

Neglect Dyslexia as a Word-Centred Impairment: A Single Case Study

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Abstract

Neglect Dyslexia is a neuropsychological syndrome in which patients commit consistently lateralised letter omission, addition, and substitution errors when reading individual words. Although neglect dyslexia frequently co-occurs with domain-general visuospatial neglect, some cases of neglect dyslexia may be best characterised as a dissociable impairment within a word-centred reference frame. This investigation employs data from a single case study of a patient who demonstrated word-centred neglect dyslexia to clarify neglect dyslexia's relationship with visuospatial neglect. AB completed the Oxford Cognitive Screen and an original reading assessment in which she read 302 words, pseudo-words, and numbers presented in normal, vertical, and mirror-reflected orientations. AB was found to commit consistently lateralised right neglect dyslexia errors (e.g. SHOWN misread as "show" or RELATED misread as "relate"). By contrast, AB did not exhibit object-centred or viewer-centred neglect. AB was also found to commit lateralised reading errors affecting the terminal portions of words when lateralised spatial bias was eliminated by presenting words vertically. Additionally, AB consistently misread terminal letters (originally right-lateralised) even when words were mirror-reflected so that these letters were presented in the left side of space. AB committed no neglect dyslexia errors when reading normally, vertically, or mirror-reflected numbers, and demonstrated a qualitatively different error pattern when reading pseudo-words. The results of this case study imply that neglect dyslexia can involve a content-specific, word-centred cognitive deficit and can be dissociated from egocentric and allocentric visuospatial neglect.

Keywords: Neglect dyslexia, transient ischaemic attack, visuospatial neglect, reading

1.0 Introduction

Reading impairment in the form of acquired dyslexia is a common and debilitating outcome of stroke (Coslett & Turkeltaub, 2016; Demeyere, Riddoch, Slavkova, Bickerton, & Humphreys, 2015; Ellis & Young, 2013; Jackson & Coltheart, 2013). Acquired dyslexia drastically impacts the way patients are able to understand and employ written information which they encounter throughout everyday activities, ranging from information presented in road signs, newspapers, or favourite novels. Understanding and accurately characterising the cognitive deficits underlying acquired dyslexia is an essential precursor to the development of effective rehabilitation strategies for these reading impairments (Newcombe, Marshall, Carrivick, & Hiorns, 1975; Nickels, 1995).

Neglect dyslexia is a form of acquired dyslexia in which patients commit consistently lateralized letter omission, addition, and/or substitution errors when reading individual words (Caramazza & Hillis, 1990a; Ellis, Flude, & Young, 1987; Ellis & Young, 2013; Jackson & Coltheart, 2013; Moore & Demeyere, 2017; Vallar, Burani, & Arduino, 2010). For example, a patient with left neglect dyslexia might read “impartial” as “partial”, “smart” as “outsmart”, or “tested” as “bested” while a patient with right neglect dyslexia might read the same words as “impart”, “smartly”, and “testing” (Vallar et al., 2010). Neglect dyslexia is most commonly characterised as a peripheral dyslexia, or a reading impairment which results from domain-general impairment to early visual feature analysis (Ellis & Young, 2013; Jackson & Coltheart, 2013; Mozer & Behrmann, 1990; Riddoch, 1990; Shallice, 1988). This classification distinguishes neglect dyslexia from central dyslexias, or reading impairments which are caused by damage to reading-specific, higher-order cognitive processes such as orthographic analysis, semantic processing, and grapheme-phoneme mapping (Coslett & Turkeltaub, 2016; Jackson & Coltheart, 2013; Rapcsak, Beeson, Henry, Leyden, Kim, Rising, Andersen, & Cho, 2009). However, previous research has strongly suggested that neglect dyslexia does not represent a

unitary syndrome, but can instead result from damage to multiple distinct cognitive mechanisms.

Caramazza and Hillis (1995) propose a framework for three distinct levels of neglect dyslexic reading impairment affecting distinct spatial reference frames: retinocentric, stimulus-centred, and word-centred. In retinocentric neglect dyslexia patients commit reading errors which are dependent on the egocentric spatial representation within retinotopic coordinates of each stimulus. For example, the neglect dyslexic patient JOD, a patient with left, retinocentric neglect dyslexia, was found to read words presented in the right hemifield with significantly greater accuracy than individual words presented in centrally or in the left hemifield (Hillis & Caramazza, 1995). This pattern of neglect dyslexia can be explained by visuospatial neglect impairment which occurs within a viewer-centred (egocentric) reference frame (Hillis & Caramazza, 1995; Vallar et al., 2010). Impairments caused by retinocentric neglect dyslexia can be expected to reliably impact the same lateralisation of viewer-centred space (Beschin et al., 1997; Driver, 1999; Li et al., 2014). While many neglect dyslexia reading impairments have been shown to appear to operate within a viewer-centred frame of reference (Hillis & Caramazza, 1995; Rapp & Caramazza, 1991; Riddoch, 1990; Vallar et al., 2010), this is not seen in all cases.

In stimulus-centred neglect dyslexia, patients commit neglect dyslexic reading errors which affect the right or left letters of individual words, regardless of whether these letters are presented in the contralesional or ipsilesional side of space (Hillis & Caramazza, 1995). Stimulus-centred neglect dyslexia reading error patterns are affected by topographical transformations of individual words (Cubelli, Pugliese, & Gabellini, 1994; Ellis et al., 1987; Hillis & Caramazza, 1995; Katz & Sevush, 1989; Patterson & Wilson, 1990). For example, one patient exhibiting stimulus-centred neglect dyslexia, VB, was found to commit neglect dyslexia reading affecting the initial letters of words when reading words presented in both the

right and left visual field (Ellis et al., 1987). However, VB was not found to commit neglect dyslexic errors when individual words were presented vertically. Additionally, the egocentric lateralisation of VB's neglect dyslexia was not found to change when words were presented upside down so that these originally right-lateralised letters now fell on the left side of the word (Ellis et al., 1987). This means that VB neglected the left side of each presented word stimuli, regardless of whether this left side contained the word's terminal or initial letters. Stimulus-centred neglect dyslexia reliably impacts letters presented on the left or right side of individual word stimuli, regardless of these letters' relative positions within individual words.

In word-centred level neglect dyslexia, patients exhibit reading impairment which selectively effects the terminal or initial letters of words, regardless of these word's spatial presentation or topographical orientation (Hillis & Caramazza, 1995). This category of neglect dyslexia is most clearly documented in Caramazza and Hillis' (1990a) case study of the neglect dyslexic patient NG. NG was a 77-year-old woman who suffered a stroke resulting in extensive lesions to the left parietal white matter and left anterior basal ganglia (Caramazza & Hillis, 1990a). Following her stroke, NG exhibited severe right unilateral visuospatial neglect both in neuropsychological assessments and everyday activities and reported reading difficulty. Caramazza and Hillis (1990a) investigated NG's reading deficit by having NG read a series of over 2,000 individual words presented under various topographical transformations. When reading normally-presented words, NG was found to commit neglect dyslexia reading errors which affected the terminal (right-lateralised) letters of these words. However, NG also misread the terminal letters of words even when interference from her visuospatial neglect was eliminated by presenting words vertically. Most notably, NG continued to commit reading errors affecting the terminal (originally right-lateralized) letters even when words were mirror-reflected so that these letters were presented in the left side of egocentric space (Caramazza & Hillis, 1990a). These findings revealed that NG's reading impairment was unaffected by

topographical stimulus transformations, implying that her neglect dyslexia was caused by a central deficit at a level of processing where grapheme information is represented within a word-centred coordinate system.

Few previous case studies have documented cases of word-centred neglect dyslexia, and there are many questions remaining open for additional research. First, it is unclear whether this word-centred error pattern can be reliably identified in a substantial proportion of cases. Second, it is not yet clear whether word-centred neglect dyslexia can be fully dissociated from visuospatial neglect. Previously documented word-centred neglect dyslexia patients have either demonstrated general visuospatial neglect which co-occurs in the same lateralisation as their neglect dyslexia (e.g. NG, RB, ML) or have not been assessed for domain-general visuospatial deficits (e.g. HH) (Caramazza & Hillis, 1990; Haywood & Coltheart, 2000; Hillis, 1990; Hillis & Caramazza, 1995). Finally, Hillis and Caramazza (1995) propose that the reference frame impaired in word-centred neglect dyslexia is common across representations of both words and objects, but it is not yet clear whether or not this claim is supported by previous evidence. Previous case studies have demonstrated that retinocentric and stimulus-centred neglect dyslexia can be dissociated from visuospatial neglect, suggesting that these deficits may involve damage to independent perceptual systems (Haywood & Coltheart, 2000; Moore & Demeyere, 2017; Vallar et al., 2010). Subsequent investigations have suggested that Hillis and Caramazza's (1995) model may not be generalisable, but instead may only apply to the processing of alphanumeric stimuli (Haywood & Coltheart, 2000).

One method for evaluating the comparative strength of evidence in support of the generalizability of Hillis and Caramazza's (1995) model is through investigating whether or not neglect dyslexia reading errors are content-specific. If the component damaged in neglect dyslexia is common to more generalised representational systems, neglect dyslexia reading impairment would not be expected to be content-specific (Ellis et al., 1987; Jackson &

Coltheart, 2013), meaning that neglect dyslexic patients might be expected to commit similar neglect based reading errors when reading words, numbers, and pronounceable pseudo-words. Previous studies which have compared real word and pseudo-word reading in patients with neglect dyslexia have found more errors when reading pseudo-words than when reading real words (Arduino, Burani, & Vallar, 2002; Brunn & Farah, 1991; Chatterjee, 1995; Cubelli & Beschin, 2005; Rusconi, Cappa, Scala, & Meneghello, 2004; Stenneken, van Eimeren, Keller, Jacobs, & Kerkhoff, 2008). These studies only considered quantitative differences in the number of errors and not qualitative comparisons of specific reading error types. We expect that drawing comparisons between error patterns when reading real and pseudo-words may help clarify whether neglect dyslexia's underlying deficit occurs within a content-specific or domain-general reference frame. Additionally, while many neglect dyslexic patients have been found to commit lateralised errors when reading numbers, this impairment has not been found in all patients (Caramazza & Hillis, 1990a; Friedmann & Nachman-Katz, 2004).

The purpose of the present investigation was to employ data from a single case study of a patient demonstrating neglect dyslexia to critically evaluate word-centred neglect dyslexia's relationship with visuospatial neglect and implications for the generalisability of Hillis and Caramazza's (1995) three-tier model of representational impairments. Specifically, this study aimed to replicate Caramazza and Hillis' (1990a) stimulus manipulation conditions to determine whether this patient's neglect dyslexia occurs within a word-centred frame of reference and to additionally investigate the effects of stimulus type manipulations (i.e. words versus pseudo-words versus numbers) to determine whether this patient's neglect dyslexia represents a content-specific deficit.

2.0 Methods and Materials

2.1 Case Report

AB was a 75-year-old woman who was admitted to the John Radcliffe Hospital's hyper-acute stroke ward after presenting with right facial weakness, right facial numbness, and dysarthria. According to AB's medical notes, these symptoms began at approximately 06:00 on the date of testing and had resolved by 07:00. AB was admitted at approximately 09:00 of the same day and completed the NIHSS at 09:34. This investigation's cognitive assessments and reading experiments were conducted between 10:30 and 11:27 am on same day, less than six hours after initial symptom onset. AB's diagnostic CT scan was collected at 14:37, 9 hours after initial symptom onset. This diagnostic CT scan examined by a professional consultant radiologist (MF) (Figure 1). This investigation identified no evidence of intracranial haemorrhage, ischaemic lesions, or space-occupying lesions. A comparison was made with an earlier CT head scan collected the previous month and no interval changes were present. AB was subsequently diagnosed with a Transient Ischemic Attack (TIA).

Acute CT scans do often produce false negatives as it takes time for ischemic lesions to develop (González, 2005; Merino & Warach, 2010). In CT scans taken within 3 hours of an ischemic event, ischemic changes are generally visible in 31-53% of patients but at 6 hours this sensitivity increases to 67% and continues to increase over time (González, 2005; Merino & Warach, 2010). AB's CT scan was collected approximately 9 hours following her initial symptom onset, meaning that if an ischemic (or haemorrhagic) stroke had occurred, it would likely have been expected to be reflected in her diagnostic scan. However, the differentiation between ischemic strokes and TIAs is generally made based on the transience of focal stroke symptoms rather than by CT scan analysis. AB was diagnosed with a TIA due to the fact that her initial motor weakness, facial droop, and slurred speech resolved within 1 hour of initial onset. If AB would have had a stroke, these symptoms would not have been expected to be transient. This symptom transience is what ultimately determined AB's diagnosis.

AB completed 10 years of education, self-reported being right-handed, and reported a past medical history of epilepsy and Rheumatoid Arthritis. AB commented on having “some trouble reading” after completing the cognitive screen.

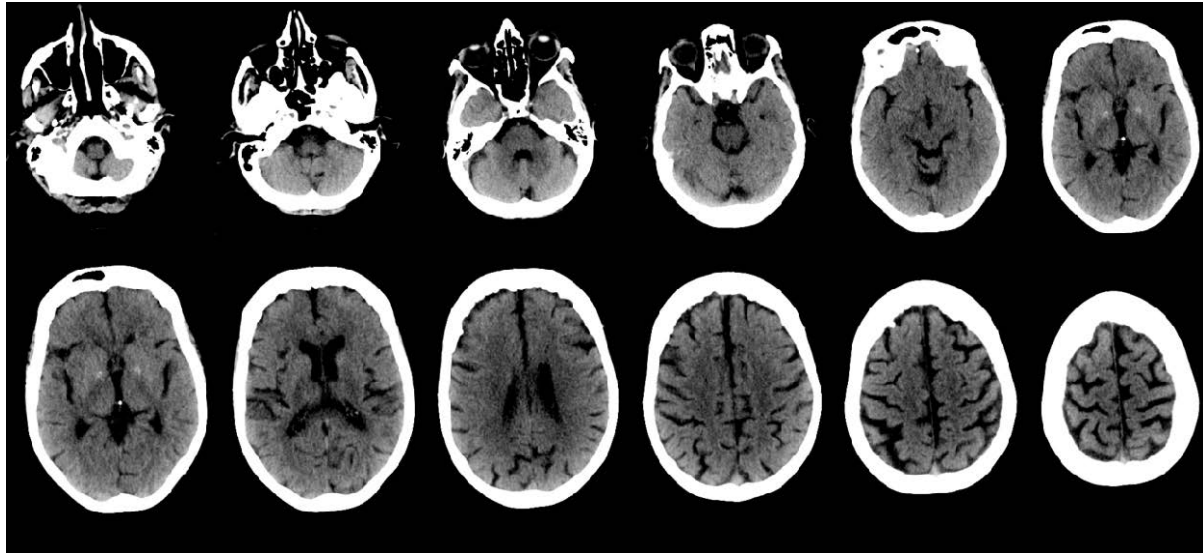


Figure 1. AB’s non-normalised, native space CT scan. No abnormalities were noted during clinical diagnostic assessment.

2.2 Materials & procedure

AB completed the Oxford Cognitive Screen (OCS) and NIH Stroke Screen (NIHSS) as a component of standardised acute stroke setting procedures. The NIHSS is a 11-item scale designed to detect and evaluate a wide range of physical and cognitive post-stroke impairments (Spilker, Kongable, Barch, Braimah, Bratina, Daley, Donnarumma, Rapp, & Sailor, 1997). NIHSS total scores range from 0-42 with 0 representing no stroke symptoms and 42 representing the most severe level of stroke impairment. The OCS is an 11-item cognitive assessment battery designed to provide a concise, comprehensive, and multi-domain summary of post-stroke cognitive impairments. The OCS is a validated, normed, and published cognitive screen, designed specifically for post-stroke cognitive screening (Demeyere, Riddoch, Slavkova, Jones, Reckless, Mathieson, & Humphreys, 2016; Demeyere, Riddoch, Slavkova, Bickerton, & Humphreys, 2015). The OCS’ cancellation task is a validated and highly sensitive

to visuospatial neglect, with 94.12% sensitivity compared to the Behavioural Inattention Test's star cancellation test (Demeyere et al., 2015). The OCS also assesses visual field deficits by asking participants to fixate on the examiner's nose and respond when the examiner's raised hands moved in the left and right upper and lower visual field quadrants. Cumulatively, the OCS evaluates five domains of cognition: language, memory, attention, praxis, and number processing (see www.ocs-test.org).

This investigation's three experimental conditions consisted of a series of reading tasks designed to detect neglect dyslexia and determine the effects of stimulus orientation and lexical content manipulations on neglect dyslexia reading errors. In each of these conditions, a series of written stimuli were presented sequentially and centrally on a tablet computer. This presentation program was written using MATLAB's Psychtoolbox (Brainard, 1997). Each stimulus was displayed in all capital letters in size 23 Arial font at the centre of the screen, and remained present for an unlimited duration, until a response was made by the participant. Given a viewing distance of approximately 50 cm, the viewing angle for the horizontal stimuli ranged from a 2.29-degree to a 9.19-degree visual angle, depending on stimulus length. Responses were recorded as correct or incorrect by the examiner through a tap on the left or right side of the screen. Audio recordings of patient responses were collected and were subsequently reviewed to confirm and code error types.

Each of this investigation's three conditions included real word, pseudo-word, or number stimuli. The words and pseudo-words used in this investigation's experiments were selected so that omission or substitution of the leftmost and rightmost letters of each stimulus could potentially yield a response with lexical content. For example, the word IMPARTIAL could be misread as either "partial" or "impart" and the pseudo-word PANOW could be misread as either "pan" or "now". These words were chosen in order to increase the probability that patients would commit neglect dyslexia reading errors (Riddoch, 1990; Vallar et al., 2010).

Similarly, this experiment's stimuli were intentionally selected to include many derivational affixes in order to increase the probability of neglect dyslexia reading errors. Words with suffixes and prefixes are generally more likely to produce neglect dyslexia reading errors than words without these affixes as derivational affixes can be substituted or omitted in many different combinations which still produce lexical responses (e.g. OBSESSED can potentially be misread as obsession, obsessing, obsesses, obsess, etc.) (Riddoch, 1990; Vallar, Burani, & Arduino, 2010).

For transparency, the full list of words, numbers, and pseudo-words is included in the supplementary materials (Appendix Tables 1-7). All stimuli types were presented in separate experimental blocks to avoid potentially confounding effects of intermixed presentation.

2.3 Experiment One: Reading Assessment

Here, we aimed to clarify whether AB exhibited a neglect dyslexia reading impairment. In this condition, AB was asked to read a series of 100 real words presented in the normal orientation on the tablet screen. This assessment consisted of 25 words with between 3 and 10 letters. In each of this investigation's experiments, stimulus presentation order was randomised within each word length category and these word-length categories were presented in ascending order so that all 3-letter stimuli were presented first, followed by all 4-letter stimuli, and so on.

2.4 Experiment Two: Orientation Manipulation

The purpose of Experiment Two was to determine the extent to which the spatial lateralisation of AB's reading impairments was modulated by topographical orientation. First, AB was asked to read a series of 32 words, 32 pseudo-words, and 16 numbers presented printed vertically down the centre of the tablet screen. AB was then asked to read 32 words, 32 pseudo-words, and 16 numbers which were presented in mirror-reflected orientation (see Figure 2 for an illustration of the two orientation conditions). The word and pseudo-word stimuli presented

in each condition consisted of words with 3-10 letters and the number stimuli consisted of equal numbers of 3 and 5 digit numbers. When reading numbers, AB was asked to name each of the individual digits out loud. The type and lateralisation of AB's reading errors in these orientation manipulations was compared to her reading errors in the initial reading assessment condition.



Figure 2. An example of the different orientation conditions with an illustration of how these conditions would be predicted to differentially impact stimulus-centred and word-centred neglect dyslexia.

2.5 Experiment Three: Stimulus Type

In Experiment Three AB was asked to read a series of 32 normally-presented pseudo-words and 16 normally-presented numbers in order to determine whether AB's neglect dyslexia represented a content-specific or domain-general impairment. The pseudo-words in this condition consisted of 3-10 letter stimuli and the numbers consisted of equal portions of 3 and 5 digit stimuli. Pseudo-word stimuli and number stimuli were presented in separate experimental blocks and were not intermixed.

AB's performance in this condition was compared to her reading error pattern in Experiment One in order to determine the extent to which stimulus type modulated the

prevalence of neglect dyslexia reading errors. Cumulatively, these three experimental conditions included 164 words, 96 pseudo-words, and 48 numbers.

2.6 Procedure

After providing informed consent, the OCS and neglect dyslexia reading assessments were administered at bedside by the experimenter. The NIHSS was conducted by trained clinicians and was reported in the medical notes. The procedure followed the protocol approved by the National Research Ethics Service (Reference: 14/LO/0648). In the neglect dyslexia reading assessment, AB was asked to read each presented word, pseudo-word, and number aloud. Stimuli presentations which were interrupted by medical staff, phone calls, or technical problems were removed from consideration ($n = 6$; 5 words, 1 pseudo-word). Audio recordings of all incorrect answers were categorised according to error type and lateralisation. Reading errors were categorised as neglect dyslexic if they involved a letter omission, addition, or substitution affecting the terminal or initial letters of words. Reading errors were classified as visual if they involved letter translocations, omissions, additions, or substitutions which were not clearly lateralised. Errors were classified as regularisations if they involved reading a pseudo-word as a visually similar real word or the phonetically correct mispronunciation of a phonetically irregular real word. Errors which did not fall into one of these category types, were unintelligible, or involved responses that were visually and semantically unrelated to the stimuli were marked as categorical.

The OCS, and Experiments 1-3 were all administered sequentially and this testing was completed within one hour. AB was given short, breaks between each task to help prevent patient fatigue. AB remained alert and engaged throughout the full duration of testing.

3.0 Results

3.1 General Cognitive Assessment Results

When assessed using the NIHSS, before participating in the reading experiments, AB demonstrated no inattention, motor weakness, language deficits, or other formal impairments and was therefore assigned a total NIHSS score of 0. When subsequently assessed with the OCS, immediately before participating in the reading experiments, AB exhibited impairments in number writing, calculation, and sentence reading (see Figure 3 for the OCS visual snapshot summary of AB's performance). In the OCS number writing task, AB miswrote "seven hundred and eight" as "7008" and "fifteen thousand two hundred" as "150020". These "extra zero" errors are commonly seen in acute stroke, previously documented in 14.2% of a sample of 667 acute stroke survivors (Haupt, Gillebert, & Demeyere, 2017). In the calculation task, AB answered one out of the 4 items correctly. AB also exhibited a clear reading impairment in the OCS sentence reading task (THOUGHT read as "though" and QUAY read as "quarry") and was therefore recruited to complete the battery of reading-specific assessments in this investigation.

AB exhibited no significant egocentric or allocentric (object-centred) visuospatial neglect impairment when completing the hearts cancellation task in the OCS (object asymmetry score = 0, space asymmetry score = -1, Total Correct = 35/50). However, AB did not rely on a consistent spatial search strategy in this task, but instead marked correct hearts in a random order across both sides of the page. AB's completed cancellation task is included in the supplementary materials (Appendix Figure 1). AB was not found to exhibit any visual field deficits which may have impacted her reading abilities.

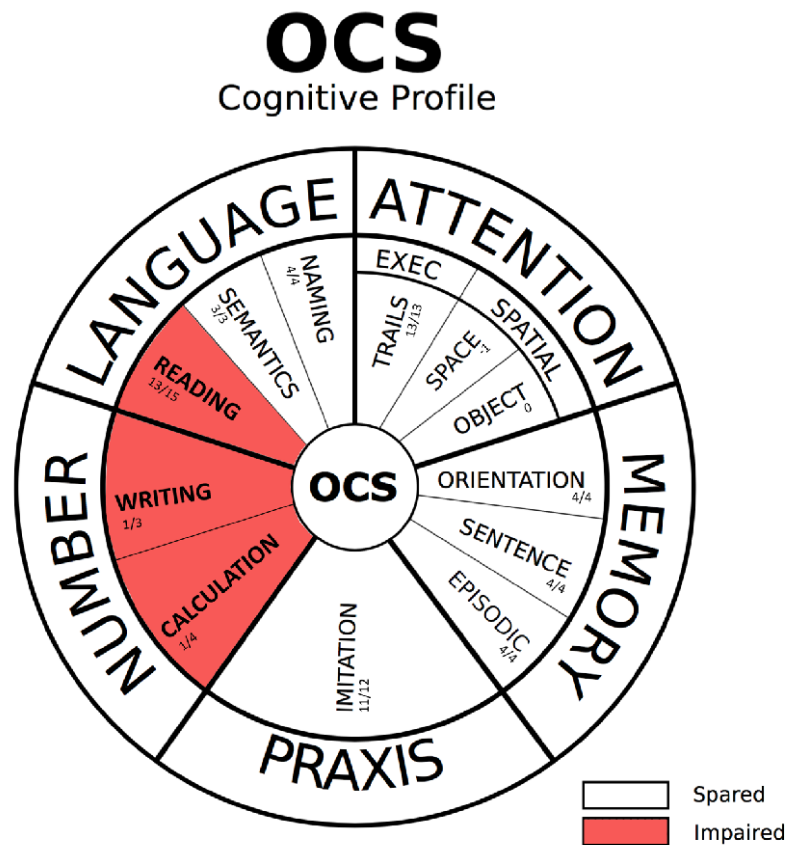


Figure 3. AB's Oxford Cognitive Screen performance summary. Cognitive domains are listed around the outer ring of the circle and individual tasks are denoted in the inner ring. AB's score on each task is listed within each task's segment. Scores which were below the cut-offs for impairment are denoted by shaded segments.

3.2 Experiment One: Reading Assessment

AB read 97 real words presented in the normal orientation. Overall, AB read 81/97 (83.51%) of these words correctly. Of the 16 reading errors AB committed, 15 were lateralised neglect dyslexic reading errors affecting the terminal letters (right side) of words. Four errors involved right-lateralised letter omissions (e.g. RELATED read as "relate", TOTALLY read as "total") and 11 errors involved right-lateralised letter substitutions (e.g. EVERY read as "even", PASSAGE read as "passenger"). See Table 1 for a summary of AB's performance on

the neglect dyslexia reading assessments and Appendix Tables 1-7 for a full report of AB's reading errors.

Table 1. *A summary of AB's reading performance in this investigation's three manipulation conditions.*

Reading Assessment Results Summary			
	Words	Pseudo-words	Numbers
Normal Presentation			
Reading Accuracy:	81/97 (83.5%)	22/32 (68.8%)	16/16 (100%)
Neglect Dyslexia Errors:	15	1	0
Other Errors:	1	9	0
Vertical Presentation			
Reading Accuracy:	22/31 (71.0%)	12/31 (38.71%)	16/16 (100%)
Neglect Dyslexia Errors:	7	9	0
Other Errors:	2	10	0
Reflected Presentation			
Reading Accuracy:	20/31 (64.5%)	7/32 (21.9%)	9/16 (56.3%)
Neglect Dyslexia Errors:	5	6	0
Other Errors:	6	19	7

3.3 Experiment Two: Orientation Manipulation

When reading vertical words, AB continued to commit omission, addition, and substitution errors affecting the terminal portion of presented words. For example, AB read GLOBE as “global”, SHOWN as “show”, STUDIED as “study”, and ADDRESSES as “address” when these words were presented printed vertically down the centre of the tablet screen. In total AB misread 9/31 vertically presented words and 6/9 of these errors were omission, addition, and substitution errors affecting the terminal letters of words. There was no significant difference between the proportion of neglect dyslexia reading errors when the stimulus was normally or vertically presented (15/97 versus 7/31 respectively; Fisher's Exact, $p = 0.41$).

When reading mirror-reflected words, AB exhibited lateralised neglect dyslexia errors in 5/31 (26.32%) of words. There was no difference in the proportion of neglect dyslexia errors

in the reflected condition versus the normal orientation (15/97 versus 5/31 respectively; Fisher's Exact, $p = 1$). Strikingly, these errors affected the terminal portions of words, despite the fact that these normally right-lateralised portions of words were now presented in the left side of space (see Figure 2). In this reflected condition, AB misread GROWN as "grow", THERE as "the", FORMAT as "formed", and OBSESSION as "obsess". 5/5 (100%) of AB's lateralised reading errors in the reflected condition affected the left side of egocentric space while 15/15 (100%) of AB's lateralised reading errors in the normal condition affected the right side of egocentric space.

3.4 Experiment Three: Stimulus Type Manipulation

There was a significant and absolute difference in the prevalence of neglect dyslexia reading errors when reading numbers and real words of comparable length (7/79 neglect dyslexia errors when reading 3 and 5 letter words versus 0/48 when reading numbers ; Fishers Exact, $p = 0.0441$) as AB did not commit any lateralised omission, addition, or substitution errors when reading numbers in the normal, vertical, and mirror-reflected conditions. AB read all numbers presented in the normal and vertical conditions correctly. Although AB did misread 7/16 numbers presented in the reflected condition, none of these number reading errors were characteristic of neglect dyslexia. 4/7 of AB's reflected number reading errors were transposition errors (e.g. 925 read as "952" and 259 read as "529") and the remaining 3/7 errors involved AB reporting that she could not read the presented stimuli and giving no response.

AB read 41/95 (43.2%) pseudo-words correctly. In line with existing neglect dyslexia literature (Riddoch, 1990; Vallar et al., 2010), this performance is significantly worse than AB's performance when reading real words (123/159 real words read correctly; Fisher's Exact $p < .0001$).

3.5 Word Familiarity, Length, and Stimuli Type Analysis Results

AB was found to exhibit a qualitatively different reading error pattern when reading pseudo-words compared to when reading real words (Figure 4). For example, AB misread 10/32 normally presented pseudo-words, but 9/10 of these errors were generalised visual ($n = 5$), regularisation ($n = 1$), no response ($n = 2$), and uncategorised ($n = 1$) reading errors (see Appendix). AB only committed 1 potential neglect dyslexia error when reading normally presented pseudo-words (MAB read as “mad”), which also involved a regularisation error. However, when reading normally-presented real words, AB committed no generalised visual errors, no uncategorised errors, 1 no response error, and 15 right-lateralised neglect dyslexia errors (Figure 4). A qualitative difference was present between AB’s real word and pseudo-word reading pattern (Figure 4). AB committed neglect dyslexia reading errors in 15/100 normally presented real words and 1/32 normally-presented pseudo-words. However, AB only read a comparatively small number of normally presented pseudo-words, meaning that the resulting statistical comparisons are underpowered and therefore not significant (Fischer’s Exact, $p = 0.1165$).

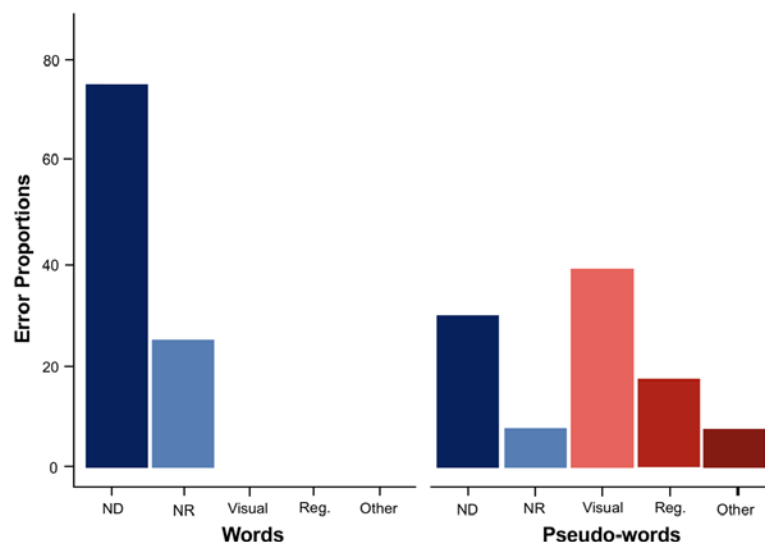


Figure 4. AB’s distribution of different reading error types when reading real words and pronounceable pseudo-words. *ND = neglect dyslexia, NR = not read, Reg. = regularisation.*

A binary logistic regression revealed that AB's likelihood to commit a neglect dyslexic reading error when reading real words was significantly modulated by word length ($X^2(1)=6.547$, $p < 0.011$), with shorter words being read more accurately than longer words. A similar model which included both length and whether or not each word included a suffix as covariates was also found to be significant ($X^2(1)=35.8$, $p < 0.001$). However, the inclusion of suffix category was not found to significantly improve this model ($p = 0.997$).

A binary logistic regression analysis revealed a significant relationship between word familiarity and AB's reading accuracy ($X^2=4.78$, $p = 0.027$), with more familiar words being read more correctly than low-frequency words (see Figure 5 for a distribution of the word frequencies by reading accuracy).

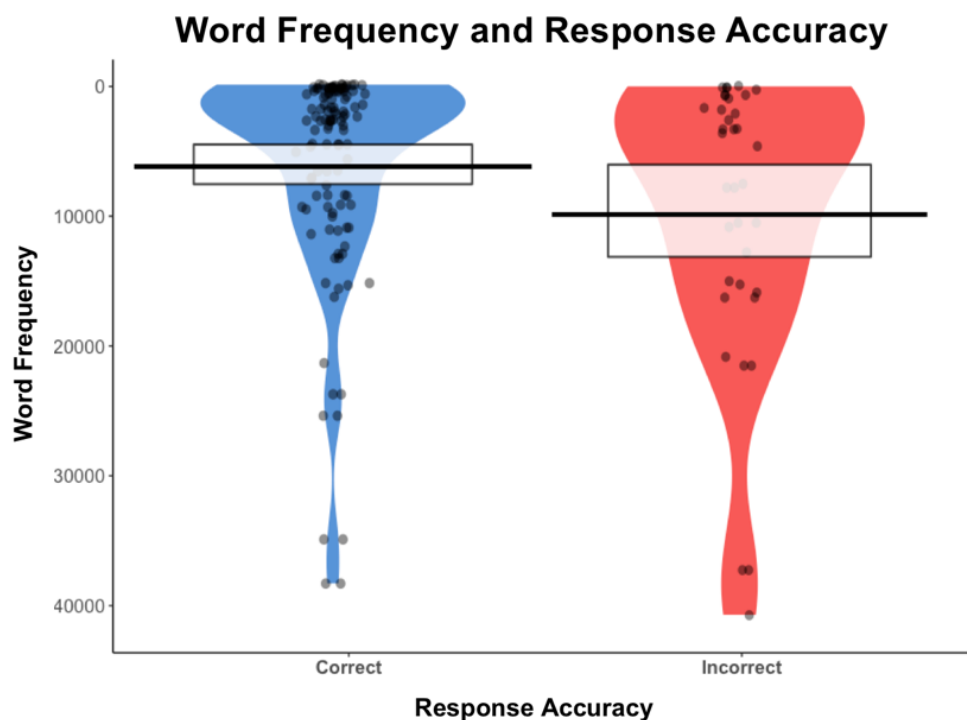


Figure 5: A Pirate plot (Phillips, 2016) of the relationship between word frequency and AB's response accuracy. As learning novel words occurs through frequent encounters with these words, word frequency statistics were considered as an adequate proxy measurement of word familiarity (Osterhout et al., 2006). These word frequency scores were assigned based on the Corpus of Contemporary American English (COCA) (Davies, 2009). Words with low word frequency scores are the most frequent. Points represent individual responses, rectangles

represent the upper and lower quartile, and blobs represent the spread of the distribution of responses.

4.0 Discussion

The purpose of the present study was to document a single case of neglect dyslexia and to investigate the effect of orientation and lexical manipulations on lateralised neglect dyslexia reading errors. AB presented after a Transient Ischaemic Attack and was found to commit consistent omission, addition, and substitution reading errors affecting the terminal letters of individual words. These errors are characteristic of neglect dyslexia (Caramazza & Hillis, 1990a; Riddoch et al., 1990; Vallar et al., 2010). Importantly, AB displayed similar proportions of neglect dyslexia errors when these stimuli were presented in normal, vertical, or mirror-reflected orientation. AB was not found to commit neglect dyslexic errors when reading numbers and exhibited a qualitatively different error pattern when reading pseudo-words versus real words. AB was found to commit a significantly higher proportion of reading errors when reading words which were less familiar.

The prevalence of AB's reading errors was found to be significantly modulated by the familiarity of each word stimuli. This is in line with findings from the NG case study (Caramazza & Hillis, 1990a), with both cases committing a higher proportion of reading errors when reading words that were less familiar compared to words which were more familiar. However, while AB's neglect dyslexia reading error pattern was in many ways similar to that of neglect dyslexia patient NG (Caramazza & Hillis, 1990a), there are important differences between these two patients.

First, NG's neglect dyslexia occurred following a left hemisphere stroke which produced substantial white matter lesions, but AB's neglect dyslexia occurred following a TIA. This is the first investigation to document a case of neglect dyslexia following a TIA. TIAs are characterised by focal stroke symptoms which resolve within 24 hours of onset (Easton et al., 2009) However, previous research has demonstrated that transient cognitive impairments

which occur following TIAs can outlast these transient focal stroke deficits (Pendlebury, Markwick, Jager, Zamboni, Wilcock, & Rothwell, 2012; Pendlebury, Wadling, Silver, Mehta, & Rothwell, 2011). AB's focal stroke symptoms, right-sided weakness and dysarthria, had fully resolved by the time of assessment, also exemplified in the NIHSS score of 0, meaning that this patient's cognitive impairments, including neglect dyslexia, outlasted the obvious focal stroke impairments. Pendlebury et al., (2011) found that less than 20% of TIA patients exhibiting reading-related transient cognitive impairments exhibited significant improvement in their cognitive impairment within the first month following their TIA, suggesting that AB's neglect dyslexia may very well persist for a significant period of time.

These findings have important implications when considered in the context of the clinical assessment of TIA patients. TIA patients may experience a range of "hidden" cognitive deficits which persist even after their more apparent physical symptoms have resolved (Pendlebury et al., 2012; Pendlebury et al., 2011). However, TIA patients are generally assessed using traditional observational methods such as the NIHSS, which focus on assessing physical deficits and may frequently fail to detect subtle cognitive impairments (Spilker et al., 1997). This highlights the need for standardised cognitive assessment within TIA patients, as these "hidden" cognitive deficits could be expected to have a significant impact on patient's daily lives following discharge (Jaillard, Naegele, Trabucco-Miguel, LeBas, & Hommel, 2009; Nys et al., Pendlebury et al., 2011; Rasquin, Lodder, Ponds, Winkens, Jolles, & Verhey, 2004).

Secondly, while NG's neglect dyslexia co-occurred with profound, similarly-lateralised egocentric visuospatial neglect, AB's neglect dyslexia was found to occur independently of both egocentric and allocentric visuospatial neglect deficits. AB exhibited no significant impairment when tested on the OCS' cancellation task, or when assessed by a trained clinician on the NIHSS' Inattention/Extinction Item. These findings illustrate a clear behavioural dissociation between neglect dyslexia and visuospatial neglect. The double dissociation model

represents the gold standard neuropsychological approach for determining whether or not two cognitive processes can occur independently of one another (Sullivan & Pfefferbaum, 2014). According to this model's logic, if two cognitive impairments can occur independently of one another, they cannot be dependent on the exact same underlying cognitive process (Sullivan & Pfefferbaum, 2014). It follows that if visuospatial neglect and neglect dyslexia are doubly dissociated, they represent independent cognitive impairments. Previous research has documented a substantial number of visuospatial neglect cases which occur independently of reading impairment (Beschlin, Cisari, Cubelli, & Della Sala, 2014; Beschlin, Cubelli, Sala, & Spinazzola, 1997; Lee, Kim, Seo, Choi, Kim, Chung, Keilman, & Na, 2009; Pouget & Sejnowski, 1997) and this present study, along with previous case studies, provide examples of neglect dyslexia which occurs independently of visuospatial neglect (Costello & Warrington, 1987; Cubelli et al., 1991; Friedmann & Nachman-Katz, 2004; Nichelli et al., 1993). This dissociation implies that neglect dyslexia and visuospatial neglect represent independent cognitive impairment. Considered in the context of the present study's findings, this provides strong evidence that AB's neglect dyslexia cannot be accurately characterised as a side-effect of egocentric or allocentric visuospatial neglect. Further, more compelling, support for this argument is provided by the findings of the orientation manipulation conditions.

Like NG, AB was found to commit lateralised reading errors which occurred within a word-centred frame of reference rather than an egocentric reference frame. AB made neglect dyslexia errors affecting the terminal letters of individual words when reading vertical words, and the prevalence of these reading errors was not found to be significantly different from the prevalence of her neglect dyslexia reading errors when reading normally presented stimuli. The vertical presentation condition was designed to remove any lateralised spatial bias within the egocentric reference frame which may have been impacting AB's reading abilities. This

manipulation was not found to significantly affect the occurrence or type of AB's neglect dyslexia reading errors, suggesting that AB's reading impairment was not caused by egocentric spatial-attentional impairments.

Further support for this conclusion is provided by AB's pattern of neglect dyslexia reading errors when reading mirror-reflected words. AB was found to commit neglect dyslexia errors when reading reflected words, but these reading errors reliably impacted the opposite lateralisation of egocentric space. Cumulatively, AB's reading error pattern within this investigation's orientation manipulation conditions strongly suggests that AB's neglect dyslexia, like NG's, is best understood as a reading deficit which occurs within the word-centred frame of reference.

Finally, in order to determine whether AB's reading impairment represented a content-specific or domain-general impairment, Experiment Three compared her reading errors when reading numbers and pseudo-words. Similar to NG, AB's reading deficits were found to be content-specific. While AB consistently committed right-lateralised omission, addition, and substitution errors when reading real words, this pattern was not observed when AB was asked to read numbers and pseudo-words. If AB's neglect dyslexia was a consequence of damage to a domain-general perceptual mechanism, her ability to read all alphanumeric stimuli would be expected to be equivalently impaired (Jackson & Coltheart, 2013; Riddoch, Humphreys, Cleton, & Fery, 1990). AB's complete lack of neglect dyslexia errors when reading numeric stimuli strongly suggests that AB's neglect dyslexia instead represents damage to a content-specific mechanism.

The qualitative difference between AB's real word and pseudo-word reading patterns provide anecdotal evidence suggesting that word-centred neglect dyslexia might not equivalently impair reading through lexical and non-lexical strategies. However, these comparisons included a relatively low number of pseudo-word stimuli, leading to

underpowered results. Future research can aim to further investigate this possibility by conducting a similar word/pseudoword comparison in a more stringent, statistically powered design.

~~AB only committed one neglect dyslexia error when reading normally presented pseudo-words compared to 15 errors when reading normally presented words. According to dual route models of reading, there are two distinct strategies which can be employed to read written stimuli (Jackson & Coltheart, 2013). In the lexical route, readers rely upon the lexicon, a mental dictionary of learned orthographic word features, meanings, and pronunciations. In the non-lexical route, readers rely upon a set of learned Grapheme Phoneme Correspondence rules which allow them to pronounce unfamiliar words (Jackson and Coltheart, 2013). Pseudo-words must be read through the non-lexical route, as they are unfamiliar to readers and are therefore not represented in the lexicon (Jackson & Coltheart, 2013). Impairment within a domain-general representational mechanism would be expected to equivalently impair when reading words with and without lexical content (Jackson and Coltheart, 2013). However, if neglect dyslexia instead occurs due to a damage to a content-specific representational process, a neglect dyslexia patient might be expected to exhibit differential impairment when reading real and pseudo-words. The qualitative difference between AB's real word and pseudo word reading may suggest that word-centred neglect dyslexia might not equivalently impair reading through lexical and non-lexical strategies. This possibility has several important implications when considered in the context of Hillis and Caramazza's (1995) three-level model of neglect dyslexia.~~

~~First, Hillis and Caramazza's (1995) model predicts that the processes impaired in word-centred neglect dyslexia represent a perceptual mechanism which is common across both word and object representation. Therefore, this representational mechanism would be expected to occur before the bifurcation of lexical and non-lexical reading routes, meaning that damage to~~

this component would be expected to produce similar error patterns in pseudo words as well as real words (Haywood & Coltheart, 2000; Hillis & Caramazza, 1991; Jackson & Coltheart, 2013). The results of this experiment suggest that it may be possible for patients with neglect dyslexia to exhibit qualitatively differential reading error patterns when reading real and pseudo words, which is not predicted by Hillis and Caramazza's (1995) model. Previous investigations have also documented neglect dyslexia which occurs in patients with differential or even no pseudo word reading impairment (Kartsounis & Warrington, 1989), providing further support for this implication. Taken together, this evidence suggests that the representational component impaired in neglect dyslexia might not necessarily be generalisable to other stimuli.

Haywood and Coltheart (2000) propose that word centred neglect dyslexia may be better understood as a content specific impairment rather than a disorder impacting domain general representational processes. While AB's differential word and pseudo word reading impairment patterns seems to provide support for this alternate theory, further research is needed on this topic. This investigation's word/pseudo word comparison investigation was unavoidably restricted by time limitations, but future research can aim to conduct a similar comparison under in a more stringent, statistically powered design.

While the findings of this investigation imply that AB's neglect dyslexia may represent a content-specific deficit, this implication is not without limitations. First, when reading number strings AB was asked to name each individual digit rather than to read the number as a whole. This means that AB's number reading involved serial, element-by-element parsing rather than reading stimuli "as a whole". This differential processing strategy may have resulted in numbers being less cognitively demanding to read than words or pseudo-words. However, the difference between AB's impairment when reading words/pseudo words and numbers remains clear and absolute in each of this investigation's conditions. Additionally, it is not quite clear

how to account for the significant, but not neglect dyslexic impairment seen in AB's pseudo-word reading. One possibility is that AB could have exhibited a comorbid impairment which selectively impacted her ability to read relying on the non-lexical route. Previous research has identified neglect dyslexic patients who exhibited comorbid attentional dyslexia reading deficits (Warrington, 1991), and it therefore seems plausible that AB may have also exhibited a comorbid reading deficit selectively affecting pseudo-word reading. One other possibility is that the impaired pseudo-word reading could be linked to her other co-occurring cognitive impairments as detected with the OCS.

First, in the number writing portion of the OCS, AB was found to write extra zeros in numbers. A previous study of acute OCS data identified this "extra zeros" number writing impairment in 14.2% of patients and concluded that this deficit was representative of impairment in activating and employing the abstract concept of "zero", which has no corresponding semantic representation (Haupt et al., 2017). Second, AB was found to exhibit significant calculation impairment. Calculation impairment is a fairly common post-stroke impairment which Demeyere et al (2015) identified in 14.2% of acute stroke patients. Finally, AB exhibited an abnormal, unstructured search strategy when completing the OCS's cancellation task. Neurologically healthy adults generally complete cancellation task in an organised, systematic manner. For example, participants frequently scan the search matrix from left to right, working their way from the top of the page to the bottom (Brucki & Nitrini, 2008; Weintraub & Mesulam, 1988). AB's failure to employ such an organised search pattern may have resulted in her substantial number of target omission errors, and suggests that AB experienced difficulty planning and employing an effective spatial search strategy. Weintraub & Mesulam (1988) found that patients with unilateral visuospatial neglect tended to exhibit erratic search patterns when completing cancellation tasks and hypothesised that this lack of systematic visual exploration is one of the factors that contributes to the perceptual deficits

seen in patients with neglect. However, AB exhibited no response asymmetry and therefore no visuospatial neglect in the cancellation task, suggesting that these two deficits represent dissociable impairments.

However, it is possible that this erratic spatial search strategy may be linked to AB's pseudo-word reading errors. The graphemes of real words can often be read in parallel, relying upon the activation of stored lexical representation rather than serial conversions to individual phonemes (Jackson & Coltheart, 2013). Conversely, reading pseudo-words requires the serial processing and phonemic conversion of each individual grapheme in the correct order (Jackson & Coltheart, 2013). AB's apparent difficulty in employing efficient spatial search strategies may have impacted this serial grapheme-phoneme conversion process, resulting in an increased number of reading errors. Future research is needed to clarify the link between spatial search strategies and the accuracy of serial grapheme-phoneme conversions.

4.1 Limitations

Several limitations of this study should be noted. First, the investigators were only able to access and assess patient AB for the duration of her hospitalisation. Given that AB was diagnosed with a TIA, she was discharged from the hospital almost immediately following clinical assessment, creating a very limited time-window for her reading error pattern to be documented. Similarly, due to the ethical protocols of our study, we are not able to contact AB again within six months of her initial assessment. This investigation dealt with these significant time constraints by limiting the number of words read in each condition. Other neglect dyslexia case studies, such as that involving NG, have reading collected data for over 2,000 individual words, but this scale of investigation was not possible for patient AB. However, this adjustment does not lessen the significance of the documented qualitative neglect dyslexia reading error pattern, but instead only lessens the statistical power of comparisons between conditions in which AB only read a small number of stimuli.

Second, some stimuli were presented twice in the reading experiments. These repeated stimuli were intentionally included in multiple orientation conditions in order to facilitate a direct comparison between AB's exact responses for the same stimuli in multiple different topographical presentations. While carry-over effects cannot be entirely ruled out, their effects should be no more than minimal each stimulus was presented a maximum of two times throughout the full hour of testing.

Finally, there was no data available detailing AB's pre-morbid cognitive abilities. This information could have also helped clarify whether the non-neglect dyslexic reading error pattern AB exhibited when reading pseudo-words was related to her TIA or was instead representative of her pre-morbid reading abilities. Finally, previous case studies have revealed that neglect dyslexia is a highly heterogeneous condition. While some patients, like AB and NG, have been found to exhibit neglect dyslexia which can be best characterised as a word-centred, content-specific deficit, this conclusion cannot be generalised to all cases of neglect dyslexia (Vallar et al., 2010). There is a lack of data from standardised assessments of substantiate samples of neglect dyslexia patients, precluding valid comparisons about the condition as a whole. Future research should aim to collect data from large groups of neglect dyslexia patients in order to facilitate conclusions about the disorder as a whole.

While this investigation was unavoidably limited in scope by our unavoidable lack of time with patient AB, the findings of this investigation still offer valuable empirical data. First, this investigation provides documentation of a case of word-centred neglect dyslexia which occurs independently of egocentric and allocentric visuospatial neglect. Other word-centred neglect dyslexia patients have either demonstrated neglect which con-occurs in the same lateralisation as their neglect dyslexia or have not been assessed for domain-general visuospatial deficits (Caramazza & Hillis, 1990; Haywood & Coltheart, 2000; Hillis, 1990; Hillis & Caramazza, 1995). This is the first reported example of a patient with word-centred

neglect dyslexia which occurs independently of visuospatial neglect, providing additional evidence that neglect dyslexia and visuospatial neglect are dissociable conditions.

Second, while many other investigations of neglect dyslexia patients have included pseudo-word reading tasks, this investigation is novel in its qualitative analysis of the specific types of these pseudo-word reading errors and its comparison between pseudo-word reading error types and real word reading error types. AB's qualitatively distinct reading pattern when reading real words and pseudo-words suggests that the component impaired in word-centred neglect dyslexia might not be generalisable to other perceptual processes, but the number of pseudo-word stimuli employed in this investigation were unavoidably low due to time constraints. Finally, there have been relatively few cases of graphemic-level neglect dyslexia documented in previous investigations, and the present study adds to this list of cases and provides novel evidence which can be applied to further understanding of the cognitive deficits which underlie this reading impairment.

5.0 Conclusions

The purpose of this investigation was to characterise a single case of neglect dyslexia reading impairment within a patient admitted for a Transient Ischemic Attack, AB. AB was found to commit consistent omission, addition, and substitution errors which exclusively impacted the terminal letters of individual words. This reading impairment was found to occur independently of both egocentric and allocentric visuospatial neglect as well as any general vision problems which may have impacted AB's reading abilities. The results of this investigation's orientation manipulation conditions strongly suggest that AB's reading impairment represents a deficit which occurs in a word-centred frame of reference and the results of this investigation stimulus type manipulations strongly suggest that AB's neglect dyslexia represents a content-specific impairment. These findings both replicate and extend the findings of Caramazza and Hillis' (1990a) investigation of the neglect dyslexic patient, NG.

Taken together, the findings of this investigation provide documentation of an additional case of word-centred neglect dyslexia and imply that word-centred neglect dyslexia may result from a content-specific representational impairment.

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Declaration of Interests

All authors declare that there are no conflicts of interest in this paper.

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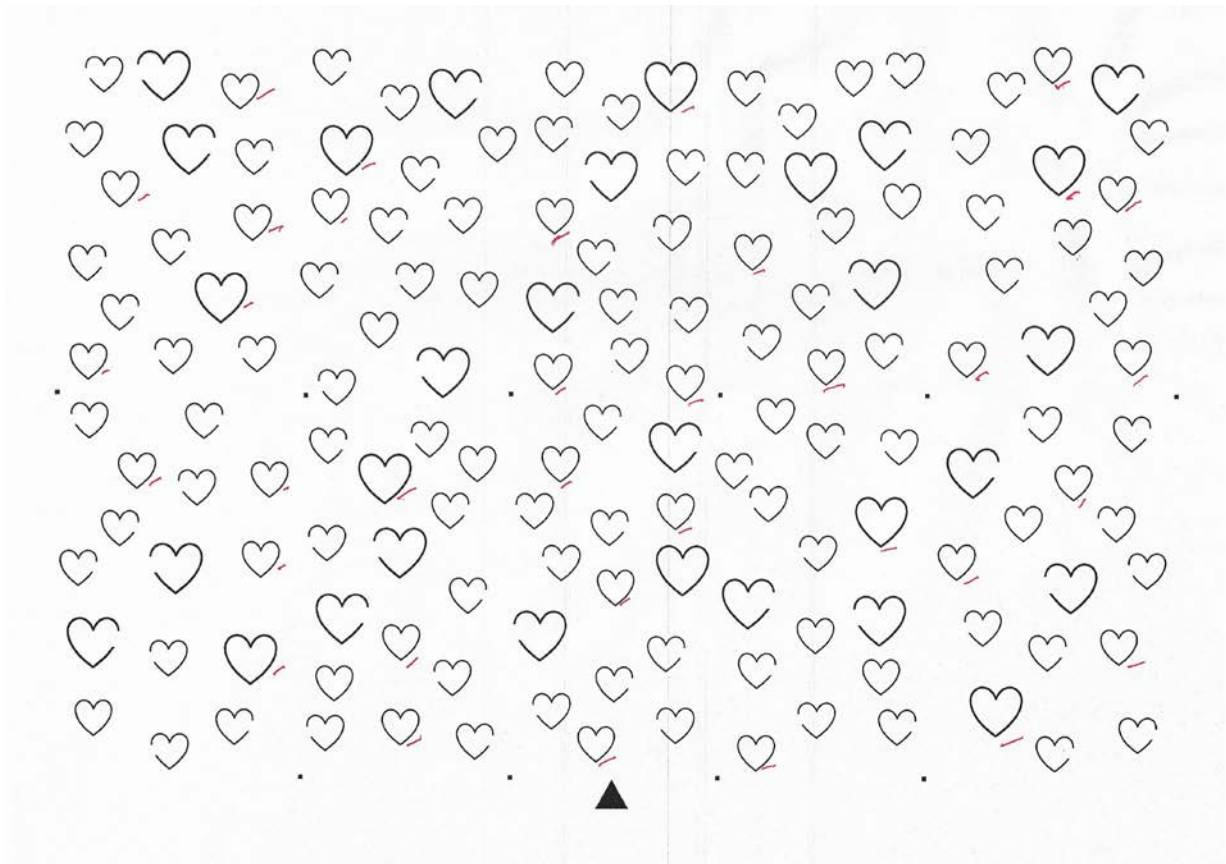
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7.0 Appendix



Appendix Figure 1. AB's completed OCS cancellation task. 35/50 target hearts were successfully identified. 14 of the correctly identified hearts were presented on the left side of space, 13 were presented on the right, and 8 were presented centrally resulting in a space asymmetry score of -1. This asymmetry score does not represent a visuospatial neglect impairment

Experiment One: Normally Presented Words

Stimulus	Freq.	Response	Error Type	Stimulus	Freq.	Response	Error Type	Stimulus	Freq.	Response	Error Type	Stimulus	Freq.	Response	Error Type
LET	159	Correct		EVENT	525	Correct		RELATED	3414	"relate"	Omission	BOOKSHELF	11458	Correct	
GOT	39	Correct		HEART	460	Correct		EXCITED	3449	"exorcists"	Substitution	BEWITCHED	34753	Correct	
ART	346	Correct		ALLOW	339	Correct		ONESELF	7731	Correct		BARTENDER	8027	"don't know"	Not Read
CAP	2320	Correct		EVERY	172	"even"	Substitution	BROTHER	614	Correct		FORGOTTEN	10116	Correct	
POD	8536	Correct		PITCH	3177	Correct		EXAMINE	1166	Correct		ADAPTABLE	15365	Correct	
RAT	6243	Correct		PLANE	1151	Correct		TOTALLY	1921	"total"	Omission	UNDEFINED	21989	"undefinable"	Substitution
TAN	9850	Correct		PLANT	623	Correct		FORTUNE	2719	Correct		ADDRESSES	1029	Correct	
RAW	2800	Correct		GROWN	16251	Correct		FOUNDER	2817	Correct		ONLOOKING	13292	Correct	
SAT	268	Correct		GLOBE	4779	Correct		DEVOTED	5186	Correct		APPEALING	7141	Correct	
HUB	6659	Correct		WOMAN	111	Correct		STUDIED	16649	"study"	Substitution	OFFSPRING	6604	Correct	
BIN	2512	Correct		SHOWN	177	"show"	Omission	KNOWING	12972	Correct		BILLBOARD	7257	Correct	
PAT	4580	Correct		IDEAL	2832	Correct		WORKING	2836	Correct		THRASHING	25323	Correct	
YES	258	Correct		PEACE	934	Correct		REMOVED	38021	"removable"	Substitution	OURSELVES	1776	Correct	
WAR	349	Correct		LOWER	2063	Correct		TOWARDS	2014	Correct		LIMESTONE	9393	Correct	
PAN	2495	Correct		GRANT	1917	Correct		UPSTAGED	21301	Correct		MISTAKEN	13103	"mistake"	Omission
MAN	94	Correct		THERE	53	Correct		UPDATED	10969	Correct		HANDSTAND	38122	Correct	
NUN	5759	Correct		POWER	271	Correct		MESSAGE	807	"messenger"	Substitution	ENCOUNTER	2728	Correct	
LAD	9567	Correct		COVER	560	Correct		THOUGHT	760	Correct		BACKSTAGE	11202	Correct	
RAM	12402	Correct		HUMAN	399	Correct		EXAMPLE	853	Correct		DELIVERED	41561	"delivery"	Substitution
SAP	15197	Correct		LABEL	2635	Correct		LEARNED	11115	"leaner"	Substitution	MILESTONE	9228	Correct	
RIB	4611	Correct		SPARE	4629	Correct		MISSING	3523	Correct		BEEKEEPER	23680	Correct	
WET	2487	Correct		START	173	Correct		READING	1586	Correct		OBSESSION	10784	"obsessed"	Substitution
WED	758	"win"	Substitution	BLAME	1807	Correct		HERSELF	792	Correct		SPIRITUAL	22108	Correct	
HOW	76	Correct		TABLE	539	Correct		PASSAGE	2224	"passenger"	Substitution				
JOG	8489	Correct													

Appendix Table 1. A complete list of all normally-presented real word stimuli (Experiment One). Each stimuli's frequency, AB's responses, and corresponding error categorisations are also provided. All stimuli in this table and in subsequent tables re listed in the order of presentation.

Experiment Two, Block One: Vertically Presented Words					
Stimulus	Response	Error Type	Stimulus	Response	Error Type
HUB	Correct		MISSING	Correct	
YES	Correct		RELATED	Correct	
GOT	Correct		ONESELF	"oneselfish"	Addition
MAN	Correct		FORTUNE	Correct	
ART	Correct		THOUGHT	"don't know"	Not Read
PAN	Correct		STUDIED	"study"	Substitution
WED	Correct		EXCITED	"exit"	Omission
WAR	Correct		SPIRITUAL	Correct	
GLOBE	"global"	Substitution	ONLOOKING	Correct	
COVER	Correct		ADAPTABLE	"table"	Omission
PITCH	Correct		BARTENDER	"don't know"	Not Read
GRANT	Correct		ADDRESSES	"address"	Omission
TABLE	Correct		BEEKEEPER	Correct	
BLAME	Correct		HANDSTAND	Correct	
SPARE	Correct		THRASHING	Correct	
SHOWN	"show"	Omission			

Appendix Table 2. AB's responses and corresponding error categorisations for Experiment

Two's vertically presented word stimuli.

Experiment Two, Block Two: Vertically Presented Pseudo-words					
Stimulus	Response	Error Type	Stimulus	Response	Error Type
KED	Correct		SANDACE	Correct	
ROP	"rope"	Addition	PASTAMP	"pasts"	Substitution
HUD	Correct		BUSHORT	"bushnot"	Visual
YOT	Correct		SIDEALS	"sideless"	Substitution
VIT	"vint"	Visual	PUREACH	Correct	
FOM	"foam"	Regularisation	DRONEWS	"downwest"	Regularisation
TEG	"get"	Visual	RANDEMORT	Correct	
MOMAR	"momaray"	Addition	GLOPFLARN	"glopflanded"	Addition
ANTOW	"ant"	Omission	FOSTEREND	"foreagain"	Visual
HATOP	"hat-top"	Visual	PLOMBITED	"plomibi"	Omission
PANOW	"pantow"	Visual	CROPSDORT	"rope"	Uncategorisable
NOTAD	Correct		BOAKSMARK	Correct	
PARAP	Correct		TRONRADAM	Correct	
HUBEN	Correct		BRONSHOVE	"bokshova"	Visual
RATUG	"rat"	Omission	SRAPIDATE	Correct	
RAREACH	"racha"	Visual			

Appendix Table 3. AB's responses and corresponding error categorisations for Experiment

Two's vertically presented pseudo-word stimuli

Experiment Two, Block Three: Vertically Presented Numbers					
Stimulus	Response	Error Type	Stimulus	Response	Error Type
696	Correct		34204	Correct	
625	Correct		65697	Correct	
321	Correct		37121	Correct	
313	Correct		2194	Correct	
215	Correct		53310	Correct	
872	Correct		23379	Correct	
697	Correct		21332	Correct	
231	Correct		39142	Correct	

Appendix Table 4. AB's responses and corresponding error categorisations for Experiment Two's vertically presented number stimuli

Experiment Two, Block Four: Reflected Words					
Stimulus	Response	Error Type	Stimulus	Response	Error Type
CAP	Correct		REMOVED	Not Read	Not Read
LAP	Correct		READOMG	Correct	
BIN	Correct		UPSTAGED	Not Read	Not Read
JOG	Correct		TOWARDS	Not Read	Not Read
POD	Correct		UPDATED	Correct	
LAB	Correct		KNOWING	Correct	
RIB	Correct		LEARNED	Correct	
SAP	Correct		BEWITCHED	Correct	
GROWN	"grow"	Omission	OBSESSION	"obsess"	Omission
WOMAN	Correct		MILESTONE	Correct	
EVERY	Correct		LIMESTONE	Correct	
POWER	Correct		REMISSION	"reminiscence"	Substitution
THERE	"the"	Omission	OURSELVES	Not Read	Not Read
START	Correct		UNDEFINED	Not Read	Not Read
FORMAT	"formed"	Substitution	ENCOUNTER	Not Read	Not Read
FOUNDER	Correct				

Appendix Table 5. AB's responses and error categories for Experiment Two's mirror-reflected words.

Experiment Two, Block Five: Reflected Pseudo-words

Stimulus	Response	Error Type	Stimulus	Response	Error Type
NAD	"dan"	Visual	LASTANK	"nastener"	Uncategorisable
GOM	"got"	Substitution	POSTAND	"posited"	Regularisation
FUB	"nup"	Uncategorisable	GAVENGE	"gavelgen"	Visual
HET	"helt"	Visual	NAMEND	"nomedend"	Visual
TAL	"jadge"	Uncategorisable	DROVEND	"divorced"	Regularisation
CAX	"cat"	Substitution	RABESTS	"rabested"	Substitution
TRA	"tart"	Regularisation	GRAMEND	"gamedend"	Visual
NEB	Correct		HALFELL	"halefen"	Visual
LOWAY	"lower"	Regularisation	VEANPLIMP	Not Read	Not Read
GALAB	"gallable"	Visual	DORPMOTAN	"doropmand"	Visual
CONIP	"conipip"	Addition	FLUBERTON	Correct	
NORAD	"noraday"	Addition	ARDORMALY	Not Read	Not Read
CAMAX	"cama"	Omission	PLANERMAT	"planement"	Regularisation
SIMAP	Correct		PLOPERMANT	Correct	
TANUP	Correct		TRANSHOULD	"tart"	Regularisation
DADIN	Correct		HARSHAND	Correct	

*Appendix Table 6. AB's responses and error categorisations for Experiment Two's mirror-reflected pseudo-words.***Experiment Two, Block Six: Reflected Numbers**

Stimulus	Response	Error Type	Stimulus	Response	Error Type
305	Correct		52634	Correct	
276	Correct		15475	"75427"	Visual
925	"952"	Visual	93467	Correct	
563	Correct		18549	"78246"	Visual
259	"526"	Visual	42662	Not Read	Not Read
224	Correct		56212	Not Read	Not Read
477	Correct		61832	Correct	
934	Correct		22791	Not Read	Not Read

Appendix Table 7. AB's responses and error categorisations for Experiment Two's mirror-reflected pseudo-words.

Experiment Three, Part One: Normally Presented Pseudo-words					
Stimulus	Response	Error Type	Stimulus	Response	Error Type
POG	Correct		CODEDAM	Correct	
WID	"wind"	Regularisation	LANDAWN	Correct	
BEM	"bream"	Visual	BESTAMP	Correct	
ARD	"don't know"	Not Read	MORALOT	Correct	
ZAM	Correct		WAVENTS	Correct	
MAB	"mad"	Substitution/Regularisation	SOMEVEN	Correct	
MOX	Correct		DOWNOG	Correct	
FAW	"flaw"	Regularisation	PRIMEAT	Correct	
DIBET	Correct		FRINPLONE	Correct	
CABOG	"bogabog"	Uncategorisable	POGFALROP	Correct	
GUNOD	"gunded"	Visual	FUEDARTH	Correct	
WEDAW	"wendrew"	Visual	TAINLANET	Correct	
FEWIN	Correct		SCRANWITCH	Correct	
VANET	Correct		DISCRAMET	"don't know"	Not Read
TOPAR	Correct		FEAMFLOMS	"feamfomems"	Visual
GASAW	Correct		GALENDANT	Correct	

Appendix Table 8. A complete list of Experiment Three's normally presented pseudo-words.

All stimuli are listed in the order of presentation.

Experiment Three, Part Two: Normally Presented Numbers					
Stimulus	Response	Error Type	Stimulus	Response	Error Type
932	Correct		87820	Correct	
272	Correct		72552	Correct	
592	Correct		98847	Correct	
147	Correct		36591	Correct	
915	Correct		77102	Correct	
645	Correct		25410	Correct	
409	Correct		98254	Correct	
367	Correct		10940	Correct	

Appendix Table 9. A complete list of Experiment Three's normally presented numbers. All

stimuli are listed in the order of presentation.