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Semantic typicality effects in acquired dyslexia: Evidence for semantic impairment in deep dyslexia

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Background: Acquired deep dyslexia is characterised by impairment in grapheme-phoneme conversion and production of semantic errors in oral reading. Several theories have attempted to explain the production of semantic errors in deep dyslexia, some proposing that they arise from impairments in both grapheme-phoneme and lexical-semantic processing, and others proposing that such errors stem from a deficit in phonological production. Whereas both views have gained some acceptance, the limited evidence available does not clearly eliminate the possibility that semantic errors arise from a lexical-semantic input-processing deficit.

Aims: To investigate semantic processing in deep dyslexia this study examined the typicality effect in deep dyslexic individuals, phonological dyslexic individuals, and controls using an online category verification paradigm. This task requires explicit semantic access without speech production, focusing observation on semantic processing from written or spoken input.

Methods & Procedures: To examine the locus of semantic impairment, the task was administered in visual and auditory modalities with reaction time as the primary dependent measure. Nine controls, six phonological dyslexic participants, and five deep dyslexic participants completed the study.

Outcomes & Results: Controls and phonological dyslexic participants demonstrated a typicality effect in both modalities, while deep dyslexic participants did not demonstrate a typicality effect in either modality.

Conclusions: These findings suggest that deep dyslexia is associated with a semantic processing deficit. Although this does not rule out the possibility of concomitant deficits in other modules of lexical-semantic processing, this finding suggests a direction for treatment of deep dyslexia focused on semantic processing.

Keywords: Deep dyslexia; Semantic typicality.

Caused by an acquired disease of the central nervous system such as stroke or traumatic brain injury, acquired dyslexia results from damage to the mature reading system and manifests as an impairment in the comprehension of written language (Ellis & Young, 1988). Deep dyslexia and phonological dyslexia are two subtypes of acquired dyslexia. Although the literature offers varying descriptions of deep dyslexia, patients exhibit several hallmark symptoms including: (1) severely impaired pseudoword reading, (2) semantic errors in oral reading, (3) visual errors in oral reading, (4) morphological

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errors in oral reading, and (5) an imageability effect in word reading with greater success in reading concrete, imageable words (Coltheart, 1980; Ellis & Young, 1988). In contrast, the hallmark of phonological dyslexia is impairment in pseudoword reading in conjunction with an absence of semantic reading errors (Beauvois & Déroutesné, 1979; Déroutesné & Beauvois, 1979; Ellis & Young, 1988). These patients may also show visual errors and imageability effects, as in deep dyslexia. However, the presence of semantic errors distinguishes between the two reading disorders (Friedman, 1996; Glosser & Friedman, 1990).

Several theories of semantic error production in deep dyslexia have been proposed, but the theories relevant to the current study include the multiple-deficit hypothesis (Morton & Patterson, 1980) and the failure of inhibition theory (Buchanan, McEwen, Westbury, & Libben, 2003). The multiple-deficit hypothesis suggests that reading deficits in deep dyslexia stem from more than one source. Referencing patient data from several case studies, Morton and Patterson (1980) suggested damage to both the non-lexical grapheme-phoneme route (to account for pseudoword reading deficits) and lexical-semantic routes (to account for semantic errors). Shallice and Warrington (1980) further proposed multiple candidates for impairment constrained to the lexical-semantic processing route: (1) impaired *access* to the semantic system, (2) impaired *processing* within the semantic system, and (3) impaired *phonological retrieval* following semantic processing. Some studies support impaired access to the semantic system, reporting differences in performance accuracy on visual and auditory tasks (Shallice & Coughlan, 1980; Shallice & Warrington, 1975). In contrast, other studies support a central semantic processing deficit, reporting individuals with deep dyslexia who show poor performance accuracy in both visual and auditory word–picture matching tasks (Newcombe & Marshall, 1980; Patterson, 1978). Still other studies support a phonological impairment, with evidence of deep dyslexic patients producing semantic errors in naming as well as reading (Marshall & Newcombe, 1966; Patterson, 1978; Saffran & Marin, 1977). Although Shallice and Warrington (1980) were able to specify possible deficit locations, they acknowledged that supporting evidence exists for all three possibilities and the problem of locating the lexical-semantic impairment still remains.

In contrast, the failure of inhibition theory (FIT) proposes that semantic errors in deep dyslexia are caused by failure to inhibit incorrect responses at the level of phonological production (Buchanan et al., 2003). Within this theoretical framework, when a word is read aloud the word's stored orthographic representation is activated, followed by activation of its semantic representation as well as spreading activation of semantically related neighbours and, in turn, these entries in the phonological lexicon are activated. In a normal reading system, incorrect responses would be inhibited, however, in deep dyslexia, FIT hypothesises that the inhibition mechanism is impaired, resulting in production of semantic errors (Buchanan et al., 2003). One critical aspect of FIT relates to how orthographic, semantic, and phonological representations are accessed, a feature of the model referred to as PEIR (Production, Explicit access, Implicit access, Representation) (Buchanan et al., 2003). PEIR proposes that production relies on explicit access, which relies on implicit access, which relies on intact representations (Buchanan et al., 2003; Colangelo & Buchanan, 2007). Authors of FIT propose that deep dyslexia is the result of a deficit in explicit access at the level of phonological production (Colangelo & Buchanan, 2007).

This hypothesis is based primarily on data from a single case of deep dyslexia, patient JO, whose responses the authors interpret as intact implicit access to semantics,

intact explicit access to semantics in the absence of production, and deficient explicit access in tasks requiring production (Colangelo & Buchanan, 2005, 2007). To test implicit access, JO completed a lexical decision task and performed within accuracy ranges of controls, leading the authors to conclude that implicit semantic processing was intact (Colangelo & Buchanan, 2005). To test explicit access to semantics with a production component, performance on an oral reading task was compared in a semantically blocked condition and an unrelated condition. JO produced significantly more semantic errors in the semantically blocked condition, so the authors argued that FIT was supported in that explicit access to phonology was not achieved (Colangelo & Buchanan, 2005, 2007). In order to further specify that this explicit access related to the phonological lexicon and not semantics, JO was given a forced choice trial for multiple lists of semantically related words, requiring silent reading of the list, followed by selection of the most semantically associated word from a field of two choices (Colangelo & Buchanan, 2005, 2007). JO's accuracy on this task was within the range of control participants' performance; thus it was concluded that explicit access to the semantic system was not impaired. Although, on the surface, this evidence may appear convincing, it is to date the only piece of evidence directly addressing the explicit semantic access capabilities of deep dyslexic individuals and is only based on data from a single case study. Additionally, although the task examined semantic access, the only measure was overall accuracy of performance, which could potentially be insensitive to processing impairments that may be detected by online measures such as reaction time.

In summary, both models of deep dyslexia discussed here provide supporting evidence, but neither is able to adequately address all the evidence, especially regarding semantic error production. To investigate semantic processing in deep dyslexia, the current study examined the semantic typicality effect using a task that requires explicit semantic access without production.

SEMANTIC TYPICALITY EFFECTS

Semantic typicality is a factor that affects the organisation of semantic categories in the mental lexicon. While the classical view of semantic categorisation considers each category to possess a set of defining features, it has been shown that not all members of a category represent these features to the same degree (Rosch, 1973, 1975). Some items in a category can be considered good or typical exemplars that possess many of the defining features of the category (e.g., *robin* in the category of *birds*), whereas others can be considered poor or atypical exemplars that possess fewer defining features of the same category (e.g., *ostrich*). Some studies have shown that typical members of a category are processed faster than atypical members, an effect known as the typicality effect (Kiran & Thompson, 2003; Rosch, 1975).

In healthy control participants the typicality effect has been found in several studies using a variety of experimental paradigms, including item ranking, lexical decision, category verification, and category naming (Casey, 1992; Hampton, 1995; Rosch, 1973, 1975). This effect also has been found for people with nonfluent Broca's, but not fluent Wernicke's aphasia. Using a category verification task Kiran and Thompson (2003) found faster reaction times (RTs) for typical as compared to atypical exemplars of category items for the nonfluent patients. However, for the fluent patients no RT differences were found for the two types of words, a finding associated with an underlying semantic deficit.

The purpose of the current study was to test for a semantic processing impairment in deep dyslexia using an online category verification paradigm identical to that used by Kiran and Thompson (2003). This task requires explicit access to the semantic system without requiring oral production. The following questions were posed: (1) Do individuals with deep dyslexia fail to show a typicality effect, which would suggest impaired semantic processing? (2) In the event that deep dyslexic readers fail to show this effect, does the impairment show up when processing both visual and auditory words? It was predicted that, in contrast to participants with deep dyslexia, both healthy control participants and phonological dyslexic participants would show a typicality effect in both visual and auditory modalities. Whereas we predicted that if a semantic impairment underlies semantic errors in deep dyslexia, the typicality effect would be absent in one or both modalities. A deficit in visual, but not auditory, processing would suggest a deficit in accessing semantic representations from the written form of lexical items; whereas deficient processing in both modalities would indicate an amodal central semantic deficit.

METHOD

Participants

Nine individuals served as adult control participants (six females; age 22 to 29, $M = 24.5$; years of education 16 to 20, $M = 17.4$) and eleven individuals with acquired dyslexia participated in this study (four females; age 47 to 69, $M = 58.2$; years of education 12 to 19, $M = 15.5$). All were monolingual English speakers, had normal or corrected-to-normal vision, and normal hearing. None reported a history of psychiatric, developmental speech-language, or neurological disorders, other than stroke in the patient participants. All patient participants demonstrated behavioural characteristics consistent with acquired dyslexia subsequent to left hemisphere cerebrovascular accident (CVA); time elapsed after CVA ranged from 2.5 to 17.5 years ($M = 6.9$ years). Control participants were recruited from Northwestern University and the surrounding community, and acquired dyslexia participants were recruited from the Northwestern University Aphasia and Neurolinguistics Laboratory and the Northwestern University Speech and Language Clinic. All participants gave informed consent in accordance with Northwestern University's Institutional Review Board.

Six individuals showed patterns consistent with a diagnosis of phonological dyslexia and five showed "deep dyslexia" patterns. Participants in the deep dyslexia group were not significantly different from those in the phonological dyslexia group for age, years of education, or years post-CVA—age, $t(9) = -0.053$, $p = .61$; years education, $t(9) = -1.46$, $p = 0.18$; years post-CVA, $t(9) = -0.87$, $p = .41$. Participants with acquired dyslexia were not significantly different from controls in years of education, $t(18) = 1.97$, $p = .07$, but control participants were significantly younger, $t(18) = -14.67$, $p < .05$.

To determine a diagnosis of acquired dyslexia, participants were administered the *Western Aphasia Battery-Revised (WAB-R)* (Kertesz, 2007), a subtest from the *Woodcock Johnson-III Diagnostic Reading Battery (WJDRB-III)* (Woodcock, Mather, & Schrank, 2004), and selected subtests from the *Psycholinguistic Assessment of Language Processing in Aphasia (PALPA)* (Kay, Lesser, & Coltheart, 1992). Although a diagnosis of aphasia was not a criterion for participant inclusion, all acquired dyslexic participants presented with aphasia as measured by the *WAB-R*, with Aphasia Quotients ranging from 51.4 to 87.6. All dyslexic participants also

demonstrated deficits in pseudoword reading on the *WJDRB-III* and on the *Nonword Reading* subtest of the *PALPA* (see Table 1). To ensure integrity of the written version of the experimental task, all dyslexic participants were required to demonstrate the ability to match single written words to pictures on the *Written Word-Picture Matching* subtest of the *PALPA*.

To distinguish between the phonological and deep dyslexia patient groups, additional subtests of the *PALPA* were administered, including the *Imageability and Frequency Reading* subtest (*PALPA* 31) and *Regularity Reading* subtest (*PALPA* 35). Individuals included in the deep dyslexia group produced semantic errors in single-word oral reading, whereas individuals in the phonological dyslexia group did not. Additionally, although participants in both the deep and phonological dyslexia groups showed effects of imageability—deep dyslexia, $t(4) = 5.404$, $p < .01$; phonological dyslexia, $t(5) = 5.809$, $p < .05$ —in single-word oral reading as demonstrated by the *Imageability and Frequency Reading* subtest of the *PALPA*, individuals in the deep dyslexia group demonstrated imageability effects of a significantly greater magnitude, $t(9) = -4.804$, $p < .01$ (see Table 1).

Materials

The stimuli used in this study were based on those used by Kiran and Thompson (2003) in their online category verification task. Three animate superordinate categories were used (birds, vegetables, and fish), with each category containing 15 typical and 15 atypical items for a total of 90 items. The typicality norms for each category were obtained from Kiran (2001), derived by asking groups of healthy young and elderly individuals to rate items on a 7-point scale based on category typicality. Within this scale a low rank (e.g., 1) indicated items judged as good members of a category, and a high rank (e.g., 7) indicated items judged as poor members of a category. The items for each category were then rank ordered using z -scores. Because low ranks represented “typical” items and high ranks represented “atypical” items, z -score calculations resulted in a range of z -scores from -1.2 on the extreme end of “typical” items to 1.3 on the extreme end of “atypical” items. For each category, typical exemplars were selected based on the 15 items with the lowest z -scores (range: -1.2 to -0.45) and atypical exemplars were selected based on the 15 items with the highest z -scores (range: 0.01 to 1.3). An additional 90 items belonging to different superordinate categories served as non-member exemplars (Kiran & Thompson, 2003). For the online category verification task each item was paired with a superordinate category label (i.e., bird, vegetable, fish), resulting in 180 word pairs. The order of stimulus presentation was randomised during the experimental task. For each superordinate category, 30 items matched the category (“yes” response) and 30 items did not match the category (“no” response).

The same 180 word pairs were used for both the visual and auditory online category verification tasks. For the visual task stimulus words were presented in 48-point Arial Black font. For the auditory task stimuli were recorded in a soundproof booth using a female voice and presented through external speakers adjusted to each participant’s sound comfort level. A Mac Book computer with Superlab 4.0 was used to present stimuli and collect accuracy and reaction time data. In the visual online category verification task the superordinate prime word was presented for 750 ms, followed by a 200-ms Inter-Stimulus Interval (ISI) and then the target word, which remained on the screen until the participant responded. This sequence was followed by a 1500-ms

TABLE 1
Language testing data for acquired dyslexic participants

	P1	P2	P3	P4	P5	P6	group mean	D1	D2	D3	D4	D5	group mean
<i>Western Aphasia Battery-Revised</i>													
Aphasia Quotient	87.6	78.2	78.1	72.6	68.1	66.8	75.2	51.4	81.8	85	54.3	59.6	66.4
Reading Score	19.8	12.8	17.4	15	12.2	18.2	15.9	13.8	17.8	18.2	11.2	10.2	14.2
<i>Psycholinguistic Assessment of Language Processing in Aphasia</i>													
Nonword reading	33%	0%	0%	33%	6%	22%	16%	6%	22%	17%	0%	6%	10%
Written word picture matching	100%	98%	100%	100%	100%	100%	100%	100%	100%	93%	88%	85%	93%
Imageability & Frequency Reading	93%	95%	98%	93%	65%	100%	91%	75%	98%	98%	45%	35%	70%
high imageability	90%	90%	90%	88%	55%	95%	85%	25%	68%	77%	0%	15%	37%
low imageability													
Regularity Reading	90%	76%	87%	87%	33%	87%	77%	70%	100%	93%	13%	40%	63%
regular	87%	83%	93%	80%	50%	77%	78%	63%	97%	87%	16%	43%	61%
exception													
<i>Woodcock Johnson-III</i>													
Nonword reading	28%	9%	19%	25%	9%	28%	20%	0%	37%	34%	9%	13%	19%
% semantic errors in total number of single words read	0%	0%	0.01%	0.01%	0.01%	0.01%	0.01%	5%	4%	5%	34%	6%	11%

P1 through P6 represent phonological dyslexic participants and D1 through D5 represent deep dyslexic participants.

inter-trial interval (ITI). For the auditory online category verification task the superordinate prime word was presented for the duration of the audio file (500–700 ms), followed by a 200-ms ISI and the audio presentation of the target word. A 1500-ms ITI followed each participant response and the next superordinate prime was presented. For both task modalities, the participant's response time was recorded from the onset of the target word.

All participants completed both the visual and auditory versions of the task, which were presented in two separate sessions on different days, with at least 5 days between the two. The order of modality presentation was counterbalanced across participants. For both modalities, participants were seated in front of the computer screen with one hand resting on a button response box. Participants were instructed to either read or listen to (depending on modality) each word pair presented and decide if the target word belonged to the preceding category. If the word was judged to be a member of the category, the participant was instructed to press the green "yes" response button on the button box. If the word was judged not to be a member of the preceding category, the participant was instructed to press the red "no" response button on the button box.

After receiving the task instructions, a 10-item training session was completed to allow practice with items similar to those used in the actual experiment and feedback on the accuracy of the participant's response was provided by Superlab 4.0. Participants were instructed to respond as quickly and as accurately as possible for all items. After the training session was completed, the experimental task was begun. To avoid effects of fatigue, during the experiment, participants were given an opportunity for two breaks, the first when a third of the items were completed and the second when two-thirds of the items were completed.

Data analysis

Accuracy and response times for each participant were recorded by Superlab 4.0. For each participant and participant group the mean and median proportions of accurate responses and response times were calculated for each independent variable. Only the response times of correct responses were included in the final statistical analysis. Due to the small number of participants in each group as well as the uneven number of participants representing each group, nonparametric statistics were used to analyse the data. For between-participants comparisons of group accuracy, Kruskal-Wallis tests were performed. For within-participants comparisons of reaction time across typicality, Friedman tests were performed to assess overall differences within participant groups and Wilcoxon Signed Rank tests were performed for pairwise comparisons of typical and atypical RTs within each participant group. To reduce the possibility of Type I statistical error, only comparisons critical to answering the research questions were conducted, resulting in a single pairwise typicality comparison (typical versus atypical) within each participant group.

RESULTS

Accuracy

Analysis of the response accuracy data showed that, in the visual task, no significant differences were found for any level of typicality— $H(2) = 0.40$, *ns*, typical; $H(2) = 1.24$,

ns, atypical; $H(2) = 4.15$, *ns*, non-member. In the auditory task no significant differences were found for any level of typicality— $H(2) = 4.08$, *ns*, typical; $H(2) = 2.32$, *ns*, atypical—except for non-member items, $H(2) = 8.90$, $p < .05$. Although a significant difference was found for non-member items in the auditory task, because this was not one of the critical questions of this study no post-hoc tests were conducted for this analysis.

Reaction time

Visual condition analysis. Analysis of the reaction time data resulted in a significant difference between typical and atypical items for the control group, $\chi^2(2) = 8.667$, $p < .05$, and the phonological dyslexic group, $\chi^2(2) = 9.00$, $p < .05$, but not for the deep dyslexic group, $\chi^2(2) = 2.8$, *ns*. To address the research questions and identify the specific level of difference within each group, a single comparison between typical and atypical items was completed. This analysis revealed that, for the control group and phonological dyslexic group, typical responses were significantly faster than atypical responses ($T = 2.00$, $p < .05$, controls; $T = 0.00$, $p < .05$, phonological dyslexic participants). However, for deep dyslexic participants this analysis revealed no significant difference between the two ($T = 3.00$, *ns*) (see Figure 1).

Auditory condition analysis. Analysis of the reaction time data resulted in a significant difference between typical and atypical items for the control group, $\chi^2(2) = 16.22$, $p < .05$, phonological dyslexic group, $\chi^2(2) = 5.33$, $p < .05$, and deep dyslexic group, $\chi^2(2) = 7.6$, $p < .05$. To address the research questions and identify the specific level of difference within each group, a single comparison between typical and atypical items was completed. This analysis revealed that, for the control group and phonological dyslexic group, typical responses were significantly faster than atypical responses ($T = 0.00$, $p < .05$, controls; $T = 0.00$, $p < .05$, phonological dyslexic participants). However, for deep dyslexic participants this analysis revealed no significant difference between the two ($T = 0.00$, *ns*) (see Figure 1).

DISCUSSION

The purpose of the current study was to identify and locate the potential semantic impairment in deep dyslexia using a task that would specifically require explicit semantic access from both visual and auditory input without requiring an oral response, thus avoiding a confound of speech production. Results indicated that healthy control and phonological dyslexic participant groups demonstrated a typicality effect in both visual and auditory modalities, but deep dyslexic participants did not demonstrate this effect in either modality. These results will be discussed in relation to each of the two research questions posed in the current study. Taking this new evidence into account, a modified theory of deep dyslexia is proposed.

The first question concerned whether or not a semantic impairment exists in deep dyslexia. The failure of inhibition theory (FIT) suggests that semantic reading errors result from failure to inhibit incorrect responses at the level of the phonological output lexicon, with all prior levels of processing intact (Buchanan et al., 2003). The evidence used to support this theory was that performance accuracy levels similar to normal controls were found for their patient, for a task requiring implicit access to semantics and a task requiring explicit access to semantics without oral production.

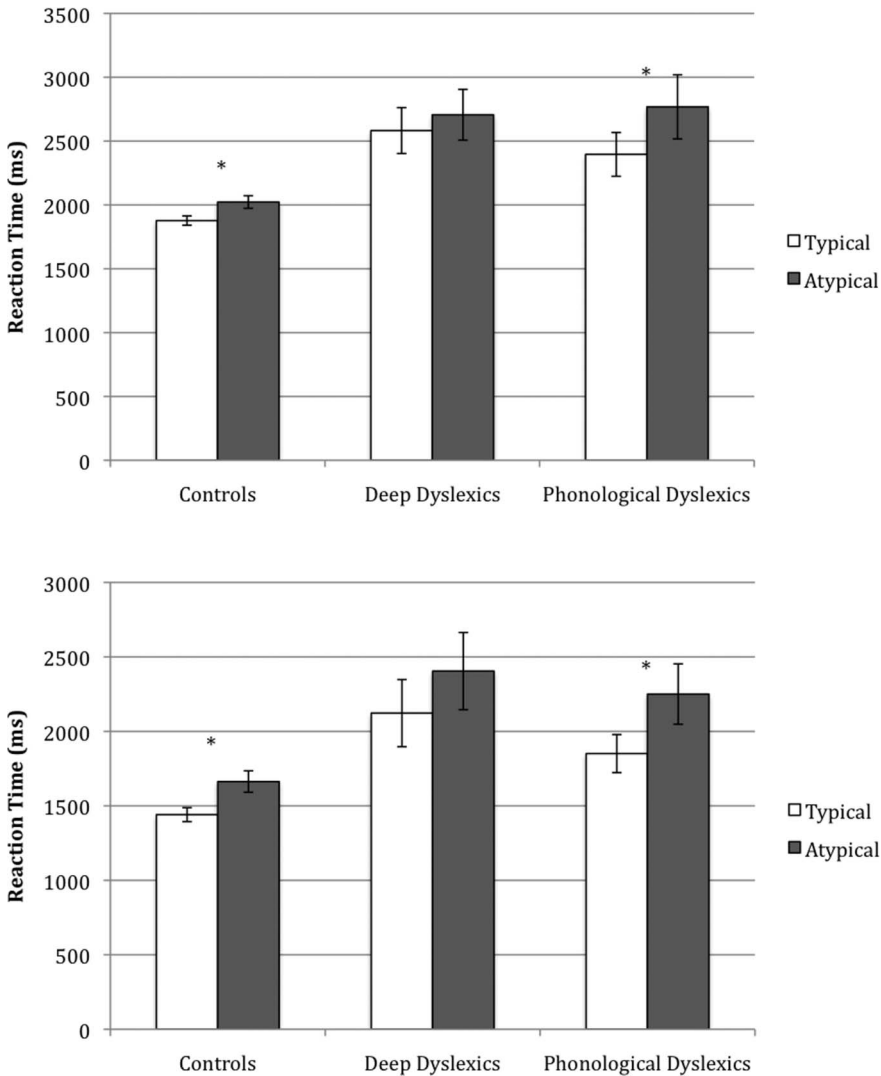


Figure 1. Mean response times for correct responses to typical and atypical in the visual task (top) and auditory task (bottom).

Although accuracy measures for this single case study did not differ from control participants, no other more sensitive measures were collected to explore the possibility of semantic processing differences. The current study examined explicit access to semantics without requiring oral production by testing a well-documented lexical-semantic processing effect (semantic typicality) using reaction time as a primary dependent measure.

It was predicted that in the visual task, if deep dyslexic participants showed a typicality effect similar to control participants, then this would suggest intact semantic processing. Conversely, differing typicality effects between the two groups would suggest impaired semantic processing. Results showed that whereas control participants

demonstrated a typicality effect, deep dyslexic participants did not. These findings suggest that in a task requiring semantic processing of written lexical items, deep dyslexic participants process semantic information differently from control participants, thus indicating a semantic impairment.

While the evidence presented here supports a semantic impairment in deep dyslexia, it does not directly test the presence or absence of a deficit at the level of the phonological output lexicon or the claim that semantic errors result from failure of inhibition. It is entirely possible, even likely, that the mechanism for semantic errors is an inability to inhibit incorrect responses. However, the current study now calls into question the level of processing at which this inhibition mechanism fails. Perhaps it is a failure to inhibit at both the semantic and phonological output lexicon levels, which is subtle at the level of semantics and only obviously detectable at the level of production.

The second question addressed the locus of the semantic impairment along the lexical-semantic reading route. Most models of lexical processing represent the semantic system as a single processing system accessed by all modalities. In order to test whether or not the semantic processing impairment in deep dyslexia affects general semantic processing or semantic access from written input, the current study examined category verification in both the visual and auditory modalities. Whereas control participants (and phonological dyslexic participants) demonstrated a typicality effect in both the visual and auditory modalities, deep dyslexic participants did not demonstrate a typicality effect in either modality. This pattern suggests that deep dyslexic participants demonstrate impairment in semantic processing. The multiple-deficit hypothesis (Morton & Patterson, 1980) conceptualises deep dyslexia as a disorder involving two separate impairments: a lexical-semantic impairment and grapheme-phoneme conversion impairment. Whereas the current study did not address grapheme-phoneme conversion, it directly addressed the locus of impairment along the lexical-semantic reading route, with the results supporting the existence of a semantic impairment in deep dyslexia. The design of the experimental task allowed a direct comparison of semantic system processing and access, with deep dyslexic participants showing impairment in semantic processing.

Toward a modified theory of deep dyslexia

Although the current study has provided additional evidence supporting and opposing various parts of the previously discussed theories, it appears that neither of these theories accounts for all the evidence. Therefore we propose a modified version of FIT. In deep dyslexia, as FIT proposes, selection inhibition is impaired. However, the lack of a semantic typicality effect in deep dyslexia may indicate an inability to efficiently select a correct lexical-semantic representation, suggesting that selection inhibition becomes impaired beginning at the level of semantics.

Summary

FIT provides a comprehensive view of deep dyslexia that compliments other theories by proposing a mechanism for semantic error production. Proponents of FIT suggest that semantic processing is intact in deep dyslexia; however, the current study suggests that deep dyslexics demonstrate semantic processing impairments. These data suggest a

modification to the FIT model, conceptualising failure of inhibition beginning at the level of semantic processing.

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