in the present study, it is not possible to reach a conclusion in relation to this issue. There is therefore the need to replicate this investigation with a larger sample. Nevertheless, from these results, it seems that how

children are using the cochlear implant is what matters in relation to deaf children's mathematical skills and not the presence or absence of the cochlear implant in itself.

#### 6. Type of educational provision

As reported before in the rationale, there could be a relation between type of educational provision and degree of hearing loss: children with more profound degrees of hearing loss attend special schools for the deaf and children with milder levels of hearing loss are attending mainstream schools. In order to investigate this relation, a chi-square analysis between degree of hearing loss and type of educational provision was carried out. Table 3.22 reports the number and percentage of children attending the three types of schools by degree of hearing loss. It is possible to observe that, in comparison to special schools for the deaf where the majority of the children are profoundly deaf, in mainstream schools, there are more deaf children with moderate hearing loss. In the schools with a unit for hearing impaired, there is almost an equal distribution of children between the three categories of hearing loss.

Table 3.22. Number and percentage of children in the different types of schools by degree of hearing loss.

<b>Degree of hearing loss</b>	<b>Mainstream</b>	<b>Unit for hearing impaired</b>	<b>Special schools for the deaf</b>
moderate	23 (48.9%)	20 (42.6%)	4 (8.5%)
severe	16 (34%)	19 (40.4%)	12 (25.5%)
profound	9 (9.1%)	36 (36.4%)	54 (54.4%)

The chi-square analysis shows a significant association between the degree of hearing loss and the types of educational provision ( $\chi^2_{(1,4)} = 43.39$ ;  $p < .001$ ). Therefore, the degree of hearing loss was considered a covariate in analyses that investigate the effects of

different types of educational provision on mathematical achievement. The results of this analysis must be interpreted with caution due to the small number of moderately deaf children in special schools and of profoundly deaf children in mainstream schools.

Type of educational provision was also identified to be a predictor of deaf children's mathematical achievement and it was expected that children attending mainstream schools would perform better than those in special schools for the deaf. In the present sample, a similar trend was observed (see Table 3.23). Children in mainstream schools obtained the highest scores in mathematics followed by those in units for hearing impaired and those in special schools for the deaf.

Table 3.23. Adjusted means and standard errors of the PIPS maths test by type of educational provision, after controlling for age, degree of hearing loss and years in education.

<b>Type of school</b>	<b>N</b>	<b>Adjusted means</b>	<b>Standard errors</b>
Mainstream school	48	4.05	.16
Unit for hearing impaired	75	3.41	.12
Special school	70	3.17	.14

Because the type of educational provision is a categorical variable whose categories cannot be treated as ordered, three analyses of covariance were carried out, considering as covariates age, years in education and degree of hearing loss. The first one compared the mathematical achievement of children attending mainstream schools and those attending a unit for hearing impaired. The results showed a significant effect of the covariate age ( $F_{(1,123)} = 12.42$ ;  $p < .001$ ) on deaf children's mathematical achievement whereas the covariates, years in education ( $F_{(1,123)} = 3.18$ ;  $p = .07$ ) and degree of hearing loss ( $F_{(1,123)} = .84$ ;  $p = .35$ ) were not significantly related to deaf children's mathematical results. There was a significant effect of type of educational provision on deaf children's mathematical achievement: those children who attend mainstream schools performed better than those attending a unit for hearing impaired ( $F_{(1,123)} = 10.74$ ;  $p < .01$ ).

The second analysis compared the mathematical results of children attending special schools for the deaf and those attending mainstream schools after controlling for age, years in education and degree of hearing loss. This analysis showed similar results regarding the three covariates: age was significantly related to deaf children's mathematical achievement ( $F_{(1,122)} = 14.83$ ;  $p < .001$ ) whereas years in education and degree of hearing loss were not significantly related to deaf children's mathematical achievement (years in education:  $F_{(1,122)} = 1.57$ ,  $p = .21$ ; degree of hearing loss  $F_{(1,122)} = .22$ ;  $p = .63$ ). There was a significant effect of type of educational provision on deaf children's mathematical achievement ( $F_{(1,122)} = 15.54$ ;  $p < .01$ ). The children attending mainstream school performed better than those attending special schools for the deaf.

The third analysis considered the mathematical results of children attending special schools for the deaf and those attending units for hearing impaired, after controlling for age, years in education and degree of hearing loss. In this analysis only the covariates age and years in education were significantly related to deaf children's mathematical achievement (age:  $F_{(1,141)} = 10.68$ ;  $p < .001$ ; years in education:  $F_{(1,141)} = 7.87$ ;  $p < .01$ ). No effect of the degree of hearing loss on mathematical achievement was observed ( $F_{(1,141)} = 1.63$ ;  $p = .20$ ) or of type of educational provision on mathematical achievement ( $F_{(1,141)} = .45$ ;  $p = .49$ ).

All these analyses confirmed that the type of educational provision affects deaf children's mathematical achievement after controlling for age, years in education and degree of hearing loss. Deaf children attending mainstream schools performed significantly better than those attending special schools for the deaf and they also obtained higher scores than those attending a school with a unit for hearing impaired whereas no difference was observed between these last two types of educational provisions.

## 7. Language used at home

The children were classified in three groups: those who speak English at home, those who use another language that is not English and those who sign at home. The following analyses aim to verify whether there is a relation between the language used at home and deaf children's mathematical achievement. In particular, the mathematical skills of those children who use English or sign at home is compared to those who use another language.

Table 3.24 reports the adjusted means and standard errors of the PIPS maths test by the language used at home after controlling for age, years in education and type of educational provision.

Table 3.24. Adjusted means and standard errors by language used at home, after controlling for age, years in education and type of educational provision.

<b>Language</b>	<b>N</b>	<b>Adjusted means</b>	<b>Standard errors</b>
English	152	3.54	.08
BSL	7	4.53	.36
Not English	34	3.31	.17

In order to investigate whether the differences in mathematics between the English native speakers or those who sign and the not native speakers is significant, an analysis of covariance was carried out comparing their mathematical attainment after controlling for age, years in education and type of educational provision. In the previous section, it was observed that there was no difference between the mathematical performance of children attending a unit for hearing impaired and those attending special schools for the deaf. For this reason, these two categories were grouped together and a dummy variable was created comparing those children attending mainstream schools and those attending other types of educational provision.

All the covariates were significantly related to deaf children's mathematical achievement (age:  $F_{(1,186)} = 26.98$ ;  $p < .01$ ; years in education:  $F_{(1,186)} = 5.33$ ;  $p < .05$ ; type of educational provision :  $F_{(1,186)} = 23.03$ ;  $p < .05$ ). There was a significant effect of language used at home on deaf children's mathematical achievement ( $F_{(1,186)} = 4.75$ ;  $p < .05$ ). Planned contrast revealed that children who were English speakers did not significantly differ in their mathematical attainment in comparison to children who use another language at home ( $t_{(2)} = .23$ ,  $p = .22$ ). Children who sign at home obtained higher scores than those whose English was not their first language ( $t_{(2)} = 1.22$ ,  $p < .05$ ). These results do not support the hypothesis that children who speak English are at an advantage in mathematics compared with those who speak another language whereas it seems to confirm that children who sign at home obtain higher scores in mathematics test than those who are not English native speakers. It is important to note that there are only 7 children who sign at home. Therefore, these results need to be taken with caution and future research should be carried out to verify these results. In the following analyses, because of the small number of cases of children signing at home, language used at home was not considered as covariate.

#### 8. Highest level of maternal education

Highest level of maternal education was hypothesised to be a predictor of deaf children's mathematical achievement.

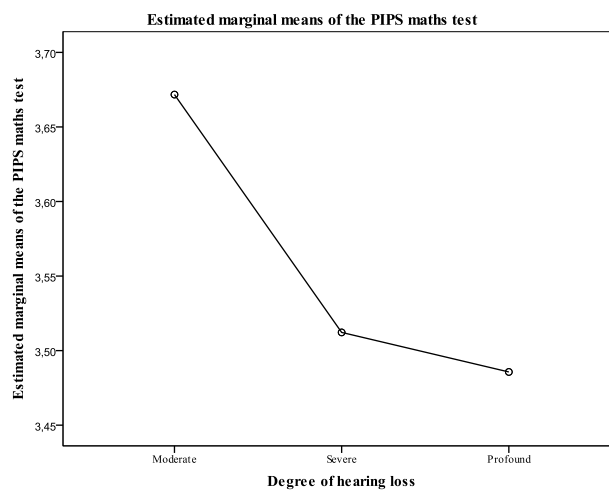
In order to address this hypothesis, a partial correlation analysis was conducted between this factor and deaf children's mathematical achievement after controlling for age, years in education and type of educational provision. No significant correlation was observed between highest level of maternal education and deaf children's mathematical achievement ( $r = .08$ ,  $p = .28$ ). For this reason, no further analysis was carried out.

## 9. Degree of hearing loss

Degree of hearing loss was hypothesised to be a predictor of deaf children's mathematical achievement and it was expected that more severe hearing losses would be associated with lower attainment scores. To investigate this relation in the present study, a correlation analysis between degree of hearing loss, the other factors found significant in the previous analyses (age, years in education, type of educational provision) and deaf children's mathematical achievement was conducted, followed by a regression analysis.

A negative significant correlation ( $r = -.15$ ;  $p < .05$ ) was found between degree of hearing loss and deaf children's mathematical achievement. Figure 3.6 shows clearly the presence of a linear relation: children with milder levels of hearing loss perform better than those with more profound levels of hearing loss.

Figure 3.6. Deaf children's performance on the PIPS maths test by degree of hearing loss, after controlling for age, years in education and type of educational provision.



A regression analysis was carried out in order to investigate whether after controlling for age, years in education and type of educational provision, degree of hearing loss explains additional variance of deaf children's mathematical achievement. The technique of the regression analysis implemented was that of fixed order regression

equations that allows the researcher to partial out the effects of the variables that must be controlled for because they have a significant association with mathematics. Age was inserted as the first step of the regression, years in education as the second step, type of educational provision as the third step and degree of hearing loss as the fourth step. The assumptions of normality, linearity and heteroscedasticity were satisfied by the model (see Appendix C1). The results demonstrated that no perfect multicollinearity (strong correlation between two or more predictors) existed within the data because the value of the variance inflation factor (VIF) was not greater than 10 and the value of tolerance statistic was not below .1. The residual terms were uncorrelated: the value of Durbin-Watson test was quite close to 2 (Field, 2009).

From Table 3.25, it is possible to observe that age, years in education and type of educational provision explain a significant amount of variance, although years in education and type of educational provision explains only 3% and 7% of the variance respectively. Age is the strongest predictor followed by the type of educational provision and years in education. After controlling for these factors, degree of hearing loss does not explain any additional variance in deaf children's mathematical achievement. For this reason, degree of hearing loss per se cannot be considered a predictor of deaf children's mathematical achievement.

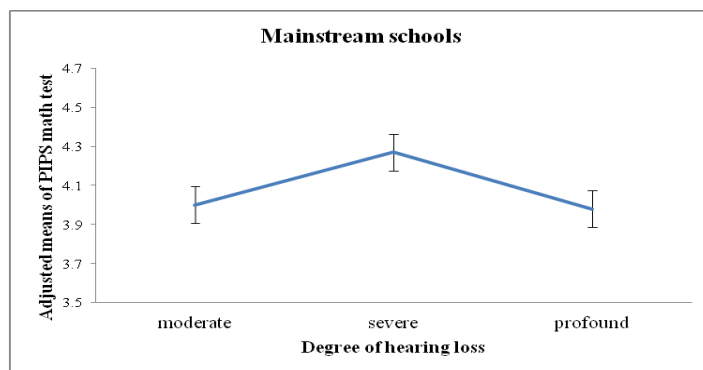
Table 3.25. The non-standardised and standardised regressions coefficients for age, years in education, type of educational provision and degree of hearing loss; PIPS maths test as outcome measure.

<b>Factors</b>	<b>R<sup>2</sup></b>	<b>Adjusted R<sup>2</sup> change</b>	<b>R<sup>2</sup> change</b>	<b>B</b>	<b>SEB</b>	<b>β</b>
Age	.28**	.27**	.28**	.33**	.08**	.42**
Years in education	.31**	.30**	.03**	.16*	.07*	.20*
Type of educational provision	.38**	.37**	.07**	.70**	.18**	.25**
Degree of hearing loss	.38	.37	.00	-.04	.05	-.06

\*, p < .05. \*\*, p < .01.

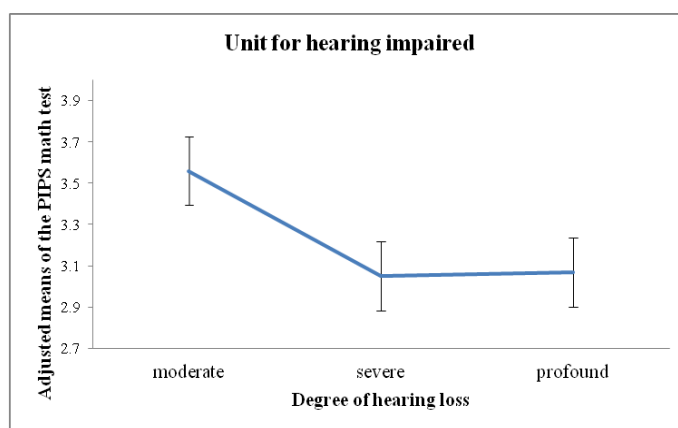
In the previous analyses, it was observed that degree of hearing loss was a confounding variable in the relation between type of educational provision and deaf children's mathematical abilities and that, after controlling for degree of hearing loss, type of educational provision continues to show a significant relation with deaf children's mathematical achievement. In this analysis, degree of hearing loss does not explain any more variance after controlling for type of educational provision. In order to investigate these contradictory results, deaf children's mathematical performance by degree of hearing loss for each of the three different types of educational provision was analysed. Figure 3.7 shows the mathematical performance of deaf children attending mainstream schools by degree of hearing loss after controlling for age and years in education. Children with milder degrees of hearing loss achieved better results than those with profound levels of hearing loss whereas severe degrees of hearing loss were performing better than those with moderate and profound degrees of hearing loss.

Figure 3.7. Adjusted means and standard errors of PIPS maths test by degree of hearing loss in mainstream schools.



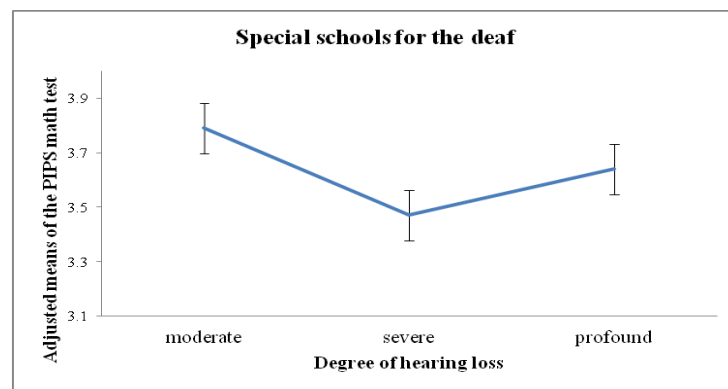
In units for hearing impaired, children with milder degrees of hearing loss obtained higher scores in mathematics compared with those with more profound degrees of hearing loss (see Figure 3.8) as observed in mainstream schools. Children with severe degrees of hearing loss performed slightly worse than those with profound degrees of hearing loss.

Figure 3.8. Adjusted means and standard errors of PIPS maths test by degree of hearing loss in unit for hearing impaired.



In special schools for the deaf, a similar trend was observed (see Figure 3.9). Deaf children with milder degrees of hearing loss achieved better results in mathematics than those with more profound degrees of hearing loss and children with severe degrees of hearing loss were performing worse in mathematics than those with profound degrees of hearing loss.

Figure 3.9. Adjusted means and standard deviations of PIPS maths test by degree of hearing loss in special schools for the deaf.



It is possible that degree of hearing loss is not a significant predictor of deaf children's mathematical achievement after controlling for type of educational provision because of the higher degree of between-groups variance of children with the same degree of hearing loss in comparison to the degree of within group of hearing loss variance. These results need to be taken with caution due to the small number of cases in each comparison. Future research should investigate these issues further with a larger number of cases.

In conclusion, deaf children's mathematical achievement is influenced by age, years in education, type of educational provision and by how well they use their cochlear implants. Children who sign at home were at an advantage compared with children who were not native speakers. In the following analyses, these factors, with the exception of the use of cochlear implant and language used at home, are taken into account when deaf and hearing children's performance in mathematics is compared.

### **3.5.3. Comparison between deaf and hearing children in their mathematical achievement**

The aim of this section is to determine the extent of deaf children's delay in mathematics in comparison to hearing children after controlling for age and years in education. Type of educational provision was found to be a significant predictor of deaf children's

mathematical achievement but it is a feature that applies only to the deaf sample. In order to take it into consideration, it would be necessary to compare the hearing sample with each type of educational provision of the deaf sample. Because of the small number of deaf children in each year for each type of educational provision, in this section, type of educational provision is not inserted as a between subject factor and only age and years in education are considered. The effect of type of educational provision on the extent of deaf children's delay in mathematics will be investigated in the later section when the analysis of the moderators is carried out.

A description of the distribution of the scores for the hearing sample is presented investigating the presence of a ceiling effect followed by the comparison of the performance of deaf and hearing children.

#### **3.5.3.1. Distribution of the scores in the PIPS mathematics test for the hearing sample**

It was hypothesised that, in the hearing sample, a ceiling effect might be observed because the same task was used for each age level. For this reason, an analysis of the distribution of the hearing sample was conducted. The distribution of hearing children's performance in the PIPS maths test was negatively skewed and high values of Kurtosis were found (the raw data are reported in the Appendix C1). In order to normalise the data, as suggested in Field (2009), two transformations were carried out. Firstly, the scores were reversed subtracting each score from the highest score obtained in the test (38). In this way, the negative skewness is transformed into a positive one that is easier to transform. Second, a square root transformation was carried out taking the square root of each score obtained from the first transformation. This transformation brings any larger scores closer to the centre (Field, 2009). After these transformations, the distribution was normalised as it is

possible to observe from the z scores obtained dividing the skewed results by the standard error and from the z scores obtained dividing the Kurtosis value by their standard error in Table 3.26. The same transformations were applied also to the deaf sample and the following analyses were carried out using these data.

Table 3.26. Skewness values, standard errors, z scores, Kurtosis value, standard error of Kurtosis and z scores of the distribution of scores of the PIPS maths test for hearing children by age.

Age	Skewness value	Standard error	z	Kurtosis value	Standard error	z
6 years	-.45	.34	-1.32	-.33	.67	-.49
7 years	.02	.18	.11	-.25	.36	-.69
8 years	-.60	.16	-.75	.59	.33	1.78
9 years	.18	.20	.86	.08	.41	.19
10 years	.21	.19	1.11	.62	.37	1.67
11 years	.12	.36	.35	.07	.72	.09

### 3.5.3.2. Comparison between deaf and hearing children on mathematical achievement

In the section on the analysis of the predictors, two main results were observed. First, degree of hearing loss was not a significant predictor of deaf children's mathematical achievement after controlling for age, years in education and type of educational provision. For this reason, in all the comparisons hearing children are compared to deaf children considered as a whole group without taking into account their different degrees of hearing loss. Second, as pointed out before, age, years in education and type of educational provision were significant predictors of deaf children's mathematical achievement. Whereas age and years in education are factors that relate also to the hearing sample, type of educational provision is a characteristic that refers only to the deaf sample. In this section, when the performance in mathematics of deaf and hearing children will be compared, only age and years in education will be considered as covariates. In the

following sections, the effect of type of educational provision on the extent of deaf children's delay in mathematics is investigated.

Figure 3.10 represents the mathematical performance of deaf and hearing children by age levels based on the transformed scores of the PIPS maths test after being subtracted from a fixed value larger than all of the scores. In this way, the comparison between deaf and hearing children is more easily interpretable because through the inversion of the transformed scores which were reversed, now high scores actually indicate high observed scores. This graph indicates that for each chronological year, hearing children outperformed deaf children in mathematical achievement. Although through the transformations used, the samples have been normalised, it is still possible to observe the presence of a ceiling effect in relation to the mathematical performance of hearing children. This will need to be taken into account in the interpretation of the results.

Figure 3.10. Deaf and hearing performance on the PIPS maths test by chronological age.

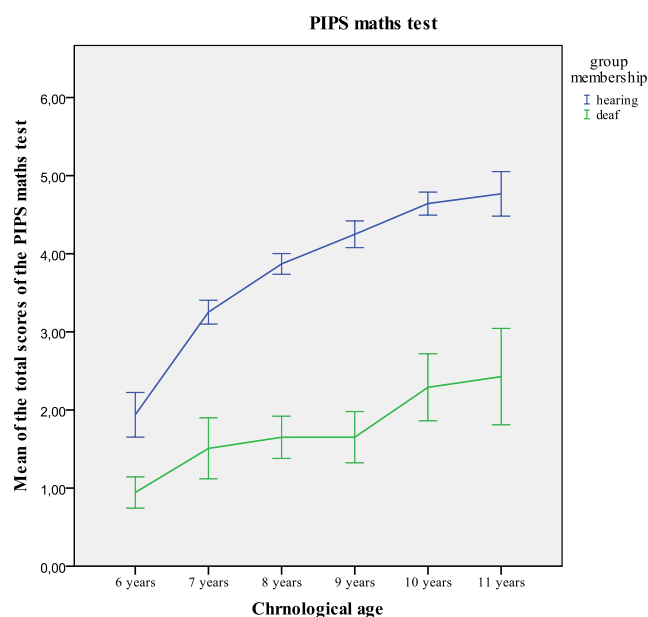


Table 3.27 reports the adjusted means and standard errors of deaf and hearing children's scores in mathematics (using the transformed scores of the PIPS maths test) by

chronological age, after controlling for years in education. It is important to note once more that, because of the transformations employed on the raw data of the PIPS maths test, now low scores correspond to high scores and high scores to low scores.

A series of analyses of covariance was conducted on the transformed scores in order to determine whether these differences in results between deaf and hearing children were significant. First, an analysis of covariance was carried out comparing the scores in the PIPS maths tests between deaf and hearing children with age and years in education as covariates in order to verify whether there was a significant overall difference between deaf and hearing children's performance in mathematics. The covariate age was significantly related to mathematical achievement (age:  $F_{(1,976)} = 416.52$ ,  $p < .001$ ), whereas years in education did not show a significant effect on deaf children's mathematical achievement ( $F_{(1,976)} = 1.04$ ,  $p = .30$ ). There was also a significant effect of group membership on mathematical achievement ( $F_{(1,976)} = 674.56$ ,  $p < .001$ ). Hearing children performed better than deaf children. Second, it was investigated whether for each year of age deaf children's performance in mathematics was significantly lower than that of hearing children of the same age. For each year of age, an analysis of covariance was conducted comparing the results of deaf and hearing children using the years in education as the covariate. Only when the children were 6 and 9 years old, the covariate years in education was significantly related to mathematical achievement (6 years old:  $F_{(1,80)} = 28.83$ ,  $p < .001$ ; 9 years old:  $F_{(1,175)} = 19.68$ ,  $p < .001$ ). The F and p values regarding deaf and hearing children are reported in Table 3.26. For each chronological year considered, a significant difference was found between deaf and hearing children's performance in mathematics.

Table 3.27. Adjusted means, standard errors, F, p values and effect sizes of the transformed reversed scores PIPS maths test for deaf and hearing by age, after controlling for years in education.

Age	Group	N	Adjusted mean	Standard error	F	p	Effect size
6 years old	Deaf	33	5.52	0.10	34.66	<.001	-.98
	Hearing	48	4.54	0.13			
7 years old	Deaf	31	4.93	0.18	67.60	<.001	-1.68
	Hearing	176	3.25	0.08			
8 years old	Deaf	54	4.86	0.13	224.50	<.001	-2.23
	Hearing	215	2.63	0.06			
9 years old	Deaf	34	4.38	0.17	109.50	<.001	-2.10
	Hearing	140	2.31	0.08			
10 years old	Deaf	22	4.17	0.20	114.07	<.001	-2.31
	Hearing	169	1.86	0.07			
11 years old	Deaf	17	3.82	0.18	20.90	<.001	-2.12
	Hearing	42	1.83	0.18			

In order to quantify the extent of the delay that deaf children have on this task, an overall effect size was calculated using the Cohen's *d* comparing the adjusted means (controlling for age and years in education) for the deaf and hearing children and dividing it by the weighted standard deviations because of the difference in the two sample sizes (Field, 2009). The effect sizes were calculated on the basis of the transformed scores of the PIPS maths test. The transformed scores were used because Cohen's *d* is based on the assumption of a normalised sample. A similar procedure was also used by Smith et al. (2002) where their sample was not normalised. In the Appendix C1, the effect sizes calculated on the un-transformed scores are reported.

The overall effect size was of -1.76. Table 3.27 reports the effect sizes calculated for each age level. There is an increase in the delay between deaf and hearing children aged from 6 to 10 years. At 9 years of age, the deaf children's delay in mathematics seems to reduce slightly but this change can be considered only as a fluctuation because at 10 years

of age, deaf children's performance drops even more compared with that of hearing children. At 11 years of age, deaf children's performance in mathematics seem to improve but this result could be due to the presence of the ceiling effect in the distribution of hearing children which makes it difficult to compare the results.

#### **3.5.4. Analysis of the moderators of deaf children's mathematical achievement**

In the previous section, it was hypothesised that age, years in education and type of educational provision were not only predictors of deaf children's mathematical achievement but also moderators of the extent of deaf children's delay in mathematics. The main aim of this section is to verify this second part of the hypothesis. In order to address this issue, it is necessary that the interaction between the moderator factor and the independent variable is significant (Baron and Kenny, 1986). As pointed out previously, because degree of hearing loss is not a predictor of deaf children's mathematical achievement, the deaf sample was considered as a whole group and was compared with the hearing sample. Therefore, the main independent variable of this analysis is group membership, deaf or hearing children.

Three analyses were conducted using the transformed scores of the PIPS maths test. Firstly, whether age is a moderator of the extent of deaf children's delay in mathematics was investigated. An analysis of variance was conducted in order to examine whether the interaction factor between age and group membership significantly influences deaf children's mathematical achievement. Table 3.28 reports the adjusted means and standard errors of PIPS maths test by age and group membership. A significant effect of group membership ( $F_{(1,988)} = 559.62$ ;  $p < .01$ ) and of age ( $F_{(1,988)} = 46.06$ ;  $p < .01$ ) on children's mathematical achievement was observed. There was a significant effect of the interaction

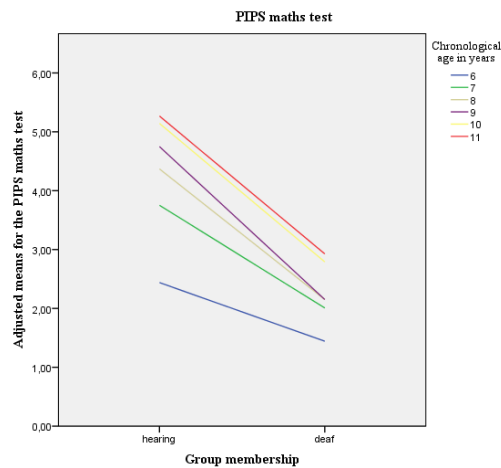
factor between group membership and children's age on children's mathematical achievement ( $F_{(1,988)} = 7.66, p < .01$ ). This result confirms that age is a moderator of the extent of deaf children's delay in mathematics.

Table 3.28. Adjusted means and standard errors of PIPS maths test by age and group membership.

<b>Chronological age</b>	<b>Group membership</b>	<b>Adjusted mean</b>	<b>Standard Errors</b>
6 years	Hearing	4.56	.97
	Deaf	5.55	1.56
7 years	Hearing	3.24	1.00
	Deaf	4.99	1.08
8 years	Hearing	2.63	.97
	Deaf	4.84	1.00
9 years	Hearing	2.25	1.00
	Deaf	4.85	1.06
10 years	Hearing	1.86	.95
	Deaf	4.21	1.02
11 years	Hearing	1.73	.92
	Deaf	4.07	1.27

In order to obtain a graphical representation of the significant influence of the interaction factor between age and group membership on children's mathematical achievement, a graph was constructed using the transformed scores subtracted from a fixed higher value (see Figure 3.11). In this way, the scores are inverted again from the transformed scores and actual high scores refer to high performance in mathematics. Deaf children in each year of age performed worse than their hearing peers. When deaf children were 8 and 9 years old, they performed as well as their hearing peers at 6 years of age. This means that older the children are, the wider the gap between deaf and hearing children in their mathematical skills.

Figure 3.11. Adjusted means of the PIPS maths test for deaf and hearing children by chronological age.



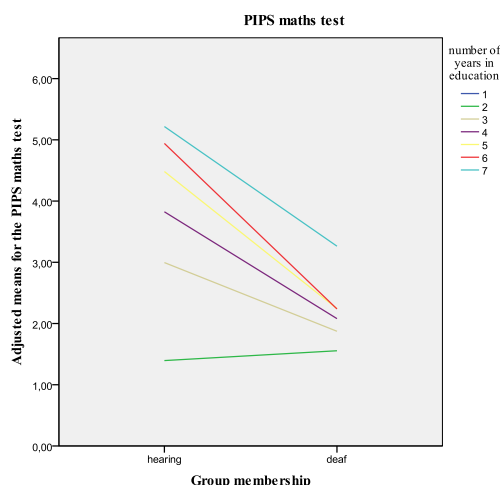
Secondly, the hypothesis that number of years spent in education is a moderator of the extent of deaf children’s mathematical attainment is examined. As for chronological age, an analysis of variance was carried out in order to verify this hypothesis. Table 3.29 reports the adjusted means, standard errors by years in education and group membership. There was a significant main effect of years in education ( $F_{(1,988)} = 51.12$ ;  $p < .01$ ) and of group membership ( $F_{(1,988)} = 296.05$ ;  $p < .01$ ) on children’s mathematical achievement. A significant effect of the interaction factor between years in education and group membership on mathematical achievement was observed ( $F_{(1,988)} = 13.97$ ;  $p < .05$ ). This means that years in education moderates the extent of deaf children’s delay in mathematics.

Table 3.29. Adjusted means and standard errors of the PIPS maths test by years in education and group membership.

<b>Number of years in education</b>	<b>Group membership</b>	<b>Mean</b>	<b>SD</b>
2 years	Hearing	5.06	.29
	Deaf	5.44	.49
3 years	Hearing	4.00	.84
	Deaf	5.12	.98
4 years	Hearing	3.17	1.05
	Deaf	4.92	1.00
5 years	Hearing	2.51	.84
	Deaf	4.75	.98
6 years	Hearing	2.06	1.03
	Deaf	4.76	1.13
7 years	Hearing	1.78	.88
	Deaf	3.73	1.24

Figure 3.12 reports the adjusted means of the PIPS maths test for deaf and hearing children by number of years spent in education. To obtain this graph, the transformed scores were subtracted from a fixed higher value. In this way, the scores are inverted again and they are easier to understand compared with the transformed scores where high scores refers to low scores. When deaf children were in school for 2 years, they perform as well as their hearing peers in mathematics but, after 7 years spent in school, deaf children obtain similar scores to those presented by hearing children after being in school for 3 years.

Figure 3.12. Adjusted means of the PIPS maths test for deaf and hearing children by years in education.



The third analysis examined whether type of educational provision is a moderator of the extent of deaf children’s mathematical achievement. Hearing children attend only mainstream schools whereas deaf children can attend three types of educational provisions: mainstream schools, units for hearing impaired and special schools for the deaf. In order to test whether the type of educational provision is a moderator of the extent of deaf children’s delay in mathematics, three comparisons were conducted to obtain means and standard deviations to use to calculate the effect sizes for each comparison. If there is a difference in the effect sizes in these comparisons, it will be possible to conclude that type of educational provision is a moderator of the extent of deaf children’s delay in mathematics. The first comparison aims to verify whether deaf children attending mainstream schools perform significantly lower than hearing children attending mainstream schools after controlling for age and years in education. The covariate age was significantly related to children’s mathematical achievement ( $F_{(1,837)}= 431.91, p< .001$ ) whereas the covariate years in education did not show a significant effect ( $F_{(1,837)}= 2.45, p= .11$ ). A significant effect of group membership on children’s mathematical achievement

was observed (see Table 3.30). Deaf children’s performances in mathematics were lower than those of their hearing peers.

Table 3.30. Adjusted means, standard errors, F and p values and effect size of the transformed reversed scores PIPS maths test for deaf and hearing children attending mainstream schools.

	<b>Adjusted means</b>	<b>Standard error</b>	<b>F</b>	<b>p</b>	<b>Effect size</b>
Deaf	4.18	.15	109.16	<.001	-1.3
Hearing	2.62	.03			

The second comparison aims to investigate whether there is a significant difference in the mathematical performance of deaf children attending a unit for hearing impaired and that of hearing children attending mainstream schools after controlling for age and years in education. The covariates age and years in education were significantly related to children’s mathematical achievement (age:  $F_{(1,862)}= 302.62, p< .001$ ; years in education:  $F_{(1,862)}=18.05, p< .01$ ). There was a significant difference between deaf and hearing children’s performance in mathematics: hearing children out-performed deaf children (see Table 3.31).

Table 3.31. Adjusted means, standard errors, F and p values and effect size of the transformed reversed scores PIPS maths test for deaf children attending unit for hearing impaired and hearing children attending mainstream schools.

	<b>Adjusted means</b>	<b>Standard error</b>	<b>F</b>	<b>p</b>	<b>Effect size</b>
Deaf	4.59	.11	302.62	<.001	-1.6
Hearing	2.62	.03			

The third comparison verified that deaf children attending special schools for the deaf performed significantly lower than hearing children attending mainstream schools after controlling for age and years in education. The covariate age was significantly related to children’s mathematical achievement ( $F_{(1,857)}= 408.35, p< .01$ ), whereas years in

education did not show any relation to children’s mathematical achievement ( $F_{(1, 857)} = .02$ ,  $p = .87$ ). A significant effect was observed between group membership and children’s mathematical achievement. Deaf children achieved lower scores in mathematics than hearing children (see Table 3.32).

Table 3.32. Adjusted means, standard errors, F and p values and effect size of the transformed reversed scores PIPS maths test for deaf children attending special schools for the deaf and hearing children attending mainstream schools.

	<b>Adjusted means</b>	<b>Standard error</b>	<b>F</b>	<b>p</b>	<b>Effect size</b>
Deaf	5.06	.12	386.27	<.001	-2.05
Hearing	2.62	.03			

In order to determine the extent of the delay between deaf and hearing children in these comparisons, effect sizes were calculated using the Cohen’s *d* comparing the adjusted means (controlling for age and years in education) for the deaf and hearing children and dividing it by the weighted standard deviations because of the difference in the two sample sizes (Field, 2009). The effect sizes were calculated on the basis of the transformed scores of the PIPS maths test. As reported before, this was chosen because the calculation of the Cohen’s *d* is based on the assumption of a normalised distribution.

When deaf and hearing children attending mainstream schools were compared, the effect size was -1.3 SD. In the case of the comparison between hearing children attending mainstream schools and deaf children attending a unit for hearing impaired, this delay increases slightly presenting an effect size of -1.6 SD. A bigger increase in the effect size is observed when hearing children attending mainstream schools and deaf children attending special schools for the deaf are compared. In this case, the effect size is -2.05 SD.

Therefore, it is possible to conclude that type of educational provision is a moderator of the extent of deaf children's delay in mathematics.

In conclusion, the present findings confirm that age, years in education and type of educational provision are moderators of the extent of deaf children's delay in mathematics.

### **3.6. Overall summary and discussion**

The present research aimed to evaluate the extent of deaf children's delay in mathematics in the UK and to investigate moderators and predictors of the extent of deaf children's delay in mathematics.

On the basis of the literature, it was hypothesised that age, years in education, type of educational provision could be predictors and moderators of the extent of deaf children's delay in mathematics. It was also predicted that gender, degree of hearing loss, causes of deafness, type and use of cochlear implant, language used at home and highest level of maternal education could influence deaf children's mathematical achievement. If the presence of these relations were found to be significant, they would be taken into account in the comparison between deaf and hearing children's performances in mathematics in order to obtain a more accurate quantification of the extent of deaf children's delay in mathematics.

In the following paragraphs, the results for each of the predictors and moderators hypothesised are discussed, followed by the results on the extent of deaf children's delay in mathematics.

## **Analyses on the predictors and moderators**

### **1. Age and years in education**

Age and years in education were found to be significantly and positively related to deaf children's mathematical achievement. This means that the older the children get and the more years of school they attend, the higher their mathematical performance. This result supports the hypothesis that age and years in education are predictors of deaf children's mathematical achievement and it is in line with the findings reported in previous studies with deaf (Moreno, 2000; Pollard and Oakland, 1985) and hearing children (Nunes et al., 2012).

Because age and years in education are strongly related, whether they are independent contributors in predicting deaf children's mathematical achievement was investigated. The results showed that age and years in education independently predict deaf children's mathematical achievement. In particular, after controlling for years in education, age seems to predict slightly more variance of deaf children's mathematical achievement than that predicted by years in education after controlling for age. The fact that each of these two factors influences deaf children's mathematical development is very interesting and highlights the presence of a wide heterogeneity in deaf children's population in terms of time in which they go to school.

Age and years in education have also been hypothesised to be moderators of the extent of deaf children's delay in mathematics. The analyses of variance conducted reported that the older the children are and the more years in education they spend, the wider is their delay in mathematics compared with their hearing peers. This means that, although deaf children are acquiring more mathematical skills over the years, this knowledge is not

sufficient to reduce or to maintain constant the delay that deaf children have in mathematics compared with their hearing peers. This is not a very comforting result and it highlights the importance of finding the factors that influence deaf children's mathematical development in order to reduce this delay.

## 2. Gender

In the present study, no difference was observed in the mathematical skills of male and female deaf children. This finding converges with those observed in previous studies (Wood et al., 1983; Epstein, Hillegeist and Grafman, 1994) and with the literature on hearing children which suggests that the gender gap for children is no longer statistically significant for mathematical attainment with girls catching up with boys (Mitchell and Karchmer, 2011).

## 3. Causes of hearing loss

Through the analysis of the literature, it was previously pointed out that it was possible that there was a relation between causes of hearing loss and degree of hearing loss (Fortnum, Marshall and Summerfield, 2002) and that causes of hearing loss affect deaf children's mathematical achievement (Jensema, 1975). In the present study, neither of these two predictions was confirmed. The absence of relation between causes of hearing loss and degree of hearing loss could be due to the different type of categorization used in Fortnum, Marshall and Summerfield (2002). It is also important to point out the small number of cases in the different categories could also have affected the results in the present study.

Previously, Moreno (2000) investigated also whether causes of hearing loss were related to deaf children's mathematical achievement. She also divided the causes into two categories: hereditary and non-hereditary. Children's mathematical skills were assessed

through the National Foundation for Educational Research (NFER). She reported the absence of a relation between causes of hearing loss and deaf children's mathematical achievement confirming the present findings. Although the present results need to be taken with caution due to the reduced amount of cases (for almost half of the children the causes were unknown), it is possible to conclude that the causes of deafness do not affect deaf children's mathematical abilities.

#### 4. Type of amplification

Type of amplification was hypothesised to be related to the degree of hearing loss and it was considered also as a possible predictor of deaf children's mathematical achievement, after controlling for degree of hearing loss. It could be that children with cochlear implants are more able to compensate for their hearing loss and therefore perform better than those using other types of amplification. The current results confirm the prediction regarding the presence of a relation between degree of hearing loss and type of amplification. Profoundly deaf children were more likely to be implanted than moderately deaf children who tend to use hearing aids. However, no significant difference was observed between those children who had cochlear implants and those with other types of amplifications, after age, years in education and degree of hearing loss were inserted as covariates. This result contradicts that reported in Thoutenhoofd's (2006) study, where deaf children using cochlear implant were found to perform better in mathematics than the other deaf children who were using other types of amplification. It is important to point out that when the mathematical performances of cochlear implanted children are compared with those of the other deaf children, Thoutenhoofd (2006) did not control for other factors that could affect deaf children's mathematical achievement such as degree of hearing loss and intelligence. The lack of controls in this last analysis can explain the different results found in the present

study. Thus, it seems that the presence of cochlear implant per se does not contribute substantially to improve children's mathematical achievement.

#### 5. Use of cochlear implant

Nunes, Pretzlik and Ilicak (2004) argued that, in relation to the cochlear implant, the crucial issue was how much the child is benefitting from it and not the presence of the cochlear implant in itself. In order to verify this hypothesis, it was investigated whether there was a relation between the children's use of the cochlear implants and deaf children's mathematical achievement. This was achieved through the analysis of the results on a parental cochlear implant questionnaire. Among the four factors measured in this questionnaire, only one was significantly related to deaf children's mathematical skills. The more independent the children were and the better they used the cochlear implants, the higher their achievement in mathematics. These results confirmed Nunes, Pretzlik and Ilicak's argument. However, because of the small number of responses obtained in this study, this finding needs to be taken with caution. Future research should verify further this issue with a larger sample.

#### 6. Type of educational provision

Type of educational provision was hypothesised to be a predictor and a moderator of the extent of deaf children's delay in mathematics. In the present study, a significant relation between degree of hearing loss and school placement was found. This result supports the hypothesis proposed by Gottardis, Nunes and Lunt (2011) that degree of hearing loss is a confounding variable in the relation between type of educational provision and deaf children's mathematical achievement. Children with milder degrees of hearing loss tend to attend mainstream schools more often than special schools for the deaf and vice versa.

However, these results have to be taken with caution due to the small number of cases in some of the conditions.

After controlling for degree of hearing loss, age and years in education, deaf children attending mainstream schools performed significantly better in mathematics compared with those attending units for hearing impaired or those attending schools for the deaf. No difference in the mathematical performance was observed between those children attending units for hearing impaired and those attending schools for the deaf. These results support with more evidence and more strict controls those observed by Kluwin and Moores (1985) and Lynas (1984) who observed that children attending mainstream school perform better than those attending other types of educational provision. This could mean that either deaf children are strong enough to cope in a normal classroom, or if they are in a units for hearing impaired they seem not to be benefitting much from the schools' provision. It is also possible that in mainstream schools, deaf children have higher cognitive abilities than those attending the other types of educational provision and this could be the reason why of the presence of better performance in mathematics in mainstream schools in comparison to the other two types of educational provisions. This hypothesis is going to be tested in the following chapter in which deaf children's cognitive skills were assessed.

These results have implications for the inclusion policy regarding inclusion of deaf children in mainstream school. Future research should investigate how the units for hearing impaired are used, how much time deaf children spend in the unit or in the classroom and the type of support they receive in the unit in order to understand the reasons for these results.

Because type of educational provision is a feature that relates only to the deaf sample, in order to investigate whether type of educational provision affects the extent of the delay that deaf children show in mathematics, a series of comparisons between hearing children's performance in mathematics and deaf children's performance attending the three different types of educational provisions were carried out. Each comparison showed that hearing children out-performed deaf children in mathematics after controlling for age and years in education. Through the analysis of the effect sizes, the widest delay observed (more than 2 SDs) was between hearing children attending mainstream schools and deaf children attending special schools for the deaf. In the other two comparisons, a delay of -1.6 SD was observed when deaf children attending units for hearing impaired children were compared with hearing children and of -1.3 SD when deaf and hearing children attending mainstream schools were compared. The presence of a variation in the effect sizes obtained in each of these comparisons confirmed the hypothesis that type of educational provision is a moderator of the extent of deaf children's delay in mathematics. It is quite surprising the increase in deaf children's delay in mathematics when deaf children attending units for hearing impaired are compared with hearing children. If we look at the characteristics of these children, it is possible to observe that in schools with a unit for hearing impaired, 32.1% of the children use another language that is not English at home, whereas hearing children are almost equally divided between English speakers and children who speak another language at home. In mainstream schools, only 9% of the deaf children speak another language than English at home and, in special schools for the deaf, this percentage increase slightly reaching 14.7%. It is therefore possible that the difficulties observed in mathematics in children attending units for hearing impaired could also be influenced by the difficulties in understanding the language.

## 7. Language used at home

It was hypothesised that deaf children speaking English as their first language or use BSL at home would perform better than those children who speak another language at home.

Two main findings were observed. In the current research, firstly, no significant difference was observed between those children speaking English at home and those who use another language, after controlling for age, years in education and type of educational provision.

This result is in contrast with that observed by Powers (2003) who analysed the factors that influence the mathematical performance of deaf 16 years old students. He reported that children who speak English at home perform better than those who speak another language at home. The difference between these results could be due to the different age range considered and to the type of mathematical tests used in the two studies.

Secondly, in the current research, children who sign at home performed significantly better than those who use another language at home, after controlling for age, years in education and type of educational provision. This finding seems to converge with those found in relation to reading achievement but it is in direct contrast with what was found by Nunes and Moreno (1998). They analysed deaf primary school mathematical abilities assessed through the NFER test and investigated whether using sign language at home has an effect on children's mathematical achievement. No difference in deaf children's mathematical performance was found between those children using sign language and those using another language at home. Thus, Nunes and Moreno (1998) rejected the hypothesis that language used at home could be a predictor of deaf children's mathematical achievement. Because of the small number of cases of deaf children signing at home in the present sample, future research should investigate this issue further with a wider sample in order to verify the present findings.

## 8. Highest level of maternal education

On the basis of the results of previous research (Powers, 2003), it was hypothesised that highest level of maternal education is a predictor of deaf children's mathematical achievement. In the present study, no significant correlation was observed between deaf children's mathematical achievement and highest level of maternal education leading to the conclusion that highest level of maternal education is not a predictor of deaf children's mathematical achievement. This is a surprising result in relation to those found in the literature relating to hearing and deaf children. A possible explanation of these results is that, in the literature, the studies (e.g. Powers, 2003) that have investigated whether maternal education is a significant predictor of deaf children's mathematical achievement had samples comprised of older children aged from 15 to 16 years old. It is possible that, in the deaf population, this factor influences more deaf children's performance when they are older than when they begin their education. Future research should consider this aspect with younger children in order to support this hypothesis.

## 9. Degree of hearing loss

On the basis of the study conducted by Gottardis, Nunes and Lunt (2011), degree of hearing loss was hypothesised to be a predictor of deaf children's mathematical achievement and it was expected that children with milder degrees of hearing loss would perform better than those with profound degrees of hearing loss. Although degree of hearing loss was significantly and negatively related to mathematical achievement, after controlling for age, years in education and type of educational provision, degree of hearing loss did not explain any additional variance of deaf children's mathematical achievement. This result converges with the findings of previous studies (e.g. Nunes and Moreno, 2002)

which showed that degree of hearing loss is not a predictor but a risk factor of deaf children's mathematical achievement.

In the present research, when type of educational provision was investigated, degree of hearing loss was found to be a confounding factor between the relation of type of educational provision and deaf children's mathematical skills. When degree of hearing loss did not add any additional variance to the prediction of deaf children's mathematical skills after taking into account type of educational provision, the between-group variance of children with the same degree of hearing loss was examined. Children with severe degrees of hearing loss presented a wide variation in the mathematical performance according to the different types of schools they attended. In mainstream schools, they performed better than children with more profound degrees of hearing loss whereas in units for hearing impaired and special schools for the deaf, they obtained lower levels of achievement. Due to the small number of cases in each condition, it was not possible to explore this issue further. Future research should analyse more closely the mathematical performance of severely deaf children in order to clarify the reasons for the modification in their mathematical performance according to the different types of educational provision they attend.

### **The extent of deaf children's delay in mathematics**

On the basis of the previous analyses on the predictors of deaf children's mathematical attainment, when deaf and hearing children's performance in mathematics was compared, age, years in education and type of educational provision were taken into account. Due to the nature of these factors (age and years in education are related both to deaf and hearing children whereas type of educational provision was related only to the deaf sample), two types of comparisons were carried out. The first compared deaf and hearing children's

performance controlling for age and years in education. Overall deaf children presented a delay of -1.76 SD below the mean in comparison to their hearing peers. Between 6 to 10 years of age, this delay increases over time from less than a standard deviation to more than two standard deviations. At 9 and at 11 years of age, small decreases in this delay were observed. These results have to be taken with caution because the reduction of the delay between deaf and hearing children could be due to the presence of a ceiling effect in the current data that makes the comparison between the performance of deaf and hearing children more difficult. Thus, it is possible that with an age appropriate test, the difference between deaf and hearing children in their mathematical skills would be wider than that observed in the present study. When the PIPS maths test for Year 2 was chosen as measure of children's mathematical skills, the possibility of observing a ceiling effect in relation to hearing children's mathematical achievement was predicted because of the use of a test that was designed for children younger than the age range being considered here. This measure was chosen because the main focus of the present research was to obtain the best evaluation of deaf children's mathematical abilities. Using age appropriate mathematical tests would not have allowed this because a floor effect would have been found in relation to deaf children's mathematical skills and, probably, some deaf children would have been excluded by their own teacher who may have been worried about stressing the child using an age-appropriate test, as observed in other research (Traxler, 2000).

The second type of comparisons controlled not only for age and years in education but also for the type of educational provision. They compared the mathematical performance of hearing children with that of each of the three types of educational provisions. In this comparison, the effect sizes varied from -1.3 SD when deaf and hearing children attended mainstream schools to around -2 SDs when hearing children were

compared to deaf children attending special schools for the deaf. This last type of comparison is more conservative and presents a more accurate quantification of the extent of deaf children's delay compared with that obtained in the previous analysis but due to the small number of cases in each condition, it was not possible to analyse the trend over time.

In conclusion, after controlling for age and years in education, deaf children present an overall delay of -1.76 SD in their mathematical achievement compared with hearing children. Among the factors considered as predictors and/or moderators of the extent of deaf children's delay in mathematics, age, years in education and type of educational provision were confirmed to predict and moderate the extent of this delay. The use of cochlear implants also influences deaf children's mathematical attainment and children who sign at home seem to be at an advantage compared with children who are not native speakers. These findings provide a better insight into the nature and extent of deaf children's delay in mathematics, highlighting risk and protective factors.

In order to reduce this delay and improve deaf children's mathematical abilities, the focus of the investigation now needs to shift to further enquiry about the nature of these difficulties. The following chapter will examine which are the factors that influence their mathematical learning.

## Chapter 4

### Longitudinal study

The survey study, described in the previous chapter, provided a quantification of deaf children's delay in mathematics compared with hearing children and analysed the influence of background factors on the extent of this delay. The overall extent of deaf children's delay in mathematics was around -1.76 SDs. This delay increases with age, the number of years spent in education and the type of educational provisions that deaf children attend. It ranged from less than -1 SD when deaf children start primary school to more than -2 SDs when they finish primary school and from -1.3 SD when deaf children attend mainstream schools to -2.05 SDs when they attend special schools for the deaf.

This significant delay in deaf children's mathematical attainment is cause for concern because the consequences of this delay do not only influence deaf children's mathematical success in school but also have negative implications for their later life. As observed by Punch, Hyde and Creed (2004) in their analysis of the literature regarding the transition from school to employment, this low performance in mathematics has constituted a serious obstacle to post-secondary education, initial employment and workforce advancement for deaf people. Adults with low mathematics skills are more likely to be unemployed than those with higher results in mathematics; among those employed, low numeracy skills are a strong predictor of low levels of employment. This lack of mathematical skills has a negative impact on people's lives in a technological society such as ours in which mathematical skills are increasingly needed and are used in a wide range of occupations and daily activities not traditionally considered to be mathematical (Punch, Hyde and Creed, 2004).

Thus, it is crucial now to analyse the nature of these difficulties in order to be able to enhance children's mathematical performance and create a path for improvement. In the present study, this issue is addressed investigating whether logical-mathematical reasoning, counting ability and working memory are independent predictors of deaf children's mathematical achievement after six months, having controlled for non-verbal intelligence, age, years in education, degree of hearing loss and types of educational provision. Analysis of a specific connection between these predictor variables and deaf children's mathematical achievement is crucial because only in this way it will be possible to understand whether these factors make unique contributions to the prediction of children's subsequent mathematical learning above and beyond the influence of children's intelligence and background factors.

Theories on how hearing children learn mathematics highlighted that working memory, logical-mathematical reasoning and counting ability could be crucial factors in a successful development of mathematical skills. These factors were hypothesised to be causes of deaf children's delay in mathematics. In order for a cause of a delay to be identified, deaf children must lag behind their hearing peers on these factors and the same measure must predict deaf children's mathematical attainment. The analysis of the literature on whether deaf children have difficulties in these factors compared with their hearing peers showed that deaf children's performances on all these three factors are below those of their hearing peers. These results satisfied the first criterion for the identification of causes of delay. Additional evidence regarding the importance of these factors in relation to children's mathematical achievement came from the examination of longitudinal studies that investigated whether these factors are also predictors of children's mathematical attainment. In hearing children, logical-mathematical reasoning was found to be one of the

strongest predictor of children's mathematical achievement above and beyond the influence of general intelligence, working memory and arithmetical skills (Nunes et al., 2011). Working memory influenced deaf children's mathematical achievement after controlling for non-verbal intelligence (Gottardis, 2009). Finally, counting skills were observed to predict mathematical achievement in hearing children with an age range between 5 and 8 years (Aubrey et al., 2006). This present research aims to investigate whether these factors influence independently deaf children's mathematical achievement. If this is found, it will satisfy the second aspect of the paradigm for the identification of causes of delay and therefore it would be possible to consider logical-mathematical reasoning, working memory and counting ability to be good candidates for causes of deaf children's delay in mathematics.

The focus of the longitudinal study is on the first years of primary school (6-8 years old children) because early identification of the factors that influence how well deaf children learn mathematics could reduce their difficulties at earlier stages of their education and therefore improve their future mathematical attainment.

In the following sections, first, the hypotheses and predictions are presented followed by design, method, findings of the present study and summary.

#### **4.1. Hypotheses and predictions**

On the basis of the analysis of the literature, the following are the hypotheses and predictions that are tested in this study:

- Counting ability, working memory and logical-mathematical reasoning are longitudinal and independent predictors of deaf children's mathematical achievement after controlling for background factors and non-verbal intelligence.
- Logical-mathematical reasoning will make the strongest contribution in the prediction of deaf children's mathematical achievement.

#### **4.2. Design**

In order to verify these hypotheses, a longitudinal study with deaf children aged from 6 to 8 years was carried out. This age range was chosen for three reasons. First, in order to help deaf children to improve their mathematical achievement, it is crucial to understand which are the types of experience that influence children's learning of mathematics in the early years in order to support them as soon as possible, reducing the difficulties that they can encounter in learning mathematics. Second, there is a mathematical achievement test which was adapted for deaf children of this age group, the mathematics test of the Performance Indicators for Primary School children (PIPS), which makes it possible to use an independently designed and validated measure as the outcome measure in the present study. Third, because this age range allows the use of the same test for the entire cohort of children, the findings will be more consistent in terms of the influence of the predictors on the outcome measure, reducing the effect of possible confounding variables. For example, if for each age, a different measure were administered and it were found that one predictor

was significant only for one group of children of a particular age, it would be not possible to determine whether this result was due to the particular age considered or due to the outcome measure used. Therefore, it would be not possible to reach any clear conclusions about the influence of this predictor on children’s mathematical achievement.

Testing took place on two occasions in this study. On the first testing occasion, Time 1, the matrices subtest of the British Ability Scale II (BAS-II), the counting task, the logical-mathematical reasoning task, and two measures of working memory ability from the Working Memory Test Battery for Children (WMTB-C) were administered.

The second testing occasion, Time 2, comprises the outcome measure, the mathematical reasoning test of the Performance Indicators in Primary School (PIPS) that is used as a measure of their mathematical achievement. On this occasion, information about the number of years each child had spent in education was collected from the school records. The interval between the first data collection and the second data collection was six months. Table 4.1 summarises the different measures used on the two testing occasions. In the following sections, the method and the results of the longitudinal study are presented.

Table 4.1. Measures used in the longitudinal study.

<b>Time 1</b>	<b>Time 2</b>
Matrices subtest from the British Ability Scale II (BAS-II) Counting task Logical-mathematical reasoning task Working memory test battery for Children (WMTB-C): <ul style="list-style-type: none"> <li>• Counting recall</li> <li>• Backward digit recall</li> </ul>	Mathematical test from the Performance Indicators in Primary School (PIPS)

### 4.3. Participants

The deaf sample recruited for this study is a sub-set of the participants in the survey study and it is composed of 118 children aged from 6 to 8 years (see previous chapter for details of the recruitment). As reported in the previous chapter, the children with mild hearing loss were excluded from the sample because previous studies (Tymms et al., 2003; Gottardis, 2009; Gottardis, Nunes and Lunt, 2011) demonstrated that the mathematical performance of these children is very similar to that of hearing children; 8 children were excluded because they had a statement of additional special educational needs.

Table 4.2 summarises the final sample size, gender, age and numbers of years in education of the sample considered in the present study.

Table 4.2. Sample size, gender, age (range, mean and SD) and numbers of years in education (range, mean and SD) of present sample.

Sample	Total sample size	Gender (boys)	Age at Time 1			Numbers of years in education at Time 1		
			Range	Mean	SD	Range	Mean	SD
Deaf children	110	57	6-8 years	7.78	.84	2-5 years	3.81	1.10

Their degree of hearing loss ranged from moderate to profound. The number and percentage of children by degree of hearing loss is reported in Table 4.3.

Table 4.3. Number and percentage of children by degree of hearing loss.

Degree of hearing loss	Total number of children	Percentage
Moderate	26	23.6
Severe	26	23.6
Profound	58	52.7

The causes of hearing loss were unknown for 41.8% and known for 58.8%. When the causes were known, the most common was genetic, followed by those related to pregnancy and post-birth diseases (see Table 4.4).

Table 4.4. Number and percentage of children by the causes of hearing loss.

Causes of hearing loss	Total number of children	Percentage
Genetic/hereditary	31	28.2
Pregnancy	22	20.0
Post-birth disease	11	10.0

All the children used some form of amplification, hearing aids or cochlear implants. The sample was divided almost equally between those who used hearing aids (56.4%) and those who used cochlear implants (43.6%).

Deaf children attending special schools for the deaf are not grouped in year groups. Information about the total number of years that children have spent in education was collected from the school records. Table 4.5 reports the years in education by chronological age. There is an association between age and years in education but there is also a considerable variation across children.

Table 4.5. Number and percentage of children by years in education and by chronological age.

Age	Years in education			
	2	3	4	5
6 years old	13 (40.6%)	14 (43.8%)	5(15.6%)	
7 years old		7 (24.1%)	16 (55.2%)	6 (20.7%)
8 years old	5 (10.2%)	12 (24.5%)	12 (24.5%)	20 (40.8%)

In the present sample, the majority of the children (48.2%) attended schools with a unit for hearing impaired children, whereas about half of the children were almost equally distributed between special schools for the deaf (23%) and mainstream schools (29%).

82.7% of the children spoke English at home whereas only 14.5% used another language (see page 118 for a description of the different languages). Only three children used British Sign language at home.

In the present sample, for 18.4%, it was not possible to obtain any information about the highest level of maternal education. For the remaining cases (N= 89), the majority (45.6%) of the mothers left school before achieving GCSE followed by those who obtained GCSEs (21.1%), A-levels (14.4%) or a degree (18.9%).

In the survey study described in Chapter 3, no significant relation was observed between deaf children's mathematical attainment and gender, causes of hearing loss, presence of cochlear implant, language used at home or highest level of maternal education. Age, years in education and type of educational provision did make independent contributions to the prediction of children's mathematics performance. Due to the significant correlations between these factors (age, years in education and type of educational provision) and children's mathematical achievement and the presence of variance in these variables in the current sample, in the subsequent analyses they were inserted in the first steps of the regression analysis. In this way, it was possible to control for their influence on deaf children's mathematical achievement.

Degree of hearing loss was not found to explain any additional variation of deaf children's mathematical achievement above and beyond the influence of age, years in education and type of educational provision. However, degree of hearing loss was a confounding factor of the relation between type of educational provision and deaf children's mathematical achievement. Therefore, degree of hearing loss was inserted as a control factor in the following analysis.

## **4.4. Measures**

### **4.4.1. Outcome measure: Mathematics test from the Performance**

#### **Indicators for Primary School (PIPS)**

The outcome measure used to evaluate deaf children's mathematical achievement is the mathematics test of the Performance Indicators for Primary Schools (PIPS). This measure was designed by the Centre for Evaluation and Monitoring (CEM) at Durham University to monitor pupils' achievement and their progress throughout primary school (Tymms et al., 2003). The characteristics and the procedure of this measure were described in details in the previous chapter in section 3.4.

### **4.4.2. Predictor variables**

#### **a. Counting task**

This task was used to evaluate deaf children's knowledge of the counting string. The children were presented with a strip on which 60 pictures of monkeys were printed and were asked to count the monkeys in their preferred communication mode (either speaking or signing). This strip was folded at the end of each decade so the researcher could stop the child at the point at which the child made more than three mistakes. The number 60 was used as stopping point because previous research (e.g. Miller and Stigler, 1987) reported that almost all the children who could count up to 60 could count to 99, showing that they mastered the rules for the formation of decade names as well as their combination with units.

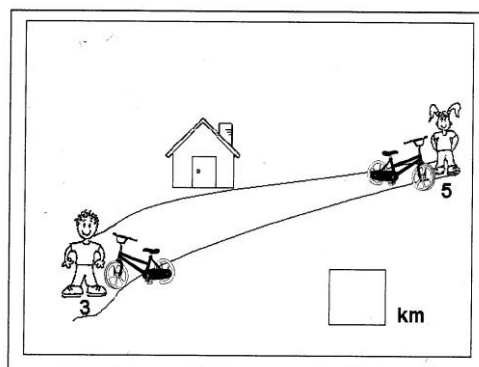
This task was administered individually and was scored 1 if the children were able to count up to 60, 0 if they could not count up to this number.

### b. Logical-mathematical reasoning task

The logical-mathematical reasoning task was designed by Nunes and Bryant and consists of 24 problems. The problems were planned in order to assess children's ability to reason about quantities and relations between quantities without taxing their arithmetical skills. Children have to reflect on the relations between the quantities in each item in order to decide how to solve the problem. Previous research (Zarfaty, Nunes and Bryant, 2004; Nunes, Bryant and Prezlik, 2006) showed that deaf children's performance on some mathematics tasks improves significantly when all the information is presented visually at the same time, so the problems are presented with the support of drawings that include all the information that the child needs. No reading is required; this is an important feature of the test because deaf children are considerably behind their hearing peers in reading (see Pagliaro, 2010) and this could negatively affect deaf children's performance.

Figure 4.1 shows one of the items presented in the test. The researcher would say to the children: "Two friends were cycling on a path. They started cycling from the house. The boy cycled 3km one way. The girl cycled 5 km the other way. How far apart are the two friends?". In this item, the calculation that is needed to solve the problem is not difficult and the difficulty is in the reasoning: the children need to understand that an addition is required to solve the problem.

Figure 4.1. An additive reasoning problem in the logical-mathematical reasoning task.



A similar item was included in the test in which the two friends started walking from the house in the same direction. In this second item, in spite of the similarity in the language of the problem, the relation between quantities is different and the problem is solved by a subtraction. In this item as well for other items of this task, the children could use counting to solve the problem if they did not know the number facts that might be used in the solution.

In previous studies (Nunes et al., 2007; Nunes et al., 2012; Nunes et al., 2009), it was observed that this task presented a good level of internal consistency (Cronbach's  $\alpha=.74$ ). Its predictive validity was assessed through the correlation with the Key Stage tests at 11 years (KS2) and at 14 years (KS3) and was .66 and .68 respectively.

### **Procedure**

A booklet composed of 24 problems, each represented through drawings that show the main information for each problem, was given to each child. This booklet was used to record the child's answer and to support the comprehension of the problem in order to avoid taxing the child's memory skills. The task was presented to each child individually and the researcher explained each problem in the communication mode most appropriate to the child, using the drawings to support her explanations.

Each problem solved correctly received a score of 1 and 0 was given in the case of an incorrect solution.

**c. Working Memory Test Battery for Children: counting recall and backward digit recall**

The Working Memory Test Battery for Children (WMTB-C), designed by Pickering and Gathercole (2001), is suitable for use with children aged between 5 and 15 years. It is composed of nine subtests designed to reflect the three component structures of the working memory model proposed by Baddeley and Hitch (1974). This test was chosen because it is a standardised working memory test for children, in which different subtests measure different components of the working memory. Previous research (e.g. Passolunghi and Siegel, 2004; Nunes et al., 2007; Gottardis, 2009) has reported that the central executive component of the working memory is a good predictor of deaf children's mathematical achievement. In this project, the two tasks that were chosen to measure this component were: the counting recall task and the backward digit recall. Both these tasks presented acceptable reliability in past research (Alloway and Gathercole, 2005) (counting recall: Cronbach's  $\alpha = .61$ ; backward digit recall: Cronbach's  $\alpha = .62$ ).

*i. Counting recall*

This task involves the simultaneous processing and maintenance of information in working memory.

A booklet with red dots was given to each child. The children were asked to count arrays of dots presented on a series of pages. Once the dots had been counted, the child was asked to recall the total number of dots on each of the pages seen, in the order that they were encountered. If the child made an error in counting the dots, the actual number counted was noted on the record form and it was this number that should be recalled.

This test is divided into 7 blocks of trials, each block contains 6 trials. In the published procedures, before beginning the test, three practice trials are presented to the children. In

the first one, only one page is presented; in the second, two pages are shown to the children and in the third trials, three pages are shown to the children. In a pilot study, these instructions were found to be confusing for deaf children because they found it very difficult to understand that, first, they would have some items with one card, then some items with two cards followed by some items with three cards. A similar difficulty was observed by Gregory (1995). On the basis of the observations made by mothers of deaf children, Gregory (1995) reported that deaf children found it hard to understand the concept of “later on” when the mothers were describing to their child what would happen in the day. In order to overcome these difficulties, the three practice trials were adapted for the present research. They were presented before each of the corresponding block of trials in order to help the children to understand the task (e.g. the first practice trial was shown to the children before the block of trials with one page; the second practice trial was presented before beginning the block of trials where children had to remember two total numbers of dots and so on). If the child responded correctly to 4 trials within the block, the researcher would proceed directly to the next block (move on rule). If the child made 3 or more errors within a block, the test was stopped.

In line with the published scoring instructions, for each sequence of dot tallies recalled in the correct order, the child was awarded a score of 1. These were summed to give an overall trials correct score. If trials were omitted as a consequence of the move on rule (the child responds correctly to 4 trials within the block), the child was given a score of 1 for each un-administered trial. Within the final block of this administered test, a score of 1 was given for any trials that were correctly recalled up to the point at which the test was stopped.

A span score was obtained from the trial correct score. This is the number of pages making up the trial sequences of the last block before the child was unable to remember them correctly. The trial scores can be transformed into a standard score according to the age of the child with a mean of 100 and standard deviation of 15. On the basis of previous research (Alloway and Gathercole, 2005; Gathercole et al., 2004), in the following analyses, the trial scores were used as total scores of children's working memory.

ii. *Backward digit recall*

This task also measures the central executive component of the working memory. It involves the spoken presentation of sequences of digits for immediate recall. The child is required to recall the list in reverse order, i.e., the recalled list should begin with the last item heard and end with the item first heard. Digits should be presented at a rate of 1 per second. Before the beginning of the task, training items are presented to the children in order for them to understand the concept of "reverse/backwards".

Because this task is presented verbally in the original format, it was decided that an adaptation would be used in this study. The digits are not only heard by the children as in the original version, but they are presented on a computer screen by the researcher. The children have to name the digits presented by the researcher on the screen in the child's preferred language and, after the digits disappear from the screen, they have to recall the list of digits in reverse order. This task was also administered individually.

As for the previous task, a span score was obtained from the trial correct score. This is the number of pages making up the trial sequences of the last block before the child was unable to remember them correctly. Also in this case, on the basis of previous research (Alloway and Gathercole, 2005; Gathercole et al., 2004; Pickering and Gathercole, 2010),

in the following analyses, only the trial scores were used as the total score of children's working memory ability.

#### **d. British Ability Scale II: matrices subtest**

The British Ability Scales II (BAS-II) (Elliott, 1996) is a measure of cognitive functioning over a wide age range (from 2.6 years to 17.11 years). In this research, only the matrices subtest of this battery was used because, as pointed out by Braden (1992; 1994) in his systematic review of the literature on deaf children's intelligence, verbal intelligence tasks are clearly not "fair" tests for the deaf population. The aim of obtaining an estimate of the children's non-verbal intelligence was to control for this factor in the longitudinal analysis. The characteristics of the test and the administration procedure are described in the Chapter 3 section 3.3.1.2.

### **4.5. Results**

Regression analyses were used to investigate whether working memory, logical-mathematical reasoning and counting ability are independent predictors of deaf children's mathematical achievement after controlling for background factors and non-verbal intelligence.

This method of investigation provides information on the relationship between each of the predictor variables (logical-mathematical reasoning, working memory and counting ability) and the outcome measure when the influence of all the other variables is taken into account. It also indicates how much of the variance in the outcome measure is explained by a particular predictor variable after the effect of all the other predictor variables previously entered into the equation are controlled for.

The PIPS maths test is used as the outcome measure. One of the assumptions of the regression analysis is that the outcome measure is normally distributed. Thus, in the first section, the distribution of the outcome measure is investigated. The results obtained from the regression analyses are presented in the second section.

#### 4.5.1. Description of the outcome measure: the PIPS mathematics test at Time 2

An analysis of the distribution was carried out considering first the description of the distribution of the PIPS maths test and then the values of skewness and those of Kurtosis.

The mean of the total score in the PIPS maths test was 14.75 (SD= 5.19). Figure 4.2 presents the distribution of the scores of the PIPS maths test.

Figure 4.2. Distribution of the scores of the PIPS maths test.

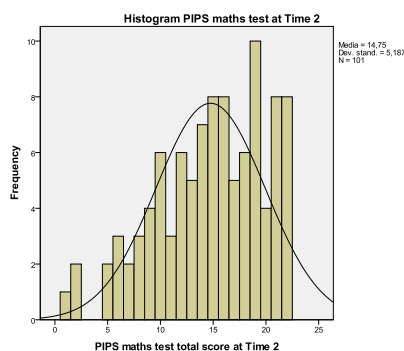


Table 4.5 reports the means, standard deviations, skewness values, standard errors, z scores obtained by dividing the skew results with the standard error, the kurtosis values, the standard errors of kurtosis and the z scores obtained by dividing the kurtosis values with the standard error by age. None of the z score values is over 1.96 (critical value to accept the hypothesis that the distribution is not normal). In view of this analysis, it is possible to conclude that the distribution of the total scores of the PIPS maths test is

normally distributed and that regression analyses will be an appropriate method for investigating the connections between the predictors and this outcome measure.

Table 4.6. Mean, SD, skewness value, standard error, z score, kurtosis value, standard error of Kurtosis and z scores of the distribution of scores of the PIPS maths test by age.

Age	N	Mean	SD	Skewness value	Standard error	z	Kurtosis value	Standard error of Kurtosis	z
6 years	32	12.41	7.33	.77	.42	1.83	.48	.82	.58
7 years	29	19.48	8.86	.60	.44	1.36	-.99	.87	1.13
8 years	49	19.72	8.97	.55	.36	1.53	-1.18	.71	1.66

#### **4.5.2. Analysis of the longitudinal predictors of deaf children’s mathematical achievement**

The aim of these analyses is to see whether there is a specific connection between each of the predictors and deaf children’s mathematical achievement (outcome measure) after taking into account what both the predictor and the outcome measure have in common with the other predictors and control variables in the analysis. The main predictor variables are: working memory, logical-mathematical reasoning and counting ability. In the present research, two measures of working memory were administered: counting recall and backward digit recall. For both the measures, the trial score was used as measure of their working memory ability. These two measures correlate significantly with each other ( $r = .56, p < .01$ ). In order to obtain only one measure of working memory and therefore a stronger predictor, the z scores of both these measures were added.

In addition to these predictor variables, it was necessary also to control for the influence of differences in children’s age at the time at which the outcome measure was administered (Time 2), their years in education at Time 2, degree of hearing loss, their non-

verbal intelligence and their type of educational provision. Degree of hearing loss was inserted in the model because, in the survey study, degree of hearing loss was reported as a confounding variable of the relation between type of educational provision and deaf children's mathematical achievement. As a measure of non-verbal intelligence, the raw total score of the matrices subtest is used because age is entered into the equation before this subtest's score. Type of education is a categorical variable with three levels. In the previous chapter, it was observed that there was no significant difference between the mathematical performance of children attending a school with a unit for the hearing impaired and that of children attending special schools for the deaf. Thus, these two categories were grouped and a dummy variable was created in which the performance of children attending mainstream schools is contrasted with the performance of children in either of the other two types of educational provision.

As an exploratory analysis, Table 4.6 reports the correlation coefficients between the predictor variables and the outcome measure. The control measures, age at Time 2, years in education at Time 2, degree of hearing loss and non-verbal intelligence and the predictor variables were also correlated with each other as well as with the outcome measure. Because type of educational provision is a dummy variable, it was not included in this analysis.

Table 4.7. Correlation coefficients among the different measures and significance levels.

<b>Predictors</b>	Years in education at Time 2	Degree of hearing loss	Non-verbal intelligence	Counting skills	Working memory	Logical mathematical reasoning	PIPS math test
Age at Time 2	.65**	.11	.40**	.40**	.42**	.46**	.42**
Years in education at Time 2		.01	.24**	.24**	.24**	.32**	.28**
Degree of hearing loss			.03	.01	.03	-.13	-.15*
Non-verbal intelligence				.38**	.61**	.64**	.51**
Counting ability					.37**	.50**	.51**
Working memory						.65**	.65**
Logical-mathematical reasoning							.78**

\*. p<.05; \*\*. p<.01

Each of the predictor variables was significantly correlated with deaf children's mathematical achievement. The strongest correlation with the outcome measure is observed between logical-mathematical reasoning and the outcome measure supporting the hypothesis that this predictor variable could make the strongest contribution to the prediction of deaf children's mathematical achievement. Working memory is also strongly related to the outcome measure whereas counting ability shows a weaker correlation with deaf children's performance in mathematics compared with the other two predictors. This last finding supports the hypothesis that there is a partial independence between counting ability and children's performance in mathematics.

Each of the control variables was significantly correlated with the outcome measure confirming the necessity to control for these factors when the relation between each of the predictor variables and the outcome measure is examined. It is important to point out that

there is a difference between finding a significant correlation between these factors (predictors or control variables) and the outcome measure and finding the second or the following steps of the regression analysis significant. In the correlation analysis, each of the factors is taken separately and its relation with the outcome measure is examined. In the regression analysis, if the second and/or the following steps are not significant, it means that they do not explain any further variance in the outcome variable after taking into account that explained by the variables entered previously.

The correlations among the predictors are quite high but none of them is above .8, which would produce the risk of multicollinearity (Field, 2009).

The correlations between the predictor variables and the control variables, age at Time 2, years in education at Time 2, and non-verbal intelligence, were positive and significant. No significant relation was observed between degree of hearing loss and the predictor variables.

To test whether logical-mathematical reasoning, working memory and counting ability make independent contributions to the prediction of the PIPS maths test after controlling for age, years in education, degree of hearing loss, type of educational provision and non-verbal intelligence, three different hierarchical fixed-order multiple regressions were carried out.

The first regression analysis verified whether logical-mathematical reasoning predicts deaf children's score on the PIPS maths test above and beyond the influence of the control variables, counting skills and working memory. In order to control for the shared variance with other factors, age at Time 2, years in education at Time 2, degree of hearing loss, non-verbal intelligence, type of educational provision, counting skills and working

memory were entered as independent steps in the regression equation before entering deaf children's total score on logical-mathematical reasoning. This method of analysis shows whether logical-mathematical reasoning accounted for a significant amount of variance in the outcome measure after the effect of the other predictors had been controlled for.

The three assumptions of the regression analysis (normality, linearity and heteroscedasticity) were satisfied by the model (see Appendix D). No outliers among the cases were found. The residual terms were uncorrelated: the value of Durbin-Watson test was quite close to 2 (Field, 2009).

Table 4.8 reports the  $R^2$ , the adjusted  $R^2$  and the  $R^2$  change observed for each step in the first regression analysis.

Table 4.8.  $R^2$ , adjusted  $R^2$  and  $R^2$  change of the regression with PIPS maths test at Time 2 as outcome variable.

<b>Steps</b>	<b><math>R^2</math></b>	<b>Adjusted <math>R^2</math></b>	<b><math>R^2</math> change</b>
Age at Time 2	.14**	.14**	.14***
Years in education at Time 2	.14	.12	.00
Degree of hearing loss	.19	.17	.05*
Non-verbal intelligence	.34*	.31*	.15***
Type of educational provision	.36**	.32**	.02*
Counting ability	.42**	.39*	.07***
Working memory	.59**	.56***	.17***
Logical-mathematical reasoning	.71**	.69**	.12***

\*,  $p < .05$ ; \*\*,  $p < .01$ ; \*\*\*,  $p < .001$ .

The total adjusted  $R^2$  showed that 71% of the variance in the PIPS maths test was accounted for by the factors inserted in the equation. Years in education did not make a significant contribution to the model but all the other factors accounted for significant portions of the variance in the PIPS maths test. Counting ability explains 7% of the

variance after controlling for background factors and non-verbal intelligence. Working memory explains an additional 17% and logical-mathematical reasoning explains a further 12% after controlling for the preceding factors. Thus, logical-mathematical reasoning is a significant predictor of deaf children's mathematical achievement and this relationship is not explained by extraneous variables such as background factors, non-verbal intelligence, counting ability and working memory.

Table 4.9 reports the un-standardised and standardised coefficients for each of the predictors by each step. These coefficients indicate the individual and unique contribution of each predictor to the model giving information on the relationship (positive or negative) of each predictor and the outcome measure (Field, 2009). The standardised coefficients, called beta value ( $\beta$ ), are all measured in standard deviations. They are directly comparable and, therefore, they provide a better insight into the importance of a predictor in the model (Field, 2009). This is why the following description of the table is focused on the beta value.

Table 4.9. Un-standardised and standardised coefficients for the regression analysis with PIPS maths test at Time 2 as outcome variable.

	<b>B</b>	<b>SE B</b>	<b>β</b>
<b>Step 1</b> Age at Time 2	3.47	.86	.38***
<b>Step 2</b> Age at Time 2 Years in education at Time 2	3.51 -.05	1.14 .93	.38*** -.00
<b>Step 3</b> Age at Time 2 Years in education at Time 2 Degree of hearing loss	3.91 -.25 -1.20	1.13 .91 .50	.42*** -.03 -.22*
<b>Step 4</b> Age at Time 2 Years in education at Time 2 Degree of hearing loss Non-verbal intelligence	2.27 -.15 -1.17 .83	1.08 .83 .45 .18	.25** -.02 -.22* .42***
<b>Step 5</b> Age at Time 2 Years in education at Time 2 Degree of hearing loss Non-verbal intelligence Type of educational provision	2.22 -.14 -.83 .80 2.17	1.07 .83 .50 .18 1.80	.24* -.02 -.16 .41*** .16
<b>Step 6</b> Age at Time 2 Years in education at Time 2 Degree of hearing loss Non-verbal intelligence Type of educational provision Counting ability	1.37 -.07 -.81 .66 2.54 5.69	1.07 .79 .48 .18 1.72 1.79	.15 -.00 -.15 .33** .13 .29***
<b>Step 7</b> Age at Time 2 Years in education at Time 2 Degree of hearing loss Non-verbal intelligence Type of educational provision Counting ability Working memory	.60 .03 -.92 .24 1.51 4.70 .77	.97 .71 .43 .18 1.56 1.63 .16	.06 .00 -.17 .12 .08 .23*** .44***
<b>Step 8</b> Age at Time 2 Years in education at Time 2 Degree of hearing loss Non-verbal intelligence Type of educational provision Counting ability Working memory Logical-mathematical reasoning	.07 -.19 -.31 -.14 1.80 1.77 1.71 .76	.80 .58 .37 .16 1.29 1.33 .42 .12	.00 -.03 -.06 -.07 .09 .11* .34*** .56***

\*.  $p < .05$ ; \*\*.  $p < .01$ ; \*\*\*.  $p < .001$

When non-verbal intelligence was inserted without controlling for other factors (see Step 4 in Table 4.9), it made a large contribution to the prediction of deaf children's mathematical achievement ( $\beta = .41$ ). However, when counting ability was considered in

the equation as the first of the specific factors predicting deaf children's mathematical achievement, the beta value of non-verbal intelligence was reduced to .33. In the seventh step, when working memory was inserted in the equation, this decrease was greater than in the previous step and non-verbal intelligence was no longer a significant predictor of deaf children's mathematical achievement. This means that there is a large overlap between the contribution made by non-verbal intelligence to the prediction of deaf children's mathematical achievement and that done by counting ability and by working memory.

The beta value of counting ability also presented a reduction from when it was inserted as the only specific predictor of deaf children's mathematical achievement ( $\beta = .29$ ) to when logical-mathematical reasoning was entered into the equation ( $\beta = .11$ ). This result highlights the presence of a large overlap between the variance explained by counting ability and that explained by logical-mathematical reasoning.

An overlap of the variance is also observed between working memory and logical-mathematical reasoning. When working memory was inserted before considering logical-mathematical reasoning, its beta value was of .44, whereas when logical-mathematical reasoning was entered into the equation, the beta of working memory was of .34.

All these results lead to the findings of the final equation presented in Step 8. Logical-mathematical reasoning is the strongest predictor of deaf children's mathematical achievement with the highest beta value ( $\beta = .56$ ) of all the factors entered into the equation followed by working memory ( $\beta = .34$ ). Counting ability is also a significant predictor but its predictive power is quite low compared with that of the other two specific predictors ( $\beta = .11$ ). None of the control variables was a significant predictor of deaf children's mathematical achievement when the predictor variables were inserted in the equation.

Because in the previous equation, after controlling for age at Time 2, years in education at Time 2 was not a significant factor and did not explain any variance of deaf children's mathematical achievement, it was removed from the subsequent analyses. In the next two regression analyses, it is expected to observe a change in the variance explained by each factor whereas no changes are expected in the beta values when all the predictors are inserted. The following tables present the values of  $R^2$ , adjusted  $R^2$ ,  $R^2$  change and the standardised and un-standardised values of the last step of the regression model when all the factors are inserted into the equation. In the Appendix C, the beta values for all the other steps are reported.

The second regression analysis aims to verify whether working memory is an independent predictor of deaf children's mathematical achievement after controlling for the control variables and counting ability and logical-mathematical reasoning. In order to test this, the same model used in the previous regression analysis was employed in this analysis varying only the order of the last three predictors. In this second regression analysis, logical-mathematical reasoning was entered as the fifth step, counting ability as the sixth step and working memory as the last step of the regression analysis. In this way, it can be verified whether working memory explains any further variance of the outcome measure after controlling for the influence of all the other factors.

As can be seen in Table 4.10, in this second regression analysis, there is an increase in the contribution that logical-mathematical reasoning (30% of the variance explained) made to the prediction of the PIPS maths test after controlling for background factors and non-verbal intelligence compared to the variance explained by the same factor when it was entered as the last step of the regression equations (12% of variance explained, see Table 4.8). At the same time, there is a corresponding decrease in the independent contribution

made by working memory. When all the other factors were controlled for, working memory contributed to a further 5% of the variance. This reflects the overlap between the variance explained by these two predictors and it is in line with the results of the correlation analysis.

Although the unique variance explained by working memory is quite small, it remains significant after controlling for all the other factors. Therefore, it is possible to conclude that working memory is an independent and significant predictor of deaf children's mathematical reasoning after controlling for the other factors.

Table 4.10.  $R^2$ , adjusted  $R^2$  and  $R^2$  change for each step; standardised and un-standardised values of the last step of the regression with PIPS maths test at Time 2 as the outcome variable; working memory as the last step of the regression.

Steps	R square	Adjusted R square	R square change	B	SEB	$\beta$
Age at Time 2	.14***	.13***	.14***	-.31	.61	-.03
Degree of hearing loss	.18*	.17*	.05*	-.33	.34	-.05
Non-verbal intelligence	.34***	.32***	.15***	-.16	.15	-.06
Type of educational provision	.36*	.33*	.02*	1.94	1.21	.08
Logical-mathematical reasoning	.65***	.63**	.30**	.76	.12	.57***
Counting ability	.66*	.64*	.01*	1.77	1.33	.10*
Working memory	.71***	.69***	.05***	1.67	.42	.33***

\*.  $p < .05$ ; \*\*.  $p < .01$ ; \*\*\*.  $p < .001$

The third regression analysis tested whether counting ability makes a significant and independent contribution in predicting scores on the PIPS maths test after taking into account the influence of the control variables, working memory and logical-mathematical reasoning. For this reason, age at Time 2 was inserted in the first step, degree of hearing loss in the second step, non-verbal intelligence in the third step, type of educational

provision in the fourth step, working memory in the fifth step, logical-mathematical reasoning in the sixth step and counting ability in the seventh step.

Table 4.11 reports the  $R^2$ , adjusted  $R^2$ ,  $\Delta R^2$  change for this third regression analysis. After controlling only for background factors and non-verbal intelligence, working memory explains 20% of the variance of deaf children's mathematical achievement. This is a big increase in the amount of variance explained compared with that when working memory was inserted as the last step of the regression analysis where it contributes for a further 5% of the variance of the scores on the PIPS maths test (see Table 4.10). This result highlights the presence of a considerable overlap of the variance explained by working memory and counting ability. This increase in the variance on the PIPS maths test explained by working memory corresponds to a reduction of the contribution of counting ability in the prediction of deaf children's mathematical achievement: when it was inserted after background factors and non-verbal intelligence, counting ability explained 7% of the variance (see Table 4.8) whereas, after controlling for all the factors inserted, counting ability contributes a further 1% of the variance of deaf children's mathematical achievement. Although the amount of variance explained by counting ability is very small, it is still significant confirming the hypothesis that counting is a longitudinal predictor of deaf children's mathematical achievement independently of logical-mathematical reasoning and working memory.

Table 4.11.  $R^2$ , adjusted  $R^2$  and  $R^2$  change for each step; standardised and un-standardised values of the last step of the regression with PIPS maths test at Time 2 as the outcome variable and counting skills as the last step of the regression.

Steps	$R^2$	Adjusted $R^2$	$R^2$ change	B	SEB	$\beta$
Age at Time 2	.14***	.13***	.14***	-.31	.61	-.03
Degree of hearing loss	.18*	.17*	.05*	-.33	.34	-.05
Non-verbal intelligence	.34***	.32***	.15***	-.16	.15	-.06
Type of educational provision	.36*	.33*	.02*	1.94	1.21	.08
Working memory	.56***	.53***	.20***	1.67	.42	.33***
Logical-mathematical reasoning	.70***	.69***	.15***	.76	.12	.56***
Counting skills	.71*	.69*	.01*	1.77	1.09	.10*

\*,  $p < .05$ ; \*\*,  $p < .01$ ; \*\*\*,  $p < .001$ .

#### 4.6. Summary

The longitudinal study aimed to determine whether logical-mathematical reasoning, working memory and counting ability are independent predictors of deaf children's mathematical achievement after taking into account background factors and non-verbal intelligence.

The technique of linear regression was implemented to verify this hypothesis. Age, years in education, degree of hearing loss, type of educational provision and non-verbal intelligence were inserted as control variables. Results showed that working memory, counting and logical-mathematical reasoning make an independent contribution to the prediction of deaf children's mathematical achievement above and beyond the contribution of the control variables. Logical-mathematical reasoning was by far the strongest predictor factor that influenced deaf children's mathematical achievement after taking into

consideration all the other factors inserted in the model. None of the control factors (age, years in education, degree of hearing loss, type of educational provision and non-verbal intelligence) inserted into the equation added any additional variance to the prediction of deaf children's mathematical achievement.

In conclusion, the present findings confirm the hypothesis that working memory, counting ability and logical-mathematical reasoning are important factors in deaf children's mathematical development and logical-mathematical reasoning is by far the strongest predictor among those considered.

## Chapter 5

### Discussion and conclusions

The aim of this chapter is to evaluate, interpret and reflect on the contributions and implications of the findings with respect to the hypotheses set out at the beginning of this thesis. The chapter starts with a summary of the main findings and provides a statement of the support for the original hypotheses before going on to discuss the consequences of the findings.

#### 5.1. Summary of the main findings

The present study firstly evaluated the extent of deaf children's delay in mathematics; identifying the factors that could predict and moderate the extent of this delay. Secondly, the longitudinal predictors of deaf children's mathematical achievement were examined.

Two studies were carried out to address these aims: a survey and a longitudinal study.

In the survey study, a significant delay in deaf children's mathematical achievement in comparison to their hearing peers was predicted. As reported in previous studies (Gottardis, Nunes and Lunt, 2011; Swanwick, Oddy and Roper, 2005), for five decades deaf children presented a substantial delay in mathematics compared with their hearing peers. In the present study, the overall extent of deaf children's delay in mathematics was -1.76 SDs, confirming that, in the U.K., deaf primary school children are far behind their hearing peers in mathematics.

Age and years in education were hypothesised to predict and moderate the extent of deaf children's delay in mathematics. Gottardis, Nunes and Lunt (2011), in their analysis

of the literature on the nature and extent of deaf children's delay in mathematics, observed that not only do age and years in education predict deaf children's mathematical achievement but also, when children begin primary school, the extent of deaf children's delay in mathematics is quite small but it increases overtime. In the present research, in the first year of primary school, deaf children presented a delay of less than one standard deviation below the mean compared with hearing children. This had more than doubled at the end of primary school. These findings confirm the hypothesis regarding the role played by age and years in education in relation to deaf children's mathematical achievement. Although deaf children acquire more knowledge throughout the course of their primary school, this seems not to be sufficient to compensate for their difficulties in mathematics compared with hearing children. There is therefore a necessity to find the factors that influence deaf children's mathematical development in order to reduce this delay.

Type of educational provision was also hypothesised to be a predictor and moderator of the extent of deaf children's delay in mathematics. Previous studies (e.g. Kluwin and Moores, 1985; Lynas, 1984) showed that children attending mainstream schools seem to obtain higher mathematical scores than those obtained by children attending the other types of educational provision. However, when degree of hearing loss was taken into account, the relation between children's mathematical performance and type of educational provision was no longer found to be significant (Wood et al., 1983). In the current study, type of educational provision was a significant predictor of deaf children's mathematical skills, after taking into account age, years in education and degree of hearing loss. When deaf and hearing children's mathematical skills were compared, the extent of deaf children's delay ranged from -1.3 SD when deaf children attended mainstream school to -2.05 SDs when they attended special schools for the deaf. The hypothesis that type of

educational provision is a predictor and a moderator of the extent of deaf children's delay in mathematics was confirmed. These findings leave open the issue about the identification of which factors contribute to the difference in the mathematics performance between those children attending mainstream schools and those attending the other two types of educational provision. It could be that either the support that deaf children obtain in mainstream schools is better than that offered in the other two types of educational provision or deaf children attending mainstream schools have not only milder hearing loss but also higher cognitive abilities compared to those children attending units for hearing impaired and special schools for the deaf. In the longitudinal study, these hypotheses were tested.

Degree of hearing loss was hypothesised to predict deaf children's mathematical achievement. Gottardis, Nunes and Lunt (2011), in their analysis of the literature, pointed out that presence or absence of a relation between degree of hearing loss and deaf children's mathematical achievement could be due to the range of hearing loss considered. When the mathematical achievement of deaf children with moderate to profound hearing loss was compared to that of hearing children, there was a greater likelihood of observing a relation between degree of hearing loss and mathematical achievement compared with when only the mathematical performance of children with mild hearing loss was considered. In the current study, there was no significant relation between the degree of hearing loss and children's mathematical achievement, after taking into account age, years in education and type of educational provision. This result provides further support to the argument that degree of hearing of hearing loss is not a cause of deaf children's difficulties in mathematics but it is a risk factor of deaf children's delay in mathematics (Nunes and Moreno, 1998).

Deaf children using cochlear implants were hypothesised to be at an advantage in mathematics compared to those using other types of amplifications. Gottardis, Nunes and Lunt (2011) pointed out that, although there are very few studies that compared the mathematical performance of deaf children using cochlear implants with that of hearing children, it seems that deaf children who use cochlear implants perform better in mathematics compared with those who use other types of amplifications. In the current survey study, there was no difference between the mathematical performance of deaf children using cochlear implants and that of children who use hearing aids as a type of amplification, after controlling for age, years in education and degree of hearing loss. This finding is clearly against the present hypothesis and it seems to suggest that there are other factors, related to the presence of cochlear implants, which could influence deaf children's mathematical achievement. In the current study, it was hypothesised that the use of cochlear implant, more than the presence of cochlear implant in itself, could influence deaf children's mathematical skills. This hypothesis was based on the argumentation presented by Nunes, Pretzlik and Ilicak (2004) who pointed out that having a cochlear implantation is a complex experience that involves different aspects such as communication, well-being, happiness, self-reliance and how much the child was functioning before the implant. It is possible to suppose that these factors could also influence children's mathematical development. In the current study, a positive significant relation was observed between the efficiency with which deaf children used their cochlear implants and their mathematical achievement. This result provides further evidence that in order to determine the effect of the use of cochlear implants on deaf children's academic achievement it is crucial to take into account how efficient they are and how much children gain from the use of this type of amplification.

Children who speak English or use sign language at home were hypothesised to be at an advantage in mathematics compared with those children who speak another language at home. Previous research (Marschark, Lang and Albertini, 2002; Mayberry, 2002; Schick et al., 2007) reported that deaf children who have early and complete access to a true language, such as a signed language, perform better academically than those for whom language acquisition has been delayed or is not fully accessible. In the survey study carried out, deaf children who speak English at home did not show any advantage in their mathematical skills compared with those who speak another language or sign at home, after controlling for age, years in education and type of educational provision. Deaf children who sign at home performed better in mathematics than those who speak another language, once age, years in education and type of educational provision were taken into account. These findings are partially in contrast with those shown in the literature. In particular, in the case of children who sign at home, this result needs to be taken with caution because there were only 7 children who signed at home in the current sample.

Finally, it was hypothesised that the maternal level of education could influence deaf children's mathematical attainment. This was based on the results reported in studies that analysed the relation between maternal education and academic achievement in hearing children (e.g. Sirin, 2005; Nunes et al., 2009c) and in deaf children (Powers, 2003). All these studies reported that maternal education significantly predicted children's academic achievement. In the current research, the highest level of maternal education was not significantly related to deaf children's mathematical achievement. This finding is in direct contrast with those observed in the literature on hearing children. A possible explanation is that parents of deaf children, not having a wide knowledge of how to communicate and

help deaf children in their development, do not influence their mathematical attainment as much as parents of hearing children.

In the longitudinal study, the main hypothesis was that working memory, counting ability and logical-mathematical reasoning were independent and longitudinal predictors of deaf children's mathematical achievement, after taking into account background factors and non-verbal intelligence. The theoretical approach proposed by Geary (2004) considers working memory as a crucial factor for children's mathematical development. Nunes and Bryant (1996), who also developed a theoretical approach on how children learn mathematics, suggest that children need to develop their logical-mathematical reasoning and learn counting skills in order to be successful in mathematics. Deaf children have difficulties in all these three factors (working memory, counting ability and logical-mathematical reasoning) in comparison to their hearing peers. Thus, these factors could also play a crucial role in the case of deaf children's mathematical development. In the present longitudinal study, working memory, logical-mathematical reasoning and counting ability were the only factors that did make independent contributions to the prediction of deaf children's mathematical abilities, after taking into account background factors and non-verbal intelligence. Logical-mathematical reasoning was the strongest predictor of deaf children's mathematical achievement independently from the contributions of the other factors inserted in the predicting model. These results confirm the hypothesis presented at the beginning of the longitudinal study and are very positive because if it is possible to improve deaf children's performance on these factors, perhaps, their mathematical skills would also be improved.

## 5.2. Empirical contributions: Demographic factors

In the UK, Gregory (1998) and later on Powers (2003) reviewed extensively the studies that analysed deaf children's academic attainment. They pointed out that there is still an open debate on the presence of a relation between deaf students' academic achievement and background factors such as degree of hearing loss, type of amplification, type of educational provision, language used at home and socio-economic factor. The current research aimed to add further knowledge on these issues investigating whether these factors are related to deaf primary school children's mathematical achievement.

### *Degree of hearing loss*

Researchers (Nunes and Moreno, 1998; Wood et al., 1983) found no significant effect or a very low correlation between degree of hearing loss and deaf children's mathematical achievement. In the present study, degree of hearing loss was significantly negatively related to deaf children's mathematical achievement but this correlation was quite low ( $r = -.15$ ). After taking into account age, years in education and type of educational provision, degree of hearing loss did not add any additional variance to the prediction of deaf children's mathematical attainment. A possible explanation for the absence of a correlation between degree of hearing loss and mathematical performance was the presence of a higher within-groups variance of degree of hearing loss in comparison to the between-groups variance of children with the same degree of hearing loss attending different types of educational provision. In mainstream school, deaf children with a severe degree of hearing loss seemed to perform better than those who were profoundly deaf, whereas in units for hearing impaired and special schools for the deaf they tended to obtain lower scores in the mathematics test compared with profoundly deaf children. These findings could lead to two hypotheses: either children with severe hearing loss attending

mainstream schools have better cognitive skills than those attending units for hearing impaired and special schools for the deaf or different types of support are given to severely deaf children in the different types of educational provision. In the present research, the number of participants was too small to carry out further analyses. Future research should examine which of these two hypotheses can be supported. A possible way of examining this issue would be to assess the cognitive skills and mathematical skills of a wide group of severely deaf children attending different types of educational provisions and analyse whether their cognitive skills differ in the three types of educational provisions and if this influences their mathematical skills.

Degree of hearing loss was also found to be a confounding factor in the relation between type of educational provision and deaf children's mathematical achievement. Children who were profoundly deaf were more likely to attend special schools for the deaf than mainstream schools. This suggests that deafness is a risk factor in relation to the type of school that children attend. Therefore, it needs to be taken into account when this background factor is related to deaf children's mathematical achievement in order to obtain reliable results.

In conclusion, the present findings support further the hypothesis that degree of hearing loss cannot be a cause of deaf children's delay in mathematics but it is a risk factor, as pointed out in previous studies that analysed the relation between degree of hearing loss and deaf children's mathematical achievement (Moreno, 2000; Nunes and Moreno, 1998).

#### *Types and use of amplification*

Gottardis, Nunes and Lunt (2011) examined the literature on the presence of a relation between cochlear implant and mathematical achievement and concluded that the presence

of cochlear implant may predict deaf children's mathematical achievement but more research is needed.

In the present study, children who used cochlear implants did not differ in their mathematical skills in comparison with children who used hearing aids, after taking into account age, years in education and degree of hearing loss. The finding, which goes against previous results observed in the literature, could be due to the use of stricter controls such as degree of hearing loss, that were employed in the previous research (Thoutenhoofd, 2006). Another reason of this discrepancy could be related to the choice of the mathematical test employed in the study. The PIPS mathematical test uses visual presentation alongside linguistic descriptions and particular attention was given to maximise deaf children's access to the meaning of the different items in the test. Therefore, the lack of difference between mathematical performance of deaf children with cochlear implants and that of deaf children with hearing aids could have also been affected by the choice of the mathematical test used in the current study.

When deaf children use cochlear implants as a type of amplification, the presence of the cochlear implant is only one of the factors that are related to this issue. Years since implantation was done, age at which the implantation was carried out and how much support the children received to adapt to the cochlear implants are some of the factors that are related to the presence of cochlear implant in itself. It is therefore possible that these factors could influence deaf children's mathematical achievement. For instance, if children are implanted in their first years since they are born or if they have been using the cochlear implant for quite a long time, they may be able to communicate better with other people, to perceive more sounds, discriminate better what these sounds mean and, generally, gain more from the use of cochlear implants compared to what a child who has just been

implanted can get. As a consequence of this, their mathematical skills could be more developed than those of other children who have only used cochlear implants for a short time. It is therefore possible that it is not the presence of the cochlear implant in itself that influences deaf children's mathematical development but how well deaf children use it (Nunes, Pretzlik and Ilicak, 2004). This was one of the hypotheses presented in the current research. The results showed that the efficiency of how deaf children used their cochlear implants was significantly and positively related to children's mathematical skills. In particular, the factors that seem to be associated with successful mathematical development were children's ability to communicate with other people, use of the cochlear implants, self-reliance, well-being and social relationships. Children who were more independent, more able to communicate with their family, who relied more on their cochlear implants to perceive the sounds around them and had better social relationships with their family members obtained higher attainment in mathematics than those who had more difficulty in these aspects. These findings bring clear evidence to the hypothesis presented by Nunes, Pretzlik, and Ilicak (2004) suggesting that it is not the presence of the cochlear implant in itself that helps deaf children's mathematical development but it is the mixture of all other factors that are related to the use of the cochlear implant that could influence deaf children's mathematical skills.

#### *Type of educational provision*

As highlighted by Mitchell and Karchmer (2011), many studies reported that deaf children attending mainstream schools seem to perform better than those attending other types of educational provisions. In the present research, type of educational provision was found to be a significant predictor and moderator of deaf children's mathematical achievement, after taking into account age, years in education and degree of hearing loss.

This seems to suggest two possibilities: either mainstream schools offer a better learning environment for deaf children than the other types of educational provision or deaf children who attend mainstream schools have higher cognitive abilities than those attending schools with a unit for hearing impaired or special schools for the deaf. In the present research, it was possible to examine these alternative hypotheses. In the longitudinal study, after taking into account non-verbal intelligence, age and degree of hearing loss, type of educational provision did not add any additional variance to the prediction of deaf children's mathematical achievement. This result supports the second hypothesis. Children attending mainstream schools have milder degrees of hearing loss and better cognitive abilities than those attending the other two types of educational provisions and this seems to influence their mathematical skills. It is therefore possible to conclude that type of educational provision may not influence deaf children's mathematical achievement per se: once cognitive skills are taken into account, the performance levels for the different types of educational provision are the same.

#### *Language used at home*

Previous studies (Marschark, Lang and Albertini, 2002; Mayberry, 2002; Schick et al., 2007) reported that early and complete access to a true language, such as a signed language, is related to successful academic achievement. Powers (2003), who analysed the influence of different background factors, such as age, gender, degree of hearing loss, socio-economic status and language used at home, on students' GCSE results, reported that language used at home was significantly related to students' academic achievement ( $\beta = .11$ ) although this result was not strongly significant ( $p = .05$ ). In the current research, children who speak English at home did not perform better in mathematics than those who use another language at home. This result is quite surprising because one might think that

deaf children who speak another language at home would be at a disadvantage in mathematics compared with those who speak only English at home. Similar results were also reported by Powers (2003) who found that when only the GCSE results in mathematics were considered, language used at home did not add any additional variance to the prediction of deaf students' results in mathematics. In conclusion, speaking a language other than English at home seems to be not a disadvantage in relation to children's mathematical skills but probably, as highlighted by Marschark and Hauser (2012), it is how much a child is able to communicate and how early and fluent is the access to language that parents provide that matters for their development.

In the current study, children who sign at home obtained higher scores in mathematics compared with those who speak another language at home but they did not differ in mathematics when compared with those who speak English. This finding is partially unexpected because on the basis of the literature (Marschark, Lang and Albertini, 2002), children who sign at home, seem to obtain higher academic performances than those children who speak English or another language at home. Although some of the schools that participated in the project claimed to focus exclusively on an oral educational approach, all of them used some sort of signing to support children in their teaching. This could explain this lack of difference in mathematics between children who sign and those who speak English. It is also important to point out that, in the current sample, there were only 7 children who sign at home. Therefore, these findings need to be taken with caution and future research should examine this issue with a larger sample of signing children.

Finally, it is necessary to take into account that, as pointed out previously, the mathematical test of the PIPS used in the present study uses visual representation alongside linguistic descriptions and the researcher made every effort to make the items more

accessible for deaf children, avoiding possible misunderstanding due to the language. This could have specifically affected the present findings on the relation between language used at home and children's mathematical attainment. Future studies should employ other measures investigating this issue.

### *Maternal education*

In hearing children, highest maternal qualification is a significant predictor of children's mathematical achievement (Nunes et al., 2009c). Children whose mothers have high levels of education perform better in mathematics compared with those whose mothers have low educational levels, even if they attend the same school (Nunes et al., 2009c; Sirin, 2005; Jimerson, Egeland and Teo, 1999; Caro, McDonalds and Williams, 2009). In the present research, this finding was not replicated in deaf children: highest level of maternal education was not significantly related to deaf children's mathematical achievement. This result converges with those reported by Gottardis (2009) in her secondary data analysis of the ALSPAC database. A possible explanation of this result could be that, in the case of deaf children, highly educated parents, too, do not have the knowledge to support their children's development, interacting with them less successfully than in the case of hearing children. Parental education and socio-economic background become less important in determining deaf children's development, making the influence of schooling a crucial factor for deaf children's mathematical development. Maybe, if parents could have more access to the knowledge that teachers of the deaf have, they would be able to provide the same type of support that they create for their hearing children.

### **5.3. Theories on how children learn mathematics and possible causes of deaf children's delay in mathematics**

In the introduction chapter, three theoretical approaches on how hearing children learn mathematics were outlined in order to determine whether they could be applied to explain deaf children's difficulties in mathematics. The first approach described was proposed by Gelman (Gelman and Gallistel, 1978) and later on by Butterworth (2000; 2005). They argued that we are born with an innate number relevant mental structure. This means that, if this theoretical approach was applied to deaf children's difficulties in mathematics, difficulties in number processing should be observed in deaf children in comparison to their hearing peers. No evidence of any difference between deaf and hearing children in their number representation processes was found in previous studies (Zarfaty, Nunes and Bryant, 2004; Arfè et al., 2011). Therefore, this approach was not investigated further in the present research.

The second theoretical approach was suggested by Geary (2004) who identifies the central components of working memory as crucial factors at the centre of the learning process. Previous studies (Marschark and Mayer, 1998; Moreno, 2000; Gottardis, 2009) reported that deaf children have low working memory capacity in comparison to hearing children, suggesting that working memory could be a factor related to deaf children's difficulties in mathematics.

The third approach was proposed by Vergnaud (1997) and embraced later by Nunes and Bryant (Nunes et al., 2007) who argued that in order for children to learn mathematics, they need to develop logical-mathematical reasoning and to understand how to use a series of conventions such as counting ability. The analysis of the literature on the difficulties that deaf children present in mathematics in comparison to hearing children showed that

deaf children are delayed in their development of logical-mathematical reasoning skills (Nunes et al., 2008; 2009a; 2009b) and counting abilities compared with their hearing peers (Secada, 1984; Leybeart and Van Cutsem, 2002). These findings suggest that logical-mathematical reasoning and counting ability could also affect deaf children's mathematical development.

The present study aimed to investigate whether these last two theoretical approaches can be applied to explain deaf children's difficulties in mathematics and therefore to determine whether working memory, logical-mathematical reasoning and counting ability could be causes of deaf children's delay in mathematics in comparison to their hearing peers.

As discussed in the introduction, according to the Bradley and Bryant (1983) paradigm, in order to establish a causal link between two variables both longitudinal and intervention studies are essential because neither method alone can support causal inferences without the contribution of the other. Both types of studies support casual inferences but they also have weaknesses. In longitudinal studies, for example, it is not possible to control for a third variable which could also affect the causal relation. In intervention studies carried out in the laboratory, there is the possibility of a lack of ecological validity whereas, in those conducted outside laboratory, it is harder to determine a causal relation because conditions in the real world setting outside the laboratory are completely different and confounding variables are more difficult to control. Only the combination of both longitudinal and intervention studies can determine the presence of a casual relation between two variables (Bradley and Bryant, 1983).

In the present research, the use of a longitudinal research strategy aimed to determine the first step of this process in order to establish whether there is a causal

relation between logical-mathematical reasoning, working memory and counting ability and deaf children's delay in mathematics. The current findings supported this hypothesis. Logical-mathematical reasoning, working memory and counting ability were longitudinal and independent predictors of deaf children's mathematical achievement, after considering background factors and non-verbal intelligence. This finding presents two direct implications. Firstly, it contributes providing additional evidence that the theoretical approach proposed by Geary and that supported by Nunes and Bryant can be applied to understand not only hearing children's mathematical development but also that of deaf children in primary school. Secondly, the first step of the process to determine a causal relation between these factors and deaf children's mathematical skills was achieved. If intervention studies also confirm that an improvement of deaf children's performances on these factors corresponds to an increase in their mathematical skills, then counting ability, logical-mathematical reasoning and working memory could be good candidates for causes of deaf children's delay in mathematics.

To the best of my knowledge, there have been no intervention studies conducted to improve deaf children's counting ability. There is therefore the necessity to fill this gap in order to verify the hypothesis that counting ability is a cause of deaf children's delay in mathematics.

As reported in Chapter 2, Nunes and Moreno (2002) conducted an intervention study which aimed to improve deaf children's understanding of logical-mathematical reasoning. In this study, they also investigated whether the improvement in their logical-mathematical reasoning skills yields an increase in their mathematical skills. The findings showed that the intervention was successful; 31% of the children made less progress than predicted and 68.2% had higher observed than predicted scores. A significant difference

indicated that the observed scores were significantly higher than the predicted scores (Nunes and Moreno, 2002). Because both intervention and longitudinal studies confirmed the presence of a relation between logical-mathematical reasoning and deaf children's mathematical achievement and in the literature it is well documented that deaf children have difficulties in developing logical-mathematical reasoning skills, there is evidence that logical-mathematical reasoning is one of the causes of deaf children's delay in mathematics. These findings provide even stronger support to the crucial role that logical-mathematical reasoning plays in hearing and deaf children's mathematical development as argued by Nunes and Bryant in their theoretical approach.

In the past, working memory capacity was viewed as a constant trait that could not be enhanced by training (Miller, 1956). Recently, as pointed out by Klingberg (2010) and by Morrison and Chien (2011) in their review of the literature, there has been a growth of studies (Holmes et al., 2009; Westerberg et al., 2007, Thorell et al., 2009; MacNamara and Scott, 2001; Turley-Ames and Whitfield, 2003; Kloo and Perner, 2003) demonstrating that working memory capacity can be expanded through targeted training. The results of these studies reported also that the training-related increases in working memory capacity yields improvements in a range of important cognitive skills (Chien and Morrison, 2010) as well as improved cognitive function in clinical populations with known working memory deficiencies (Kilngberg et al., 2005). These findings seem to suggest that working memory capacity is governed by the same laws of plasticity that characterise other parts of the brain.

On the basis of this new conception of working memory, Nunes et al. (2011) investigated whether deaf children's working memory capacity could be improved through training. They designed a working memory intervention programme for deaf children (age

5-12 years) that used visual and verbal rehearsal strategies combined with unguided practice in computer games that aimed at developing implicit orientation processes in biased attention tasks. A significant difference was found between the intervention and the comparison group, after taking into account age, non-verbal intelligence and the pre-test score. The intervention group had an advantage of 0.27 points compared with the baseline group and a clear effect of practice was observed, showing that the intervention programme was effective (Nunes et al., 2011). These findings point out that deaf children's working memory ability can be improved through training but it is still not clear whether this increase in their working memory skills also has an impact on their mathematical skills.

Currently, there are concerns regarding whether working memory training is really a panacea for cognitive enhancement. Morrison and Chien (2011), in their meta-analysis of the studies that employed working memory training, pointed out that there is great variability across studies in terms of training, findings and of the measures employed in the pre- and post-test. This makes it very difficult to compare the different results reported in the studies and to be sure about the actual efficacy of the working memory training. Morrison and Chien (2011) also observed that the test score improvements showed in the studies may be achieved through various influences on the expectations or level of investment of participants rather than on the intentionally targeted cognitive processes. For example, in anticipation of the goals of the experiment, the participants may put a greater effort into their performance during the post-training assessment. This difficulty is most problematic when studies employ no control group (e.g. Holmes et al., 2010) or no-contact control group (e.g. Jeaggi et al., 2008; Schmiedek, Lovden and Lindenberger, 2010). Finally, Morrison and Chien (2011) highlighted that the studies often used only one task on

the basis of which generalisation is drawn. They give as an example the study conducted by Jaeggi et al. (2008) who claimed to have demonstrated an impact of working memory training on fluid intelligence. In reality, Jaeggi et al. (2008) demonstrated a significant impact of training only on a single task (Bochumer Matrizen-test, BOMAT) that was used to assess fluid intelligence. This task directly relied on the ability to store information in spatial working memory, which was precisely the skill that was practised during training. Morrison and Chien (2011) concluded that, at the moment, it is not possible to reach a clear conclusion on whether working memory training produces a real improvement of working memory capacity. Further studies should use standardised tests and take into consideration the influence of expectations on participants in order to verify the efficacy of working memory training on improving children's working memory capacity and other cognitive skills.

This need for further investigation also has to be applied to the studies on deaf children's working memory training. Future research should replicate the study conducted by Nunes et al. (2011) analysing whether, after employing the working memory training, deaf children's mathematical attainment improved compared with that of their hearing peers. If this was verified, working memory could be considered another cause of deaf children's delay in mathematics compared with their hearing peers.

In conclusion, on the basis of the evidence obtained by the current research both the theoretical approach proposed by Geary and that suggested by Nunes and Bryant can be applied to explain deaf children's difficulties in mathematics suggesting that deaf children's mathematical development is only delayed from that of hearing children. Only in the case of logical-mathematical reasoning is there enough empirical evidence that supports the hypothesis that this factor could be one of the causes of deaf children's delay

in mathematics. Regarding working memory and counting ability, more research needs to be carried out before reaching a definitive conclusion.

#### **5.4. Practical implications**

The current findings also present positive practical implications in terms of helping deaf children to improve their mathematical skills. Firstly, in the longitudinal study, when both control and predictor variables were inserted into the regression equation, none of the control variables (age, years in education, degree of hearing loss, type of educational provision and non-verbal intelligence) explained any additional variance of deaf children's mathematical attainment. These factors cannot be modified through teaching practice or any other kind of support given to the deaf children. Thus, the lack of significance of these factors in predicting deaf children's mathematical skills is very positive in terms of helping deaf children in their mathematical development because it leaves room for other factors to be related to their mathematical attainment.

Secondly, counting ability and logical-mathematical reasoning predicted deaf children's mathematical achievement independently from the contribution of background factors and non-verbal intelligence. The question now is if and how it is possible to improve deaf children's abilities on these factors.

Counting involves not only the memorisation of the number words in a fixed order but also the understanding of how number labels are generated in order to surpass simple memorisation of labels (Nunes, 2004). Evidence of the presence of these rules comes from studies that analysed the mistakes that hearing children make when they count. In the first part of the string, formed by number labels that have to be memorised, hearing children make mistakes such as omission of one or more words, reversal and repetitions (Ginsburg,

1977; Fuson, 1988). Once they reach twenty and the subsequent decades, children are most likely to stop counting and say they do not know what comes next when they reach a decade plus nine (Ginsburg, 1977; Fuson, Richards and Briars, 1982). Children can also repeat a decade or skip a decade altogether without disrupting the pattern of decade plus 1, plus 2 and so on (Nunes, 1996). Miller and Stigler (1987) observed that almost all the children who could count up to 60 could also continue counting up to 99. These mistakes and this large increase of knowledge of the number string (from 60 to 99) suggest that children understand and learn the logical property of number labels, that Nunes (2004) named additive composition, and use it to acquire the knowledge of the counting string.

According to the language spoken, counting systems can be completely regular or can present both regularities and irregularities in relation to the way in which the number labels are formed. Chinese children for example have to learn a regular system: there is a basic set of labels in the system (from 1 to 10) and from 11 to 99 the number words are a combinations of the basic labels generated through a simple set of rules in a completely regular system (Nunes, 1996; Nunes, 2004). English children, in contrast, have to learn a system that has regularities and irregularities. There are twelve labels that need to be learned; the decades words share a common ending (-ty) giving an idea of regularity in the system but in some cases the stems present changes when they become part of a decade label. As argued by Nunes (1996) in her analysis of the literature on the differences between learning to count in English, French and Chinese, the regularity of the system could influence not only the learning of number labels but also the learning of the rules that guide the creation of the number labels. Miller and Stigler (1987) showed that it is easier to learn the number words in a regular counting system such as Chinese than in a less regular system such as English. Chinese children aged from 5 to 6 years counted up to higher

numbers than American children and count sets of objects more successfully. Miller and Stigler (1986) argued that this was due to the Chinese's better understanding of the number labels rather than their understanding of one-to-one correspondence. Lines and Bryant (1993) compared the performance of Chinese and English 6 year old children with the aim to determine whether the regularity of the counting system influenced children's understanding of additive composition that is at the base of counting system. They assessed children's additive composition skills using the Shop Task. In this task, children were asked to pay certain sums of money for their pretended purchases using either coins of one denomination only (e.g. 1p) or coins with different values (e.g. 5p and 1p or 1p and 10p). Lines and Bryant (1993) reported the absence of a difference in the performance of English and Chinese children when only 1p coins were used. The Chinese children did significantly better than English children in this task when coins of different denominations were mixed. Lines and Bryant (1993) argued that the greater regularity of the Chinese counting labels appears to facilitate the understanding of additive composition of numbers. In view of these findings, it is clear that, in order to count, children need to understand the additive composition that will support their memorisation of the number labels. Both the understanding of additive composition and the memorisation of number labels seem to be facilitated by the regularity of the counting system.

For deaf children, counting seems to be more difficult than for hearing children for two reasons. Firstly, the memorisation of the number labels requires serial recall and, as pointed out at the beginning of this thesis, deaf children have difficulties in this task compared to hearing children (Marschark and Mayer, 1998; Marschark, Lang and Albertini, 2002). Secondly, deaf children seem to present difficulties in developing their

understanding of additive composition when compared to hearing children (Nunes et al., 2009b).

Deaf children can learn counting, either by using the oral counting string or through BSL. In the first case, the task is more complicated than for hearing children because deaf children need to learn phonological items in a fixed order. Nunes and Moreno (1998) examined the counting ability of severely to profoundly deaf children educated orally in BSL and SSE (Sign Support English). Many deaf children showed phonological confusion errors and, in their second and third year of primary school, these children were still unable to count up to 60, an ability that was acquired by hearing children at the end of the first year of school. Nunes and Moreno (1998) suggested that the difficulty in learning the labels in a fixed order could explain the delay observed in deaf children's learning of the counting string in comparison with hearing children.

BSL relies more on rule-based learning than English does (Nunes, 2004). The numbers 1 to 5 are formed keeping the hand upright, the palm towards the signer and extending the fingers in an ordered fashion, starting with the index, moving across the small finger and the thumb. All five fingers indicate number 5. The number 6 is signed with the hand in the horizontal orientation and the thumb extended; the remaining fingers are then extended to sign numbers up to 9. Numbers 10, 11 and 12 are irregular. The numbers from 13 to 19 are signed in the same way as in the units but are associated with a waving movement in the horizontal or vertical direction. The number 20 onwards is signed as 2 and 0 with a spatial displacement indicating the same organisation as in writing (Nunes, 2004). As pointed out by Nunes (2004), the rule-based composition of BSL should make it easier for deaf children to learn the counting labels than in English because the number of items to be recalled without the support of rules is smaller in BSL than in English. As for hearing

children, the presence of a more regular system in BSL than in oral English could also support both the understanding of additive composition and the acquisition of a good flexibility of their knowledge of the counting string.

Secada (1984) and Leybaert and Van Cutsem (2002) investigated the counting ability of severely and profoundly deaf preschool children who sign comparing it with that of hearing children. In one of the tasks, they asked children to answer the question “what comes after  $x$ ?” and to count backwards. After matching deaf children’s counting skills with those of their hearing peers, deaf children were better both at answering this question and at counting backwards compared with the hearing children, showing a better flexibility of their knowledge of the counting string. These findings seem to support that, once the problem of memorising the number labels is overcome, deaf children who sign have better flexibility and understanding of the rules of counting than their hearing peers.

Another way of supporting deaf children’s development of the counting string could be to make deaf children explicitly aware of additive composition. Nunes et al. (2009b) carried out a brief intervention study aimed at determining whether it is possible to improve deaf children’s understanding of additive composition through teaching. After a very short teaching programme based on solving a series of problems in the Shop Task, the intervention group improved their additive composition skills compared to the control group. This result supports the hypothesis that it is possible to improve deaf children’s additive composition skills through a teaching programme.

In conclusion, learning the number labels is fundamental for counting but it is not possible to do it if children do not understand additive composition. The memorisation of the number labels is a difficult task for deaf children because of the nature of the task but it could be improved and supported through teaching if children are supported in their

understanding of additive composition and if sign language is used as the language to learn the number labels.

As discussed extensively in Chapter 2, regarding logical-mathematical reasoning, different studies (Nunes et al., 2009b; Nunes and Moreno, 2002; Nunes et al., 2008; Nunes et al., 2009a) analysed whether the performance of deaf children in logical relations such as additive composition, inversion between addition and subtraction and one-to-many correspondence could be improved through very short intervention programmes. The method used in all these studies was very similar. The children involved in the project were randomly assigned to an intervention and a control group and they were tested at pre-test, immediate post-test and delayed post-test. The results of all these studies showed that, at post-test, the intervention group significantly out-performed the control group on the different tests used: in the inversion task (Nunes et al., 2008), in the multiplicative reasoning problems (Nunes et al., 2009a) and in the Shop Task (Nunes et al., 2009b). These findings support the hypothesis that it is also possible to improve deaf children's understanding of logical relations through very short training sessions.

In summary, the findings that counting ability and logical-mathematical reasoning are independent longitudinal predictors of deaf children's mathematical achievement are very positive because both these factors can be improved through teaching training. Thus, if teaching trainings on these two factors were to be implemented at the beginning of school, deaf children's delay in mathematics in comparison with their hearing peers could be reduced.

## **5.5. Strengths and limitations of the current study**

The main strength of this research is that it helps in gaining understanding of the factors that predict deaf children's mathematical development longitudinally. This also has important implications in relation to the identification of possible causes of deaf children's delay in mathematics. The present research also provides a recent and rich picture of deaf children's mathematical achievement in the UK through the years in primary school, providing useful information not only on the extent of deaf children's delay in mathematics but also on the moderators of the extent of this delay. Both these aspects (the identification of longitudinal predictors and of moderators of the delay) are crucial in order to help deaf children to improve their mathematical abilities.

This research has three main drawbacks. The first limitation is the use of a mathematics test that may have been considered too easy for hearing children in the comparison between hearing and deaf children. On the one hand, if an age-appropriate test had been used to assess the children's mathematical achievement, a valid assessment of hearing children's mathematical performance would have been obtained, but deaf children's mathematical skills would probably have been underestimated, causing a floor effect for their mathematical performances. On the other hand, the use of a test considered too easy for hearing children allowed for a reliable representation of deaf children's mathematical skills but, at the same time, this could have caused a ceiling effect for the hearing children's mathematical performance. It is important to point out that the focus of the present research was to evaluate deaf children's mathematical achievement avoiding an underestimation of their performance. Previous research (Traxler, 2000) with deaf children excluded from the study those children whose teachers expected them to be frustrated by the age appropriate test; this has resulted in biased sampling of deaf children. As described

in Chapter 3, when the measure of mathematical achievement was described, the use of Year 2 mathematical assessment for all the participants in all the age ranges aimed to avoid possible sample bias. Therefore, although a ceiling effect with hearing children could influence the findings, the criticism of using a selected sample of deaf children or a test which is inappropriate for them is circumvented.

The second issue concerns the measures adopted in the research. All the tests selected here were originally designed for hearing children and later adapted for deaf children. In the literature, there is still an open discussion about the consequences of the use of these types of measures. It is possible that the selection of these measures could have had a negative effect on deaf children's performance because they were not created considering at the centre of their design the strengths and weaknesses of deaf children that could affect their performance. However, all these measures have been used previously in other research with deaf children and it was not feasible in the context of this research to design measures for deaf children, standardise them and use them with a hearing group for the purpose of comparison.

The third limitation is that deaf children's intelligence was assessed using only one subtest of the BAS-II. Braden (1994), in his analysis of the literature on deaf students' intelligence, argued that in order to obtain a fair assessment of deaf children's intelligence in comparison to hearing children, non-verbal tests should be used instead of verbal tests. Verbal tests are based on the assumption that the individual being tested has been exposed to the verbal content of the items approximately as often as the participants in the normative sample (Braden, 1994). Because deaf people's exposure to the language environment is often restricted, low scores of deaf persons on a verbal intelligence test could merely reflect that the deaf person has been denied the opportunity to acquire verbal

knowledge due to the hearing loss. Thus, in the present research, a non-verbal test, the matrices subtest of the BAS-II, was chosen. The choice to use only one subtest was done with the aim of avoiding stress and frustration during the assessments. In total, the assessments took around one hour and often pauses were necessary while conducting them in case the children were tired. The result of the current study shows that non-verbal intelligence was not a significant predictor of deaf children's mathematical achievement when working memory, logical-mathematical reasoning and counting ability were taken into account in the predictive model. The studies (e.g. Nunes et al., 2012; Gottardis, 2009; Nunes et al., 2007) that used a more complete assessment of deaf and hearing children's intelligence reported that this factor influences significantly children's mathematical achievement. It is therefore possible that when a wider assessment of general intelligence is considered, non-verbal intelligence will contribute significantly to the prediction of deaf children's mathematical achievement.

## **5.6. Suggestions for future research**

As reported in the previous chapters, Nunes and Bryant (1996) pointed out that counting skills and logical-mathematical reasoning are crucial factors for hearing children's successful mathematical development. The literature on deaf children has well documented that deaf children present a delay in their acquisition of these two factors in comparison to their hearing peers. This was the argumentation that led to the hypothesis that logical-mathematical reasoning and counting skills could be causes of deaf children's mathematical achievement.

As described previously, in order to establish whether two factors are in a causal relation both longitudinal and intervention studies need to be employed (Bradley and Bryant, 1983). The present longitudinal study found that counting ability and logical-

mathematical reasoning independently predict deaf children's mathematical achievement, above and beyond the influence of non-verbal intelligence and background factors. This finding confirmed the first step of the paradigm to determine whether these two factors are possible causes of deaf children's delay in mathematics.

To the best of my knowledge, there have been no intervention studies that aimed to improve deaf children's counting ability. Previous research observed that an improvement in logical-mathematical reasoning leads to an increase in deaf children's mathematical skills (Nunes and Moreno, 2002). In this study, Nunes and Moreno (2002) considered the different logical relations (one-to-many correspondence, additive composition, inversion between addition and subtraction) that are at the basis of the concept of logical-mathematical reasoning as a whole. It would be interesting to examine whether each of these logical-relations would contribute independently to deaf children's mathematical achievement.

Future research should focus on completing the second step of the process to determine whether logical-mathematical reasoning and counting skills are possible causes of deaf children's delay in mathematics. A possible research project could focus on implementing a series of intervention programmes aimed to improve deaf children's counting ability and each logical relation that is at the basis of the concept of logical-mathematical reasoning. This research project would aim to determine the effectiveness of these interventions and to analyse whether counting and each logical relation contribute independently to the prediction of deaf children's mathematical skills. To address these aims, a longitudinal design will be employed.

The participants in this research project will be from moderately to profoundly deaf children who are at the beginning of their first year of primary school. Deaf children with

special additional needs other than deafness will be excluded in order to avoid possible confounding.

At the beginning of the project, deaf children's general mathematical skills will be assessed through a standardised test. Counting ability and their logical relations skills will be also assessed. These tests will provide a baseline for their mathematical abilities. A non-verbal intelligence test will also be carried. This will be used as a control factor when the mathematical skills of the two groups will be compared.

The participants in this research will be randomly assigned to an intervention and a control group. A series of intervention programmes will be delivered to the intervention group. The first intervention programme will be aimed at improving children's acquisition of the counting skills. The intervention will focus on teaching deaf children the counting string using BSL, showing them the regularities of the counting system. This will be the first intervention because the learning of the counting string is the first step in the understanding of the concept of number. This will be followed by an intervention on developing deaf children's additive composition that is a crucial element that children need to grasp in order to move from oral to written counting. This could be achieved using the intervention programme developed by Nunes et al. (2009b) using the Shop Task. Later on, an intervention programme on inversion between addition and subtraction will be carried out with the aim of improving deaf children's problem solving skills in the context of additive reasoning. Finally, an intervention on increasing deaf children's one-to-many correspondence will be implemented. This is another important factor that is at the basis of multiplicative reasoning.

To the control group, a series of other activities not related to those carried out with the intervention group will be offered. In this way, the control group could also benefit from taking part in the research project.

After each intervention programme, tests aimed to verify whether the intervention group improved in comparison to the control group in the skills that were the focus of the particular intervention completed will be administered. In order to do so, the same tests used at the beginning of the project on counting and logical relations will be employed.

After all these interventions are completed, children's mathematical skills will be assessed using the same standardised test that was used at the start of the project in order to determine whether children's mathematical skills improved after the interventions compared with the control group. The data can be analysed carrying out regression analyses of deaf children's mathematical skills where age, non-verbal intelligence and the scores on the mathematical achievement test conducted at the start of the project will be considered as control variables. The scores of the tests of counting ability and of each logical relation obtained at the start of the project will be inserted as predictors. The results of these analyses will provide information on the presence of independent contributions of the different interventions carried out on deaf children's mathematical achievement.

## **5.7. Concluding remarks**

Throughout primary school, deaf children's mathematical skills are substantially behind those of their hearing peers and this gap is increasing according to children's age, the years spent in education and the types of educational provision attended. The use of cochlear implant and the access to sign language at home seem also to be protective factors for a successful mathematical performance.

Logical-mathematical reasoning, counting ability and working memory are longitudinal and independent predictors of deaf children's mathematical achievement, after controlling for non-verbal intelligence and background factors. Logical-mathematical reasoning is the strongest among these predictors. The current findings, together with those reported in the literature in relation to intervention studies and comparative studies between deaf and hearing children on logical-mathematical reasoning, provide good evidence for the possibility that this factor could be a good candidate for causes of deaf children's delay in mathematics.

## References

Action on Hearing Loss (2012) *Deafness*. (Online). Available from:

<http://www.actiononhearingloss.org.uk/your-hearing/about-deafness-and-hearing-loss/deafness/describing-deafness.aspx> (Accessed 19 September 2012)

Adams, J. and Hitch, G. (1997) Working memory and children's mental addition. *Journal of Experimental Child Psychology*, **67** (1), 21-38.

Allen, T. E. (1986) Patterns of academic achievement among hearing impaired students: 1974 and 1983. In: A. N. Schildroth and M. Karchmer (eds.). *Deaf children in America*. San Diego, CA: College-Hill press, 161-206.

Allen, T. E., and Karchmer, M. (1990). Communication in classrooms of deaf students: Student, teacher, and program characteristics. In: H. Bornstein (ed.). *Manual communication: Implications for education*. Washington, DC: Gallaudet University Press, 45-66.

Allen, T. E. and Osborn, T. I. (1984) Academic integration of hearing-impaired students: Demographic, handicapping, and achievement factors. *American Annals of the Deaf*, **129** (2), 100-113.

Alloway, T. P. and Alloway, R. G. (2010) Investigating the predictive roles of working memory and IQ in academic attainment. *Journal of Experimental Child Psychology*, **106**, 20-29.

Alloway, T. P. and Gathercole, S. (2005) *Working memory and short-term sentence recall in young children*. *European Journal of Cognitive Psychology*, **17** (2), 207-220.

- Andersson, U. (2008) Working memory as predictor of written arithmetic skills in children: the importance of central executive functions. *British Journal of Educational Psychology*, **78**, 181-203.
- Ansell, E. and Pagliaro, C. (2006) The relative difficulty of signed arithmetic story problems for primary level deaf and hard-of-hearing students. *Journal of Deaf Studies and Deaf Education*, **11**, 153-170.
- Archbold, S. et al. (2002) Parents and their deaf child: Three years after cochlear implantation. *Deafness and Educational International*, **4**, 12-40.
- Arfè, B. et al. (2011) Analogical and symbolic comparison of numerosity in preschool children with cochlear implants. *Deafness and Education International*, **13**, 34-45.
- Aswal, G. S. (2001) Intelligence as correlates of achievement in mathematics across different levels of SES. *Psycholinguia*, **31** (2), 127-130.
- Aubrey, C., Dahl, S. and Godfrey, R. (2006) Early mathematical development and later achievement: further evidence. *Mathematics Education Research Journal*, **18** (1), 27-46.
- Aunola, K. et al. (2004) Developmental dynamics of math performance from preschool to grade 2. *Journal of Educational Psychology*, **96** (4), 699-713.
- Baddeley, A. D. (1986) *Working memory*. Oxford: Clarendon Press.
- Baddeley, A. D. and Hitch, G. (1974) Working memory. In: G.A. Bower (ed.). *The Psychology of Learning and Motivation*. Academic Press: New York, 47-89.
- Barbosa, H. (in press) *Mathematical abilities of young Brazilian deaf children-a comparative study*.

- Baron, R. M. and Kenny, D. A. (1986) The moderator-mediator variable distinction in social psychology research: conceptual, strategic and statistical considerations. *Journal of Personality and Social Psychology*, **51**, 1173-1182.
- Barrouillet, P. and Lepine, R. (2005) Working memory and children's use of retrieval to solve addition problems. *Journal of Experimental Child Psychology*, **91** (3), 183-204.
- Bartels, M. et al. (2002) Heritability of educational achievements in 12-year-olds and the overlap with cognitive ability. *Twin Research*, **5**, 544-553.
- Bavelier, D. et al. (2001) Impact of early deafness and early exposure to sign language on the cerebral organization for motion processing. *Journal of Neuroscience*, **21**, 8931-8942.
- Binet, A. and Simon, Th (1905) La misère physiologique et al misère sociale. *L'année psychologique*, **12**, 1-24.
- Braden, J. P. (1992) Intellectual assessment of deaf and hard-of-hearing people: a quantitative and qualitative research synthesis. *School Psychology Review*, **21**, 89-94.
- Braden, J. P. (1994) *Deafness, Deprivation and IQ*. New York: Plenum Press.
- Braden, J. P., Kostrubala, C. E. and Reed, J. (1994) Why do deaf children score differently on performance vs. motor-reduced nonverbal intelligence tests? *Journal of Psychoeducational Assessment*, **12**, 357-363.
- Bradley, L. and Bryant, P. (1983) Categorizing sounds and learning to read-a causal connection. *Nature*, **301** (3), 419-421.

British Association for Teachers of the Deaf (BATOD) (2011) *CRIDE report on 2011 survey on educational provision for deaf children in England*. (Online). Available from:

<http://www.batod.org.uk/index.php?id=/publications/survey/CRIDE2011.pdf>

(Accessed 7 February 2012).

Bull, R., Blatto-Vallee, G. and Fabich, M. (2006) Subitizing, magnitude representation, and magnitude retrieval in deaf and hearing adults. *Journal of Deaf Studies and Deaf Education*, **11** (3), 290-302.

Bull, R., Epsy, K. A. and Weibe, S. A. (2008) Short-term memory, working memory, and executive functioning in preschoolers: longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology*, **33** (3), 205-228.

Bull, R., Marschark, M. and Blatto-Vallee, G. (2005) SNARC hunting: examining number representation in deaf students. *Learning and Individual Differences*, **15**, 223-236.

Bull, R., Marschark, M. and Covertino, C. (2011) Numerical estimation in deaf and hearing adults. *Learning and Individual Differences*, **21** (4), 453-457.

Bull, R. and Sherif, G. (2001) Executive functioning as a predictor of children's mathematical ability: inhibition, switching and working memory. *Developmental Neuropsychology*, **19**, 273-293.

Butterworth, B. (2000) *The mathematical brain*. Macmillan: London.

Butterworth, B. (2005) The developmental of arithmetical abilities. *Journal of Child Psychology and Psychiatry*, **46** (1), 3-18.

- Butterworth, B., Cipollotti, L. and Warrington, E. K. (1996) Short-term memory impairment and arithmetical ability. *Quarterly Journal of Experimental Psychology*, **49A**, 251-262.
- Caro, D. H., McDonalds, J. T. and Willms, J. D. (2009) Socio-economic status and academic achievement trajectories from childhood to adolescent. *Canadian Journal of Education*, **32** (3), 558-590.
- Chalifoux, L. M. (1990) The implications of congenital deafness for working memory. *American Annals of the Deaf*, 136 (3), 292-299.
- Chien, S. J. (1993) *Cognitive addition: strategy choice in young children with normal hearing and children with hearing impairment*. UMI Dissertation Services.
- Chien, J. M. and Morrison, A. B. (2010) Expanding the mind's workspace: training and transfer effects with a complex working memory span task. *Psychonomic Bulletin and Review*, **17** (2), 193-199.
- Cipolotti, L. and van Harskamp, N. (2001) Disturbances of number processing and calculation. In: R. S. Berndt (ed.). *Handbook of neuropsychology* (2nd ed., vol. 3). Amsterdam: Elsevier Science.
- Conrad, R. (1972) Short-term memory in the deaf: a test for speech coding. *British Journal of Psychology*, **63** (2), 1920-1952.
- Conrad, R. (1979) *The deaf school child language and cognitive function*. London: Harper and Row.
- Coolican, H. (2006) *Introduction to Research Methods in Psychology*. Great Britain: Hodder Headline Group.

- Davis, S. and Kelly, R. (2003) Comparing deaf and hearing college students' mental arithmetic calculation under two interference conditions. *American Annals of the Deaf*, **148** (3), 213-221.
- Deary, I. J. et al. (2007) Intelligence and educational achievement. *Intelligence*, **35** (1), 13-21.
- Deheane, S. (1992) Varieties of numerical abilities. *Cognition*, **44**, 1-42.
- Dehaene, S. et al. (2003) Three parietal circuits for number processing. *Cognitive Neuropsychology*, **20**, 487-506.
- De Smedt, B. et al. (2009) Working memory and individual differences in mathematics achievement: a longitudinal study from first grade to second grade. *Journal of Experimental Child Psychology*, **103**, 186-201.
- De Villiers, J. et al. (1993) Gestural communication in oral deaf mother-child pairs: language with a helping hand? *Applied Psycholinguistics*, **14**, 319-347.
- Dye, M., Hauser, P. C. and Bavelier, D. (2008) Visual attention in deaf children and adults. In: M. Marschark and P. C. Hauser (ed.). *Deaf cognition: foundations and outcomes*. New York: Oxford University Press.
- Elliott, C. D. (1996) *The British Ability Scale II*. Windsor, Berkshire: NFER-NELSON Publishing Company.
- Epstein, K. I., Hillegeist, E. G. and Grafman, J. (1994) Number processing in deaf college students. *American Annals of Deaf*, **139** (3), 336-347.
- Field, A. (2009) *Discovering statistics using SPSS*. London: Sage.

- Fortnum, H., Marshall, D. H. and Summerfield, A. Q. (2002) Epidemiology of the UK population of hearing-impaired children, including characteristics of those with and without cochlear implants-audiology, aetiology, comorbidity and affluence. *International Journal of Audiology*, **41**, 170-179.
- Fortnum, H. et al. (2002) Hearing-impaired children in the UK: education setting and communication approach. *Deafness and Education International*, **4** (3), 123-141.
- Frostdad, P. (1999) Deaf children's use of cognitive strategies in simple arithmetic problems. *Educational Studies in Mathematics*, **40**, 129-153.
- Frostdad, P. and Ahlberg, A. (1999) Solving story-based arithmetic problems: achievement of children with hearing impairment and their interpretation of meaning. *Journal of Deaf Studies and Deaf Education*, **4** (4), 283-293.
- Fuchs, L. S. et al. (2005) The prevention, identification, and cognitive determinants of math difficulty. *Journal of Educational Psychology*, **97** (3), 493-513.
- Fuson, K. C. (1988) *Children's counting and concepts of numbers*. New York: Springer-Verlang.
- Fuson, K. C., Richards, J. and Briars, D. J. (1982) The acquisition and elaboration of the number word sequence. In C. J. Brainerd (ed.) *Children's logical and mathematical cognition*. New York: Spinger-Verlag, 33-92.
- Gallistel, C. R. and Gelman, R. (1992) Preverbal and verbal counting and computation. *Cognition*, **44**, 43-74.

Gathercole, S. and Pickering S. (2000) Working memory deficits in children with low achievements in the national curriculum at 7 years of age. *British Journal of Educational Psychology*, **70** (2), 177-194.

Gathercole, S. E. et al. (2004) The Structure of Working Memory From 4 to 15 Years of Age. *Developmental Psychology*, **40**, 177-190.

Geary, D. C. (1993) Mathematical disabilities: cognitive, neuropsychological and genetic components. *Psychological Bulletin*, **114**, 345-362.

Geary, D. C. (1996) Sexual selection and sex differences in mathematical abilities. *Behavioral and Brain Sciences*, **19**, 229-284.

Geary, D. C. (2004) Mathematics and learning disabilities. *Journal of Learning Disabilities*, **37** (1), 4-15.

Geary, D. C. (2005) *The origin of mind: evolution of the brain, cognition, and general intelligence*. Washington, DC, US: American Psychological Association.

Geary, D. C., Hamson, C. O. and Hoard, M. K. (2000) Numerical and arithmetical cognition: a longitudinal study of process and concept deficits in children with learning disability. *Journal of Experimental Child Psychology*, **77**, 236-263.

Geary, D. C., Hoard, M. K. and Hamson C. O. (1999) Numerical and arithmetical cognition: patterns of functions and deficits in children at risk for mathematical disability. *Journal of Experimental Child Psychology*, **74**, 213-239.

Geary, D. C. et al. (2007) Cognitive mechanism underlying achievement deficits in children with mathematical learning disability. *Child Development*, **78** (4), 1343-1359.

- Gelman, R. (2000) The epigenesis of mathematical thinking. *Journal of Applied Developmental Psychology*, **21** (1), 27-37.
- Gelman, R. and Gallistel, C. R. (1978) *The child's understanding of number*. Cambridge, MA: Harvard University Press.
- Gelman, R. and Meck, E. (1983) Preschooler's counting: principles before skill. *Cognition*, **13**, 343-359.
- Gelman, R. and Meck, E. (1986) The notion of principle: the case of counting. In: S. Hiebert (ed.). *Conceptual and procedural knowledge: the case of mathematics*. Hilldale, NJ: Erlbaum, 29-57.
- Gibbens, K. P. (1993) Medical management of otitis media and sensori-neural hearing loss in children. In: K. Mogford-Bevan and J. Sadler (eds.). *Child Language Disability*. (Vol. 3: Hearing Impairment). Clevedon, England: Multilingual Matters.
- Ginsburg, H. P. (1977) *Children's arithmetic. The learning process*. New York: Van Nostrand.
- Glasgow, M. (2009) *Explanation of audiological terms and procedures*. (Online). Available from: <http://www.batod.org.uk/content/articles/audiology/refreshers/general/G1-terms.pdf>. (Accessed 19 September 2012).
- Gorard, S. (2001). *Quantitative Methods in Educational Research: The role of numbers made easy*. London: Continuum.
- Gottardis, L. (2009) *Working memory and mathematical achievement in hearing impaired children: a secondary data analysis*. (Unpublished master's dissertation). University of Oxford, UK.

- Gottardis, L., Nunes, T. and Lunt, I. (2011) A synthesis of research on deaf and hearing children's mathematical achievement. *Deafness and Education International*, **13** (3), 131-150.
- Gregory, S. (1995) *Deaf children and their families*. Cambridge University Press.
- Gregory, S. (1998) *Issues in deaf education*. London: D. Fulton.
- Hauser, P. et al. (2007) Visual constructive and visual-motor skills in deaf native signers. *Journal of Deaf Studies and Deaf Education*, **12** (2), 148-157.
- Herman, R. et al. (2004). *Assessing BSL development: receptive and production test*. City University, London.
- Hermelin, B. and O'Connor, N. (1975) The recall digits by normal, deaf and autistic children. *British Journal of Psychology*, **66** (2), 203-209.
- Hitch, G. J., Arnold, P. and Philips, L.J. (1983) Counting processes in deaf children's arithmetic. *British Journal of Psychology*, **74**, 429-437.
- Hitch, G. and McAuley, E. (1991) Working memory in children with specific arithmetical learning difficulties. *British Journal of Psychology*, **82** (3), 375-386.
- Holmes, J. (2009) Adaptive training leads to sustained enhancement of poor working memory in children. *Developmental Science*, **12** (4), F9-F15.
- Holmes, J. and Adams, J. W. (2006) Working memory and children's mathematical skills: implications for mathematical development and mathematics curricula. *Educational Psychology: An International Journal of Experimental Educational Psychology*, **26** (3), 339-366.

- Holmes, J. et al. (2010) Working memory deficits can be overcome: impacts of training and medication on working memory in children with ADHD. *Applied Cognitive Psychology*, **24** (6), 827-836.
- Holt, J. A. (1994) Classroom attributes and achievement test scores for deaf and hard-of-hearing students. *American Annals of the Deaf*, **139** (4), 430-437.
- Howell, D. C. (1997) *Statistical methods for psychology*. Belmont, CA: Duxbury Press.
- Hyde, M., Zevenbergen, R. and Powers, D. (2003) Deaf and hard of hearing students' performance on arithmetic word problems. *American Annals of the Deaf*, **148** (1), 56-64.
- Jamieson, J. R. (1994) Instructional discourse strategies: differences between hearing in deaf mothers of deaf children. *First Language*, **14**, 153-171.
- Jeaggi, S. M. et al. (2008) Improving fluid intelligence with training on working memory. *Proceeding of the National Academy of Science of United States of America*, **105** (19), 6829-6833.
- Jencks, C. (1979) *Who gets ahead? The determinants of economic success in America*. New York, NY: Basic Books.
- Jensema, C. J. (1975). *The relationship between academic achievement and the demographic characteristics of hearing impaired children and youth* (Series R, No. 2). Washington, DC: Gallaudet College, Office of Demographic Studies.
- Jensen, A. R. (1998) *The g factor: the science of mental ability*. New York: Praeger.
- Jimerson, S., Egeland, B. and Teo, A. (1999) A longitudinal study of achievement trajectories: factors associated with change. *Journal of Educational Psychology*, **91** (1), 116-126.

Jordan, N. C., Hanich, L. B. and Kaplan, D. (2003) A longitudinal studies of mathematical competencies in children with specific mathematics difficulties versus children with comorbid mathematics and reading difficulties. *Child Development*, **74** (3), 834-850.

Jordan, N. C. et al. (2007) Predicting first grade math achievement from developmental number sense trajectories. *Learning Disabilities Research and Practice*, **22** (1), 36-46.

Karchmer, M. A. and Mitchell, R. E. (2003) Demographic and achievement characteristics of deaf and hard-of-hearing students. In: M. Marschark and P. E. Spencer (eds.). *Oxford Handbook of deaf studies, language, and education*. New York: Oxford University Press.

Keeler, M. L. and Swanson, H. L. (2001) Does strategy knowledge influence working memory in children with mathematical disabilities? *Journal of Learning Disabilities*, **34**, 418-434.

Klingberg, T. (2010) Training and plasticity of working memory. *Trends in Cognitive Sciences*, **14** (7), 317-324.

Klingberg, T. et al. (2005) Computerized training of working memory in children with ADHD- a randomized control trial. *Journal of the American Academy of Child and Adolescent Psychiatry*, **44** (2), 177-186.

Kloo, D. and Perner, J. (2003) Training transfer between card sorting and false belief understanding: helping children apply conflicting descriptions. *Child Development*, **74** (6), 1823-1839

Koontz, K. L. and Berch, D. B. (1996) Identifying simple numerical stimuli: processing inefficiencies exhibited by arithmetic learning disabled children. *Mathematical Cognition*, **2**, 1-23.

Kornilaki, E. (1999) *Young children's understanding of multiplicative concepts. A psychological approach*. London: Institute of Education, University of London.

Korvorst, M., Nuerk, H. and Willmes, K. (2007) The hands have it: number representations in adult deaf signers. *Journal of Deaf Studies and Deaf Education*, **12** (3), 362-372.

Kluwin, T. N. and Moores, D. F. (1985) The effects of integration on the mathematics achievement of hearing-impaired adolescents. *Exceptional Children*, **52**, 153-160.

Kluwin, T. N. and Stinson, M. S. (1993) *Deaf students in local public high schools*. Springfield, Illinois: Charles C Thomas.

Landerl, K., Bevan, A. and Butterworth, B. (2004) Developmental dyscalculia and basic numerical capacities: A study of 8-9 year old students. *Cognition*, **93**, 99-125.

Leahey, E. and Guo, G. (2001) Gender differences in mathematical trajectories. *Social Forces*, **80**, 713-732.

Lean, G. H., Clements, M. A. and Del Campo, G. (1990) Linguistic and pedagogical factors affecting children's understanding of arithmetic word problems: a comparative study. *Educational Studies in Mathematics*, **21**, 165-191.

Leybaert, J. and Van Cutsem, M. N. (2002) Counting in sign language. *Journal of Experimental Child Psychology*, **81**, 482-501.

Lines, S. and Bryant, P. E. (1993) Counting in English and Chinese: Linguistic effects on number understanding. Unpublished manuscript.

Lynas, W. (2005) Controversies in the education of deaf children. *Current Paediatrics*, **15** (3), 200-206.

- MacNamara, D. and Scott, J. (2001) Working memory capacity and strategy use. *Memory and Cognition*, **29** (1), 10-17.
- Maltby, M. T. and Knight, P. (2000) *Audiology*. London: David Fulton Publisher.
- Marschark, M. (2003) Cognitive functioning in deaf adults and children. In: M. Marschark and P. E. Spencer (Ed.) *Oxford handbook of deaf studies, language and education*. New York: Oxford University Press, 464-477.
- Marschark, M. and Hauser, P. C. (2012) *How deaf children learn*. New York: Oxford University Press.
- Marschark, M., Lang, H. G. and Albertini, J. A. (2002) *Educating deaf students*. New York: Oxford University Press.
- Marschark, M. and Mayer, C. (1998) Mental representation and memory in deaf adults and children. In: M. Marschark and M. D. Clark (eds.). *Psychological Perspectives on Deafness, Vol. 2*. Mahwah, NJ: Erlbaum, 53-77.
- Marschark, M., Rothen, C. and Fabich, M. (2007) Effect of cochlear implants on children's reading and academic achievement. *Journal of Deaf Studies and Deaf Education*, **12** (3), 269-282.
- Marschark, M. and Wauters, L. (2008) Language comprehension and learning by deaf students. In: M. Marschark and P. C. Hauser (ed.). *Deaf cognition: foundations and outcomes*. New York: Oxford University Press, 309- 350.
- Marschark, M., et al. (2011) Evidence-based practice in educating deaf and hear-of-hearing children: teaching to their cognitive strengths and needs. *European Journal of Special Needs Education*, **26** (1), 3-16.

Masataka, N. (2006) Differences in arithmetic subtraction of nonsymbolic numerosities by deaf and hearing adults. *Journal of Deaf Studies and Deaf Education*, **11** (2), 139-143.

Mason, S. (1993) Electric response audiometry. In: B. McCormick (ed.). *Practical aspects of Audiology: paediatric audiology 0-5 years (2<sup>nd</sup> edition)*. Newcastle upon Tyne: Whurr Publishers.

Mayberry, R. I. (2002) Cognitive development in deaf children: the interface of language and perception in neuropsychology. In: S.J. Segalowitz and I. Rapin (eds.). *Handbook of neuropsychology, volume 8, part 2*. Amsterdam: Elsevier, 71-107.

Mazzocco, M. M. and Thompson, R. E. (2005) Kindergarten predictors of math learning disability. *Learning Disabilities Research and Practice*, **20** (3), 142-155.

McCormick, B. (1995) *The medical practitioner's guide to paediatric audiology*. Cambridge: Cambridge University Press.

McCracken, W. and Sutherland, H. (1991) *Deaf-ability not disability: a guide for parents of hearing impaired children*. Clevedon: Multilingua Matters.

McCrick, K. and Wynn, K. (2004) Large-number addition and subtraction by 9 month-old infants. *Psychological Science*, **15** (11), 776-781.

McCrick, K. and Wynn, K. (2007) Ratio abstraction by 6-month-old infants. *Psychological Science*, **18** (8), 740-745.

McLean, J. and Hitch, G. (1999) Working memory impairments in children with specific arithmetic learning difficulties. *Journal of Experimental Child psychology*, **74** (3), 240-260.

- Miller, G. A. (1956) The magical number seven plus or minus two: some limits on our capacity for processing information. *Psychological Review*, **63**, 81-97.
- Miller, K. F. and Stigler, J. W. (1987) Counting in Chinese: Cultural variation in a basic skill. *Cognitive Development*, **2**, 279-305.
- Mitchell, R. E. and Karchmer, M. A. (2011) Demographic and achievement characteristics of deaf and hard-of-hearing students. In: M. Marschark and P. E. Spencer (eds.) *Oxford Handbook of deaf studies, language, and education*. New York: Oxford University Press.
- Miura, I. T. et al. (1988) Effects of language characteristics on children's cognitive representation of number: cross-national comparisons. *Child Development*, **59**, 1445-1450.
- Moreno, C. (2000) *Predictors of mathematics attainment in hearing impaired children*. (Unpublished PhD thesis) University of London, UK.
- Morrison, A. B. and Chien, J. M. (2011) Does working memory training work? The promise and challenge of enhancing cognition by training working memory. *Psychonomic Bulletin and Review*, **18**, 46-60.
- Mulhern, G. and Budge, A. (1993) A chronometric study of mental addition in profoundly deaf children. *Applied Cognitive Psychology*, **7**, 53-62.
- National Deaf Children's Society (NDCS) (2011a) *Different types of schools for deaf children* (Online). Available from: [http://www.ndcs.org.uk/family\\_support/useful\\_links\\_and\\_organisation/glossary/mainstream\\_school\\_1\\_1.html](http://www.ndcs.org.uk/family_support/useful_links_and_organisation/glossary/mainstream_school_1_1.html) (Accessed 11 December 2012)
- National Deaf Children's Society (NDCS) (2011b) *Understanding your child's hearing tests*. (Online). Available from:

[http://www.ndcs.org.uk/family\\_support/understanding\\_your\\_child\\_hearing\\_tests/](http://www.ndcs.org.uk/family_support/understanding_your_child_hearing_tests/)

(Accessed 19 September 2012).

Northern, J. L. and Downs, M. P. (1991) *Hearing in children (4<sup>th</sup> edition)*. Baltimore, MD: Williams and Wilkins.

Nunes, T. (1996) What is the difference between one, un, and yi? In H. Mansfield, N. A. Pateman and N. Bedharz (eds.), *Mathematics for tomorrow's young children: international perspectives on curriculum*, Kluwer Academic Publishers. 177-185.

Nunes, T. (2004) *Teaching mathematics to deaf children*. London: Whurr Publishers, Ltd.

Nunes, T. (2012) Deaf children's difficulties in mathematics learning. In S. Lerman (ed.)

*Encyclopedia of Mathematics Education*. Available from:

[http://www.springerreference.com/docs/navigation.do?=&Encyclopedia+of+Mathematics+Education+\(Humanities%2C+Social+Sciences+and+Law\)-book188](http://www.springerreference.com/docs/navigation.do?=&Encyclopedia+of+Mathematics+Education+(Humanities%2C+Social+Sciences+and+Law)-book188)

(Accessed 21 September 2012).

Nunes, T. and Bryant, P. (1996) *Children doing mathematics*. Oxford: Blackwell.

Nunes, T., Bryant, P. and Prezlik, U. (2006) *Using deaf children's visual skills to promote mathematics learning*. Paper presented at the 19<sup>th</sup> Meeting of the International Society for the Study of Behavioural Development, August, Melbourne.

Nunes, T., Bryant, P. and Watson (2009) *Key understandings in mathematics learning*. Nuffield Foundation.

Nunes, T. et al. (2007) The contribution of logical reasoning to the learning of mathematics in primary school. *British Journal of Developmental Psychology*, **25** (1), 147-166.

Nunes, T. et al. (2008) Deaf children's understanding of inverse relations. In M. Marschark and P. C. Hauser (eds.) *Deaf Cognition Foundations and Outcomes*. Oxford: University Press, 201-225.

Nunes, T. et al. (2009a) Deaf children's informal knowledge of multiplicative reasoning. *Journal of Deaf Studies and Deaf Education*, **14** (2), 260-277.

Nunes, T. et al. (2009b) *Developing deaf children's understanding of additive composition*. Paper presented at the AERA meeting, San Diego.

Nunes, T. et al. (2009c) *Development of Maths capabilities and confidence in primary school*. London: Department for Children, Schools and Families.

Nunes, T. et al. (2009d) Teaching children about the inverse relation between addition and subtraction. *Mathematical Thinking and Learning*, **11** (1-2), 61-78.

Nunes, T. et al. (2011) A game-based working memory intervention for deaf children. In S. De Wannemacker, S. Vandercruysse and G. Clarebout (Eds.) *Serious Games: The challenge*. Berlin Heidelberg: Springer-Verlag, 31-39.

Nunes, T. et al. (2012) The relative importance of two different mathematical abilities to mathematical achievement. *British Journal of Educational Psychology*, **82**, 136-156.

Nunes, T. and Moreno, C. (1998) Is hearing impairment a cause of difficulties in learning mathematics. In: C. Donald (eds.) *The development of mathematical skills*. Hove: Psychology Press, 227-254.

Nunes, T. and Moreno, C. (2002) An intervention program to promote deaf pupils' achievement in numeracy. *Journal of Deaf Studies and Deaf Education*, **7**, 120-133.

- Nunes, T., Pretzlik, U. and Ilicak, S. (2004) Validation of a Parent outcome questionnaire from pediatric cochlear implantation. *Journal of Deaf Studies and Deaf Education*, **10** (4), 330-356.
- O'Connor, N. and Hermelin, B. (1972) Seeing and hearing and space and time. *Perception and Psychophysics*, **11**, 46-48.
- Padden, C. and Ramsey, C. (1998) Reading ability in signing deaf children? *Topics in Language Disorders*, **18** (4), 30-46.
- Passolunghi, M. C., Cornoldi, C. and De Liberto, S. (1999) Working memory and inhibition of irrelevant information in poor problem solvers. *Memory and Cognition*, **27**, 779-790.
- Passolunghi, M. C., Mammarella, I. C. and Altoè, G. (2008) Cognitive abilities as precursors of the early acquisition of mathematical skills during first through second grades. *Developmental Neuropsychology*, **33** (3), 229-250.
- Passolunghi, M. C. and Siegel, L. (2004) Working memory and access to numerical information in children with disability in mathematics. *Journal of Experimental Child Psychology*, **88** (4), 348-367.
- Passolunghi, M. C., Vercelloni, B. and Schadee, H. (2007) The precursor of mathematics learning: working memory, phonological ability and numerical competence. *Cognitive Development*, **22**, 165-184.
- Piaget, J. (1952) *The child's conception of number*. London: Routledge and Kegan Paul.
- Piazza, M. et al. (2002) Re subitizing and counting: implemented as separate or functionally overlapping processes? *Neuro Image*, **15** (2), 435-446.

- Pickering, S. and Gathercole, S. (2001) *Working memory test battery for children*. Psychological Corporation, UK.
- Pickering, S. and Gathercole, S. (2010) Distinctive working memory profiles in children with special educational needs. *Educational Psychology: An International Journal of Experimental Educational Psychology*, **24** (3), 393-408.
- Pintner, R. and Patterson, D. G. (1917) A comparison of deaf and hearing children in visual memory for digits. *Journal of Experimental Psychology*, **2**, 76-88.
- Pisoni, D. B. et al. (2008) Efficacy and effectiveness of cochlear implants in deaf children. In: M. Marschark and P. C. Hauser (ed.). *Deaf cognition: foundations and outcomes*. New York: Oxford University Press, 52-101.
- Pollard, G. and Oakland, T. (1985) Variables associated with the educational development of residential deaf children. *Special Services in the Schools*, **1** (4), 67-82.
- Powers, S. (2003) Influences of student and family factors on academic outcomes of mainstream secondary school deaf students. *Journal of Deaf Studies and Deaf Education*, **8** (1), 57-78.
- Powers, S., Gregory, S. and Thoutenhoofd, E. D. (1998) The educational achievements of deaf children: a literature review (Research Report No. 65). Norwich, UK: Department for Education and Employment.
- Proksch, J. and Bavelier, D. (2002) Changes in the spatial distribution of visual attention after early deafness. *Journal of Cognitive Neuroscience*, **14**, 687-701.
- Punch, R., Hyde, M. and Creed, P.A. (2004) Issues in the school-to-work transition of hard of hearing adolescents. *American Annals of the Deaf*, **149** (1), 28-38.

- Reich, Hambleton, D. and Houldin, B. K. (1977) The integration of hearing impaired children in regular classroom. *American Annals of the Deaf*, 122, 534-543.
- Reiss, H. and Judd, C. (2000) *Handbook of Research Methods in Social and Personality Psychology*. United Kingdom: Cambridge University Press.
- Riley, M., Greeno, J. G. and Heller, J. L. (1983) Development of children's problem solving ability in arithmetic. In: H. Ginsburg (ed.). *The development of Mathematical Thinking*. New York: Academic Press, 153-196.
- Schick, B. et al. (2007) Language and theory of mind: a study of deaf children. *Child Development*, **78** (2), 376-396.
- Schmeidek, F., Lovden, M. and Lindenberger, U. (2010) Hundred days of cognitive training enhance broad abilities in adulthood: Findings from the COGITO study. *Frontiers in Aging Neuroscience*, **2** (27), 1-10.
- Secada, W. G. (1984) *Counting in sign: the number string, accuracy and use*. Unpublished PhD, Department of Education, Northwestern University, Evanston, Illinois.
- Siegel, L. S. and Linder, B. A. (1984) Short-term memory processes in children with reading and arithmetic learning disabilities. *Developmental Psychology*, **20** (2), 200-207.
- Singleton, J. L. et al. (1998) From sign to word: considering modality constraints in ASL/English bilingual education. *Topics in Language Disorders*, **18** (4), 16-29.
- Sirin, S. R. (2005) Socio-economic status and academic achievement: a meta-analytic review research. *Review of Educational Research*, **75** (3), 417-453.
- Sladen, D. P. et al. (2005) Visual attention in deaf and normal hearing adults: effects of stimulus compatibility. *Journal of Speech, Language and Hearing Research*, **48**, 1-9.

- Smith, R. C. et al. (2002) Effects of cigarette smoking and nicotine nasal spray on psychiatric Symptoms and cognition in schizophrenia. *Neuropsychopharmacology*, **27**(3), 479-497.
- Starkey, P., Spelke, E. S. and Gelman, R. (1990) Numerical abstraction by human infants. *Cognition*, **36**, 97-127.
- Stern, E. (2006) *Transitions in mathematics: from intuitive quantification to symbol-based mathematics*. Paper presented at the ISSBD meeting, July, Melbourne.
- Sternberg, R. J., Grigorenko, E. L. and Bundy, D.A. (2001) The predictive value of IQ. *Merrill-Polmer Quarterly*, **47**, 1-41.
- Stewart, D. and Kluwin, T. (2001). *Teaching deaf and hard-of-hearing students: Content, strategies, and curriculum*. Boston, MA: Allyn & Bacon.
- Stinson, M. S. and Kluwin, T. N. (2011) educational consequences of alternative school placements. In: M. Marschark and Spencer (eds). *Oxford Handbook of deaf studies, language and education*. New York: Oxford University Press.
- Swanson, H. L. (2011) Working memory, attention, mathematical problem solving: a longitudinal study of elementary school children. *Journal of Educational Psychology*, **103** (4), 821-837.
- Swanson, H. L. and Beebe-Frankenberger, M. (2004) The relationship between working memory and mathematical problem solving in children at risk for serious math difficulties. *Journal of Educational Psychology*, **96**, 471-491.

Swanson, H. L. and Sachse-Lee, C. (2001) Mathematical problem solving and working memory in children with learning disabilities: both executive and phonological processes are important. *Journal of Experimental Child Psychology*, **79**, 294-321.

Swanwick, R., Oddy, A. and Roper, T. (2005) Mathematics and deaf children: an exploration of barriers to success. *Deafness and Education International*, **7** (1), 1-21.

Swanwick, R. and Watson, L. (2005) Literacy in the homes of young deaf children: common and distinct features of spoken language and sign bilingual environments. *Journal of Early Childhood Literacy*, **5** (3), 53-78.

Thorell, L. B. et al. (2009) Training and transfer effects of executive function in preschool children. *Developmental Science*, **12** (1), 106-113.

Thoutenhoofd, E. (2006) Cochlear implanted pupils in Scottish schools: 4-years school attainment data. *Journal of Deaf Studies and Deaf Education*, **11**, 171-188.

Todman, J. and Seedhouse, E. (1994) Visual-action code processing by deaf and hearing children. *Language and Cognitive Processes*, **4**, 129-141.

Traxler, C. B. (2000) The Stanford achievement test, 9<sup>th</sup> edition: national norming and performance standards for deaf and hard of hearing. *Journal of Deaf Studies and Deaf Education*, **5**, 337-348.

Turley-Ames, K. J. and Whitfield, M. M. (2003) Strategy training and working memory task performance. *Journal of Memory and Language*, **49** (4), 446-468.

Tymms, P. et al. (2003) Young deaf children and the prediction of reading and mathematics. *Journal of Early Childhood Research*, **1**, 197-212.

- Van Luit, J. E. H., Van Rijt, B. A. M. and Pennings, A. H. (1994) *Utrechtse Getalbegrip Toets (Utrecht Test of Number Sense)*. Doetinchem, The Netherlands: Graviant.
- Vergnaud, G. (1979) The acquisition of arithmetical concepts. *Educational Studies in Mathematics*, **10**, 263-274.
- Vergnaud, G. (1997) The nature of mathematical concepts. In: Nunes T., Bryant (ed.). *Learning and teaching mathematics. An international perspective*. Hove: Psychology Press, 1-28.
- Vernon, M. (2005) Fifty years of research on the intelligence of deaf and hard-of-hearing children: a review of the literature and discussion of the implications. *Journal of Deaf Studies and Deaf Education*, **10** (3), 225-231.
- Wechsler, D. (1992) *WISC-III UK Manual*. Sidcup, Kent: The Psychological Corporation, Harcourt Brace Jovanovich.
- Westerberg, H. et al. (2007) Computerized working memory training after stroke-A pilot study. *Brain Injury*, **21** (1), 21-29.
- Wood, H. A. et al. (1983) The mathematical achievements of deaf children from different educational environments. *Journal of Educational Psychology*, **54**, 254-264.
- Wynn, K. (1992) Addition and subtraction by human infants. *Nature*, **358**, 749-750.
- Wynn, K. (1998) Psychological foundation of number: numerical competence in human infants. *Trends in Cognitive Sciences*, **2** (8), 296-303.
- Xu, F. and Spelke, E. S. (2000) Large number discrimination in 6-month-old infants. *Cognition*, **74**, B1-B11.

Zarfaty, Y., Nunes, T. and Bryant, P. (2004) The performance of young deaf children in spatial and temporal number task. *Journal of Deaf Studies and Deaf Education*, **9**, 315-326.

## **Appendices**

**Appendix A:** “A synthesis of research on deaf and hearing children’s mathematical achievement” by Gottardis, L., Nunes, T., and Lunt, I.

**Appendix B:** Ethics

Appendix B1: Research Approval from the Inter-Divisional Research Ethics Committee

Appendix B2: CUREC Application Form 1

Appendix B3: CUREC Application Form 2

Appendix B4: School Head information letter

Appendix B5: Parent consent letter

Appendix B6: Cochlear implant questionnaire

**Appendix C:** Additional results from Chapter 3- Survey study

Appendix C1: Additional figures and tables presented in the chapter

Appendix C2: Analyses excluding children with 1 SD below the mean in their non-verbal intelligence task.

**Appendix D:** Additional results from Chapter 4-Longitudinal study

## **Appendix A**

### **A synthesis of research on deaf and hearing children's mathematical achievement**

**L. Gottardis, T. Nunes and I. Lunt (2011)**

## Appendix B1

### Research approval from the Inter-Divisional Research Ethics Committee

SOCIAL SCIENCES & HUMANITIES  
INTER-DIVISIONAL RESEARCH ETHICS COMMITTEE

Hayes House, 75 George Street, Oxford. OX1 2BQ  
Tel: +44(0)1865 614871 Fax: +44(0)1865 614855  
[ethics@socsci.ox.ac.uk](mailto:ethics@socsci.ox.ac.uk) [www.socsci.ox.ac.uk](http://www.socsci.ox.ac.uk)

Co-ordinator of the IDREC  
Social Sciences Divisional Office

Ref. SSD/2/3/IDREC

Miss Laura Gottardis,  
Department of Education



February 10, 2010

Dear Miss Laura Gottardis,

#### Application for research ethics approval

Ref No.: SSD/CUREC2/09-57

**Title: Deaf Primary School children's achievements in mathematics**

The above application has been considered on behalf of the Social Sciences and Humanities Inter-divisional Research Ethics Committee (IDREC) in accordance with the procedures laid down by the University for ethical approval of all research involving human participants.

I am pleased to inform you that, on the basis of the information provided to the IDREC, the proposed research has been judged as meeting appropriate ethical standards, and accordingly approval has been granted.

Should there be any subsequent changes to the project, which raise ethical issues not covered in the original application, you should submit details to the IDREC for consideration.

Yours sincerely,

A handwritten signature in black ink that reads 'Chris Ballinger'.

Dr Chris. Ballinger

cc: Prof. Terezinha Nunes, Department of Education, 15 Norham Gardens  
Lisa Currie, Department of Education, 15 Norham Gardens

## Appendix B2

University of Oxford

CENTRAL UNIVERSITY RESEARCH ETHICS COMMITTEE (CUREC)

### IDREC Checklist

<b>*Principal investigator/supervisor/student researcher (title and name):</b>	Miss Laura Gottardis
<b><u>FOR STUDENT RESEARCH PROJECTS ONLY</u> Name of Supervisor:</b>	Prof. Terezinha Nunes
<b>Department or institute:</b>	Departement of Education
<b>Address for correspondence:</b>	Flat 100 Block C Castle Mill, Roger Dudman Way, Oxford, OX1 1AF
<b>E-mail and telephone contact:</b>	<a href="mailto:laura.gottardis@education.ox.ac.uk">laura.gottardis@education.ox.ac.uk</a> 07748812067

FAQ  
12

**Before completing this checklist**, please ensure you have consulted the following CUREC guidance documents available on the CUREC website at <http://www.admin.ox.ac.uk/curec/resrchapp/index.shtml>:

[Guidance on approval process](#)

[Glossary](#)

[FAQs](#)

This checklist is the first stage of the University of Oxford's scrutiny procedure for \*research involving \*human participants. (Definitions of terms marked with an asterisk are to be found in CUREC's glossary and guidance).

The University aims to ensure that all research is subject to *appropriate* ethical scrutiny. This form is designed to identify those projects which fall outside CUREC's remit; those which fall within CUREC's remit but which pose low risks to participants and so need scrutiny only through this checklist; and those which fall within CUREC's remit and which pose greater risk to participants and so need more scrutiny. If you need further advice or if you have comments about this form, please consult the [relevant IDREC officer](#) (please see: <http://www.admin.ox.ac.uk/curec/oxonly/contact.shtml>).

FAQ  
26

The checklist should be completed by the \*principal investigator/supervisor/student researcher (under the guidance of his/her supervisor) undertaking or supervising research which comes under CUREC's responsibility. Please carry out a risk assessment of the project, in consultation with all researchers involved, using the checklist and CUREC's other documentation.

This form does not cover research governance, satisfactory methodology, or the health and safety of employees and students. As principal investigator, it is your responsibility to ensure that requirements in these areas are met.

Office use only:

IDREC Ref. No. \_\_\_\_\_

Date of confirmation that checklist accepted on behalf of IDREC: // //

## Section A

*Title and brief lay description of \*research (about 150 words), plus description (about 200 words) of the nature of participants (including the criteria for inclusion/exclusion, method of recruitment, attaching samples of participant information and consent forms), purpose of the research, methods to be used, how professional guidelines are being applied (if applicable) and use to which the results/data will be put.*

Deaf Primary School children's achievements in mathematics.

### *Brief description of the research*

The last extensive U.K. survey of deaf children's mathematics achievement was done in 1984 and described the attainments of school leavers. In spite of changes in educational provision and technological innovations, small scale studies between 1980 and 2000 show no improvement in deaf children's mathematics attainment; they continue to lag behind their hearing peers.

In order to understand the causes of this delay, we need to know whether the same factors that predict hearing children's achievement also predict deaf children's; this would support new efforts to develop interventions for deaf children.

Nunes et al. (2007) showed that, in a hearing sample, there are three main factors that seem to predict mathematical achievement in children. These are non-verbal intelligence, logical-mathematical reasoning and working memory. This research project aims to analyse whether these factors predict deaf children's achievements as well.

### *Further description*

#### Aims

The project has two main goals: (1) to provide a large scale survey of deaf children's mathematics achievements in primary school, analysing the relation between the background variables and achievement; (2) to investigate longitudinally the connections between different aspects of mathematical knowledge (knowledge of number facts, mathematical reasoning) and cognitive competence (general intelligence, working memory) among deaf children.

#### Participants

The project will be developed in three years. A large sample (N=180) of deaf children aged 6 to 11 years will participate. The children will be selected in order to represent different

regions, educational approaches and communities.

The deaf children will be selected on the basis of their level of hearing loss (only children with a moderate to profound hearing loss will be selected) and on the age. No deaf children with mild hearing loss and additional needs will be considered in the research.

Information about demographic variables (hearing loss, age and cause of loss, home language, parental education), medical interventions (hearing aids or cochlear implant, period in which the hearing advice was fitted, level of use of cochlear implant (using a measure validated by Nunes et al. 2005)), and educational history (years in formal education, type of educational provision) will be collected.

#### Method

The participants will be recruited among the extensive network of collaborating schools and teachers who contributed to previous research project conducted by Prof. Nunes. A letter will be sent to the teachers and schools where the research will be explained. Through them, a consent form will be sent to the parents for asking the permission for the participation of their children to this project and for realising the consent for demographic variables about their children.

In the first year of the project, the younger children's numeracy level (6-8) will be assessed. They will be given a sample of items from the PIPS, which will include items designed for the school year below and year appropriate items. Children who attain 50% on year-appropriate items will complete this assessment, in order to avoid ceiling effects. They will be given measures of non-verbal intelligence, logical-mathematical reasoning and working memory, to be used as predictors of achievement.

In the second year, the older children's (9-11) mathematics achievement will be measured, using the same strategy of sampling items employed with the younger children.

In the third year, the children from younger sample will be re-assessed in mathematics achievement in order to evaluate the predictive value of the measures obtained in the first year.

The assessments will be administered by the student. The assessments for the younger children are administered individually. The PIPS mathematics achievement tests can be administered to deaf children in the classroom from age 9.

General descriptions of the performance by age level will be complemented by multilevel modelling in the prediction of longitudinal gains with the sample retested during the project.

The survey will provide an urgently needed description of levels of deaf children's numeracy achievement; the analyses of predictors of success will help to clarify the nature of deaf children's difficulties and paths to improvement.

The data will be kept in accordance of the Data Protection Act.

***List all \*sites where project will be conducted:***

Attached lists of the schools that participate in the project

***Anticipated duration of project:***

\_35\_ months

<b>Anticipated start and end dates:</b>	From 15 / 11 / 2009 until 15/ 09/2012		
<b>Name and status (e.g. 3<sup>rd</sup> year undergraduate; post-doctoral research assistant) of others taking part in the project:</b>	Laura Gottardis: first year DPhil		
<b>External organisation funding the research (if applicable - see also Section D):</b>	ESRC and RNID		
	Does the funding body require some form of monitoring of the conduct of the research until completion (eg. annual ethical re-approval of the study)?	<b>YES</b>	<b>NO</b>
			x
<b>Please indicate what training on research ethics you have received, e.g. online training in ethics/human subject protection etc.</b>	I completed a MSc in Educational Research Methodology, which includes a component on ethical issues in research with vulnerable children. I completed BSL Stage 1, which includes a discussion of “deaf awareness” (i.e. awareness of issues in interactions with deaf people). I also observed an experienced teacher and researcher working with deaf children and was observed by her using the same tasks with deaf children.		

## Section B

(Please put a tick in the yes/no column as appropriate to indicate your response).

<b>1). Does your study primarily aim to monitor and/or improve the performance of a particular service provider?</b>	<b>YES</b>	<b>NO</b>
		√
<b>2) Will your conclusions be applicable wholly or primarily to that service provider?</b>	<b>YES</b>	<b>NO</b>
		√
<b>3) Are you conducting your study on behalf of or at the request of a service provider?</b>	<b>YES</b>	<b>NO</b>
		√

If you have answered ‘yes’ to any question in section B it is likely that your study is \*audit, not \*research. Please check the CUREC glossary and if your study is audit you need not submit your proposal for ethical scrutiny. If you have answered ‘no’ to all questions please proceed to section C.

## Section C

(Please put a tick in the yes/no column as appropriate to indicate your response).

<b>1) Will the research involve *human participants recruited by means of their status as present or past NHS *patients or their relatives or carers or present or past NHS staff?</b>	<b>YES</b>	<b>NO</b>
		√
<b>2) Will the research involve *personal data of any of the people listed in question C</b>	<b>YES</b>	<b>NO</b>

<i>1 above ?</i>		√
3) <i>Will the research in whole or part be carried out on NHS premises or using NHS facilities?</i>	YES	NO
		√
4) <i>Does the research involve administering any drug, placebo, or other substances to participants in the European Union (EU)?</i>	YES	NO
		√
5) <i>Does the research involve ionising radiation in the EU?</i>	YES	NO
		√
6) <i>Does the research involve human genetic research in the EU?</i>	YES	NO
		√
7) <i>Does the research involve magnetic resonance imaging in the EU?</i>	YES	NO
		√
8) <i>Does the research involve use of organs or other bodily material of past and present NHS patients?</i>	YES	NO
		√
9) <i>Does the research involve any other *invasive procedure (Class A) not described above?</i>	YES	NO
		√
10) <i>Does the research involve *human participants aged 16 and over who do not have *capacity to consent for themselves?</i> <i>[Please note that the definition of *capacity has been altered by the Mental Capacity Act 2005; see the <a href="#">Glossary</a> on the CUREC website for further information]</i>	YES	NO
		√

**If you have answered ‘yes’ to any question in section C please stop work on this checklist as you will need to submit your proposal to the appropriate NHS ethics committee.** Further details may be obtained from the website <http://www.nres.npsa.nhs.uk>. Please submit the NHS Ethics Committee approval to the relevant IDREC officer for information when received.

If your research involves any of the above procedures but will be carried out by University of Oxford staff wholly outside the EU, your research will be reviewed by OXTREC (<http://www.tropicalmedicine.ox.ac.uk/oxtrecreframeset.htm>). **If you have answered ‘no’ to all questions so far, please proceed to section D.**

## Section D

(Please put a tick in the yes/no column as appropriate to indicate your response).

<i>1) Is the study to be funded by the US National Institutes of Health or another US federal funding agency?</i>	<b>YES</b>	<b>NO</b>
		√

**If you have answered ‘yes’ to the question in section D please stop work on this checklist as you will need to submit your proposal to OXTREC which uses separate documentation** (<http://www.tropicalmedicine.ox.ac.uk/oxtrecreframeset.htm>).

**If you have answered ‘no’ to all questions so far, please proceed to section E.**

## Section E

(Please put a tick in the yes/no column as appropriate to indicate your response).

<i>1) Are all the data about people to be used in your study previously collected anonymised data which neither you nor anyone else involved in your study can trace back to the individuals who provided them (e.g. census data, administrative data, secondary analysis)? Please refer to the definition of *personal data in the glossary and FAQ no. 6 for further guidance.</i>	<b>YES</b>	<b>NO</b>
		√

FAQ  
6

**If you have answered ‘yes’ to the question in section E please stop work on this checklist as you do not need to secure ethical approval for your study. There is no need to submit any details to IDREC as such research does not constitute research involving human participants for review purposes.**

**If you have answered ‘no’ to all questions so far, please proceed to section F.**

## Section F

Methods to be used in the study (**tick** as many as apply: this information will help the committee understand the nature of your research and may be used for audit).

<b>METHOD USED</b>	<b>PLEASE TICK</b>
<i>Unstructured interview</i>	
<i>Semi-structured interview</i>	
<i>Structured interview</i>	
<i>Questionnaire</i>	√
<i>Analysis of existing records</i>	

<i>Participant performs verbal/paper and pencil/computer based task</i>	√
<i>Measurement/recording of motor behaviour</i>	
<i>Audio recording of participant</i>	
<i>Video recording or photography of participant</i>	
<i>Physiological recording from participant</i>	
<i>Participant observation</i>	
<i>Systematic observation</i>	
<i>Observation of specific organisational practices</i>	
<i>Other (please specify)</i>	

## Section G

(Please put a tick in the yes/no column as appropriate to indicate your response).

See  
protocols

<i>1). Have you made arrangements to obtain written *informed consent from participants?</i>	<b>YES</b>	<b>NO</b>
	√	
<i>2) Have you made arrangements to ensure that *personal data collected from participants will be held in compliance with the requirements of the Data Protection Act?</i>	<b>YES</b>	<b>NO</b>
	√	
<i>3) If your research involves any use of *personal data obtained from a *third party, have you checked to ensure that the *third party has arrangements in place to permit disclosure?</i>	<b>Y E S</b>	<b>N/ A NO</b>
		√
<i>4) Does the research involve as participants *people whose ability to give free and informed consent is in question?</i>	<b>YES</b>	<b>NO</b>
	√	
<i>5) Does the research involve any alteration of participants' normal patterns of sleeping, eating, or drinking?</i>	<b>YES</b>	<b>NO</b>
		√
<i>6) Is there a significant risk that the research will expose participants to visual, auditory, or other environmental stimuli of a level or type that could have</i>	<b>YES</b>	<b>NO</b>

<i>short- or long-term harmful physical effects?</i>		√
7) <i>Is there a significant risk that the research will induce anxiety, stress or other harmful psychological states in participants that might persist beyond the duration of the test/interview?</i>	YES	NO
		√
8) <i>Does the research involve exposing participants to any physical or psychological hazard, beyond those of their usual everyday life, not covered by questions 6 and 7?</i>	YES	NO
		√
9) <i>Does the research involve any *invasive procedure (Class B)?</i>	YES	NO
		√
10) <i>Will the research elicit information from participants that might render them liable to criminal proceedings (e.g. information on drug abuse or child abuse)?</i>	YES	NO
		√
11) <i>Does the research involve the *deception of participants?</i>	YES	NO
		√
12) <i>Will the research require a participant to spend more than 2 hours in any single session on activities designed by the researcher (NB this time restriction does not refer to situations where participants are observed going about activities not devised by the researchers e.g. observation of lessons in schools)?</i>	YES	NO
		√
13) <i>Will the research involve a significant risk of any harm of any kind to any participant not covered above?</i>	YES	NO
		√

**If any of your answers in section G are in a shaded box, please complete section H. If all your answers in section G are in the unshaded boxes, please complete section I.**

### Section H

One or more aspect(s) of your research project suggest(s) that it may pose risks to participants (see shaded box(es) ticked in section G).

<i>Are all the aspects of your project which caused you to tick a shaded box in section G fully covered by research protocol(s) which has/ve received IDREC/CUREC approval?</i>	YES	NO √
	Please give IDREC protocol number (s).  Please proceed to section I.	Please complete this form AND form CUREC/2 and submit both to the relevant Inter Divisional Research Ethics Committee.

FAQs  
19-22

FAQ  
26

<p><b><i>If you answered NO to question 1) in Section G concerning informed consent but a section of the Code of Practice governing your research activity is relevant, are you going to apply the standard set out in the Code of Practice?</i></b></p>	<p>Name of Code of Practice and section number:</p> <p>Please ensure that the description in section A indicates how the Code is applied and proceed to section I.</p>	<p>Please complete this form AND form CUREC/2 and submit both to the relevant Inter Divisional Research Ethics Committee.</p>
--	--	---

**Section I**

**Complete this section only if you do not need to submit form CUREC/2.**

**FAQs  
19&26**

I understand my responsibilities as principal researcher/supervisor/student researcher as outlined on p.1 of this form and in the CUREC glossary and guidance.

I declare that the answers above accurately describe my research as presently designed and that I will submit a new checklist should the design of my research change in a way which would alter any of the above responses so as to require completion of CUREC 2/full scrutiny by an IDREC. I will inform the relevant IDREC if I cease to be the principal researcher on this project and supply the name and contact details of my successor if appropriate.

**FAQs  
28&32**

**Signed by principal researcher/supervisor/student researcher:**.....  
.....

**Date:**.....

**Print name** (block capitals).....

**Signed by supervisor:**.....(for student projects)

**Date:**.....

**Print name**

(block capitals).....

I understand the questions and answers that have been entered above describing the research, and I will ensure that my practice in this research complies with these answers.

**Signed by associate/other researcher:**  
.....

**Print name** (block capitals).....

**Date** .....

I have read the research project application named above. On the basis of the information available to me, I:

- (i) consider the principal researcher/supervisor/student researcher to be aware of her/his ethical responsibilities in regard to this research;
- (ii) consider that any ethical issues raised have been satisfactorily resolved or are covered by CUREC approved protocols, and that it is appropriate for the research to proceed without further formal ethical scrutiny at this stage (noting the principal researcher's obligation to report should the design of the research change in a way which would alter any of the above responses);
- (iii) am satisfied that the proposed project has been/will be subject to appropriate \*peer review and is likely to contribute something useful to existing knowledge and/or to the education and training of the researcher(s) and that it is in the \*public interest.
- (iv) [FOR DEPARTMENTS/FACULTIES WITH A DEPARTMENTAL RESEARCH ETHICS COMMITTEE (DREC) OR EQUIVALENT BODY - PLEASE DELETE IF NOT APPLICABLE] confirm that this checklist (and associated research outline) has been reviewed by the Department's Research Ethics Committee (DREC)/equivalent body, and attach the associated report from that body.

**Signed:**.....(Head of department or nominee e.g Chair of DREC, Director of Graduate Studies for student projects)

**Print name** (block capitals).....

**Date:**.....

---

**Please send an electronic copy and a paper copy of this completed checklist to whichever of the IDRECs is more suitable (Social Sciences or Medical Sciences), keeping a copy for yourself.**

**Forms may be sent by email (without signature), where both the note of submission from the researcher and the note of endorsement from the supervisor/Head of Department are sent from a University of Oxford email address. IDRECs and/or CUREC will review a sample of completed checklists and may ask for further details of any project.**

## **FINAL CHECK**

To prevent delay please check each of the following before submitting the application.

Have you completed Section A and answered all relevant questions in Sections B-H?

Have you defined all technical terms and abbreviations used?

Have you included all questionnaires and participant information, consent forms, advertisements, and surveys to be used?

Have you included all relevant approvals and supporting letters?

Have you declared all potential conflicts of interest?

Are all pages (including appendices and attachments) numbered?

Are all relevant declarations in Section I complete and any necessary authorisations obtained (by email or by signing the form)?

Revised May 2009

## Appendix B3

University of Oxford

### CENTRAL UNIVERSITY RESEARCH ETHICS COMMITTEE (CUREC)

Not all research project leaders need to fill in this form. **Before starting work on this form**, please fill in CUREC's checklist (CUREC/1) which will show if you need to complete this form. Please also ensure you have consulted the following CUREC guidance documents available on the CUREC website (<http://www.admin.ox.ac.uk/curec/resrchapp/index.shtml>):

FAQs  
14-20

[Guidance on approval process](#)

[Glossary](#)

[FAQs](#)

Definitions of terms marked with an asterisk are to be found in CUREC's glossary and guidance.

#### SECTION 1: PROJECT TITLE, RESEARCHERS, AND CONTACT DETAILS

##### 1. Person to whom IDREC/CUREC should direct correspondence.

###### **\*Principal investigator/supervisor/student researcher**

Title and name: Miss Laura Gottardis

Appointment:

Department: Department of Education

Institution: Harris Manchester College, University of Oxford

Address: Flat 100 Block C Castle Mill, Roger Dudman Way, Oxford, OX1 1AF

Phone: 07748812067

Fax:

e-mail: [laura.gottardis@education.ox.ac.uk](mailto:laura.gottardis@education.ox.ac.uk)

Will you need training to participate in this project?

Yes  No

###### **FOR STUDENT RESEARCH PROJECTS ONLY**

Name of Supervisor: Prof. Terezinha Nunes

FAQ  
12

##### 2. Full project title and proposed starting date:

Deaf Primary School children's achievements in mathematics

FAQs  
13&29

<b>Office use only:</b>	IDREC Ref. No. _____
Application date:    /    /	
Approval Period: from    /    /	to    /    /
Signature of IDREC approver: _____	
Name (printed) and position of approver: _____	
Date applicant informed of approval:    /    /	

**3. Are you submitting this project to another ethics committee or has it been previously submitted to an ethics committee?**

- Yes - provide details.
- No

Submitted CUREC form 1; informed of the necessity to complete protocol CUREC 2
--

*If other relevant approvals for this research are required (e.g. from other universities' ethics committees) please attach them.*

**4. Have you made use of professional/CUREC guidelines in framing your research project and preparing documentation?**

Note: the CUREC guidelines are available online (<http://www.admin.ox.ac.uk/curec/oxonly/protocols/guidelines.shtml>) or by emailing [curec@admin.ox.ac.uk](mailto:curec@admin.ox.ac.uk)

- Yes - provide details. Download from internet
- No – explain why not.

--

**5. Researchers involved in this project**

Please supply one completed copy of this box for each researcher.

*For each researcher who requires training to participate in this project, describe training on a **separate page** and include the name of the trainer(s).*

<b>*Associate researcher/student researcher</b>
Title and name:
Appointment:
Department:

Institution:	
Address:	
Phone:	Fax:
e-mail:	
Role in this project: Qualifications and relevant experience for this project: Degree course (if relevant):  Will this researcher be approved by the principal researcher as competent to obtain *informed consent from participants?	
Will this researcher need training to participate in this project? <input type="checkbox"/> Yes <input type="checkbox"/> No	

## SECTION 2: PROJECT DESCRIPTION

### 6. Description of project

Please give a description (300-800 words) of your project to supplement the information already provided in Section A of the checklist (CUREC/1), detailing those aspects of the project which involve \*human participants, particularly any aspect which is beyond already established and accepted techniques. Please attach all other documents (e.g. questionnaire, recruitment advertisements, participant information, and consent forms) that you plan to use in the study. **Please note that detailed scientific background is not required unless directly relevant to ethical issues.**

All the procedures used in the research are established and accepted techniques. The reason for completing this form is that the participants are children.

### 7. Literature search

If the research involves significant risk to the human participants please describe what literature searches have been undertaken to obtain information to aid risk reduction/management.

N/A

## SECTION 3: RESEARCH INVOLVING CONTACT WITH \*HUMAN PARTICIPANTS

If the project does NOT involve contact with\*human participants, but only use of data

about them, do NOT complete this section, but go to Section 4. If you are not completing Section 3 please delete it from your application to save paper.

## 8. Description of participants

How many participants will be involved in the project?

180: 90 deaf children in the age range 6-8 and 90 deaf children in the age range 9-11.

## 9. Details of participants

- (a) What types of people will be recruited e.g. students,\* children, people with learning disabilities? [Please see the [Glossary](#) on the CUREC website for information on how the meaning of \*capacity to consent has been altered by the Mental Capacity Act 2005]

deaf children and parents

- (b) What will be the age range of participants?

Deaf children aged between 6 and 11 years old

- (c) How will the competence of participants to give \*informed consent be determined?

Deaf primary school children who are willing and able to engage with the tests will be asked to participate. The head-teacher, the teacher and the parent will be asked for consent before approaching the child. The letter to the parent indicates that the child will be given the opportunity to say whether she/he wants to participate or not. The children will be asked for consent at the time of testing. Because these are deaf children, the best way to consult them is indeed at the time when they are invited to participate. Literacy is a challenge for them and they cannot be asked for consent by letter. The best method to communicate with them is by approaching them individually, explaining what they are about to do, and giving them the opportunity to decide. Many deaf children have difficulty in understanding conditional clauses and time intervals so adding a delay in allowing for them to think would not help but would confuse them. Any child who is unwilling or unable to engage with our tests will be not be persuaded to do so.

- (d) What are the \*defining criteria for participation in the study?

Deaf children aged between 6 and 11 years with hearing loss between moderate and profound and without other additional needs. Parents will be asked to fill in a questionnaire about the use of the cochlear implant, if the children have implants.

## 10. Recruitment of participants

- (a) Describe how, where, and by whom participants will be identified, approached, and recruited.

The supervisor of this project has an extensive network of collaborating schools and teachers, who contributed to previous projects. A letter will be sent by the student to these schools and teachers asking them to participate in this project.

- (b) If your research involves any use of \*personal data obtained from a \*third party,

describe the steps you have taken to ensure that the \*third party has arrangements in place to permit disclosure.

Parents of the deaf children will permit disclosure of date of birth, language used at home, parental education, level of child's hearing loss, use of hearing aids or cochlear implant, period in which the hearing device was fitted, years in formal education and type of educational provision.

(c) Will any \*unequal relationships exist between anyone involved in the recruitment and the potential participants?

Yes

No

If yes:

(i) Describe the nature of the unequal relationship.

It is possible that an inevitable unequal relationship will exist between the researcher and the deaf children involved in the research because the researcher is an adult from Oxford University and the child is a student in primary school.

(ii) Explain how ethical problems arising from the unequal relationship will be resolved.

The fact that the University where the researcher is studying is Oxford does not mean much for primary school deaf children. The asymmetry of the relationship, though inevitable, is taken into account in the manner that the researcher interacts with the children. The researcher will endeavour to put the children to feel at ease by approaching them in a friendly manner, engaging them in a relation that seeks to create a sense of mutual interest, and assuring them that they can ask questions about anything, if the researcher has not explained them clearly. Throughout the session, the researcher will check with the children whether they want to carry on with the next task.

(d) Describe any \*financial or other rewards which will be offered to participants.

N/A

## 11. \*Participant information

It is essential that written information is easily understandable by participants. Failure to provide this information in appropriate lay language is the most frequent reason for delays in ethical approval.

(a) Will participants receive **written** information about the project before giving their consent?

Yes - please attach. (see attached letter to parents)

No - give reasons.

N/A

(b) Who will give the participants the information and how?

The parent letters will be sent to parents by the teacher of the school attended by the children. Consent cannot be obtained from the children in written form as most deaf children find reading comprehension a great challenge. The children will be asked in their preferred language, oral or signed, whether they want to participate in the tasks.

(c) Does the research involve deliberate \*deception of participants?

Yes- explain why the real purpose of the research needs to be concealed and how and when participants will be told of the deception.

No

(d) Please describe the basis on which you have decided how long participants will have to think about the information provided before giving consent.

Teachers suggest that parent letters should be returned within a week. In their experience, most parents return the letters within a day or two, if it has not been misplaced.

## 12. \*Informed consent

(a) Will you obtain written consent?

Yes - please attach \*consent form.

No - explain how consent will be obtained and recorded and why this method is used.

(b) If participants are unable to give valid consent, how and from whom will you obtain consent? [Please see the [Glossary](#) on the CUREC website for information on how the meaning of \*capacity to consent has been altered by the Mental Capacity Act 2005]

Teachers and parents will be asked to give consent initially. The child will also be given the opportunity to decide whether they do the tasks or not.

(c) List those researchers who will, with the authorisation of the principal researcher (or supervisor in the case of student researchers), secure the consent of participants.

N/A

### 13. Consequences of participation

(a) What are the potential risks or actual ill effects of participation (if any) e.g. invasive procedures, distress, deception etc, and what will be done to minimise these risks

(i) to the participants?

None

(ii) to the researchers?

None

(iii) to others (e.g. the university, family)?

None

(b) Is there a need for support or counselling?

Yes - describe the form of support or counselling and how, when, and by whom it will be conducted.

No

N/A

(c) Is there a need for debriefing or follow-up discussion?

Yes - describe the form of debriefing or follow-up discussion and how, when, and by whom it will be conducted.

No

A report of the research will be sent to the schools by the researcher at the end of the project.

(d) Are there any potential benefits to the participants?

Yes - describe them below

No

Through the analyses of the predictors of mathematical achievement in deaf children, we hope to clarify the nature of deaf children's difficulties and paths to improvement. Participants will benefit directly as the teachers will be able to use the assessments to help them design the children's personal educational programme.

### 14. \*Adverse events

How will adverse events be monitored and reported?

In the unlikely event that a child becomes upset during testing, the researcher will deal with the situation sensitively, as she is trained to do so. However, the procedures have been used many times with deaf children previously and the children enjoy the assessments.

**15. Monitoring**

Explain how and by whom (e.g. supervisor in the case of student research projects) the ethical aspects of the project will be monitored to ensure that they conform to the procedures set out in this application.

The research student will have regular meetings with the supervisor to monitor the procedures set out in the application.

**SECTION 4: RESEARCH INVOLVING COLLECTION, USE, OR \*DISCLOSURE OF \*PERSONAL DATA**

Your project must meet the standards laid down in the Data Protection Act (1998) with respect to the collection, use, and storage of \*personal data about \*human participants.

Please delete questions or parts of questions that you are not required to answer to save paper.

**16. Need I complete this section?**

Does the project involve the collection, use or disclosure of personal information including sensitive and/or genetic information?

No – you need not complete this section. **Go to Section 5.**

Yes – you must answer questions in this section. **Go to Question 17.**

**17. Type of activity proposed**

Does the research involve:

(a) disclosure of personal information?

Yes

No

(b) collection of personal information?

Yes – **go to Question 18**

No – **go to Question 20**

**18. Collection of information directly from individuals**

(a) Does the project involve collection of information directly from individuals about themselves?

No – **go to Question 19.**

Yes – answer the following questions:

**(b)** Do the \*participant information and the \*consent form include the following:

the name of the study?	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No
the name and status (e.g. doctoral student) of the researcher collecting the information and how to contact him/her?	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No
the purpose of the study?	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No
declarations that the participant has read the participant information sheet?	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No
has had the opportunity to ask questions about the study and has received satisfactory answers to questions, and any additional details requested?	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No
understands that s/he may withdraw from the study without penalty at any time by advising the researchers of this decision?	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No
understands that this project has been reviewed by, and received ethics clearance through, the University of Oxford Central University Research Ethics Committee?	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No
understands who will have access to personal data provided, how the data will be stored; and what will happen to the data at the end of the project?	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No
agrees to participate in this study?	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No
understands how to raise a concern and make a complaint?	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No

If you answered 'no' to any of these questions, explain why this information has not been included in the participant information and the consent form.

N/A
-----

**(c)** Are the consent form and participant information on headed letter paper which bears the name of the University and the name and address of the department to which the principal researcher is attached?

Yes

No - explain why not.

(d) Are the participant and the researcher who secures the consent required to sign, print and date their names?

Yes

No -explain why not.

**19. Collection of information from a third party**

(a) Does the project involve collection of information about an individual from a source other than the individual?

No – **Go to Question 20.**

Yes – complete the following sections.

(b) List the individuals or organisations from which information will be collected. If information will be collected from more than one source, state which information or records will be collected from each source.

(c) Have all organisations from which the information is to be collected agreed to provide the information or to allow access to the information?

Yes - attach a copy of each letter of agreement. Provide details of any conditions imposed by the organisation(s) concerning the release of the information.

No - explain how and when the agreement of the disclosing organisation will be obtained.

(d) Will the information be potentially or actually ascribable to an individual when it is received?

No – **go to Question 20.**

Yes – answer the following questions:

(e) Does the project involve collection of information without the consent of the individual to whom it relates?

No – **go to Question 20.**

Yes – answer the following questions:

- (f) Give reasons why information will not be collected in a way which prevents its ascription to an individual.

- (g) Why will consent not be obtained from the individual(s) whom the information describes? [Please see the [Glossary](#) on the CUREC website for information on how the meaning of \*capacity to consent has been altered by the Mental Capacity Act 2005]

**20. Form in which data are to be stored**

Are the data to be kept

- (a) with an open identifier i.e. in non-anonymised form  Yes  No
- (b) as anonymised but potentially identifiable data  Yes  No
- (c) as anonymised, non identifiable data  Yes  No

**21. Use or disclosure of information about individuals**

- (a) Does the project involve the use or disclosure of information potentially or actually ascribed to an individual?

No – go to Question 22.

Yes – answer the following questions

- (b) Does the project involve use or disclosure of information without the consent of the individual whom the information describes?

No – go to Question 22.

Yes – answer the following questions:

- (c) What are the specific purposes for which the information will be used?

- (d) Is the purpose for which the information will be used related to the purpose for which the information was originally collected?

Yes – give details.

No – give details.

- (e) Describe in detail which information or records will be disclosed to which organisations.

- (f) Give reasons why information will not be used or disclosed in a way which prevents its ascription to an individual. (If the answer is the same as for question 19 (f), write 'as above'.)

- (g) Why will consent not be obtained from the individual(s) whom the information describes? (If the answer is the same as for question 19 (g), write 'as above'.)

- (h) Explain why the proposed use or disclosure of information is in the public interest. The public interest in the proposed research must substantially outweigh the public interest in respecting individual privacy.

**22. Data collection, storage, and disposal**

- (a) How many records will be collected, used or disclosed? Specify the information that will be collected, used, or disclosed e.g. date of birth, medical history, number of convictions.

Number of records: 3  
Type of information: date of birth, level of hearing loss, type of sensory device used. These will be stored in password protected computer files.

- (b) How, where, and under what security arrangements will electronic and paper data be stored? Who will have and control access to the information?

SPSS files on computers identified by ID number  
Papers forms in locked cabinet in research office

- (c) When, how and by whom will the information be disposed of?

SPSS files: participants will be only identifiable by identity number

- (d) How will the privacy of individuals be respected in any publication arising from this project?

Individuals will not appear in any publications; only statistics of participants will appear in publications.

- (e) Have you explained in the \*participant information and \*consent form that maintenance of confidentiality of information is subject to normal legal requirements?

Yes

No – explain why not.

N/A

### 23. Adverse and unforeseen events

How will adverse and unforeseen events relating to the collection, use, or disclosure of information be managed, monitored and reported?

The researcher named in the project will take responsibility for the data collection. She will be in close contact with the teachers who are in a position to discuss with parents whether there are adverse events related to the project.

## SECTION 5: MISCELLANEOUS ISSUES

### 24. \*Conflict of interest

- (a) Do researchers on this project have a financial or other interest in its conduct or outcomes?

Yes – give details.

No

- (b) If there is a conflict of interest, have you declared it in your \*participant information and \*consent form?

Yes

No – explain why not.

N/A

- (c) Are there any other potential conflicts of interest e.g. research findings that could compromise the researcher's relationship with the university?

N/A

**25. \*Peer review**

Has this project been peer reviewed?

- Yes – explain by whom (e.g. by a, tutor, supervisor, funding body etc) and with what outcome
- No – explain why not.

The ESRC and the RNID have reviewed the proposal and are willing to sponsor the project.

**26. Funding**

List all bodies and individuals from whom funding has been or will be sought.

Source	Amount in £	Status of Funds			
		Available		Applied for	
ESRC	fees	Yes <input checked="" type="checkbox"/> No <input type="checkbox"/>	Yes <input type="checkbox"/> No <input type="checkbox"/>		
RNID	12000	Yes <input checked="" type="checkbox"/> No <input type="checkbox"/>	Yes <input type="checkbox"/> No <input type="checkbox"/>		

**27. Reporting of results**

(a) Will the project outcomes be made public at the end of the project?

- Yes – describe the intended report and how and to whom it will be made available.
- No – explain why not

Interim report to the RNID on recruitment of schools; the transfer and the confirmation reports will be presented to the RNID; DPhil thesis will be presented to the RNID; publication will be submitted to a professional journal that reaches all teachers who are members of the British Association of Teachers of the Deaf.

(b) Will a report(s) of the project outcomes (for example, individual or group data) be made available to participants at the end of the project?

- Yes – describe report and how it will be made available.
- No – explain why not.
- N/A

A written summary is sent to the schools at the end of the project.

**28. Declaration by researchers**

**Full project title:**

I/We, the researcher(s) agree:

- To start this research project only after obtaining approval from IDREC/CUREC;
- To carry out this research project only if funding is adequate to enable it to be

carried out according to good research practice and in an ethical manner;

- To provide additional information as requested by IDREC/CUREC before approval is secured and as research progresses;
- To maintain the confidentiality of all data collected from or about project participants;
- To notify IDREC in writing immediately of any proposed change which would increase the risks that any participant is exposed to and await approval before proceeding with the proposed change;
- To notify IDREC if the principal researcher on the project changes and supply the name of the successor;
- To notify IDREC in writing within seven days if any serious \*adverse event occurs in the course of research;
- To use data collected only for the study for which approval has been given;
- To grant access to data only to authorised persons; and
- To maintain security procedures for the protection of personal data, including (but not restricted to): removal of identifying information from data collection forms and computer files, storage of linkage codes in a locked cabinet and password control for access to identified data on computer files.

FAQs  
28&32

FAQ  
33

Signed by principal researcher/supervisor/student researcher:.....

Date:.....

Print name (block capitals)...LAURA GOTTARDIS.....

Signed by supervisor:.....(for student projects)

Date:.....

Print name (block capitals).....

Signed by associate/other researcher: .....

Print name (block capitals).....

Date .....

**29. Certification by \*principal researcher/supervisor/student researcher and head of department**

**Full project title:** Deaf Primary School children's achievements in mathematics

**Certification by \*principal researcher/supervisor/student researcher**

I accept responsibility for the conduct of this research project.

I certify that all researchers and other personnel involved in this project are appropriately qualified and experienced or will undergo appropriate training to fulfil their role in this project.

Signed by principal researcher/supervisor/student researcher:.....

Date:.....

Print name (block capitals).....LAURA GOTTARDIS.....

**Acceptance by head of department/other senior member of the department if the principal researcher is the head of department**

I have read the research project application named above.

On the basis of the information available to me, I judge the principal researcher/supervisor/student researcher to be award of her/his ethical responsibilities in regard to this research. I am satisfied that the proposed project has been/will be subject to appropriate peer review and is likely to contribute to existing knowledge and/or to the education and training of the researcher(s) and that it is in the public interest.

Name of head of department/other senior member of the department (e.g Chair of DREC, Director of Graduate Studies for student projects):

.....

Signature .....

Date.....

**FINAL CHECK**

To prevent delay please check each of the following before submitting the application.

Have you answered all relevant questions in Sections 1-5?

Have you defined all technical terms and abbreviations used?

Have you included all questionnaires and participant information, consent forms, advertisements, and surveys to be used?

Have you included all relevant approvals and supporting letters?

Have you declared all potential conflicts of interest?

Are all pages (including appendices and attachments) numbered?

Have you completed the declaration by researcher(s)?

Have you completed the certification by principal researcher and head of department?

Revised July 2008

## Appendix B4

### School Head Information Letter



Date

Dear Head Teacher (to be replaced with name),

I am writing to ask you if your school would like to participate in a project entitled, “Deaf Primary School children’s achievement in mathematics,” funded by Royal National Institute for Deaf People (RNID). If you agree to participate in the research, then we will ask also for the parents’ and the children’s agreement. There are no recent surveys of deaf children’s mathematical achievement in the U.K. so a new survey would be valuable. This research is part of my work towards a doctorate in education at the University of Oxford.

Our aim is to find out more about deaf children’s achievements in mathematics and how their level of achievement might be raised in the future. In particular, we are interested in deaf children without any additional educational needs and in the age range 6 to 11 years. The children aged 6-8 will participate in two assessments of their mathematical and cognitive skills. The first assessment will take place during this year and the second in the following year. The children aged 9-11 will only participate in one assessment, which could take place during this year or the next.

I will be carrying out the assessments during individual sessions in the child’s preferred mode of communication. I have passed BSL1, am currently taking BSL 2 and have discussed the BSL presentation of all the questions with Diana Burman, an experienced teacher of the deaf who has worked in developing the signed instructions for the assessments. The sessions will last approximately 40 minutes and might be divided in two sessions so that the children do not become too tired. I have gone through the CRB check and can provide the certificate when we meet.

All the information collected will be confidential. The way the information is stored in our computers makes it impossible for individual children to be identified. The child’s teacher and the parent will be able to have access to the information on the child’s mathematics attainment, which can be used to develop the child’s personalised educational programme. No information about individual children will be made available to anyone else. This is in agreement with the Data Protection Act.

I’m attaching a model of the letter to parents which we normally use when seeking their consent. If you have suggestions regarding the letter stemming from your own practice, please do let me know.

I will be contacting you by telephone within about one week so you have an opportunity to ask any questions you might have.

Best wishes,

Oxford 1<sup>st</sup> November 2009  
Laura Gottardis  
Department of Education  
University of Oxford  
15 Norham Gardens  
Oxford OX2 6PY

## Appendix B5

### Consent Parent Letter

Date

Dear Parents,



I am writing to ask your permission to allow your child to take part in a research project entitled, “Deaf Primary School children’s achievements in mathematics,” which is funded Royal National Institute for Deaf People (RNID). Your child’s school has kindly agreed to cooperate with the research and now we are asking your permission for your child to take part. Your child will also be given the opportunity to decide whether or not to complete the tasks.

Our aim is to find out more about deaf children’s achievements in mathematics and how their level of achievement might be raised in the future.

The children will participate in an assessment of their mathematical and cognitive skills. I will carry out the assessments during individual sessions at your child’s school; the sessions will last approximately 40 minutes and might be divided in two sessions so that the children do not become very tired.

All the information collected will be confidential. The way the information is stored in our computers makes it impossible for individual children to be identified. You and your child’s teacher will be able to have access to the information on your child’s progress in mathematics, which can be used to develop your child’s personalised educational programme. No information about individual children will be made available to anyone else. This is in agreement with the Data Protection Act.

At the end of the study we will write a brief summary of our findings, which we think will be help teachers in teaching mathematics to deaf children in the future. If you decide that your child will not participate in the study, this will not affect your child’s education.

The research will be carried out by me, Laura Gottardis. I am a doctorate student at the Department of Education of the University of Oxford. If you have any questions you would like to ask before replying, please do not hesitate to contact me by telephone on 07748812067 or by email [laura.gottardis@education.ox.ac.uk](mailto:laura.gottardis@education.ox.ac.uk).

In order for your child to participate in the project, please complete and return the attached form to your child’s class teacher. If at any point you decide to withdraw your child from the project, you can do so without having to provide any explanation.

Thank you for your help.

Oxford 1<sup>st</sup> November 2009  
Laura Gottardis  
Department of Education  
University of Oxford  
15 Norham Gardens  
Oxford OX2 6PY



**Parents consent form**

**To be returned to your child's teacher**

**Title of Project:**

Deaf Primary School children's achievements in mathematics

Child's name: .....

Class teacher: .....

I agree to my child's participation in this study.

Parent signature: .....

## Appendix B6

Project: Deaf Primary School children's achievements in mathematics



### Parents' views and experiences with pediatric cochlear implant questionnaire

Child's name .....

Date.....

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
1) Communication is difficult even with people she knows well.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2) Immediately after implantation her/his ability to communicate was poorer.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3) The help I give her/him has become more productive now he/she has her implant.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4) Before implantation she/he obtained no benefit at all from her hearing aids.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5) S/he does not have a close relationship with her grandparents.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6) S/he is totally reliant on her implant all the time.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7) S/he knows when I want her attention because s/he she can hear me call.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8) I worry that the implant will break down.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9) S/he is unable to cope with mainstream school.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10) It has been a problem getting someone to look after the family when we go to the Implant Center.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
11) Progress during the first few months seemed very slow.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
12) I can seldom leave her/him to do something on her own.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
13) The program at the Implant Centre should emphasize speaking and listening.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
14) I worry that s/he will blame me for my decision for him/her to have an implant.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
15) S/he has needed more help from me since she received her/his implant.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
16) S/he still shows signs of frustration in her behavior.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
17) I am concerned that my child will be rejected by the by the deaf community because of the implant.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
18) The quality of her/his speech gives me cause for concern.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
19) A lot of help at first means a child needs less help later.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
20) I get more time to myself because of her/his increased independence.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
21) Only experienced teams should carry out cochlear implantation.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
22) The costs of travel to the Implant Center are a problem.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
23) S/he is keeping up well with children of her/his own age.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
24) Sign support is helpful for a considerable time after implantation.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
25) I wish to participate in meetings with other families having an implanted child.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
26) Progress after implantation has exceeded my expectation	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
27) We can now chat even when s/he cannot see my face.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
28) Making the decision to proceed with the implantation was the most difficult part for me.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
29) It was a difficult time waiting for the results of the assessments before implantation.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
30) S/he was socially isolated before getting her implant.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
31) The local school and support services adequately meet.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
32) A significant change has been improvement in his/her confidence.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
33) S/he was very dependent on us before the implant.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
34) We feel the need for advice from the Implant Center concerning her future.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
35) S/he can now amuse herself listening to music or watching TV or playing games.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
36) We are reliant on the Implant Centre Center for technical advice about her implant.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
37) I am concerned about her/his future school placement	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
38) Other children in the family resented the time and attention taken up by the implant.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
39) The process of implantation was no more intrusive than expected.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
40) S/he does not make friends easily outside the family.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
41) It is essential that she is encouraged to wear the processor all the time.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
42) S/he is sociable within the family.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
43) A positive attitude is a great help towards successful use of the implant.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
44) Regular tuning and checking of the implant system are essential.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
45) At least one visit per year by Implant Centre staff is essential.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
46) S/he shares in family situations more than before implantation.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
47) Before proceeding with implantation, parents should obtain as much information and advice as possible.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
<b>48)</b> S/he is as independent as most other children of her age.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>49)</b> Parents should have a choice in the use of sign language.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>50)</b> It was useful to meet other families with an implanted child before deciding on an implant.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>51)</b> I am happy about her progress at school.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>52)</b> I can now let her play outside as she is aware of the sound of traffic.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>53)</b> The most important factor in choosing an implant device is its reliability.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>54)</b> S/he is still unable to cope in new situations.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>55)</b> I am confident that long-term electrical stimulation will not be a problem.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>56)</b> The whole process of implantation is still stressful.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>57)</b> I expected her/him to talk once s/he had her implant.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>58)</b> I worry that ultimately s/he may be neither part of the deaf nor the hearing world.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>59)</b> Her/his relationship with brothers and sisters has improved.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>60)</b> It was important to me that my child could hear sounds from traffic for safety reasons.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>61)</b> His/her behaviour has improved since s/he had her implant.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>62)</b> I believe now that my child will have reasonable prospects for employment.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>63)</b> S/he has become argumentative since getting his/her implant	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>64)</b> A parent of a child with an implant needs to be patient as benefits may take time to show.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
<b>65)</b> It has been hard to take time off work for the appointments at the Implant Center.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>66)</b> S/he is less frustrated than before s/he had the implant.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>67)</b> S/he takes part in family relationships on an equal footing with other members.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>68)</b> I find it easier to communicate with her/him by speaking than by signing.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>69)</b> I give the same amount of help as before the implant.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>70)</b> I chose implantation for my child so s/he would have a chance to become part of the hearing world.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>71)</b> S/he is totally reliant on her implant at school.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>72)</b> S/he continues to be a happy child and good fun to be with.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>73)</b> His/her use of spoken language has developed	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>74)</b> Now s/he is talkative and engages others in conversation	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

# Appendix C1

## Additional figures and tables presented in the Chapter 3

### 1. Distributions of the PIPS maths test using the raw data in the deaf sample by age.

Figure C1.1. Distribution of the PIPS maths test for 6 year old deaf children.

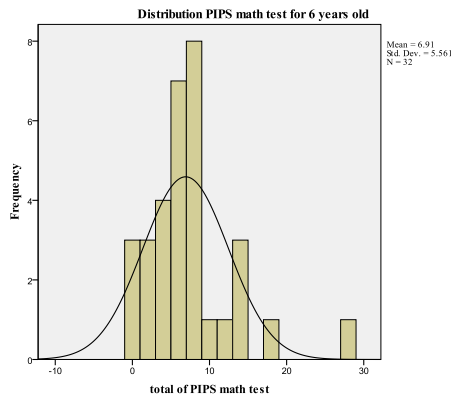


Figure C1.2. Distribution of the PIPS maths test for 7 year old deaf children.

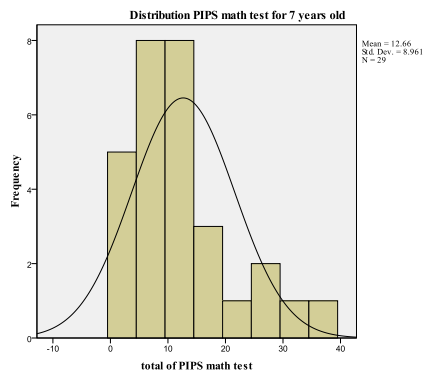


Figure C1.3. Distribution of the PIPS maths test for 8 year old deaf children.

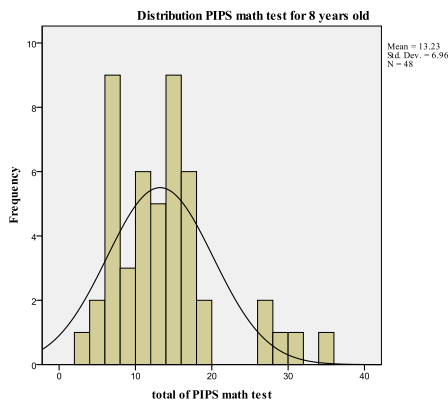


Figure C1.4. Distribution of the PIPS maths test for 9 year old deaf children.

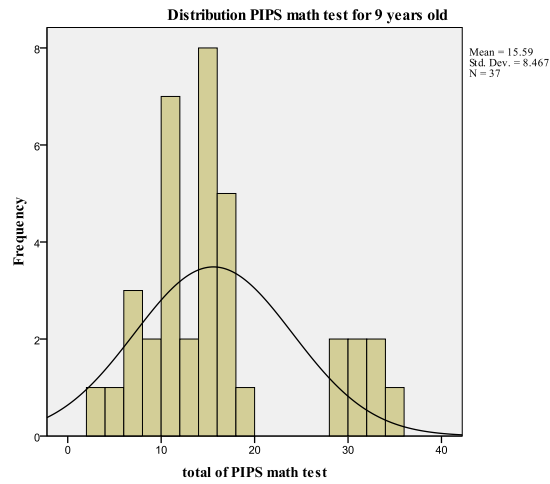


Figure C1.5. Distribution of the PIPS maths test for 10 year old deaf children.

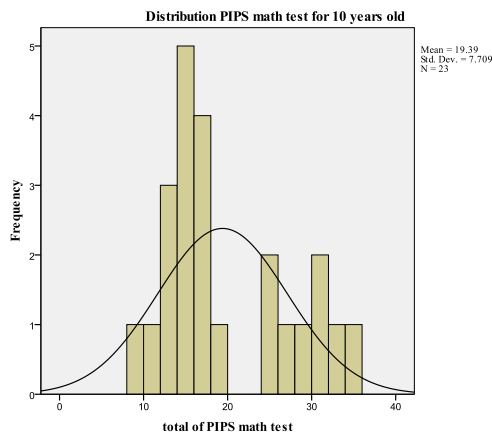


Figure C1.6. Distribution of the PIPS maths test for 11 year old deaf children.

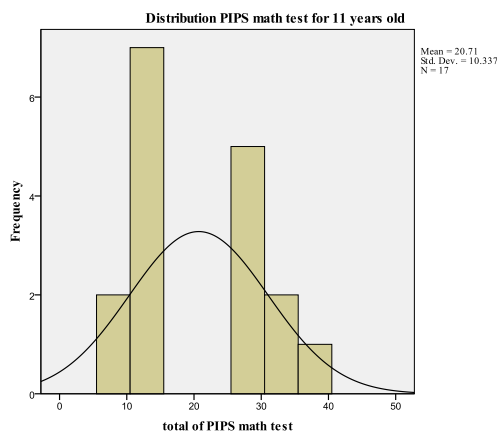


Table C1.1. Skewness values, standard error, z scores, Kurtosis value, standard error of Kurtosis, z scores of the distribution of raw scores of the PIPS maths test by age for the deaf sample.

Age	Skewness value	Standard error	z	Kurtosis value	Standard error	z
6 years	1.67	.41	4.07	4.42	.81	5.45
7 years	1.19	.43	2.76	.65	.84	.77
8 years	1.20	.34	3.53	1.65	.67	2.46
9 years	1	.38	2.63	.34	.71	.48
10 years	.68	.48	1.42	-1.01	.93	-1.09
11 years	.15	.55	.27	-1.87	1.06	-1.76

**2. Assumptions of the regression with age in the first step, years in education in the second step and transformed scores of the PIPS maths test as the outcome measure in the deaf sample.**

Figure C1.7. Histogram of the standardised residuals for PIPS maths test as outcome measure.

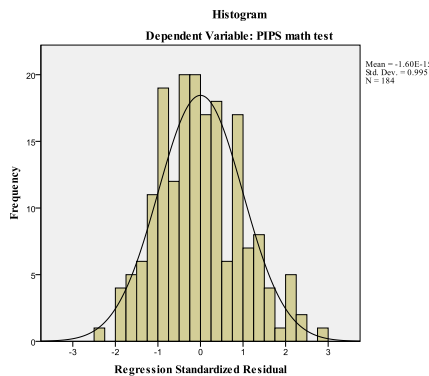


Figure C1.8. Normal Probability plot of Regression Standardised Residual for the PIPS maths test as outcome measure.

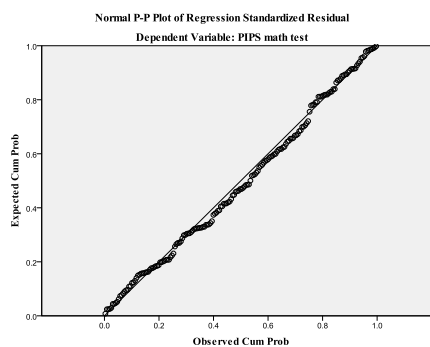
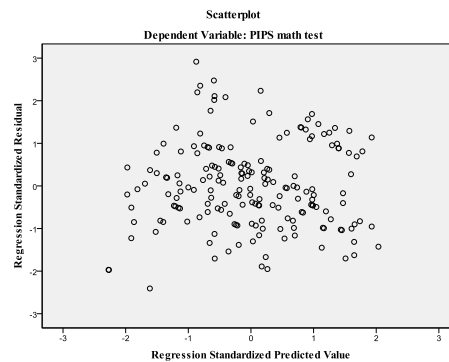


Figure C1.9. Scatterplot of the regression standardised predicted value compared with the regression standardised residuals for the PIPS maths test as outcome measure.



3. Assumptions of the regression with age in the first step, years in education in the second step, type of educational provision in the third step and degree of hearing loss in the fourth step; transformed scores of the PIPS maths test as the outcome measure.

Figure C1.10. Histogram of the standardised residuals for PIPS maths test as outcome measure.

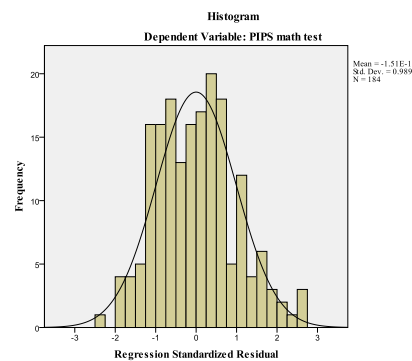


Figure C1.11. Normal Probability plot of Regression Standardised Residual for the PIPS mathematics test as outcome measure.

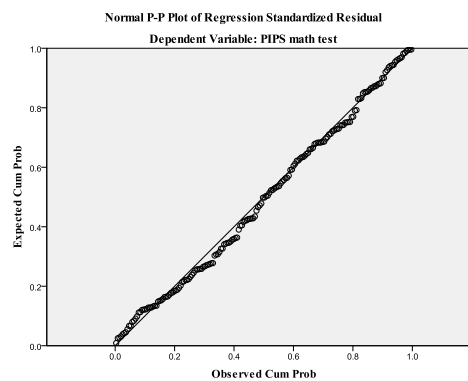
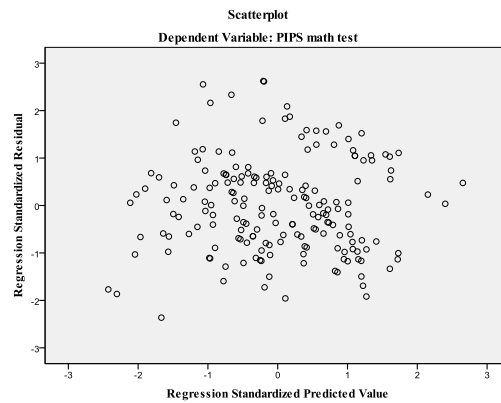


Figure C1.12. Scatterplot of the regression standardised predicted value compared with the regression standardized residuals for the PIPS maths test as outcome measure.



#### 4. Distributions of the raw total scores of the PIPS maths test by age for the hearing sample.

Figure C1.13. Distribution of the PIPS maths test for 6 year old hearing children.

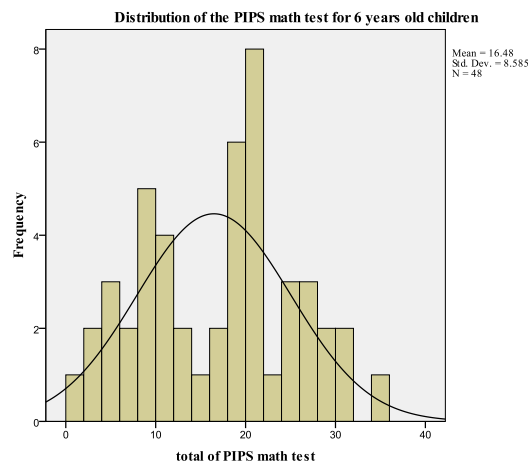


Figure C1.14. Distribution of the PIPS maths test for 7 year old hearing children.

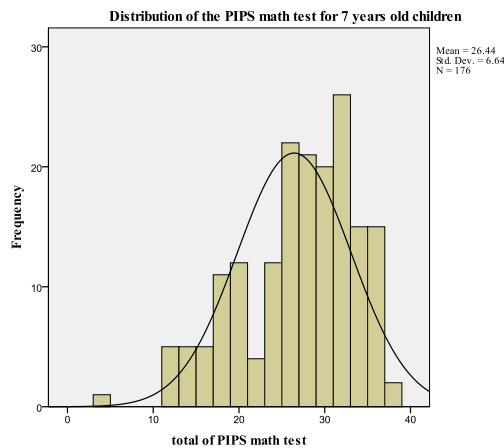


Figure C1.15. Distribution of the PIPS maths test for 8 year old hearing children.

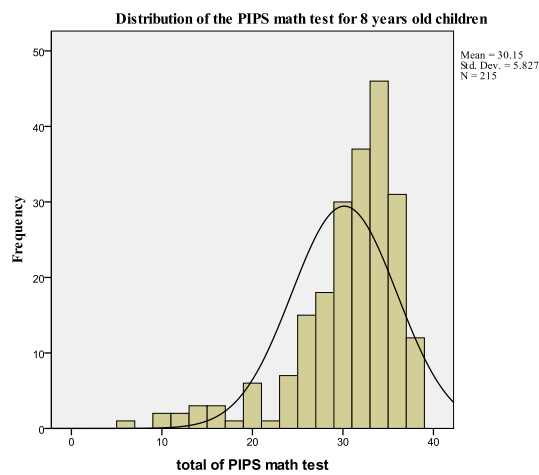


Figure C1.16. Distribution of the PIPS maths test for 9 year old hearing children.

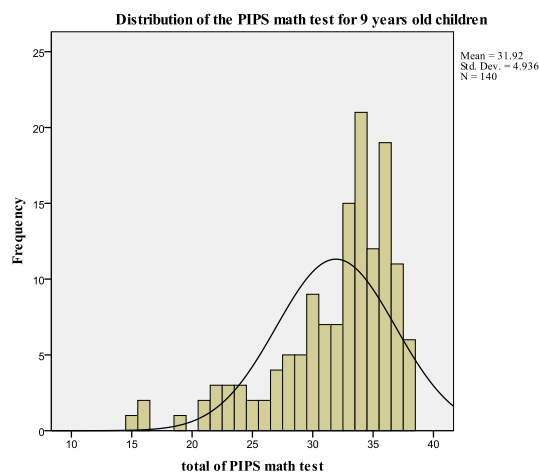


Figure C1.17. Distribution of the PIPS maths test for 10 year old hearing children.

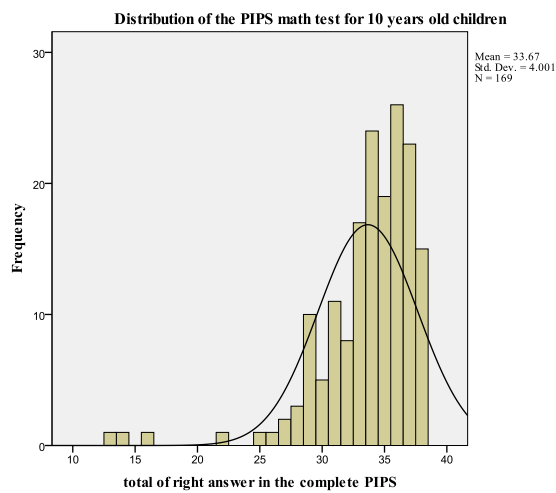


Figure C1.18. Distribution of the PIPS maths test for 11 year old hearing children.

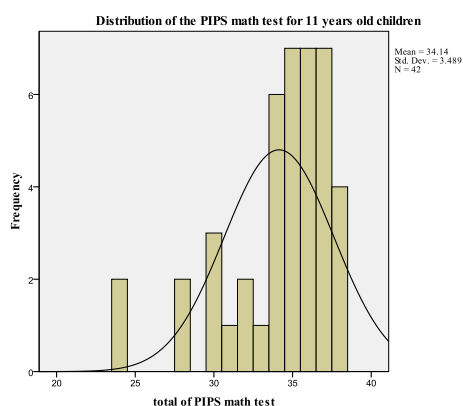


Table C1.2. Skewness values, standard error, z scores, Kurtosis values, standard error and z scores of the distribution of raw scores of the PIPS maths test by age for the hearing sample.

Age	Skewness value	Standard error	z	Kurtosis value	Standard error	z
6 years	.08	.34	0.23	-.90	.67	1.34
7 years	-.68	.18	-3.77	-.09	.36	.02
8 years	-1.64	.16	-10.25	3.03	.33	9.18
9 years	-1.31	.20	-6.55	1.49	.41	3.63
10 years	-2.34	.19	-2.6	8.48	.37	22.91
11 years	-1.43	.36	-3.97	1.81	.72	2.51

Table C1. 3. Effect sizes calculated on the un-transformed scores of the PIPS maths test.

Age	Effect sizes
6 years	-1.29
7 years	-2.05
8 years	-2.64
9 years	-3.09
10 years	-3.11
11 years	-2.39

## Appendix C2

### Analyses excluding children with 1 SD below the mean in their non-verbal intelligence task.

In the present sample, there are 30 children who performed 1 SD below the mean in the Matrices subtest of the BAS-II.

There is an equal proportion of male and female children. The majority (17) of this children are profoundly deaf whereas the remaining is equally divided between moderate and severe levels of hearing loss. The causes of deafness is either genetic, pregnancy related or post-birth disease showing an similar number of children in each of these categories. Half of these 30 children used hearing aids and half used cochlear implants. The majority (17) of them attended special schools for the deaf followed by unit for hearing impaired (8) and mainstream schools (5). Almost all these children were English native speakers and there is an equal distribution in the proportion of the levels of maternal education in all the categories.

#### 1. Distributions of the raw score of the PIPS maths test by age for the deaf sample.

Figure C2.26. Distribution of the PIPS maths test for 6 year old deaf children.

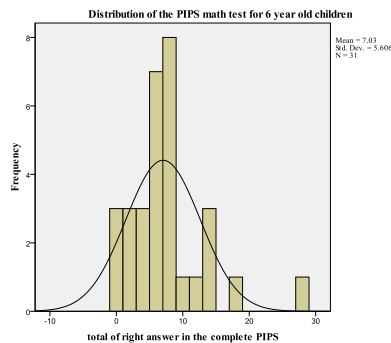


Figure C2.27. Distribution of the PIPS maths test for 7 year old deaf children.

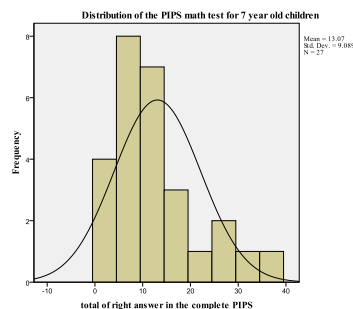


Figure C2.28. Distribution of the PIPS maths test for 8 year old deaf children.

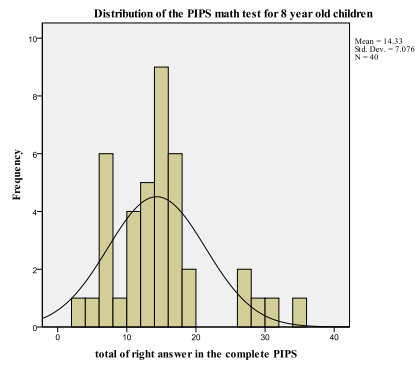


Figure C2.29. Distribution of the PIPS maths test for 9 year old deaf children.

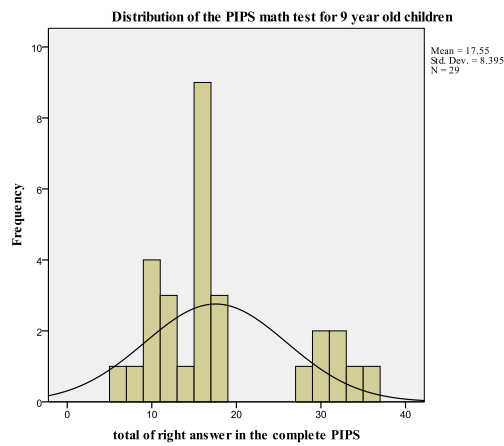


Figure C2.30. Distribution of the PIPS maths test for 10 year old deaf children.

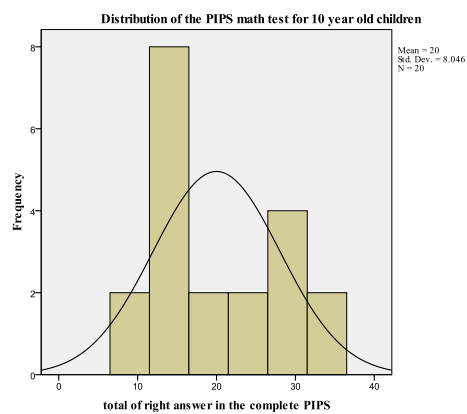


Figure C2.31. Distribution of the PIPS maths test for 11 year old deaf children.

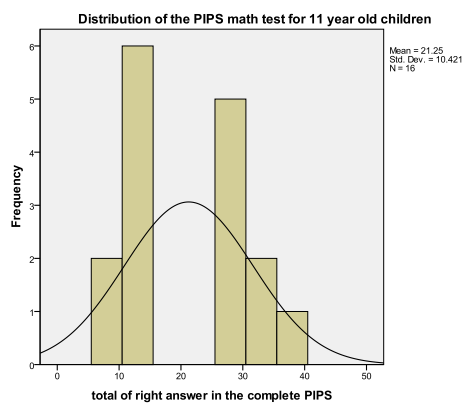


Table C2.3. Skewness values, standard error, z scores. Kurtosis value, standard error and z scores of the distribution of raw scores of the PIPS maths test by age for the deaf sample.

Age	Skewness value	Standard error	z	Kurtosis value	Standard error	z
6 years	1.63	.42	3.88	4.28	.82	5.21
7 years	1.14	.45	2.53	.44	.87	.50
8 years	1.04	.37	2.81	1.38	.73	1.89
9 years	.89	.43	2.06	-.45	.84	-.53
10 years	.49	.51	0.96	-1.31	.99	-1.32
11 years	.03	.56	.06	-1.90	1.09	-1.74

Because the data were positively skewed and high values of Kurtosis were found, a square root transformation was conducted.

**2. Correlation between age, years in education and deaf children’s mathematical achievement.**

Table. C2.4. Correlation between age, years in education and deaf children’s mathematical achievement.

Outcome measure	Age	Years in education
Deaf children’s mathematical achievement	.56**	.51**

\*\* .p<.01

**3. Regression analysis with age in the first step and years in education in the second; transformed scores of the PIPS maths test as the outcome measure.**

Figure C2.32. Histogram of the standardised residuals for PIPS maths test as outcome measure.

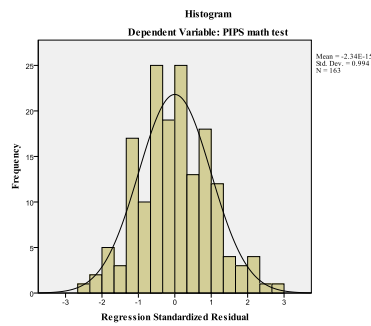


Figure C2.33. Normal Probability plot of Regression Standardised Residual for the PIPS maths test as outcome measure.

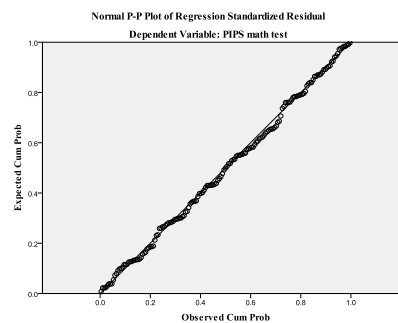


Figure C2.34. Scatterplot of the regression standardised predicted value compared with the regression standardized residuals for the PIPS maths test as outcome measure.

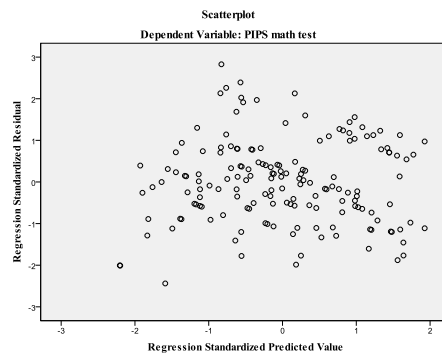


Table C2.5. The unstandardised and standardised regressions coefficients for age and years in education; PIPS maths test as outcome measure.

Steps	R <sup>2</sup>	Adjusted R <sup>2</sup>	R <sup>2</sup> change	B	SEB	β
Age	.30**	.30**	.30**	.30	.07	.39***
Years in education	.33**	.32**	.02**	.18	.07	.22**

\*\* .p<.01; \*\*\*. p<.001.

**4. Regression analysis with years in education in the first step and age in the second; transformed scores of the PIPS maths test as the outcome measure.**

Figure C2.35. Histogram of the standardised residuals for PIPS maths test as outcome measure.

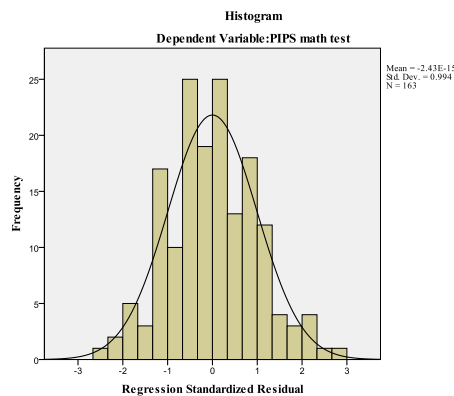


Figure C2.36. Normal Probability plot of Regression Standardised Residual for the PIPS maths test as outcome measure.

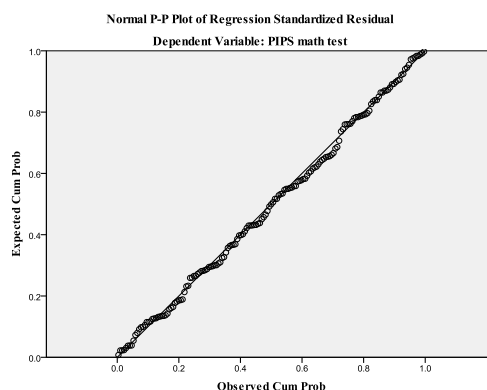


Figure C2.37. Scatterplot of the regression standardised predicted value compared with the regression standardized residuals for the PIPS maths test as outcome measure.

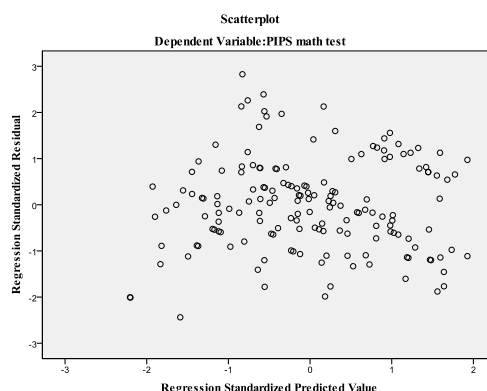


Table C2.6. The unstandardised and standardised regressions coefficients for years in education as the first step and age as the second step; PIPS maths test as outcome measure.

Steps	R <sup>2</sup>	Adjusted R <sup>2</sup>	R <sup>2</sup> change	B	SEB	β
Years in education	.26**	.26**	.26**	.18	.08	.22**
Age	.33**	.32**	.07**	.30	.07	.39***

\*\* . p<.01; \*\*\* . p<.001.

**5. Analysis of covariance between gender and deaf children’s mathematical achievement after controlling for age and years in education.**

Table C2.7. Adjusted means, standard errors, F and p value of the PIPS maths test by gender, after controlling for age and years in education.

<b>Gender</b>	<b>N</b>	<b>Adjusted Means</b>	<b>Standard errors</b>	<b>F</b>	<b>p</b>
Male	85	3.53	.11	1.49	.22
Female	78	3.72	.11		

Both the covariates age and years in education were significantly related to deaf children’s mathematical achievement (age:  $F(1,163)= 17.93, p<.01$ ; years in education:  $F(1,163)= 4.93, p<.05$ )).

**6. Chi-square analysis between degree of hearing loss and causes of hearing loss.**

Table C2.8. Number and percentage of children with or without hereditary causes of hearing loss by degree of hearing loss.

<b>Type of causes</b>	<b>Moderate</b>	<b>Severe</b>	<b>Profound</b>
Hereditary	10 (21.3%)	8 (17%)	29 (61.7%)
Non hereditary	13 (26%)	9 (18%)	28 (56%)

There was no significant relation between causes of hearing loss and degree of hearing loss ( $\chi^2(2)=.37, p=.83$ )

**7. Analysis of covariance between causes of hearing loss and deaf children’s mathematical achievement after controlling for age and years in education.**

Table C2.9. Adjusted means and standard error in the PIPS maths test by causes of hearing loss, after controlling for age and years in education.

<b>Causes of hearing loss</b>	<b>N</b>	<b>Adjusted Mean</b>	<b>Standard error</b>	<b>F</b>	<b>p</b>
Genetic/hereditary	47	3.62	.15	.69	.41
Non-genetic causes	50	3.45	.14		

Both the covariates age and years in education were significantly related to deaf children’s mathematical achievement (age:  $F(1,97)= 11.76, p<.01$ ; years in education:  $F(1,97)= 5.96, p<.05$ )).

**8. Chi-square analysis between degree of hearing loss and type of amplification.**

Table C2.10. Presence or absence of cochlear implant by degree of hearing loss.

<b>Degree of hearing loss</b>	<b>Absence of cochlear implant</b>	<b>Presence of cochlear implant</b>
Moderate	34 (36.6%)	9 (12.9%)
Severe	29 (31.2%)	9 (12.9%)
Profound	30 (32.3%)	52 (74.3%)

There was a significant relation between type of amplification and degree of hearing loss ( $\chi^2 (2)=28.28, p<.01$ )

**9. Analysis of covariance between type of amplification and deaf children’s mathematical achievement after controlling for age, years in education and degree of hearing loss.**

Table C2.11. Adjusted means, standard errors, F and p value in the PIPS maths test by type of amplification, after controlling for age, years in education and degree of hearing loss.

<b>Type of amplification</b>	<b>N</b>	<b>Adjusted means</b>	<b>Standard errors</b>	<b>F</b>	<b>p</b>
Cochlear Implant	70	3.75	.11	3.13	.08
Absence of cochlear implant	93	3.45	.13		

Both the covariates age and years in education were significantly related to deaf children’s mathematical achievement (age:  $F(1,163)=19.90, p<.01$ ; years in education:  $F(1,163)=4.81, p<.05$ ). The covariate degree of hearing loss did not show any significant relation with deaf children’s mathematical achievement ( $F(1,163)=2.04, p=.15$ ).

**10. Chi-square analysis between degree of hearing loss and type of educational provisions.**

Table C2.12. Number and percentage of children in the different types of schools by degree of hearing loss.

<b>Degree of hearing loss</b>	<b>Mainstream</b>	<b>Unit for hearing impaired</b>	<b>Special schools for the deaf</b>
moderate	21 (48.8%)	18 (26.9%)	4 (7.5%)
severe	14 (32.6%)	17 (25.4%)	7 (13.2%)
profound	8 (18.6%)	32 (47.8%)	42 (79.2%)

There was a significant relation between type of educational provision and degree of hearing loss ( $\chi^2(2)=36.87, p<.01$ )

**11. Analysis of covariance between mainstream schools and unit of hearing impaired and deaf children's mathematical achievement after controlling for age, years in education and degree of hearing loss.**

Table C2.13. Adjusted means, standard errors, F and p value in the PIPS maths test in mainstream schools and in unit for hearing impaired, after controlling for age, years in education and degree of hearing loss.

<b>Type of educational provision</b>	<b>N</b>	<b>Adjusted means</b>	<b>Standard errors</b>	<b>F</b>	<b>p</b>
Mainstream	43	3.97	.15	10.90	<.01
Unit for hearing impaired	67	3.30	.12		

The covariate age was significantly related to deaf children's mathematical achievement ( $F(1,110)=11.68, p<.01$ ). Both the covariates years in education and degree of hearing loss did not show any significant relation with deaf children's mathematical achievement (years in education:  $F(1,110)=2.22, p=.14$ .; degree of hearing loss:  $F(1,110)=.45, p=.50$ ).

**12. Analysis of covariance between mainstream schools and special schools for the deaf and deaf children’s mathematical achievement after controlling for age, years in education and degree of hearing loss.**

Table C2.14. Adjusted means, standard errors, F and p value in the PIPS maths test in mainstream schools and in special schools for the deaf, after controlling for age, years in education and degree of hearing loss.

Type of educational provision	N	Adjusted means	Standard errors	F	p
Mainstream	51	4.16	.16	7.21	<.01
Special schools for the deaf	53	3.44	.16		

The covariate age was significantly related to deaf children’s mathematical achievement ( $F(1,104)=19.68, p<.01$ ). Both the covariates years in education and degree of hearing loss did not show any significant relation with deaf children’s mathematical achievement (years in education:  $F(1,104)=.21, p=.64.$ ; degree of hearing loss:  $F(1,104)=.16, p=.69$ ).

**13. Analysis of covariance between unit of hearing impaired and special schools for the deaf and deaf children’s mathematical achievement after controlling for age, years in education and degree of hearing loss.**

Table C2.15. Adjusted means, standard errors, F and p value in the PIPS maths test in unit for hearing impaired and in special schools for the deaf, after controlling for age, years in education and degree of hearing loss.

Type of educational provision	N	Adjusted means	Standard errors	F	p
Unit for hearing impaired	67	3.44	.13	.06	.81
Special schools for the deaf	53	3.49	.15		

Both the covariates age and years in education were significantly related to deaf children’s mathematical achievement (age:  $F(1,120)=10.79, p<.01$ ; years in education:  $F(1,120)=5.14, p<.05$ ). The covariate degree of hearing loss did not show any significant relation with deaf children’s mathematical achievement ( $F(1,120)=1.51, p=.22$ ).

**14. Analysis of covariance between language used at home and deaf children’s mathematical achievement after controlling for age, years in education and type of educational provision.**

Table C2.16. Adjusted means, standard errors, F and p value by language used at home, after controlling for age, years in education and type of educational provision.

Language	N	Adjusted means	Standard errors
English	131	3.62	.08
BSL	6	4.68	.38
Not English	26	3.38	.19

All the three covariates, age, years in education and type of educational provision, were significantly related to deaf children’s mathematical achievement (age:  $F(1,163)=26.85$ ,  $p<.01$ ; years in education:  $F(1,163)=5.04$ ,  $p<.05$ ; type of educational provision:  $F(1, 163)=20.91$ ,  $p<.05$ ). There was a significant effect of language at home on deaf children’s mathematical achievement ( $F(1,163)= 4.62$ ;  $p<.01$ ). Planned contrast showed that children who sign at home performed better in mathematics in comparison to children who speak another language ( $t(2)=1.30$ ;  $p<.05$ ). Children who speak English as their first language did not show any significant difference with children who use another language at home ( $t(2)= .25$ ;  $p=.22$ ). These findings support partially the hypothesis that children speaking English or sign are at advantage in mathematics in comparison to deaf children speaking another language. Due to the small number of cases of children who sign, it was not possible to investigate this issue further and future research should verify these results.

**15. Correlation between highest level of maternal education and deaf children’s mathematical achievement.**

Table C2.17. Correlation between highest level of maternal education and deaf children’s mathematical achievement after controlling for age, years in education and type of educational provision.

	PIPS maths test
Highest level of maternal education	-.02 (p=.93)

Highest level of maternal education is not a significant predictor of deaf children’s mathematical achievement.

**16. Assumptions of the regression with age in the first step and years in education in the second step, type of educational provision in the third step and degree of hearing loss in the fourth step; transformed scores of the PIPS maths test as the outcome measure.**

Figure C2.38. Histogram of the standardised residuals for PIPS maths test as outcome measure.

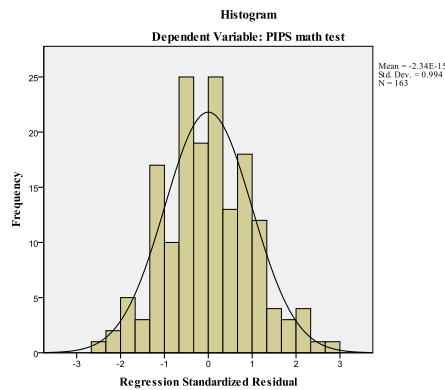


Figure C2.39. Normal Probability plot of Regression Standardized Residual for the PIPS maths test as outcome measure.

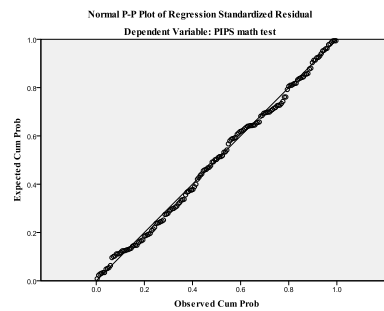


Figure C2.40. Scatterplot of the regression standardised predicted value compared with the regression standardized residuals for the PIPS maths test as outcome measure.

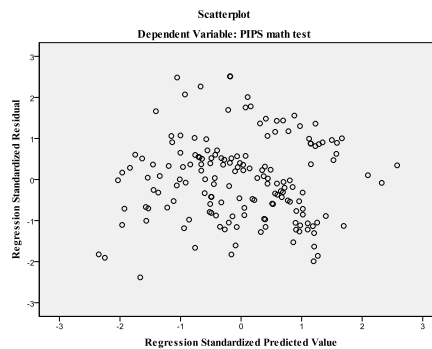


Table C2.18. The unstandardised and standardised regressions coefficients for age, years in education, type of educational provision and degree of hearing loss; PIPS maths test as outcome measure.

Factors	R <sup>2</sup>	Adjusted R <sup>2</sup> change	R <sup>2</sup> change	B	SEB	β
Age	.31**	.30**	.30**	.35**	.07**	.45**
Years in education	.33**	.32**	.02**	.16*	.07*	.19*
Type of educational provision	.40**	.39**	.07**	.70**	.19**	.25**
Degree of hearing loss	.41	.39	.00	-.04	.05	-.05

\*, p<.05. \*\*, p<.01.

Degree of hearing loss is not a significant predictor after controlling for age, years in education and type of educational provision.

### **17. Comparison between deaf and hearing children's in their mathematical performance after controlling for years in education.**

An overall comparison between deaf and hearing children's mathematical achievement after controlling for age and years in education showed that the covariates age and years in education are significantly related to children's mathematical achievement (age:  $F(1,954)=6.21, p<.01$ ; years in education:  $F(1,954)=129.20, p<.05$ ). A significant difference between the deaf children's performance in mathematics and that of hearing children was found: hearing children achieved higher scores than deaf children in the PIPS maths test ( $F(1,954)=408.89, p<.01$ ). The overall effect size was -1.5 SD.

Table C2.19. Adjusted means, standard errors, F, p values and effect sizes of the PIPS mathematics test for deaf and hearing by age, after controlling for years in education.

Age	Group	N	Adjusted mean	Standard error	F	p
6 years old	Deaf	30	5.51	0.10	32.26	<.001
	Hearing	48	4.54	0.13		
7 years old	Deaf	27	4.88	0.20	59.33	<.001
	Hearing	176	3.25	0.08		
8 years old	Deaf	43	4.65	0.15	148.88	<.001
	Hearing	215	2.63	0.06		
9 years old	Deaf	26	4.17	0.20	75.43	<.001
	Hearing	140	2.31	0.08		
10 years old	Deaf	21	4.10	0.23	82.17	<.001
	Hearing	169	1.86	0.07		
11 years old	Deaf	16	3.62	0.36	14.06	<.001
	Hearing	42	1.83	0.18		

The covariate, years in education, was significantly related with children's mathematical achievement when children were 6 ( $F(1,78)=27.88, p<.01$ ), 8 ( $F(1,258)=8.62, p<.01$ ) and 9 years old ( $F(1,166)=17.19, p<.01$ ).

Table C2.20. Effect sizes calculated on the transformed and untransformed scores of the PIPS maths test.

Age	Un-transformed effect size	Transformed effect size
6 years	-1.71	-1.21
7 years	-1.91	-1.63
8 years	-2.41	-2.10
9 years	-2.30	-1.86
10 years	-3.00	-2.33
11 years	-1.67	-1.79

**18. A full factorial analysis of variance between the mathematical performance of deaf and hearing children with age as a between factors.**

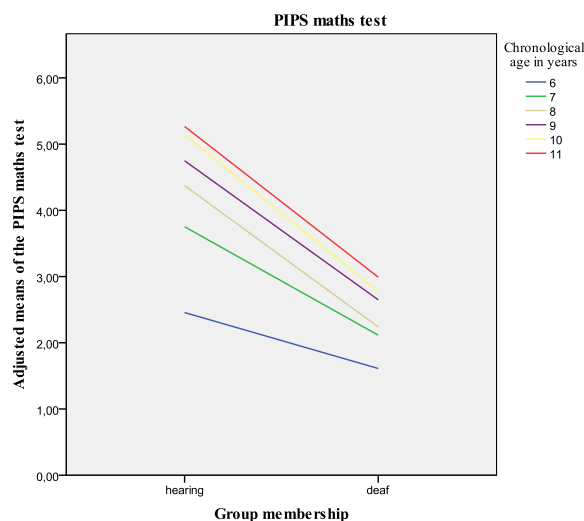
Table C2. 21. Adjusted means and standard errors of the PIPS maths test by chronological age.

Age	Group membership	Adjusted means	Standard errors
6 years	Deaf	5.43	.57
	Hearing	4.54	.98
7 years	Deaf	4.88	1.11
	Hearing	3.24	1.00
8 years	Deaf	4.76	.88
	Hearing	2.62	.97
9 years	Deaf	4.35	1.10
	Hearing	2.25	1.00
10 years	Deaf	4.22	1.07
	Hearing	1.85	.95
11 years	Deaf	4.01	1.28
	Hearing	1.73	.92

A significant effect of group membership ( $F_{(1,941)} = 423.61$ ;  $p < .01$ ) and of age ( $F_{(1,941)} = 41.15$ ;  $p < .01$ ) on children's mathematical achievement was observed. There was a significant interaction between group membership and children's age ( $F_{(1,941)} = 5.53$ ,  $p < .01$ ).

A graph was constructed in order to obtain a clear interpretation of the interaction effect between chronological age and group membership (see Figure C2.41). This reports the adjusted means of the PIPS maths test by chronological age. The adjusted means were obtained subtracting the transformed scores from a fixed higher value. In this way, the scores are inverted again and they are easier to understand. Deaf children in each year of age performed worse than their hearing peers. When deaf children were 8 years old, they performed as well as their hearing peers at 6 years of age. This means that older the children are, wider the gap between deaf and hearing children in their mathematical skills is.

Figure C2.41. Adjusted means of the PIPS maths test by chronological age.



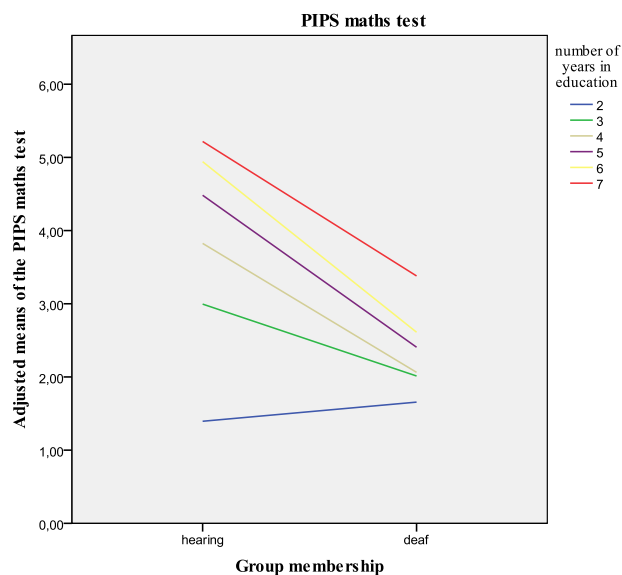
**19. A full factorial analysis of variance between the mathematical performance of deaf and hearing children with years in education as between factors.**

Table C2. 22. Adjusted means and standard errors of the PIPS maths test by numbers of years in education.

Number of years in education	Group membership	Adjusted means	Standard errors
2 years	Deaf	5.34	.48
	Hearing	5.60	.29
3 years	Deaf	4.98	1.05
	Hearing	4.00	.84
4 years	Deaf	4.93	.83
	Hearing	3.17	1.06
5 years	Deaf	4.59	.99
	Hearing	2.51	.84
6 years	Deaf	4.38	1.17
	Hearing	2.06	1.04
7 years	Deaf	3.62	1.25
	Hearing	1.78	.88

A significant effect of group membership ( $F_{(1,950)}= 214.03$ ;  $p < .01$ ) and of age ( $F_{(1,950)}= 48.67$ ;  $p < .01$ ) on children's mathematical achievement was observed. There was a significant interaction between group membership and children's age ( $F_{(1,950)}= 10.28$ ,  $p < .01$ ). This means that age is a moderator of deaf children's mathematical achievement. Figure 3.12 reports the adjusted means of the PIPS maths test for deaf and hearing children by number of years spent in education. The adjusted means were obtained subtracting the transformed scores from a fixed higher value. In this way, the scores are inverted again and they are easier to understand. For each years spent in school, deaf children obtained lower scores than their hearing peers in mathematics. After 7 years spent in school, deaf children performed as well as hearing children attending school for 4 years. This shows how there is an increase in the extent of the delay that deaf children have in mathematics.

Figure C2.42. Adjusted means of the PIPS maths test by numbers of years in education.



**20. Analysis of covariance between deaf and hearing children attending mainstream school after controlling for age and years in education.**

Table C.23. Adjusted means, standard errors, F and p values and effect size for deaf and hearing children attending mainstream schools.

	<b>N</b>	<b>Adjusted means</b>	<b>Standard errors</b>	<b>F</b>	<b>p</b>	<b>Effect size</b>
Deaf	42	4.41	.13	76.27	.00	-1.30
Hearing	791	2.60	.03			

The covariates age and years in education were both significantly related to children's mathematical achievement. (age:  $F(1,832)=2.62$ ,  $p<.05$ ; years in education:  $F(1,832)=140.08$ ,  $p<.01$ ).

**21. Analysis of covariance between deaf attending unit for hearing impaired and hearing children attending mainstream school after controlling for age and years in education.**

Table C.24. Adjusted means, standard errors, F and p values and effect size for deaf attending unit for hearing impaired and hearing children attending mainstream schools.

	<b>N</b>	<b>Adjusted means</b>	<b>Standard errors</b>	<b>F</b>	<b>p</b>	<b>Effect size</b>
Deaf	65	4.50	.12	212.11	.00	-2.02
Hearing	791	2.64	.03			

The covariates age and years in education were both significantly related to children's mathematical achievement. (age:  $F(1,856)=2.41$ ,  $p<.05$ ; years in education:  $F(1,856)=131.19$ ,  $p<.01$ ).

**22. Analysis of covariance between deaf attending special schools for the deaf and hearing children attending mainstream school after controlling for age and years in education.**

Table C.25. Adjusted means, standard errors, F and p values and effect size for deaf attending special schools for the deaf and hearing children attending mainstream schools.

	<b>N</b>	<b>Adjusted means</b>	<b>Standard errors</b>	<b>F</b>	<b>p</b>	<b>Effect size</b>
Deaf		4.48	.13	177.64	.00	-1.98
Hearing	791	2.61	.03			

The covariates age and years in education were both significantly related to children's mathematical achievement. (age:  $F(1,847) = 2.73, p < .05$ ; years in education:  $F(1,847) = 138.73, p < .01$ ).

# Appendix D

## Results from the longitudinal study

Figure D1. Histogram of the standardized residuals for PIPS maths test at Time 2 as outcome measure.

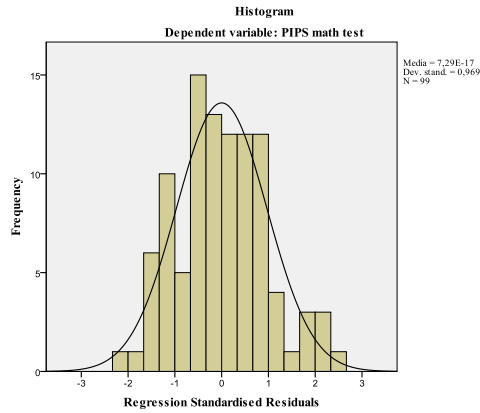


Figure D2. Normal Probability plot of Regression Standardized Residual for the PIPS maths test at time 2 as outcome measure.

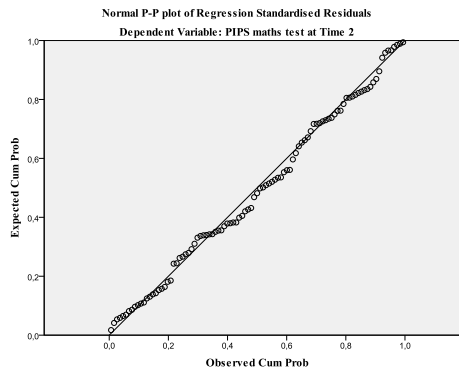


Figure D3. Scatterplot of the regression standardized predicted value compared with the regression standardized residuals for the PIPS maths test as outcome measure.

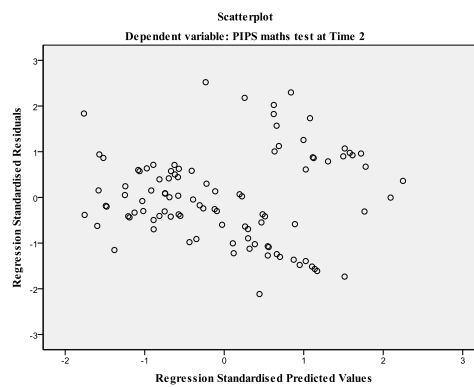


Table D1. Un-standardised and stanadrised coefficients for the regression analysis with PIPS maths test at Time 2 as outcome variable; working memory as the last step.

<b>Steps</b>	<b>B</b>	<b>SE B</b>	<b>β</b>
<b>Step 1</b>			
Age	3.42	.86	.37***
<b>Step 2</b>			
Age	1.90	.85	.21**
Non-verbal intelligence	.84	.18	.43
<b>Step 3</b>			
Age	2.12	.82	.23**
Non-verbal intelligence	.84	.17	.42**
Degree of hearing loss	-1.16	.45	-.22**
<b>Step 4</b>			
Age	2.10	.82	.23**
Non-verbal intelligence	.80	.18	.41***
Degree of hearing loss	-.82	.49	-.15
Type of educational reasoning	2.77	1.77	.14
<b>Step 5</b>			
Age	.26	.64	.03
Non-verbal intelligence	.00	.16	.00
Degree of hearing loss	-.11	.37	-.12*
Type of educational provision	2.40	1.31	.12
Logical-mathematical reasoning	1.02	.11	.76***
<b>Step 6</b>			
Age	.06	.65	.00
Degree of hearing loss	-.00	.16	-.00
Non-verbal intelligence	-.14	.37	-.03
Type of educational provision	2.34	1.30	.12
Logical-mathematical reasoning	.97	.12	.72***
Counting	2.12	1.43	.11*

\*, p<.05; \*\*, p<.01; \*\*\*, p<.001

Table D2. Un-standardised and standardised coefficients for the regression analysis with PIPS maths test at Time 2 as outcome variable; counting as the last step.

<b>Steps</b>	<b>B</b>	<b>SE B</b>	<b>β</b>
<b>Step 1</b>			
Age	3.42	.86	.37**
<b>Step 2</b>			
Age	1.90	.84	.21**
Non-verbal intelligence	.84	.18	.43***
<b>Step 3</b>			
Age	2.12	.82	.23**
Non-verbal intelligence	.84	.18	.42**
Degree of hearing loss	-1.16	.45	-.22**
<b>Step 4</b>			
Age	2.10	.82	.23**
Non-verbal intelligence	.80	.18	.41***
Degree of hearing loss	-.82	.49	-.15*
Type of educational provision	2.77	1.77	.14
<b>Step 5</b>			
Age	.71	.72	.07
Non-verbal intelligence	.23	.17	.11
Degree of hearing loss	-.92	.41	-.17
Type of educational provision	1.91	1.48	.09
Working memory	2.98	.46	.59**
<b>Step 6</b>			
Age	-.15	.60	-.02
Non-verbal intelligence	-.16	.15	-.08
Degree of hearing loss	-.32	.35	-.06
Type of educational provision	1.98	1.22	.10
Working memory	1.71	.42	.34***
Logical-mathematical reasoning	.80	.11	.60***

\*. p<.05; \*\*. p<.01; \*\*\*. p<.001