

Higher-Order Mentalising and Executive Functioning

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- We test relationships between higher-order mentalising and other cognitive skills.
- We identify and replicate a correlation with emotion recognition.
- We find no relationship with self-reported empathy.
- Of inhibition tests only temporal discounting relates to higher-order mentalising.

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Abstract

Higher-order mentalising is the ability to represent the beliefs and desires of other people at multiple, iterated levels – a capacity that sets humans apart from other species. However, there has not yet been a systematic attempt to determine what cognitive processes underlie this ability. Here we present three correlational studies assessing the extent to which performance on higher-order mentalising tasks relates to emotion recognition, self-reported empathy and self-inhibition. In Study 1a and 1b, examining emotion recognition and empathy, a relationship was identified between individual differences in the ability to mentalise and an emotion recognition task (the Reading the Mind in the Eyes task), but no correlation was found with the Empathy Quotient, a self-report scale of empathy. Study 2 investigated whether a relationship exists between individual mentalising abilities and four different forms of self-inhibition: motor inhibition, executive inhibition, automatic imitation and temporal discounting. Results demonstrate that only temporal discounting performance relates to mentalising ability; suggesting that cognitive skills relevant to representation of the minds of others’ are not influenced by the ability to perform more basic inhibition. Higher-order mentalising appears to rely on the cognitive architecture that serves both low-level social cognition (emotion recognition), and complex forms of inhibition.

Keywords: mentalising; empathy; social cognition; social networks; executive functioning; inhibition.

Abbreviations:

RMET: Reading the Mind in the Eyes task

EQ: Empathising Quotient

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1. Introduction

27 The ability to understand the recursively embedded mindstates of other people (variously
28 known as theory of mind, mentalising or mind-reading) is an important product of human
29 evolutionary history that has profound implications for the way we interact with our world
30 (e.g. Tomasello, Carpenter, Call, Behne, & Moll, 2005). Being able to interpret the mental
31 states of others is likely to have dramatically improved the human capacity to engage with
32 complex social networks, thus allowing the development of larger social groups, facilitating
33 cultural knowledge exchange, and contributing dramatically towards our success as a species
34 (e.g. Dunbar, 2003; Frith & Frith, 2010). During human evolutionary history, mentalising
35 likely developed alongside other forms of social functioning and more general executive
36 abilities (Schulz, 2009). There has been a long running debate as to whether theory of mind
37 is a distinct (modular) cognitive capacity in its own right (a domain specific phenomenon) or
38 essentially just an emergent property of underlying aspects of executive function such as
39 memory, causal reasoning, and inhibition (a domain general phenomenon) (Barrett &
40 Dunbar, 2003; Carlson, Moses, & Breton, 2002; Carlson, Moses, & Hix, 1998; Davis & Pratt,
41 1995; Leslie, Friedman, & German, 2004; Leslie & Polizzi, 1998).

42 While there is compelling evidence for some role of executive functioning in
43 mentalising, the evidence remains somewhat ambiguous and subject to dispute. Formal
44 theory of mind (the ability to believe that someone else believes something) is the first stage
45 in a recursive series of belief states known as the levels (or orders) of intentionality whose
46 limit, in normal human adults, appears to lie at around fifth order (i.e. A believes that B
47 believes that C believes that D believes that E believes something) (Dennett, 1983;
48 Kinderman, Dunbar, & Bentall, 1998; Stiller & Dunbar, 2007). These higher order
49 competences appear to have significant implications for adult sociality: individual differences

50 in mentalising are correlated with the size of adult social networks (Powell, Lewis, Roberts,
51 García-Fiñana, & Dunbar, 2012; Stiller & Dunbar, 2007), as well as the social skills of older
52 children (Liddle & Nettle, 2006) and adults (Corcoran, Mercer, & Frith, 1995; Kerr, Dunbar,
53 & Bentall, 2003). However, the relationship between executive functioning and mentalising
54 has only been studied in 3-6 year old children with second order intentionality (e.g. Carlson,
55 Moses, & Claxton, 2004), and it is unclear whether this relationship is still relevant to adults,
56 who are capable of higher levels of intentionality.

57 Whether or not executive function competences are involved in the development of
58 theory of mind in young children, there remain two separate possibilities for the subsequent
59 development of higher order competences: (1) these might be scaffolded by formal theory of
60 mind (and hence represent some kind of modularised recursion) or (2) the higher orders may
61 explicitly depend on individual differences in executive function skills to maintain their
62 multi-level recursive structure. Higher order mentalising improves throughout development
63 to the end of adolescence (Henzi et al., 2007; Keulers, Evers, Stiers, & Jolles, 2010; Liddle &
64 Nettle, 2006), suggesting that formal theory of mind is a first stage in the development of this
65 process. However, the fact that there is significant individual variation in mentalising
66 competences in adults, with the upper limit varying across fourth to sixth order intentionality
67 (Powell, Lewis, Dunbar, García-Fiñana, & Roberts, 2010; Stiller & Dunbar, 2007), tends to
68 favour the second explanation – and would fit better with the evidence that theory of mind
69 itself is dependent on a child's executive cognition skills. However, neither of these
70 possibilities has been tested as yet and therefore neither can be dismissed outright.

71 In addition to the possible role of executive function in the development of higher
72 order mentalising skills, one could envisage potential roles for other aspects of 'hot'
73 cognition such as empathy or emotion recognition. In so far as empathising and emotion
74 recognition require one to put oneself in another's place and/or be able to recognise their

75 internal emotional state, both facilitate thinking about mindstates. Emotion state recognition,
76 at least, has a long developmental trajectory, and may not become automated until early
77 adulthood (Deeley et al., 2008). The current paper explores relationships between
78 mentalising, emotion state recognition and a key component of executive function
79 (inhibition). Working memory, a conventional executive function skill, has previously been
80 shown to be correlated with mentalising skills (Stiller & Dunbar, 2007), and here it is treated
81 simply as a confound.

82

83 **1.1 Higher-order Mentalising**

84 Premack & Woodruff (1978) originally described ‘theory of mind’ in chimpanzees as the
85 ability to impute mental states to oneself and others, in order to make predictions about future
86 behaviour. This ability was subsequently explored as a competence that can be applied
87 recursively, involving the representation of several ‘levels’ of mindstates iterated within each
88 other (e.g. ‘Jane *believes* that John *thinks* that Sarah *wants* to...’). Basic false-belief tasks test
89 second-order mentalising (or theory of mind, as conventionally defined), assessing whether it
90 is possible for one person to recognise that someone else can hold beliefs that differ from
91 their own. Non-human primates typically fail on these tasks (Call & Tomasello, 1999, 2008;
92 Krachun, Call, & Tomasello, 2010; but see O’Connell & Dunbar, 2003; Cartmill & Byrne;
93 2007), and human infants appear to also fail before a certain age (e.g. Apperly & Butterfill,
94 2009, although there is some controversy regarding the age at which this might occur: e.g.
95 Apperly, 2012; Heyes, 2014), suggesting that the step from first- to second-order mentalising
96 is important. Normally developed adults, however, can deal with a much larger number of
97 iterated mindstates and in many everyday cases it is *essential* to understand complexity far
98 beyond the false beliefs of one other individual. For example, Yoshida et al. (2010) claim that
99 to complete even a basic cooperative task subjects have to *believe* that the other *believes* that

they *intend* to cooperate (i.e. three orders). Linguistic communication arguably requires interlocutors to go one level beyond this, to fourth order, or even to fifth order in the case of more advanced exchanges (especially irony and sarcasm: see Papp, 2006; Sperber, 1994). Similar arguments can be made for activities such as being part of a religious community (Dunbar, 2003), exhibiting moral reasoning (Shultz & Dunbar, 2014), proactive thinking (Bateman & Crant, 1993; Kirby, Kirby, & Lewis, 2002), and appreciating and producing literature (Carney, Wlodarski, & Dunbar, 2014; Dunbar, 2005; Zunshine, 2006).

The crucial importance of the developmental and evolutionary step from first- to second-order mentalising has resulted in a tendency to test adult ability solely at these levels, without explicitly exploring individual differences in performance at higher levels (Ahmed & Stephen Miller, 2011; Bull, Phillips, & Conway, 2008; Gregory et al., 2002; Lough, Gregory, & Hodges, 2001; Phillips et al., 2011; Santiesteban et al., 2012). These types of assessment are likely to be subject to a ceiling effect and, additionally, fail to capture the considerable variation in individual mentalising skill (Kinderman et al., 1998; Powell et al., 2010; Stiller & Dunbar, 2007), thus limiting comparison with other cognitive abilities. However, a test that *is* specifically designed to assess variability in performance during higher-order mentalising was introduced by Kinderman, Dunbar, & Bentall (1998). In this test, participants read a story containing several levels of iterated mental states, and answer comprehension questions of varying complexity regarding these iterated mental states. This approach has demonstrated individual variability in performance, which has been shown to relate to social attribution (Kinderman et al., 1998), estimates of social network size (Lewis, Rezaie, Brown, Roberts, & Dunbar, 2011; Powell et al., 2014, 2012; Stiller & Dunbar, 2007), and volume of the orbital prefrontal cortex (Lewis et al., 2011; Powell et al., 2014, 2010), with women performing better than men on average (Powell et al., 2010; Stiller & Dunbar, 2007). Tests adapted for use with children have also demonstrated that performance relates to aspects of general social

competence, as rated by teachers (Liddle & Nettle, 2006). These findings suggest that the test taps into cognitive abilities which are relevant to how individuals interact in their everyday social and cultural life.

Given that mentalising ability above level two is unique to humans, reaches adult-level competence relatively late in development (Dunbar, 2013; Henzi et al., 2007), and is associated with crucial parts of social cognition and sophisticated cultural behaviours (including language, religion, and literature), it is important to look at higher-order mentalising as an ability distinct from simple false belief attribution. In what follows, we investigate three skills that might support higher-order mentalising: empathy, emotion recognition, and inhibition.

1.2 Mentalising, Emotion Recognition and Empathy

Intuitively, we might expect a relationship to exist between the ability to represent the mental states of other people and the ability to read their emotions and experience empathy.

However, this depends on what theory of mind is, and which factors play a role in its development during childhood. ‘Simulation theory’ (e.g. Gallese & Goldman, 1998) argues that we mentally enact the mental states of other people in order to understand their thought processes, while ‘theory theory’ (e.g. Gopnik & Wellman, 1992, 2012) claims that we go through a more cognitive process of thinking through what someone might do, and why, in order to determine their mental state. While Simulation theory predicts that empathy is an important part of the ability to mentalise, this is not necessarily the case for theory theory (it would be possible to accurately theorise about the mindstate of another person without experiencing any empathy with them, or even necessarily detecting their emotions).

Similarly, psychologists studying empathy have identified a number of separate components (Davis, 1983), which can be more broadly grouped into ‘affective’ and ‘cognitive’ empathy,

which are distinguishable on the basis of self-report and represent the tendency to feel the emotions of others compared with the ability to theorise about their behaviour (Reniers, Corcoran, Drake, Shryane, & Völlm, 2011). These two sets of theories both highlight a fundamental difference between immediate ‘hot’ cognition, and slower, more theoretical cognition. The two methods of understanding others are not mutually exclusive; it is likely that we use both ‘hot’ cognition (emotion recognition and affective empathy) and theorising during any mentalising task (Apperly & Butterfill, 2009), with variability along a continuum dependent on development (Frith, 2012) and our familiarity with an individual and the situation involved (c.f. Beckes, Coan, & Hasselmo, 2013; Wilkinson & Ball, 2012).

If empathising skills play a role in mentalising in adults we would expect there to be a robust relationship between performance on tasks that index these two abilities. While there have been some previous investigations into the relationship between various forms of empathising and mentalising (e.g. Gregory et al., 2002; Santiesteban et al., 2012), these did not use tests that assess higher-order mentalising ability. One study that did use tests to index higher-order mentalising (adapted from those described above) did not find a correlation between performance on these tasks and the Reading the Mind in the Eyes task (Rice & Redcay, 2014). However, the adaptations made to the mentalising test used in this study limited it to assessing only second- to fourth-order mentalising—levels at which nearly all normally developed individuals are competent (Kinderman et al., 1998). Another recent experiment has shown a relationship between mentalising ability, emotion recognition, and a form of empathising, but this did not involve questions with mentalising beyond level three (Dodell-Feder, Lincoln, Coulson, & Hooker, 2013). With ceiling effects limiting the variability in performance, the requirements to accurately assess a relationship between mentalising and other measures are most likely not met.

1.3 Mentalising and Inhibition

Executive functioning is an umbrella term relating to our ability to monitor and plan actions in order to successfully carry out goal-related tasks. Tests of executive function tend to fall into three major categories: inhibition, task shifting and working memory (e.g. Hughes, 1998; Maehara & Saito, 2011; Mahy et al., 2014). The ability to plan and control behaviour involved in executive functioning also requires a degree of metacognition (i.e. generating thoughts about thoughts). As such, we might expect executive functioning to have some relationship with mentalising; the ability to form thoughts about thoughts need not be affected by whether the target thoughts belong to oneself or another (e.g. Frith, 2012). Nevertheless, a previous investigation of several aspects of executive functioning (focusing on memory, attention and planning) and higher-order mentalising abilities in adolescents suggested there were no significant relationships between the two (Stylianou, 2007). This study, however, did not specifically focus on inhibitory control, which is worthy of further investigation as detailed below.

Evidence suggests that the ability to inhibit one's own behaviour relates to social skills more generally, both developmentally (Carlson et al., 2002, 2004; Hughes, 1998) and throughout the lifespan (Casey et al., 2011; Mischel, Shoda, & Peake, 1988). In addition, inhibition and mentalising seem to involve the activity of similar neural structures. It has been demonstrated that the medial region of BA10 is particularly relevant to mentalising ability (e.g. Contreras & Schirmer, 2013; Van Overwalle & Baetens, 2009) as well as the ability to perform inhibition tasks (Garavan, Ross, & Stein, 1999) and suppress one's own thoughts in favour of an alternative (e.g. future) perspective (Burgess, Scott, & Frith, 2003). It is possible that inhibition allows us to suppress our own thoughts in order to theorise about those of others (c.f. Frith, 2012), or alternatively a relationship may exist because in order to function within complex social networks humans must forgo their own immediate

gratification in order to ensure that group-level goals are achieved (e.g. Mischel, Shoda, & Rodriguez, 1989; Mischel, 1961). In other primate species, it has been demonstrated that good performance in inhibition tasks is associated with species that are phylogenetically closer to humans (Rosati, Stevens, Hare, & Hauser, 2007), have larger key brain regions (Shultz & Dunbar, 2010), and those with more cognitively demanding and complex fission-fusion social dynamics (Amici, Aureli, & Call, 2008).

As with empathising, there have been attempts to assess the relationship between mentalising and inhibition that have focussed on low-level mentalising abilities (Bull et al., 2008), or on only some forms of inhibition (e.g. automatic imitation: Santiesteban et al., 2012). However, there is an emerging literature which suggests that inhibition comprises a further set of separable abilities, such as more immediate motor control compared with more complex evaluation of the long term consequences of accepting immediate reward (Caswell, Bond, Duka, & Morgan, 2015; Koch, Gade, Schuch, & Philipp, 2010). On the basis of this literature, the current study includes an updated battery of inhibition tests to assess whether there is a relationship with the ability to mentalise at higher levels that allows us to distinguish between four different aspects of inhibition (motor inhibition, cognitive inhibition, automatic imitation and temporal discounting).

1.4 The current study

The studies reported here test whether normally functioning adults demonstrate a relationship between their performance on higher-order mentalising tasks and their ability to exhibit empathy, emotion recognition and inhibition. Since working memory capacity is known to correlate with mentalising competences, the dependent variable here is the residual of mentalising competence score regressed on working memory score so as to remove the effect of working memory. The independent variables are the Reading the Mind in the Eyes task

(RMET), a validated test which involves directly identifying the emotions expressed in photos of eyes (Baron-Cohen & Wheelwright, 2001), and an eight-item version of the Empathy Quotient (EQ), a validated scale of the tendency to empathise (Wakabayashi et al., 2006). These two elements are not necessarily equivalent to self-reported affective and cognitive empathy, but represent the ability to directly read emotions compared with the tendency to self-report empathic abilities (a more cognitive process). In order to assess inhibition, different tests index the four different abilities previously highlighted (motor inhibition, cognitive inhibition, automatic imitation and temporal discounting.) Motor inhibition requires people to monitor performance and be able to control their own movement after an action plan has been prepared, and can be tested using a classic Go/No-Go task (e.g. Rubia et al., 2001). Stroop tasks (Stroop, 1935) similarly require performance monitoring but are more cognitively demanding as they involve higher-order inhibition of semantic content (cognitive inhibition), rather than simple motor inhibition. Automatic imitation tasks are also related directly to motor skills, but involve observing the action of another person and inhibiting the tendency to replicate those movements in favour of an alternative action (Brass, Bekkering, Wohlschläger, & Prinz, 2000). Finally, temporal discounting tasks measure the ability to refuse immediate small rewards in favour of greater long-term rewards (Mischel, 1961). The latter might be seen as being especially important in the context of sociality where maintaining group cohesion may require individuals to forgo some of their immediate selfish goals in order to allow other group members a fair share of the resources provided by group action (Dunbar, 2012). Since failure to do this will typically result in group fission, temporal discounting forms of inhibition may be especially important for species as intensely social as humans.

We predict that emotion recognition and self-reported empathy should not correlate directly with higher-order mentalising if these abilities relate to an immediate and direct

connection with the mental state of another person, whereas higher-order mentalising involves higher level processing and more cognitive processing about others' behaviour. If they do show a positive correlation with mentalising competences, this suggests that mentalising skills depend on quite low level cue recognition abilities rather than modelling others' mental states. We predict that there will be a positive relationship between higher-order mentalising abilities and inhibition, but that this might be restricted to only those inhibition tasks requiring complex forms of inhibition similar to those involved in inhibiting one's own mindstate. A significant negative relationship between any of the tests of inhibition and higher-order mentalising would be quite a clear sign that the ability to inhibit thoughts and actions does not improve mentalising, so here our hypotheses are explicitly unidirectional.

2. Study 1

Study 1 investigated the relationship between empathising and mentalising ability using two different versions of the mentalising task (both adapted from Stiller & Dunbar, 2007). The second version, tested on a small sample, was based on an improved version of the mentalising task designed both as a shorter version (less demanding on subjects) and to balance true and false questions: in order to use this improved version in study 2, study 1b was designed to ensure that the two versions of the mentalising task yielded similar results. As such, it also provides an independent test of the main results of study 1a. This mentalising task requires participants to read several short stories, each approximately 200 words long, that describe the interactions and behaviours of various fictional characters in an everyday scenario (such as going to the Post Office; full stories included in Supplementary Materials). Participants are instructed to read each story carefully, after which time they are presented with several statements about each story and asked to answer whether they are true or false.

These questions take two forms: general memory questions involving factual information at levels of complexity ranging from two to seven (e.g. level two: “*Sam bought a bus ticket*”; level three: “*Sam asked about finding a Post office so that he could send a birthday present*”, etc., where level one is always the subject’s own belief); and mentalising questions involving mindstates, varying between two and seven levels of embeddedness (e.g. level two “*Sam wanted to buy a stamp*”; level three “*Helen thought that Sam wanted to buy a birthday card for his grandmother*”, etc., with the subject’s own mind state being level one as before).

2.1 Methods

Study 1a was run on Amazon Mechanical Turk, and included 303 US-based participants who were paid US\$2.50 for their time (age $M = 37.1$, $SD = 11.9$, 141 males, 98% native English speakers, 2% non-native English speakers reporting ‘very good’ or ‘good’ English); Study 1b was run on the UK consumer panel provider *Maximiles* to independently verify the results of Study 1a and included 26 participants (age $M = 53$, $SD = 15$, 17 males) who were paid £3 for their time. In both studies participants were tested online and asked to perform the RMET, which involves identifying the emotions expressed in photos of eyes by choosing the most appropriate emotion from a list of four possible options (Baron-Cohen & Wheelwright, 2001), and to complete the EQ questionnaire, a self-report scale of the tendency to empathise (Wakabayashi et al., 2006). Participants were also asked to list the initials of all the individuals from whom they would “seek advice, support or help in times of severe emotional or financial distress”, which has been shown to evince the size of people’s most intimate social network layer (Dunbar & Spoors, 1995). Given that for most people this network layer is limited to approximately five people, subjects were only offered up to nine people to list for this question. Study 1a used an adapted version of three of the Stiller & Dunbar (2007) story tasks and questions, and this was further refined for Study 1b so as to balance the

number of true and false questions within stories in order reduce the amount of random noise in the data (see Supplementary Material). In Study 1b, a computer error meant that one of the negative empathy quotient questions was not saved for all participants, so scores do not include this question for Study 1b only.

Mentalising data were all analysed in the same manner: mentalising questions and memory questions were coded for whether they were answered correctly or incorrectly by scoring either a one or a zero respectively. Mentalising performance and memory performance in this task are known to be very well correlated (Stiller & Dunbar, 2007), so scores on the mentalising questions were regressed against scores on the memory questions, and the residuals were used as a measure of mentalising ability after accounting for potential effects of memory and other confounding factors (e.g. task concentration). This value will be referred to as ‘mentalising score’. The RMET was scored by adding the number of correct answers. Network size was the number of individuals listed, with participants who entered nine individuals excluded from analysis (given that there were only nine boxes to enter information into, creating an artificial ceiling effect).

For all studies, the design was approved by the University of Oxford Combined University Research Ethics Committee (CUREC). Since explicit directional hypotheses are being tested, all statistical tests are one-tailed.

2.2 Results

In Study 1a, Spearman’s correlations demonstrated a relationship between mentalising scores and the RMET ($\rho = .21, p < .001, n = 279$; Figure 1), but not between mentalising scores and EQ ($\rho = .027, p = .33, n = 282$). As has been demonstrated previously, there was also a relationship between mentalising score and intimate network size ($\rho = .15, p = .013, n = 228$; Figure 1). In order to check for gender effects, we tested models including mentalising scores

and gender as predictors. For the empathy quotient these demonstrated a significant effect of gender with females ($M = 43$, $SD = 7.5$) performing marginally better than males ($M = 40$, $SD = 7.3$; $b = 3.68$, $t(276) = 4.15$, $p < 0.001$), but no effect of mentalising scores ($p = .4$). Scores on the RMET were not predicted by gender ($p = 0.5$), but were predicted by mentalising score ($b = .54$, $t(273) = 4.9$, $p < 0.001$). Network size was predicted by gender, with females reporting marginally larger networks ($M = 4.0$, $SD = 1.7$) than males ($M = 3.5$, $SD = 1.7$; $b = 0.54$, $t(223) = 2.4$, $p = 0.02$), with mentalising score having no significant effect ($p = 0.3$).

Study 1b demonstrated similar results: mentalising scores were correlated with the RMET ($\rho = .42$, $p = .015$, $n = 26$) and with network size ($\rho = .37$, $p = .03$, $n = 26$) (Figure 2), but not with EQ ($\rho = .25$, $p = .1$, $n = 26$). In this sample, linear models including gender and mentalising scores did not demonstrate any significant effects of gender (all p -values > 0.2), while all other results remained unchanged (i.e. RMET and network size were predicted by mentalising score while EQ was not).

2.3 Discussion

Study 1a and 1b demonstrated converging results in terms of the relationship between empathising abilities and mentalising ability. A relationship did exist between mentalising and the ability to read emotions. However, EQ, a self-report measure of the tendency to empathise with other people, did not relate to performance on mentalising tasks. Across the two studies there is a substantial difference in the correlation coefficients: the coefficients are higher for every relationship in Study 1b which used a refined version of the mentalising task. These refinements included balancing the questions presented by having one true and one false question at each level of mentalising and memory (see Supplementary Material). The difference in effect size is thus more likely to reflect methodological changes rather than any inconsistencies in the results. As has been previously reported, there was a positive

correlation between mentalising ability and network size in both studies, and, as has been reported in all previous studies, some gender differences were found in the larger sample for the empathising quotient and network size.

3. Study 2

Study 2 was a lab-based study, and tested participants specifically on a number of inhibition tasks to determine how performance on these various measures related to their ability to mentalise. Mentalising was tested using the improved task from Study 1b, while inhibition was measured using four different tasks: a go/no-go task, Stroop task (Stroop, 1935), automatic inhibition task (Brass et al., 2000), and a temporal discounting task (Mischel, 1961).

3.1 Methods

Fifty-eight participants, who were either students or members of the general public, were recruited using an online recruitment database, SONA, or advertisements in the local press (mean age = 26.3, SD = 8.9; 22 male); they were paid £5 for 30 minutes of their time. Participants were tested on four independent tests of executive functioning, followed by a test of mentalising ability.

3.1.1 Go/No-go task. In this task, participants were presented with a series of letters in the centre of the computer screen. Letters were either a P or an R, with one P displayed for every 5 times an R was displayed. Participants had to respond to P's by pressing the right arrow key as quickly as possible, but had to ignore R's. This is a standard test of response inhibition (e.g. Donders, 1969), with the current implementation written into a test battery freely available with the experimental software PsychoPy2 v. 1.78 (Peirce, 2007, 2009). The

number of times the participant erroneously responded to an R was used as an inverse score of the ability to inhibit a motor response.

3.1.2 Stroop task. A classic Stroop task was used in which participants had to respond to one word presented on the screen at a time. Every time the word displayed was either 'red', 'green' or 'blue' and was written in red, green or blue text. Participants were told to respond only to the word that was displayed on the screen, pressing the left arrow key for red, the middle arrow key for green or the right arrow key for blue. Response times for incongruous trials (i.e. when the text did not match the colour) were subtracted from the congruous trials (i.e. when the colour of the word was the same as the described colour), and the result was used as a measure of cognitive inhibition (Stroop, 1935).

3.1.3 Automatic inhibition task. This task acts as a form of Stroop task in which congruity is presented as a visual finger movement stimulus (Brass et al., 2000). Participants were asked to respond by moving either their first finger or second finger in response to the moving image of a hand. These images involved similar movement of either a first or second finger, but also included a number, either 1 or 2. In the first part of the task, participants were asked to respond by pressing the key corresponding to either the first or second finger movement in the image. In the second part, they were asked to respond by moving their first finger if the number 1 was displayed, or their second finger if the number 2 was displayed. The response times to incongruent trials (i.e. when the finger movement was different from the movement indicated by the number) were subtracted from the response times to congruent trials, and the result was taken as an indicator of the tendency to automatically imitate the movements of another person.

3.1.4 Temporal discounting task. The temporal discounting task involved a commonly used protocol (Bickel, Odum, & Madden, 1999), in which participants were asked what they would rather receive in terms of monetary recompense at four different time-points

in the future: in one week, in one month, in six months or in one year. Participants were asked, 'Would you rather receive [amount x] now, or [amount y] in [time period]?', and responded by pressing the left arrow key for the first option or the right arrow key for the second option. Amount x started at ~ £300 (with some random variability of up to 5% around the value) and amount y started at ~ £1000 (with some random variability of up to 5% around the value) and amount x was varied using a staircase procedure, increasing if participants preferred amount y, and decreasing if participants preferred amount x to reach an equilibrium point (i.e. when the two amounts were similarly rated). This resulted in four amounts of money, corresponding to each of the four time-points. These values were then regressed against the values of the four time-points (calculated in years), and the coefficient for the regression line was taken as a measure of the degree of temporal discounting that the participant engaged in. A more negative regression line indicates that when the large reward is further in the future participants will accept smaller immediate rewards, suggesting a greater tendency to choose immediate gratification over longer term rewards (Mischel, 1961).

Once again, explicit hypotheses are being tested, so all statistical tests are directional (i.e. one-tailed).

3.2 Results

Mentalising ability was calculated as in Study 1, as the residual of total correct intentionality questions regressed against total correct factual memory questions. Five left-handed participants were excluded from analysis in the automatic imitation task because a mirrored left hand was displayed, and it is likely that left-handed participants would respond differently. In addition, two outlying data points (with results greater than 3 standard deviations below the mean) were excluded for the Stroop task. Results demonstrated no significant correlations between mentalising ability and performance on the Go/No-go task (ρ

= .056, $p = .34$, $n = 58$), the Stroop task ($\rho = .042$, $p = .38$, $n = 56$), or the automatic imitation task ($\rho = .036$, $p = .40$, $n = 53$). However, there was a weak significant relationship in the predicted direction between the slope of regression lines in the temporal discounting task and mentalising ability, shown in Figure 3 ($\rho = .22$, $p = .05$, $n = 58$).

3.3 Discussion

In Study 2, there were no significant correlations between mentalising ability and three of the four inhibition tasks. While the go/no-go test, Stroop task and automatic imitation were very clearly unrelated to mentalising, there was a relationship with temporal discounting. This suggests that temporal discounting shares some of the same cognitive underpinnings as the ability to mentalise. Temporal discounting is a test of the most complex form of inhibition, and indexes the ability to put off one's own immediate reward in favour of a longer term benefit. It is perhaps unsurprising that this is most related to the ability to mentalise, which might require inhibiting one's own beliefs or desires in favour of thinking about someone else's.

4. General Discussion

Individual variation in mentalising performance across two independent groups of participants was found to correlate with scores obtained on the RMET, but not to the EQ. This suggests that mentalising might have some constituent skills in common with some aspects of empathy, namely the ability to correctly read others' mental state cues, but not with other more generic cognitive aspects of social cognition of the kind indexed by the EQ questionnaire. The two sets of participants in these two studies had different nationality and age profiles, so the relationship demonstrates at least some degree of generalisability across participants taking part in English language online surveys. In relation to more general

inhibition skills, there was no relationship between tests of mentalising and most of the inhibition tasks suggesting that the ability does not relate more generally to forms of executive functioning. The positive correlation with temporal discounting might reflect some common basis for these two abilities, although this relationship was relatively weak and tests were one-tailed. It should be noted that by indexing mentalising by regressing scores of the factual memory questions against those on the intentionality question we have minimised the possibility of indexing general intelligence or its constituent parts (such as working memory). The memory questions and intentionality questions are very similar in content, varying primarily as to whether they are about the mindstates of characters or concern factual information presented in the narratives, so the mentalising scores calculated here should be very closely linked to social skills alone. This means that even if performance on other tasks such as the RMET relate to general intelligence (c.f. Baker, Peterson, Pulos, & Kirkland, 2014) this does not fully explain why scores on the RMET relate to residual mentalising scores.

The current results suggest there is a dissociation between how higher-order mentalising relates to RMET and the EQ. Although these two tests correlate with one another they potentially index different forms of empathic ability. The RMET could be described as a very direct measure of the ability to interpret the emotional mindstates of another person while the empathy quotient relates more to the socially desirable quality of caring about the feelings of other people. It is perhaps surprising that the more direct measure of the RMET relates to higher-order theorising about mental states (e.g. Kalbe et al., 2010), and further investigation is required to determine exactly why this is the case.

It is possible that having the capacity to easily interpret the emotional mindstate of another individual frees up additional cognitive resources during social situations to allow access to more complex mental states. During development, as mentalising skills become

more automatic (Blakemore, 2008), these extra cognitive resources might translate into better general performance on all social tasks. An alternative possibility would be that mentalising and empathy capacities can both be explained by a common propensity for greater social engagement, leading to a tendency to both learn how to read facial expressions better and to attend to cues of higher-order social cognition. In contrast, EQ did not demonstrate a relationship with mentalising, which supports previous evidence suggesting that self-reported empathy may be independent of objectively quantified mind-reading ability (Realo et al., 2003, although note this previous study did not assess high-order mentalising). Self-reported measures of empathy are problematic in that they are not objectively verified, and individuals may lack the metacognitive skills required for accurate self-assessment of their own empathy abilities, with some evidence suggesting that those who score themselves highly on sensitivity are actually particularly bad at this (e.g. Ames & Kammrath, 2004). EQ may, therefore be limited in its ability to assess empathy, whereas the RMET assesses individuals' actual ability to accurately interpret the mental states of other people, making it more likely to correlate with actual mentalising performance.

Here we did not specifically measure different forms of self-reported empathy that have previously been identified (Davis, 1983), but were interested in a broader comparison of emotion reading (with the RMET) and self-reported empathy (with the EQ). It is possible that further separation of elements of self-reported empathy might specifically reveal differences in how affective and cognitive empathy relate to low and high-order mentalising abilities. The tests of higher-order mentalising abilities as used here should also be more generally compared to other scales and measures of social skills in order to develop a better test battery of these abilities.

We replicated previous findings demonstrating that self-reported social network size is correlated with high-order mentalising competences (Lewis et al., 2011; Stiller & Dunbar,

2007), and confirm that such a relationship exists independently of short-term memory capacity. While superior higher-order mentalising ability does relate to social network size, the current study cannot determine causality (but see Powell et al., 2012). It is feasible that being able to perform higher-order mentalising means people can manage more friends, or that having more friends leads to an improvement in mentalising ability (e.g. Stolk, Hunnius, Bekkering, & Toni, 2013), or that both are driven by some external third factor.

Although the aim here was not to look at gender effects, some differences were identified between the sexes in terms of the relationship between measured variables in the large online sample. Although there was no relationship between mentalising scores and the empathy quotient, there was a gender effect, with women scoring higher than men on the test, as has previously been reported (Baron-Cohen & Wheelwright, 2004; Lawrence & Shaw, 2004). The relationship between performance on the RMET and mentalising ability was not affected by gender however, and further investigation could specifically test whether previously identified gender differences in this test (Baron-Cohen & Jolliffe, 1997) might be better explained by higher average mentalising abilities in women, or may in fact have been spurious when originally identified (c.f. Baron-Cohen & Wheelwright, 2001). Indeed, past research has found that gender differences are only prominent in self-report measures of empathy, suggesting the presence of demand characteristics rather than innate differences (Eisenberg & Lennon, 1983). In the large sample, gender acted as a better predictor of network size than mentalising ability but this was not the case in the smaller sample, suggesting again that this should be more specifically investigated in future to determine what is driving the relationship.

Except in the case of temporal discounting, there were no clear relationships between the tests of inhibition and higher-order mentalising ability. This is in agreement with previous results which have suggested that inhibition and social cognition are to some extent

independent in adults (Santesteban et al., 2012). In contrast, temporal discounting did correlate with mentalising competences, although this relationship was only a weak one. Temporal discounting might be an essential ability for the management of social interactions: if we are unable to delay our own immediate desire for personal gratification, then long term social interaction would be difficult (for example, when having to share food resources with others). The fact that other, lower-level, mainly perceptual forms of inhibition did not relate to mentalising ability in the current study suggests that being able to inhibit one's own behaviour in these very basic ways is not important in order to engage socially. This is particularly significant, given that we might have expected some components of executive functioning to be present in higher-order mentalising as tested here, although both the positive and null results should ideally be independently replicated. Of particular interest is the lack of a relationship with automatic imitation, which has previously been shown to relate to interoception (bio-physical self-perception) (Ainley, Brass, & Tsakiris, 2014), and which might thus be expected to relate to social behaviour.

4.1 Conclusions

The current results support the idea that low-level empathising and more complex aspects of executive functioning constitute part of the scaffolding for high-level mentalising abilities. To effectively represent the iterated mindstates of other people, we need the initial capacity to read the emotions of one other person, coupled with the ability to hold in mind alternative versions of the world (i.e. inhibit a notion of one model of the world in favour of a different one). Our results do not suggest, however, that all forms of inhibition are vital in higher-order mentalising, making it likely that this social skill is to some extent independent from other low level forms of inhibition. More detailed investigation might both confirm this fact and make it possible to determine the extent to which abilities such as delaying immediate

549 rewards are necessary precursors for higher-order mentalising. This finding opens the
550 possibility that mentalising skills might be improved through the honing of inhibitory
551 behaviour and emotion recognition, which might be useful in creating novel strategies to
552 enhancing the development of social behaviour more generally.

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838 Table 1. Descriptive statistics from all studies.

Study	Measure	<i>Mean</i>	<i>SD</i>	<i>N</i>
1a	Intentionality score	25.0	3.8	303
	Memory score	20.9	3.3	303
	Mentalising score	0	2.6	303
	RMET	26.9	4.8	279
	EQ	41.5	7.6	282
	Network size	3.7	1.7	228
1b	Intentionality score	17.8	3.1	26
	Memory score	19.2	1.8	26
	Mentalising score	0	2.9	26
	RMET	25.9	6.2	26
	EQ	33.8	6.1	26
	Network size	3.1	2.1	26
2	Intentionality score	26.1	2.8	58
	Memory score	29.3	2.5	58
	Mentalising score	0	2.2	58
	Go/No-go	1.2	1.2	58
	Stroop	-0.1	0.1	56
	Automatic imitation	-0.03	0.03	53
	Temporal discounting	-72.4	83.2	58

839

840

841 Figure 1. Correlation between mentalising score and Reading the Mind in the Eyes score (left
842 panel), and intimate network size (right panel) in Study 1a.

843 Figure 2. Correlation between mentalising score and Reading the Mind in the Eyes score (left
844 panel), and intimate network size (right panel) in Study 1b.

845 Figure 3. Relationship between temporal discounting and mentalising score ($p = 0.05$) in
846 Study 2.

Figure 1
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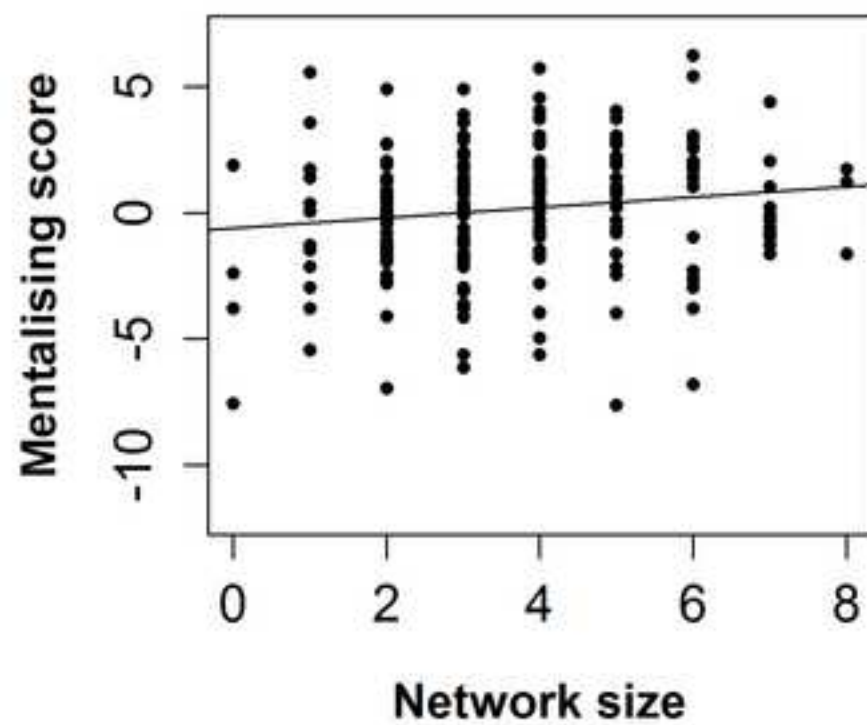
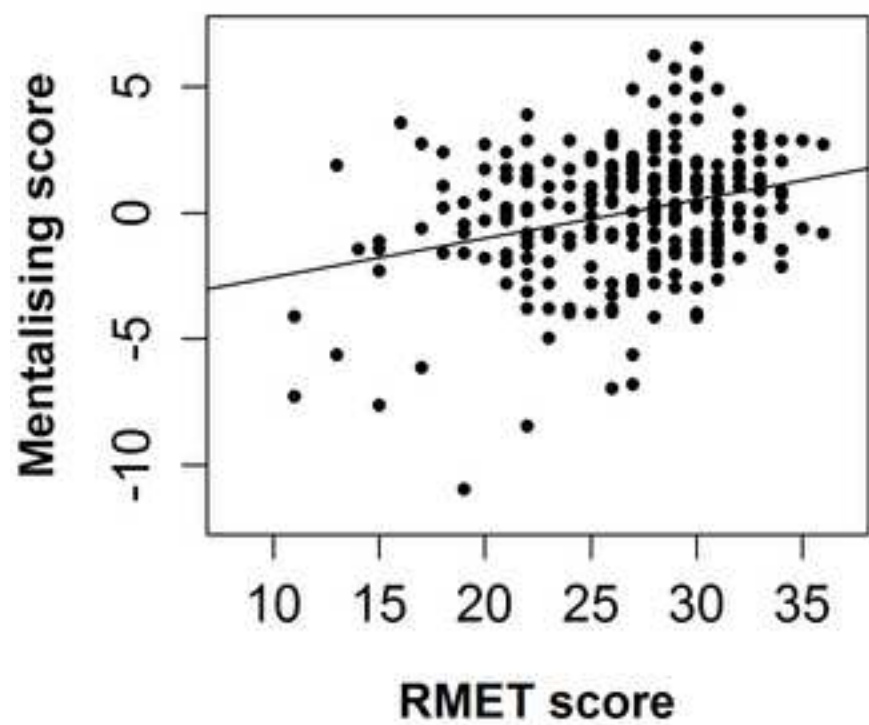


Figure 2
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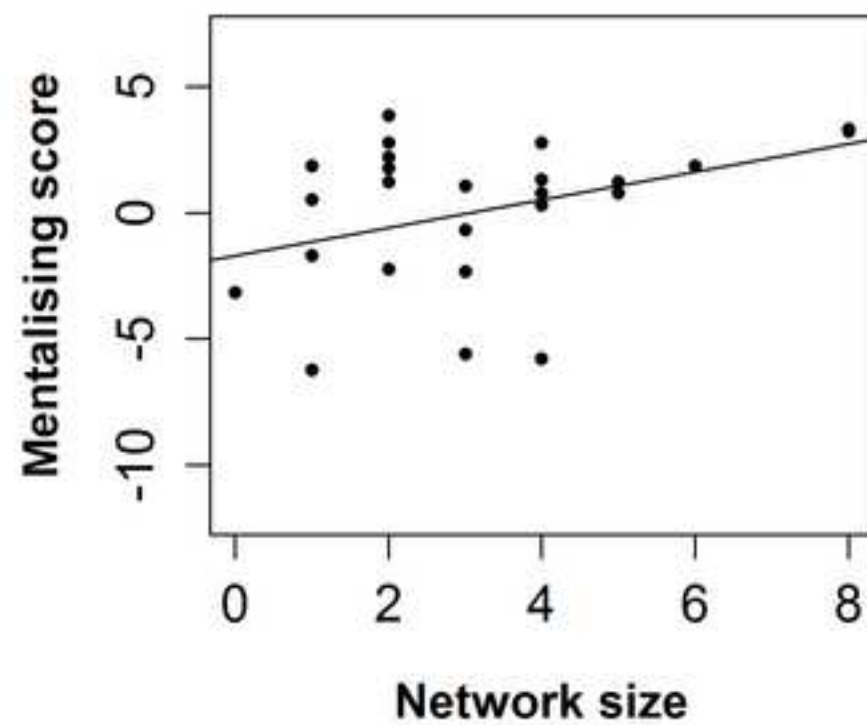
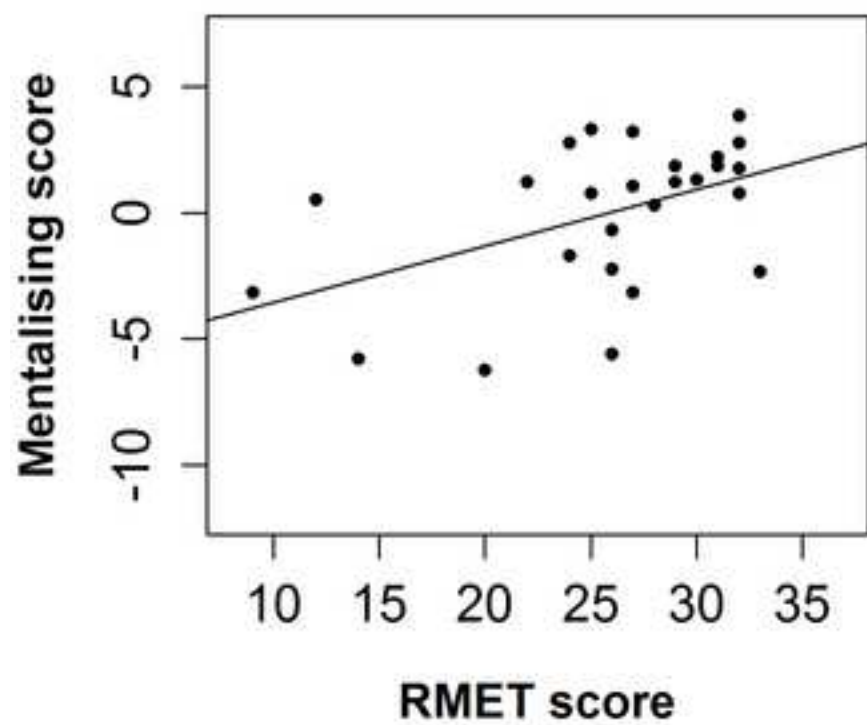
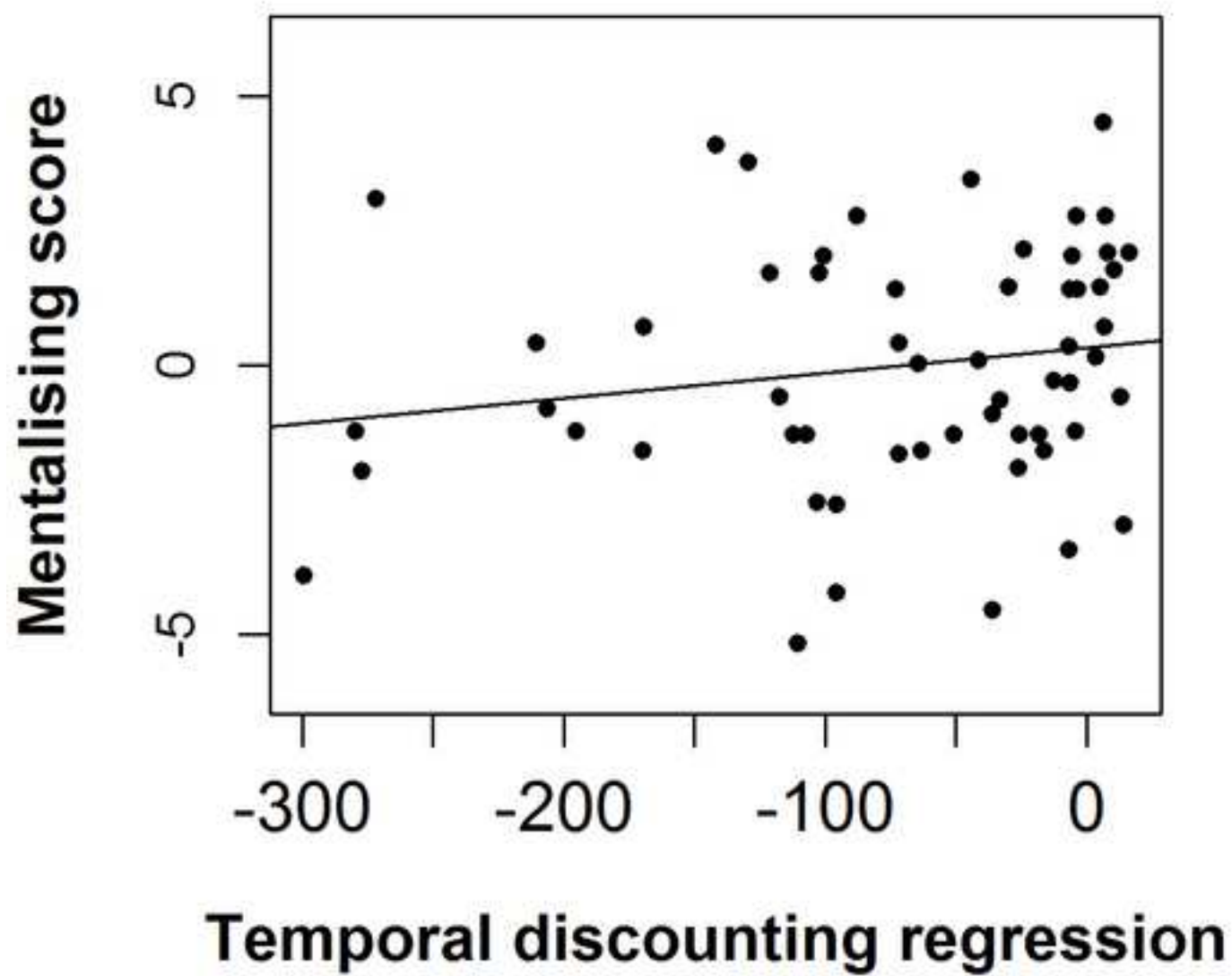


Figure 3
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Supplementary Material. Mentalising tests used in Study 1b and Study 2, with answers and levels

An Imposing Memory Task

An Imposing Memory Task

This test contains three very short stories. After each story, there are a number of questions about the story. For each story set, please READ the story twice, then click next to continue an answer the questions that follow.

Please answer TRUE or FALSE to each of the questions that follow each story. If the question asks for information that is not easily inferred through your reading of the story, please indicate your answer as being FALSE – PLEASE DO NOT GUESS. Please work through as quickly as possible.

DO NOT change any answer once you have answered it, go with your instinct

Story 1: Where's the Post Office?

Sam wanted to find a Post Office so he could send a birthday card to his grandmother. He was already late, as her birthday was the next day. Because he would not get to see his grandmother on her birthday, he was worried about whether the card would get to her on time.

As Sam was new to the area, he asked his colleague Helen if she could tell him where to find a Post Office. Helen told him that she thought there was a Post Office in Elm Street. When Sam got to the building on Elm Street, he found it had shut down. A notice on the door said that the Post Office had moved to new premises in Bold Street. So Sam went to Bold Street. But by the time he got there, the Post Office had already closed for the day.

Sam wondered if Helen, who was the office prankster, had deliberately sent him on a wild goose chase. When he got back, he asked his friend Pete, who worked in the same office, whether he thought it was likely that Helen had deliberately misled him. Pete thought that, since Sam had been anxious about sending the birthday card, it was unlikely that Helen would have deliberately tried to catch him out.

After you have read the story twice, please click next to continue.

Now please read each of the following statements and indicate with a T or an F whether you think they are TRUE or FALSE.

	answer	level	type
Pete wanted Sam to know that he suspected that Helen had not wanted Sam to know that the Post Office was really on Bold St.	false	7	I
Sam, who was friends with Pete and who knew Helen, asked Helen about finding the Post Office because he had been told that it had moved.	false	7	M
Helen thought that Sam wanted to buy a birthday card for his grandmother.	false	4	I
Sam asked about finding a Post office so that he could send a birthday present.	false	3	M
Sam told Pete that, because he was looking for the Post office, he had asked Helen where to find it and that she had told him it was on Elm St.	true	7	M
Sam, whose grandmother had a birthday, was new to the office.	true	3	M
Pete thought that Helen wanted Sam to know that she realised that the Post Office was no longer on Elm St.	false	6	I
Pete hoped that Sam would understand that he thought that Helen had wanted Sam to know where the Post Office actually was.	true	7	I
Pete thought that Sam's suspicion that Helen wanted to trick him was wrong.	true	5	I
Pete wanted Sam to know that he thought that Helen believed that the Post Office was on Elm Street.	true	6	I
Pete, who was Helen's colleague, and who told Sam that Helen was the office prankster, was Sam's friend.	false	5	M
Helen was a colleague of Sam's.	true	2	M
Pete assumed that Helen didn't know that the Post Office had moved.	true	4	I
Helen, whom Sam spoke to to find out where the Post Office was, and Pete, who was a friend of Sam's, were in the same team.	true	5	M
Helen thought that Sam wouldn't believe that she knew where the Post Office was.	false	5	I
Sam, who had asked Helen to tell him where the Post Office was, told her that it had moved and was now on Elm St.	false	6	M
Sam couldn't send the card because when he got to the Post Office, it was closed.	true	4	M
After Sam left Bold Street, he went back to the office and spoke to Helen.	false	4	M
Helen deliberately tricked Sam.	false	3	I

Sam asked Helen about finding a Post Office because his card, which was for his grandmother's birthday, wouldn't arrive on time unless he sent it that day.	true	6	M
Sam's grandfather had a birthday.	false	2	M
Sam believed Helen about where the Post Office was.	true	3	I

Story 2: John's problem

It was Friday afternoon, and John thought it might be fun to go to see a movie after work. At first, he wasn't sure whom he should ask to go with him. He really wanted to ask his colleague Sophie, whom he fancied, but he thought that maybe she didn't like him enough to be willing to miss her Friday dance class to go to a movie with him. He could, of course ask his friend Adam, who often watched movies with him.

Then he happened to see Pippa. He knew that Pippa was one of Sophie's friends. She would know whether Sophie would be willing to go to a movie with him. "Hey Pippa!" he said, "I thought I might go and see a movie after work. I was wondering whether you and Sophie would like to come too. Would you ask Sophie whether she would like to go with us?"

Pippa looked surprised. John had never asked her to do anything with him before, but she knew that he was very keen on Sophie. She began to suspect that John wanted to find out whether she knew if Sophie might want to go.

After you have read the story twice, please click next to continue.

Now please read each of the following statements and indicate with a T or an F whether you think they are TRUE or FALSE.

	Level	Answer	Type
Sophie had dance classes on Thursday afternoons	2	false	M
John knew that Pippa realised that he actually wanted to find out whether her friend Sophie wanted to come along to the film	6	false	I
John wanted Sophie to figure out that he realised that her friend Pippa already knew that he liked Sophie	7	false	I
John knew that Sophie liked her Friday night dance classes	4	true	I
John didn't realise that Pippa guessed that he actually wanted to find out if she knew whether her friend Sophie would want to go to a film	7	true	I
John didn't want Pippa to realise that he actually wanted to go to a film just with Sophie	5	true	I
Rather than asking Adam, John asked Sophie to go along to the film with him	4	false	M
Pippa told Sophie that John had said that Adam had asked him whether Sophie would miss her dance class to see a film with Adam	6	false	M
John saw Pippa, who was Sophie's friend, so he asked her whether, if he went to a film, they would both come even though Sophie had a dance class	7	true	M
Pippa told Sophie, who had a dance class, that John had told her that Adam couldn't go to the film so he invited them to come	6	true	M
Pippa was surprised when John asked her whether she would come along to a film	4	true	M
Pippa thought that Adam knew that Sophie liked her dance classes	5	false	I
John asked Pippa to ask Sophie to come to a film with them but didn't invite Adam to come	5	true	M
Pippa suspected that John had asked her because he thought that she would know what Sophie would want to do	6	true	I
Adam suggested to John that, if he saw Pippa, he should ask her to go to a film with him	5	false	M
Pippa told John that Sophie, who was her friend, would say no if he asked her to go to a film, because she had a dance class	7	false	M
John wanted to see a film after work	3	true	I
Pippa, who was Sophie's friend, went to dance classes	3	false	M

Pippa thought that Sophie wouldn't want to miss her Friday dance class	4	false	I
John fancied Pippa	3	false	I
John asked Adam to go to a film with him	2	true	M
Sophie was Pippa's friend and was in the same office as John	3	true	M

Story 3: The Cafeteria

Hannah was a bit late in getting to the cafeteria and by the time she got her lunch, there weren't many seats left. She noticed that there was one place free at the table where Emma and her boyfriend Matt and their friends always sat. So she went over and asked them if she could sit with them. Emma looked up and said "Oh actually, I was saving that seat for Abbie. Sorry!" So Hannah kept walking around the cafeteria trying to find somewhere to sit.

Eventually she sat down with her colleague Carolyn at a table in the corner. Carolyn noticed that Hannah was looking upset and asked her what was wrong, so Hannah explained what had happened. Then she said "Abbie wasn't feeling well this morning so she went home. Emma can't have been saving the seat for her – she was just making up any old excuse. The real reason that she didn't want me to sit with them is that she's jealous – she thinks her boyfriend Matt has a crush on me, but it isn't true!"

Carolyn told her that she and Emma had been in a meeting all morning, so wouldn't have known that Abbie was off sick. "She probably really was saving the seat for Abbie – she always does. Besides, we sat with them yesterday and that didn't bother her, so I don't think she's jealous of you."

After you have read the story twice, please click next to continue.

Now please read each of the following statements and indicate with a T or an F whether you think they are TRUE or FALSE.

	Answer	Level	Type
Abbie was sitting at Carolyn's table.	false	2	M
After Hannah sat down, Carolyn told her that Emma, who was sitting at a different table, was saving a seat for Abbie because her training meant that Abbie was late.	false	7	M
Carolyn wanted Hannah to realise that she did not believe that Emma's reason for saying that the seat was for Abbie was that she thought that her boyfriend Matt like Hannah.	true	7	I
Hannah thought that Carolyn already knew that Emma guessed that Hannah realised that Emma's boyfriend Matt liked her.	false	7	I
Hannah wanted Carolyn to know that she didn't believe that Matt, Emma's boyfriend, did actually like her.	true	6	I
Carolyn, who was Hannah's friend and who wasn't sitting with Emma, told Hannah that Emma, who had been in training, always saved a seat for Abbie, who was off sick.	true	7	M
Carolyn thought that Hannah liked Emma's boyfriend Matt.	false	4	I
Carolyn told Hannah that Emma had been at training.	true	3	M
Emma, who was sitting with Matt, told Hannah that, although she usually saved a seat for Abbie, today she wasn't because Abbie was sick.	false	6	M
Carolyn thought that Hannah would realise that Emma had been hoping that Hannah wanted to sit at their table.	false	6	I
Hannah, who asked Emma if she could sit with them, sat with Carolyn, because Emma said the seat that was free was for Abbie.	true	6	M
Carolyn, who was Hannah's friend, said that Abbie had been in training.	false	4	M
Carolyn hoped that Hannah would realise that Emma didn't know that Abbie had gone home.	true	5	I
Hannah wanted to sit with Emma.	true	3	I
When Hannah came over, Carolyn noticed that she was upset so she asked her what the matter was.	true	5	M
Matt was Emma's boyfriend.	true	2	M
Emma thought that her boyfriend Matt realised that Hannah liked	false	5	I

him.			
Emma told Hannah that she couldn't sit with them because the seat which was free was for Abbie.	true	4	M
Emma knew that Abbie was sick.	false	3	I
Hannah thought that Emma knew that Abbie had gone home sick.	true	4	I
Emma told Hannah that Abbie had had to go home sick.	false	3	M
Hannah told Emma that Abbie, who was sick, was going to go home, so she didn't need to save her a seat.	false	5	M