Running Head: Executive fluency in adult dyslexia

Verbal and non-verbal fluency in adults with developmental dyslexia: Phonological processing or executive control problems?

James H. Smith-Spark [a], Lucy A. Henry [b], David J. Messer [c], and Adam P. Zięcik [a]

[a] London South Bank University, London, United Kingdom

[b] City University, London, United Kingdom

[c] The Open University, Milton Keynes, United Kingdom

Author Contact

James H. Smith-Spark, Division of Psychology, School of Applied Sciences, London South Bank University, 103 Borough Road, London, SE1 0AA, United Kingdom

Email smithspj@lsbu.ac.uk

Telephone +44 (0)20 7815 5884

Fax +44 (0)20 7815 8099

Abstract

The executive function of fluency describes the ability to generate items according to specific rules. Production of words beginning with a certain letter (phonemic fluency) is impaired in dyslexia, whilst generation of words belonging to a certain semantic category (semantic fluency) is typically unimpaired. However, in dyslexia, verbal fluency has generally been studied only in terms of overall words produced. Furthermore, performance of adults with dyslexia on non-verbal design fluency tasks has not been explored but would indicate whether deficits could be explained by executive control, rather than phonological processing, difficulties. Phonemic, semantic, and design fluency tasks were presented to adults with dyslexia and without dyslexia, using fine-grained performance measures and controlling for IQ. Hierarchical regressions indicated that dyslexia predicted lower phonemic fluency, but not semantic or design fluency. At the fine-grained level, dyslexia predicted a smaller number of switches between subcategories on phonemic fluency, whilst dyslexia did not predict the size of phonemically-related clusters of items. Overall, the results suggested that phonological processing problems were at the root of dyslexia-related fluency deficits; however, executive control difficulties could not be completely ruled out as an alternative explanation. Developments in research methodology, equating executive demands across fluency tasks, may resolve this issue.

Keywords:

Developmental Dyslexia; Naming Fluency; Verbal Fluency; Design Fluency; Adult Cognition; Executive Functioning

Verbal and non-verbal fluency in adults with developmental dyslexia: Phonological processing or executive control problems?

Developmental dyslexia (henceforth, dyslexia) is typically characterized by a persistent difficulty with decoding the written word (e.g., Lyon, Shaywitz & Shaywitz, 2003; Siegel, 2006). The severity of the phonological processing deficits associated with dyslexia has led to theoretical explanations placing such problems at the core of the condition (e.g., Vellutino, 1979; Vellutino, Fletcher, Snowling & Scanlon, 2004; see Castles & Friedmann, 2014, for a recent review). However, dyslexia-related problems in a broad range of executive functioning (EF) tasks have also been found in children (see Booth, Boyle & Kelly, 2010, for a meta-analysis) and adults (e.g., Brosnan et al., 2002; Smith-Spark, Henry, Messer, Edvardsdottir & Zięcik, 2016). Executive functioning refers to higher-order cognitive processes such as planning, problem solving, inhibiting habitual responses in favour of more novel task-appropriate behaviour, self-monitoring performance, adapting responses in the light of changing task or environmental demands, organizing and sequencing behaviour, and shifting between different cognitive operations or representational sets (e.g., Andrés, 2003; Fisk & Sharp, 2004; Miyake & Friedman, 2012; Miyake et al., 2000; Pennington & Ozonoff, 1996; Rabbitt, 1997; Stuss & Benson, 1997).

Whilst a broad range of EFs have been found to be impaired in dyslexia, the current paper focused on one particular EF, namely fluency, in adults with dyslexia. Fluency is well-recognized as a measure of EF (e.g., Luo, Luk & Bialystok, 2010; Pennington & Ozonoff, 1996) and describes the ability to generate verbal or non-verbal items according to certain rules. This type of ‘executive’ fluency (often called “naming fluency” when referring to the production of verbal items) should be distinguished from reading fluency, which involves the smooth coordinated flow of reading. Although measures of executive fluency have been obtained previously in dyslexia (e.g., Kinsbourne, Rufo, Gamzu, Palmer & Berliner, 1991; Snowling, Nation, Moxham, Gallagher & Frith, 1997), the multifaceted nature of the task (e.g., Troyer, Moscovitch & Winocur, 1997) underlines the need for finer-grained analyses of performance to be undertaken (e.g., Henry, Messer & Nash, 2015; Luo et al., 2010). The current research was designed to provide more detailed analyses than previously employed, by exploring subcomponents of performance and measuring both verbal and non-verbal fluency in the same sample of adults.

In verbal fluency tasks, participants are asked to generate as many words as they can in a set time (usually 60 seconds) whilst adhering to specific rules. Phonemic fluency tasks require participants to produce words beginning with a certain letter, such as F, A, or S (e.g., Benton, 1968; Borkowski, Benton & Spreen, 1967), whilst semantic fluency tasks ask participants to name words that belong to a particular semantic category, such as animals or vegetables (Newcombe, 1969).

The rule-based nature of performance means that controlled access of information held in long-term memory is required to carry out the task successfully (e.g., Fisk & Sharp, 2004). As a result, verbal fluency tasks make considerable demands on higher-order cognitive abilities such as cognitive flexibility, strategic planning, the production of non-habitual responses, the suppression of previously generated responses, and error-monitoring (e.g., Phillips, 1997; Rosen & Engle, 1997; Ruff, Light, Parker & Levin, 1997). Of the two types of verbal fluency task, lower demands are placed on higher-order cognitive processes by semantic fluency than phonemic fluency (e.g., Ardila, Ostrosky-Solís & Bernal, 2006).

Generating semantic category members is a more usual activity than generating words beginning with a certain letter, as people have existing schemata to deploy when generating semantically-associated items and easier access to subcategories (Shao, Janse, Visser & Meyer, 2014; Troyer et al., 1997). Semantic fluency, thus, entails a lesser degree of task novelty (an important component of any EF task; e.g., Phillips, 1997; Shallice & Burgess, 1991) and, consequently, is likely to require fewer executive resources than phonemic fluency (e.g., Shao et al., 2014).

Reduced rates of production on phonemic fluency tasks have been reported in individuals with dyslexia. This has been found to be the case in both children (e.g., Brosnan et al., 2002; Cohen, Morgan, Vaughn, Riccio & Hall, 1999; Felton & Wood, 1989; Frith, Landerl & Frith, 1995; Landerl, Fussenegger, Moll & Willburger, 2009; Menghini et al., 2010; Miller-Shaul, 2005; Moura, Simões & Pereira, 2014; Plaza, Cohen & Chevrie-Muller, 2002; Reiter, Tucha & Lange, 2005; Varvara, Varuzza, Sorrentino, Vicari & Menghini, 2014) and adults (e.g., Hatcher, Snowling & Griffiths, 2002; Kinsbourne et al., 1991; Marzocchi et al., 2008; Miller-Shaul, 2005; Moore, Brown, Markee, Theberge & Zvi, 1995; Snowling et al., 1997; Wilson & Lesaux, 2001). Furthermore, non-significant trends towards lower phonemic fluency scores in adults with dyslexia have also been reported (Brosnan et al., 2002; Brunswick, McCrory, Price, Frith & Frith, 1999; Felton, Naylor & Wood, 1990). Another verbal fluency task involving phonological processing, rhyme fluency (in which participants are asked to produce words which rhyme with a target word), has also been found to be significantly worse in adult students with dyslexia (Hatcher et al., 2002).

In contrast to phonemic fluency, the study of semantic fluency in dyslexia has not resulted in such consistent findings. In children, a number of studies have failed to find dyslexia-related differences (Frith et al. 1995; Griffiths, 1991; Hatcher et al., 2002; Landerl et al., 2009; Marzocchi et al., 2008; Mielnik, Lockiewicz & Bogdanowicz, 2015; Plaza & Guitton, 1997), with a similar pattern of null results being reported in adults by several authors (Frith et al., 1995; Reid, Szczerbinski, Iskierka-Kasperek & Hansen, 2007). However, set against this evidence, some studies have found deficits in both children (Levin, 1990; Menghini et al., 2010; Moura et al., 2014; Plaza et al., 2002; Reiter et al., 2005; Varvara et al., 2014) and in adults (Snowling et al., 1997).

Nearly all investigations of verbal fluency in dyslexia have been limited to recording the number of stimuli correctly generated in the time allotted. However, Frith et al. (1995) explored performance at a finer-grained level in children, addressing both phonemic and semantic fluency. They measured the number of new words generated on four successive 10-item trials. The children with dyslexia and age- and IQ-matched controls did not differ in the number of new words produced on later trials of either the phonemic or semantic fluency tasks. Frith et al. argued that children with dyslexia had a mental lexicon that was of equivalent size to that of controls, with group differences in phonemic fluency being due to the difficulties that children with dyslexia had in accessing these words by their initial phoneme.

Differences in strategy use between children with and without dyslexia when performing verbal fluency tasks have been suggested by several authors (Frith et al., 1995; Reiter et al., 2005; Reid et al., 2007; although see Mielnik et al., 2015, for an opposing view). Any group-related differences in strategy use may be associated with EF impairments. Possible disparities in strategy use in verbal fluency performance resonate with a broader literature on dyslexia and strategy generation and utilization. Relative to controls, people with dyslexia show deficits in organized performance, manifesting problems with generating strategies and applying them efficiently to the task at hand (e.g., Levin, 1990; Torgeson, 1977). More recently, Bacon, Parmentier, and Barr (2013) have argued that adults with dyslexia do not have the cognitive flexibility to shift from one strategy to another unless they are told explicitly to do so.

Collecting new and more detailed data about executive fluency performance and strategy use in individuals with dyslexia can provide information relevant to these issues. In the current study, this was achieved by following the lead of Troyer et al. (1997). They emphasized the importance of studying two components of verbal fluency performance, known as clustering and switching, in addition to obtaining total output measures.

Clustering refers to the successive generation of words belonging to a particular phonemic or semantic subcategory (usually in spurts or temporal clusters with short intervals between items; e.g., Bousfield & Sedgewick, 1944; Henry & Crawford, 2004), until all items belonging to that particular subcategory are exhausted and the individual searches for a new subcategory from which to generate items. Clustering is argued to draw on verbal memory and word storage processes mediated by the temporal lobe of the brain (Troyer et al., 1997). Clustering can proceed relatively automatically even in individuals with low working memory spans (e.g., Rosen & Engle, 1997).

Switching refers to the ability to switch from one subcategory to another in an efficient manner. On a phonemic fluency task, an individual might switch from producing “fit, fin, fib” (a cluster of three phonemically-related members, varying only in their final phoneme) to continue with “fat, fan, far, fad” (a cluster with different phonemically-related members). Similarly, on a semantic fluency task, an individual might switch from “oranges, pears, apples, cherries” (a cluster of four semantically-related members, i.e., fruits which grow on trees) to continue “grapes, tomatoes” (fruits that grow on the vine, with a cluster size of two). Troyer et al. (1997) argued that switching involves EF processes to a greater extent than clustering, linking it to frontal lobe function. Switching is an effortful process, requiring strategic search, conscious control, and cognitive flexibility to shift between representational sets (e.g., Mayr, 2002; Troyer, 2000).

Research on switching and clustering within verbal fluency tasks in dyslexia is almost entirely lacking. To the authors’ knowledge, this measure has only been examined by Mielnik et al. (2015), who reported no group differences in the number of switches between clusters in children with and without dyslexia on a phonemic fluency task. However, they did find that children with dyslexia generated fewer clusters and switched fewer times on a semantic fluency task. Whilst these results are consistent with other research on verbal fluency in Polish (Reid et al., 2007), the findings do not fit the typical pattern of phonemic fluency impairment associated with dyslexia in the English language, the focus of the vast majority of the research literature and the current study.

A further detailed measure of verbal fluency is provided by measuring response output rate over the four 15s quartiles of a one-minute task (e.g., Crowe, 1998; Hurks et al., 2006). Response output rate tends to decline over the 60s trial, especially after the initial 15s have elapsed (e.g., Crowe, 1998; Hurks et al., 2006). Hurks et al. proposed that initial performance relies on automatic processes to access common or prototypical items, resulting in a relatively large number of items being generated during this timeframe. Once these initial items have been exhausted, effortful, controlled processes which draw on executive resources are required to access further items (e.g., Crowe, 1998).

Executive fluency can also be assessed using non-verbal tasks (e.g., Ruff, Light & Evans, 1987) and these provide an opportunity to explore (and separate) phonological processes from executive control processes. Non-verbal (or figural/design fluency) tasks require individuals to draw straight lines between constellations of printed dots to form as many novel patterns as they can within a set time limit. Existing research on design fluency in dyslexia is limited, but Griffiths (1991) found no significant difference in output between children with and without dyslexia. However, Reiter et al. (2005) criticized this study for presenting participants with templates to form patterns, thereby reducing novelty and, thus, the EF resources demanded by the task (c.f., Shallice & Burgess, 1991). Instead, Reiter et al. used the Five-point test (Regard, Strauss & Knapp, 1982). Participants were presented with a sheet of paper containing squares, each of which consisted of a fixed pattern of five dots arranged symmetrically. They created as many different patterns as possible in two minutes by joining dots in each square using one or more straight lines. Reiter et al. found a design fluency decrement in children with dyslexia and arged that this deficit was the result of reduced productivity related to the effective use of strategies. Reiter et al. further claimed that their design fluency task required greater levels of creativity and was more abstract than that used by Griffiths.

The current study investigated the performance of university students with and without dyslexia on three types of executive fluency task (phonemic, semantic, and design). As has been argued by McLoughlin, Fitzgibbon and Young (1994), it is important to understand the cognition of adults with dyslexia in its own right rather than simply extrapolating from evidence obtained from children with dyslexia. The cognitive challenges of adults with the condition are likely to be different to those experienced by children with dyslexia and, thus, need to be documented in order to highlight areas of weakness which require support. Recently, Smith-Spark et al. (2016) identified problems in adults with dyslexia across a range of different EF domains in both the laboratory setting and under everyday conditions. However, whilst that paper was more wide-ranging in its coverage of EFs than previous research, it could not cover all domains of EF. The current paper, therefore, built upon this work to extend recent research on adults into the EF domain of fluency.

Performance on the verbal fluency tasks was expected to follow the typical pattern reported in the previous literature on both adults and children, such that dyslexia-related deficits would be apparent on phonemic fluency (e.g., Kinsbourne et al., 1991; Moore et al., 1995; Wilson & Lesaux, 2001), and not semantic fluency (e.g., Frith et al., 1995; Griffiths, 1991; Hatcher et al., 2002; Plaza et al., 2002; Plaza & Guitton, 1997). Measures of switching, clustering, and performance over time presented more nuanced and novel methods of exploring verbal fluency in dyslexia that allowed an understanding of the role of executive control, as well as language processes. Additionally, the inclusion of a non-verbal task allowed fluency performance to be divorced from phonological processes, permitting the isolation of EF as a contributory factor to poorer fluency in dyslexia. It was hypothesized that, if there are general EF weaknesses in dyslexia, impairments on the design fluency task would be found, whereas if only phonological processing difficulties were to underlie poorer fluency performance in dyslexia, no impairments should emerge when a non-verbal fluency measure is used.

Method

Participants

Fifty-six university students took part in the study (44 females, 12 males, mean age = 24 years, *SD* = 5, range = 18-34 years). All spoke English as their first language and received either a small honorarium or course credit for participating. Participants were allocated to one of two groups on the basis of their self-declared dyslexia status, resulting in a group of 28 individuals with dyslexia and a control group of 28 individuals without dyslexia (22 females, 6 males in each group). The two groups did not differ significantly in age, $t(54) = 1.56$, $p = .125$. Checks of the dyslexia status of both groups were performed and are described below. Table 1 shows the demographic characteristics of the two groups, together with their mean scores on the IQ and screening measures reported in this section.

TABLE 1 ABOUT HERE

All 28 participants in the group with dyslexia had been independently diagnosed by an educational psychologist and showed the experimenter documentation to this effect prior to testing. None of the participants in the control group reported reading or writing problems when questioned verbally. Self-reports of not having dyslexia are accurate (Nicolson & Fawcett, 1997), but measures of reading and spelling ability were administered to support the validity of the two participant groups.

The ability to decode novel words is impaired even in compensated adult readers with dyslexia (Brachacki, Fawcett & Nicolson, 1994; Finucci, Guthrie, Childs, Abbey & Childs, 1976), making nonsense word reading performance highly sensitive to the presence of dyslexia (see also Hatcher et al., 2002). Reading ability was, therefore, assessed using the Nonsense Word Reading Passage (NWR) taken from the Dyslexia Adult Screening Test

(DAST; Fawcett & Nicolson, 1998). This task required the timed reading of a passage containing both real words and orthographically legal nonsense words. Reading speed and accuracy were combined to produce a composite measure of performance. Scoring penalties were incurred if a participant’s reading proved to be slow or error-prone. The control group performed significantly better than the group with dyslexia on the DAST nonsense passage, $t(30.119) = 6.09$, $p < .001$, $d = 1.26$. All the control participants scored above the normative age-specific cut-off point for identifying an individual as being “at risk” of dyslexia.

Spelling was assessed using the spelling component of the Wechsler Objective Reading Dimensions (WORD; Wechsler, 1993). Participants were presented with a series of words to spell within the context of a sentence. Testing was terminated after six successive incorrect spelling responses. The control group spelt significantly more words correctly on the WORD spelling test than the group with dyslexia, $t(34.943) = 5.65$, $p < .001$, $d = 1.21$. The raw spelling scores were also used to calculate a spelling age for each participant. Raw scores of 42/50 and above indicated that the participant had a spelling age of greater than 17 years (the ceiling on the task) and, therefore, his or her performance fell in the typical adult range. Seventeen of the participants with dyslexia had a spelling age of less than 17 years, whilst all the control participants had spelling ages in the adult range.

The Block Design, Picture Completion, Vocabulary, and Comprehension subtests of the Wechsler Adult Intelligence Scale – Fourth UK Edition (WAIS-IV; Wechsler, 2010) were administered in order to calculate a short-form IQ for each participant. None of these measures is sensitive to the presence of dyslexia, meaning that they provide a good estimate of an individual’s cognitive ability independent of dyslexia (Turner, 1997). There was no statistically significant difference in short-form IQ between the participant groups, $t(54) = 1.12$, $p = .267$. However, short-form IQ was statistically controlled in all of the analyses reported subsequently. This statistical control was exerted for two reasons: firstly, a p-value of greater than .50 has been recommended to ensure that groups are adequately matched for IQ in developmental studies (Mervis & Klein-Tasman, 2004) and, secondly, a positive relationship has been reported between IQ and verbal fluency performance (e.g. Ardila, Pineda, & Rosselli, 2000).

Materials

The Letter Fluency, Category Fluency, and Design Fluency subscales from the Delis-Kaplan Executive Function System (D-KEFS; Delis, Kaplan & Cramer, 2001) standardized battery of tests were employed to assess the EF of fluency.

Design

Separate hierarchical multiple regression analyses were used to determine whether the presence of dyslexia was a significant predictor of total responses generated, valid responses, number of errors, number of switches, words per cluster, and the total number of items generated in each quartile of Letter and Category Fluency. However, in the case of Category Fluency, it was not possible to assess the data on boys' names for each individual participant since these might be highly subjective and idiosyncratic (e.g., classmates, family members). Thus, in line with Henry et al. (2015; see also Troyer et al., 1997), the boys' names trial was omitted from the finer-grained analyses conducted on the number of switches, cluster size, and quartiles data gathered from Category Fluency. In all hierarchical regressions, short-form IQ was entered as a predictor in Block 1 and participant group in Block 2.

Cluster size is often counted from the second word of a cluster but, in accordance with Henry et al.'s (2015) argument that this could lead to misleading results if there are many single word clusters relative to the number of multiword clusters, single words were counted as separate clusters as well as multiword groups of phonemically or semantically words.

Due to the nature of the task and responses, Design Fluency could only be analyzed in terms of total responses generated, total valid responses, and total number of errors.

For both the Category Fluency Switching and Design Fluency Switching trials, measures were taken of total number of correct trials and total number of correct switching responses.

Procedure

Full ethical approval was granted by the appropriate University Research Ethics Committee. Participants gave informed consent to take part. The IQ and screening measures were administered in a preliminary session held on a separate day to the administration of the fluency tasks.

For both D-KEFS Verbal Fluency tasks, the participants carried out a series of 60s trials. Letter Fluency required the participants to name verbally as many different words beginning with a particular letter of the alphabet as they could, with the restriction that none of the words could be numbers or the names of places or people. There were three trials, requiring responses to the letters F, A, and S respectively. The second task, Category Fluency, required participants to produce as many different words that belonged to a particular semantic category as possible. One trial required the names of animals to be generated, whilst the other asked for boys' names. The third task was Category Switching, wherein participants were given 60s to generate words as quickly as possible, alternating between two different semantic categories (fruits and furniture).

The D-KEFS Design Fluency subtest was also made up of three tasks. The participants were presented with an answer booklet with rows of boxes each containing a number of dots. In the first task (Filled Dots), the participants were asked to draw a different design in each box, by connecting dots and using only four straight lines. They were also told that each line that they drew must join at least one other line at a dot (i.e. no line could be drawn in isolation from the remaining lines). They were asked to draw as many different patterns as possible in 60 seconds. The second task (Empty Dots Only) followed the same rules as the first task except that the boxes contained both empty and filled dots and the participants were instructed only to use the empty dots to make different patterns within an array of filled and empty dots. For scoring purposes, performance on these two tasks was combined. The third task, Switching, was based on the same principles, but the participants were asked to switch alternately between empty and filled dots in each design.

A debriefing followed the completion of the second session.

Results

Letter Fluency

Table 2 summarizes the results of the separate hierarchical regression analyses carried out on each of the dependent variables generated on Letter Fluency.

TABLE 2 ABOUT HERE

In Step 1, the total number of responses, the total number of valid responses, the number of switches, and performance on Quartiles 1, 2, and 3 were all significantly predicted by short-form IQ.

In Step 2, the presence of dyslexia was found significantly to predict total responses generated, valid responses, the number of switches, and performance on Quartiles 1, 2, and 4. Dyslexia did not significantly predict the number of words generated per cluster.

Category Fluency

In Step 1, short-form IQ significantly predicted the total number of responses, the number of valid responses, and performance in Quartiles 3 and 4.

In Step 2, the presence of dyslexia did not predict significantly any measure of Category Fluency (see Table 3).

TABLE 3 ABOUT HERE

Design Fluency

In Step 1, short-form IQ was a significant predictor of total number of responses and total number of valid responses generated on Design Fluency.

In Step 2, the presence of dyslexia did not significantly predict Design Fluency performance in terms of either the total number of designs produced or the total number of correct designs generated (see Table 4).

TABLE 4 ABOUT HERE

Switching Fluency

Hierarchical multiple regressions were also performed on total correct responses and total switching accuracy on the Category Switching and Design Switching fluency trials. The analyses are presented in Table 5.

TABLE 5 ABOUT HERE

For Category Switching, total correct responses and total switching accuracy were found to be predicted significantly by short-form IQ. However, the presence of dyslexia did not significantly predict performance on any of the measures.

For Design Switching, total correct responses and total switching accuracy were significantly predicted by short-form IQ. Again, the presence of dyslexia was not predictive of scores on either measure.

Discussion

The Letter, Category, and Design Fluency performance of adults with and without dyslexia was investigated using the D-KEFS (Delis et al., 2001). Hierarchical regression models were used to determine whether the presence of dyslexia was a significant predictor of executive fluency. After controlling for short-form IQ, adults with dyslexia performed significantly more poorly on nearly every measure of Letter Fluency, but did not differ significantly from controls on measures of Category Fluency or Design Fluency (or for the respective Switching conditions within these tasks).

On Letter Fluency, the presence of dyslexia was found to be related to fewer items being generated overall and fewer valid responses being produced. Group membership did not significantly predict the number of errors made by the participants. The finding of reduced phonemic fluency output is in accordance with previous studies in both children (e.g., Brosnan et al., 2002; Cohen et al., 1999; Felton & Wood, 1989; Frith et al., 1995; Moura et al., 2014; Reiter et al., 2005; Varvara et al., 2014) and adults with dyslexia (e.g., Hatcher et al., 2002; Kinsbourne et al., 1991; Moore et al., 1995; Wilson & Lesaux, 2001).

However, as highlighted in the Introduction, the current study extended previous research by also providing much finer-grained analyses of performance. In the case of Letter Fluency, a smaller number of switches was associated with the presence of dyslexia, suggesting that some degree of EF deficit in dyslexia may contribute to poorer phonemic fluency performance. The number of words generated per cluster was not, however, associated with the presence of dyslexia. Although non-significant results should be interpreted cautiously, the absence of a relationship between dyslexia and cluster size is consistent with Frith et al.’s (1995) argument that dyslexia-related verbal fluency problems are due to difficulties with accessing words based on their phonological characteristics rather than differences in vocabulary size.

For both groups, response output declined progressively over the four quartiles of the Letter Fluency task, with the drop in the number of items generated being most notable between the first and second quartiles. As mentioned previously, Hurks et al. (2006) have argued that once the relatively automatic access to prototypical items has been exhausted, more controlled, effortful searching is required in verbal fluency tasks. These controlled searches draw more heavily on executive resources and, thus, a dyslexia-related executive deficit in phonemic fluency (rather than a phonological processing deficit) should manifest itself in a greater effect of dyslexia in later quartiles than in earlier ones; instead, the analyses of the individual 15s divisions of the 60s task suggested that there was a pervasive phonological processing problem affecting their phonemic fluency performance across most quartiles; the presence of dyslexia significantly predicted the number of valid responses being made in Quartiles 1, 2, and 4. The performance of the group with dyslexia was also lower in Quartile 3, but not to a statistically significant extent, and performance in this quartile was found to have the strongest relationship to short-form IQ. However, it should be acknowledged that there is uncertainty about the extent to which the contribution of EF increases across the four quartiles, so it is still possible that part of the impaired performance of the group with dyslexia could be due to EF difficulties within each quartile. In addition, while the group with dyslexia produced clusters of a similar size to the group without dyslexia, they produced fewer such clusters, and it is possible that this is a result of EF impairments which limit the production of later clusters (c.f., Crowe, 1998).

A further point can be made about the finding that switching was significantly affected by dyslexia, whereas clustering was unaffected. Of the two processes, switching is argued to draw on executive processes whilst clustering does not (Troyer, 2000). Further to this, Troyer proposes that clustering on phonemic fluency tasks draws on phonemic analysis to generate items within a phonemically-related cluster. Under this view, the phonological processing difficulties of the group with dyslexia should have manifested themselves in lowered cluster scores, but this was not found to be the case. The results of the current study would, thus, argue against Reiter et al.'s (2005) proposition that phonemically-based strategies within clusters are reduced in dyslexia. However, it should be noted that at the inter-cluster level, the results also indicate that adults with dyslexia are poorer at the phonological retrieval process and are less able to identify additional clusters, thereby limiting performance. Taken together, the findings concerning Letter Fluency provide suggestive, rather than clear, evidence of an EF impairment in adults with dyslexia. This strengthens the hypothesis that a phonological-related deficit in adults with dyslexia (see Castles & Friedmann, 2014) results in poorer Letter Fluency performance.

Whilst Category Fluency performance was numerically lower in the group with dyslexia, group membership did not significantly predict scores on any of the measures taken. These findings are consistent with much of the previous literature on semantic fluency in dyslexia (e.g., Frith et al., 1995; Griffiths, 1991; Hatcher et al., 2002; Plaza & Guitton, 1997) in terms of failing to find reduced overall output. Further to this, they also extend the previous work in indicating no group-related relationships at a finer-grained level either.

The presence of dyslexia was also not a significant predictor of performance on Design Fluency. Design fluency has only previously been studied in children with dyslexia (Griffiths, 1991; Reiter et al., 2005). The current findings suggest that design fluency is not affected by dyslexia in adulthood, consistent with the results of Griffiths (1991) with children. Given that no phonological processing is required on the task and its high novelty in terms of task demands, the non-significant results would again support the argument that it is phonological processing deficits, and not EFs, that are responsible for dyslexia-related difficulties on fluency tasks. According to this interpretation, phonological impairments are the cause of lower performance on phonemic fluency tasks alone and have no effect on the semantic and design fluency tasks.

However, there is another interpretation which can also explain the findings. As noted in the Introduction, performance on phonemic fluency tasks is generally worse than on semantic fluency tasks (e.g., Ardila et al., 2006). This is likely to be because of the higher cognitive demands including EF processes (e.g., Ardila et al., 2006). It is, thus, conceivable that the increased EF demands associated with phonemic fluency are responsible for the deficits on the Letter Fluency task and not phonological processing problems per se. Accordingly, executive dysfunction could be claimed to be at the root of the dyslexia-related deficits found on phonemic fluency tasks. However, one potential problem with this explanation is that the Design Fluency task was even more novel (joining dots together in novel patterns tending not to be a common everyday activity) and difficult (as indexed by its higher standardized-β correlations with short-form IQ) than the Letter Fluency task. Given this, differences in the performance of the two groups might be expected, yet none were detected. Therefore, in the absence of an experimental design equating EF demands across the phonemic, semantic, and design fluency tasks, it is not possible fully to separate out the effects of executive dysfunction from phonological processing impairments as the underlying cause of the poorer performance of individuals with dyslexia on phonemic fluency tasks. Future research, adopting just such a design, would fully resolve this matter.

It also should be pointed out that the finer-grained analyses indicated that the group with dyslexia made significantly fewer switches when phonemic analysis was required, but there was no difference in the size of the clusters. The pattern of these difficulties was, thus, suggestive of an EF impairment. The absence of an influence of dyslexia on cluster size suggests that phonological representations and/or basic phonological retrieval processes were intact in the current sample of adults with dyslexia. On the other hand, when an attentional orienting response was required to identify and move to a different phonemic cluster, a dyslexia-related difficulty emerged. Whilst switching requires conscious control, attentional resources, and executive involvement (e.g., Mayr, 2002; Troyer et al., 1997), clustering can proceed relatively automatically even in individuals with low working memory spans (e.g., Rosen & Engle, 1997); just such lowered working spans are typically associated with adults with dyslexia (e.g., Smith-Spark & Fisk, 2007; Smith-Spark, Fisk, Fawcett & Nicolson, 2003; Smith-Spark et al., 2016).

The prediction of executive fluency from short-form IQ scores was not the focus of the paper, but the findings deserve review. Overall, short-form IQ was a good predictor of fluency performance, having a moderate positive relationship with the total number of responses and the number of valid responses on all three fluency tasks. However, short-form IQ only predicted the number of switches made by participants on Letter Fluency. Furthermore, there was no significant relationship between short-form IQ and cluster size on either task. Short-form IQ was a stronger predictor of performance on Letter Fluency than it was on Category Fluency, perhaps reflecting the former's greater cognitive complexity (e.g., Ardila et al., 2006). Performance over Quartiles 1, 2, and 3 of Letter Fluency were all significantly predicted by short-form IQ, with the strongest correlation being found in Quartile 3. The strength of the associations is broadly equivalent to the weak to moderate positive relationships found by Ardila et al. (2000) between IQ measures and both phonemic and semantic fluency in children. There was also a stronger positive relationship between short-form IQ and performance on Design Fluency than on the two verbal fluency measures, as highlighted previously in this section.

Conclusions

Executive fluency has been explored more comprehensively and in more depth in this paper than in previous dyslexia research. The findings indicate widespread dyslexia-related difficulties with phonemic fluency, but no impairments on any of the measures taken of either semantic or design fluency. However, whilst lowered performance was found across most of the phonemic fluency measures, the difficulties were not entirely pervasive, since the number of words produced within phonemic clusters was not predicted by the presence of dyslexia. These more nuanced measures of executive fluency suggest a possible role for EF in explaining the poorer performance of people with dyslexia on phonemic fluency tasks. Whilst the weight of the evidence obtained in the present paper points, at a general level, towards a phonologically-related explanation of the dyslexia-associated deficits, the present use of more nuanced measures of phonemic fluency continues to raise questions about what is the appropriate interpretation of findings relating to EF, fluency, and dyslexia. Further research is needed to answer these remaining questions about executive fluency in dyslexia and to consider the important theoretical points which they raise about the condition.

References

Andrés, P. (2003). Frontal cortex as the central executive of working memory: Time to revise our view. *Cortex, 39,* 871-895.

Ardila, A., Ostrosky-Solís, F., & Bernal, B. (2006). Cognitive testing toward the future: The example of Semantic Verbal Fluency (ANIMALS). *International Journal of Psychology, 41,* 324-332.

Ardila, A., Pineda, D., & Rosselli, M. (2000). Correlations between intelligence test scores and executive function measures. *Archives of Clinical Neuropsychology, 15,* 31-36.

Bacon, A. M., Parmentier, F. B. R., & Barr, P. (2013). Visuospatial memory in dyslexia: Evidence for strategic deficits. *Memory, 21,* 189-209.

Benton, A. L. (1968). Differential behavioural effects in frontal lobe disease. *Neuropsychologia, 6,* 53-60.

Booth, J. N., Boyle, J. M. E., & Kelly, S. W. (2010). Do tasks make a difference? Accounting for heterogeneity of performance of children with reading difficulties on tasks of executive function: Findings from a meta-analysis. *British Journal of Developmental Psychology, 28,* 133-176.

Borkowski, J. G., Benton, A. L., & Spreen, O. (1967). Word fluency and brain damage. *Neuropsychologia, 5,* 135-140.

Bousfield, W. A., & Sedgewick, C. H. W. (1944). An analysis of restricted associative responses. *Journal of General Psychology, 30,* 149-165.

Brachacki, G. W. Z., Fawcett, A. J., & Nicolson, R. I. (1994). Adults with dyslexia have a deficit in voice recognition. *Perceptual and Motor Skills, 78,* 304-306.

Brosnan, M., Demetre, J., Hamill, S., Robson, K., Shepherd, H., & Cody, G. (2002).

Executive functioning in adults and children with developmental dyslexia. *Neuropsychologia, 40,* 2144-2155.

Brunswick, N., McCrory, E., Price, C. J., Frith, C. D., & Frith, U. (1999). Explicit and implicit processing of words and pseudowords by adult developmental dyslexics: A search for Wernicke's Wortschatz? *Brain, 122,* 1901–1917.

Castles, A., & Friedmann, N. (2014). Developmental Dyslexia and the Phonological Deficit Hypothesis. *Mind and Language, 29,* 270-285.

Cohen, M. J., Morgan, A. M., Vaughn, M., Riccio, C. A., & Hall, J. (1999). Verbal fluency in children: Developmental issues and differential validity in distinguishing children with attention-deficit hyperactivity disorder and two subtypes of dyslexia. *Archives of Clinical Neuropsychology, 14,* 433-443.

Crowe, S.F. (1998). Decrease in performance on the verbal fluency test as a function of time: Evaluation in a young healthy sample. *Journal of Clinical and Experimental Neuropsychology, 20*, 391–401.

Delis, D. C., Kaplan, E., & Kramer, J. (2001). *Delis-Kaplan Executive Function System*. San Antonio, TX: Psychological Corporation.

Fawcett, A. J., & Nicolson, R. I. (1998). *The Dyslexia Adult Screening Test (DAST).* London: The Psychological Corporation.

Felton, R. H., Naylor, C. E., & Wood, F. B. (1990). The neuropsychological profile of adult dyslexics. *Brain and Language*, *39*, 485-497.

Felton, R. H., & Wood, F. B. (1989). Cognitive deficits in reading disability and attention deficit disorder. *Journal of Learning Disabilities, 22,* 3-13.

Finucci, J. M., Guthrie, J. T., Childs, A. L., Abbey, H., & Childs, R. (1976). The genetics of specific reading disability. *Annals of Human Genetics, 50,* 1-23.

Fisk, J. E., & Sharp, C. A. (2004). Age-related impairment in executive functioning: updating, inhibition, shifting, and access. *Journal of Clinical and Experimental Neuropsychology, 26,* 874-890.

Frith, U., Landerl, K., & Frith, C. (1995). Dyslexia and verbal fluency: More evidence for a phonological deficit. *Dyslexia, 1,* 2-11.

Griffiths, P. (1991). Word-finding ability and design fluency in developmental dyslexia. *British Journal of Clinical Psychology, 30,* 47-60.

Hatcher, J., Snowling, M. J., & Griffiths, Y. M. (2002). Cognitive assessment of dyslexic students in higher education. *British Journal of Educational Psychology, 72,* 119-133.

Henry, J. D., & Crawford, J. R. (2004). A meta-analytic review of verbal fluency performance following focal cortical lesions. *Neuropsychology, 18,* 284-295.

Henry, L. A., Messer, D. J., & Nash, G. (2015). Executive functioning and verbal fluency in children with language difficulties. *Learning & Instruction, 39,* 137-147.

Hurks, P. P. M., Vles, J. S. H., Hendriksen, J. G. M., Kalff, A. C., Feron, F. J. M., Kroes, M., et al. (2006). Semantic category fluency versus initial letter fluency over 60 seconds as a measure of automatic and controlled processing in healthy school-aged children. *Journal of Clinical & Experimental Neuropsychology, 28,* 684-695.

Kinsbourne, M., Rufo, D. T., Gamzu, E., Palmer, R. L., & Berliner, A. K. (1991). Neuropsychological deficits in adults with dyslexia. *Developmental Medicine and Child Neurology, 33,* 763-775.

Landerl, K., Fussenegger, B., Moll, K., & Willburger, E. (2009). Dyslexia and dyscalculia:

Two learning disorders with different cognitive profiles. *Journal of Experimental Child Psychology, 103,* 309-324.

Levin, B. E. (1990). Organisational deficits in dyslexia: Possible frontal lobe dysfunction. *Developmental Neuropsychology, 6,* 95-110.

Luo, L., Luk, G. & Bialystok, E. (2010). Effect of language proficiency and executive control on verbal fluency performance in bilinguals. *Cognition, 114,* 29-41.

Lyon, G. R., Shaywitz, S. E., & Shaywitz, B. A. (2003). A definition of dyslexia. *Annals of Dyslexia, 53,* 1–14.

Marzocchi, G. M., Oosterlaan, J., Zuddas, A., Cavolina, P., Geurts, H., Redigolo, D., Vio, C. & Sergeant, J. A. (2008). Contrasting deficits on executive functions between ADHD and reading disabled children. *Journal of Child Psychology and Psychiatry, 49,* 543–552.

Mayr, U. (2002). On the dissociation between clustering and switching in verbal fluency: Comment on Troyer, Moscovitch, Winocur, Alexander and Stuss. *Neuropsychologia, 40,* 562-566.

McLoughlin, D., Fitzgibbon, G., & Young, V. (1994). *Adult dyslexia: Assessment, counselling and training.* London: Whurr.

Menghini, D., Finzi, A., Benassi, M., Bolzani, R., Facoetti, A., Giovagnoli, S., Ruffino, M., & Vicari, S. (2010). Different underlying neurocognitive deficits in developmental dyslexia: A comparative study. *Neuropsychologia, 48,* 863-872.

Mervis, C. B., & Klein-Tasman, B. P. (2004). Methodological issues in group-matching designs: α levels for control variable comparisons and measurement characteristics of control and target variables. *Journal of Autism and Developmental Disorders, 34,* 7-17.

Mielnik, A., Lockiewicz, M., & Bogdanowicz, M. (2015). Semantic and phonological verbal fluency in students with dyslexia. *Acta Neuropsychologica*, *13,* 253-266.

Miller-Shaul, S. (2005). The characteristics of young and adult dyslexic readers on reading and reading related cognitive tasks as compared to normal readers. *Dyslexia, 11,* 132–151.

Miyake A., & Friedman N. P. (2012). The nature and organization of individual differences in executive functions: Four general conclusions. *Current Directions in Psychological Science, 21,* 8-14.

Miyake A., Friedman N. P., Emerson M. J., Witzki A. H., Howerter A., & Wager T. D. (2000). The unity and diversity of executive functions, and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41,* 49-100.

Moore, L.H., Brown, W.S., Markee, T.E., Theberge, D.C., & Zvi, J.C. (1995). Bimanual coordination in dyslexic adults. *Neuropsychologia, 33,* 781-793.

Moura, O., Simões, M. R., & Pereira, M. (2014). Executive functioning in children with developmental dyslexia. *The Clinical Neuropsychologist, 28,* S20-S41.

Newcombe, F. (1969). *Missile wounds of the brain.* London: Oxford University Press.

Nicolson, R. I., & Fawcett, A. J. (1997). Development of objective procedures for screening and assessment of dyslexic students in higher education. *Journal of Research in Reading*, *20*, 77-83.

Pennington, B. F., & Ozonoff, S. (1996). Executive functions and developmental psychopathology. *Journal of Child Psychology and Psychiatry, 37,* 51-87.

Phillips, L. H. (1997). Do "frontal tests" measure executive function? Issues of assessment and evidence from fluency tests. In P. M. A. Rabbitt (Ed.), *Methodology of frontal and executive function* (pp. 191-213). Hove, East Sussex: Psychology Press.

Plaza, M., Cohen, H., & Chevrie-Muller, C. (2002). Oral language deficits in dyslexic children: weaknesses in working memory and verbal planning. *Brain & Cognition, 48,* 505-512.

Plaza, M. & Guitton, C. (1997). Working memory limitation, phonological deficit, sequential disorder and syntactic impairment in a child with a severe developmental dyslexia. *Dyslexia, 3,* 93-108.

Rabbitt, P. (1997). Introduction: Methodologies and models in the study of executive function. In P. Rabbitt (Ed.), *Methodology of frontal and executive function* (pp. 1-38). Hove, UK: Psychology Press.

Regard, M., Strauss, E., & Knapp, P. (1982). Children's production on verbal and non-verbal fluency tasks. *Perceptual and Motor Skills, 55,* 839-844.

Reid, A. A., Szczerbinski, M., Iskierka-Kasperek, E., & Hansen, P. (2007). Cognitive profiles of adult developmental dyslexics: Theoretical implications. *Dyslexia, 13,* 1-24.

Reiter, A., Tucha, O., & Lange, K. W. (2005). Executive functions in children with dyslexia. *Dyslexia, 11*, 116-131.

Rosen, V. M., & Engle, R. W. (1997). The role of working memory capacity in retrieval. *Journal of Experimental Psychology: General, 126*, 211-227.

Ruff, R.M., Light, R.H., & Evans, R.W. (1987). The Ruff Figural Fluency Test: A normative study with adults. *Developmental Neuropsychology, 3,* 37-51.

Ruff, R. M., Light, R. H., Parker, S. B., & Levin, H. S. (1997). The psychological construct of word fluency. *Brain and Language, 57,* 394-405.

Shallice, T., & Burgess, P. W. (1991). Deficits in strategy application following frontal lobe damage in man. *Brain, 114,* 727-741.

Shao, Z., Janse, E., Visser, K., & Meyer, A. S. (2014). What do verbal fluency tasks measure? Predictors of verbal fluency performance in older adults. *Frontiers in Psychology, 5,* Article 772.

Siegel, L. S. (2006). Perspectives on dyslexia. *Paediatrics & Child Health, 11,* 581-587.

Smith-Spark, J. H., & Fisk, J. E. (2007). Working memory functioning in developmental dyslexia. *Memory, 15*, 34-56.

Smith-Spark, J. H., Fisk, J. E., Fawcett, A. J., & Nicolson, R. I. (2003). Central executive impairments in adult dyslexics: Evidence from visuospatial working memory performance. *European Journal of Cognitive Psychology, 15*, 567-587.

Smith-Spark, J. H., Henry, L. A., Messer, D. J., Edvardsdottir, E., & Zięcik, A. P. (2016). Executive functions in adults with developmental dyslexia. *Research in Developmental Disabilities, 53-54,* 323-341.

Snowling, M. J., Nation, K., Moxham, P., Gallagher, A., & Frith, U. (1997). Phonological processing skills of dyslexic students in higher education: A preliminary report. *Journal of Research in Reading, 20,* 31-41.

Stuss, D. T., & Benson, D. F. (1997). The frontal lobes and the control of cognition and memory. In E. Perecman (Ed.), *The frontal lobes revisited* (pp. 141-158). New York: IRBN Press.

Torgeson, J. K. (1977). The role of nonspecific factors in the task performance of learning disabled children: A theoretical assessment. *Child Development*, *48*, 56-60.

Troyer, A. K. (2000). Normative data for clustering and switching on verbal fluency tasks. *Journal of Clinical and Experimental Neuropsychology, 22,* 370-378.

Troyer, A. K., Moscovitch, M., & Winocur, G. (1997). Clustering and switching as two components of verbal fluency: Evidence from younger and older healthy adults. *Neuropsychology, 11*, 138-146.

Turner, M. (1997). *Psychological assessment of dyslexia.* London: Whurr.

Varvara, P., Varuzza, C., Sorrentino, A. C. P., Vicari, S., & Menghini, D. (2014). Executive functions in developmental dyslexia. *Frontiers in Human Neuroscience, 8*(120).

Vellutino, F. R. (1979). *Dyslexia: Theory and research.* Cambridge, MA: MIT Press.

Vellutino, F. R., Fletcher, J. M., Snowling, M. J., & Scanlon, D. M. (2004). Specific reading disability (dyslexia): What have we learned in the past four decades? *Journal of Child Psychology and Psychiatry, 45*, 2-40.

Wechsler, D. (1993). *The Wechsler Objective Reading Dimensions.* London: The Psychological Corporation.

Wechsler, D. (2010). *Wechsler Adult Intelligence Scale – Fourth UK Edition*. San Antonio, TX: The Psychological Corporation.

Wilson, A.M., & Lesaux, N.K. (2001). Persistence of phonological processing deficits in college students with dyslexia who have age-appropriate reading skills. *Journal of Learning Disabilities, 34,* 394-400.

Author note

Correspondence concerning this article should be addressed to James H. Smith-Spark, Division of Psychology, School of Applied Sciences, London South Bank University, 103 Borough Road, London, SE1 0AA, United Kingdom.

The authors would like to thank Tina Šorc for her assistance in data collection.

Table 1:

Mean scores for the background measures. *Standard deviations in parentheses.*

	Group with dyslexia	Group without dyslexia
Age (years)	24.64	22.75
	(4.62)	(4.48)
WAIS-IV short-form IQ	108.38	105.96
	(7.75)	(8.38)
DAST non-word reading score	78.75	92.71
	(11.80)	(2.84)
WORD spelling test raw score	40.39	44.89
	(3.93)	(1.52)

Table 2

Summaries of the hierarchical multiple regression analyses conducted on the Letter Fluency task. For each regression, short-form IQ was entered at Block 1 and participant group was entered at Block 2 (without dyslexia = 0, with dyslexia = 1). For Block 2, information is provided on the total variance accounted for by the model (total R^2), change in R^2 (ΔR^2), and the standardized β-values for the two predictor variables. Significance values are given where they are relevant. Means and SDs for the two participant groups are also presented.

Letter Fluency measure	Total R^2	ΔR^2 Block 2	β Short-form IQ	β Presence of Dyslexia	Mean score (SD) of the group with dyslexia	Mean score (SD) of the group without dyslexia
Total responses	.257	.147 **	.391 **	-.388 **	36.07 (9.91)	43.21 (10.95)
Valid responses	.265	.140 **	.410 **	-.379 **	35.50 (9.55)	42.07 (10.47)
Total errors	.038	.035	-.027	-.190	0.54 (0.80)	1.07 (1.78)
Number of switches	.198	.095 *	.368 **	-.311 *	29.18 (8.81)	33.54 (7.94)
Words per cluster	.013#	.013	.057	-.112	1.26 (0.18)	1.29 (0.12)
Quartile 1	.184	.087 *	.356 **	-.259 *	15.04 (3.61)	16.71 (3.15)
Quartile 2	.128	.128 **	.300 *	-.358 **	8.36 (2.47)	10.64 (3.51)
Quartile 3	.221	.039	.457 ***	-.218	6.50 (2.94)	7.32 (3.40)
Quartile 4	.077	.077	.216	-.277 *	5.71 (2.90)	7.54 (3.50)

Key: *$p < .05$; **$p < .01$; ***$p < .001$. # Overall regression model was not significant.

For Quartile 2, IQ was not entered in Block 1 due to collinearity problems.

Table 3:

Summaries of the hierarchical multiple regression analyses conducted on the Category Fluency task. See Table 2 for explanations of the analyses.

Category Fluency measure	Total R^2	ΔR^2 Block 2	β Short-form IQ	β Presence of Dyslexia	Mean score (SD) of the group with dyslexia	Mean score (SD) of the group without dyslexia
Total responses	.154	.046	.361 **	-.216	42.57 (7.45)	45.25 (9.12)
Valid responses	.148	.047	.351 **	-.218	42.11 (7.64)	44.86 (9.03)
Total errors	.017#	.006	-.115	.080	0.93 (1.36)	0.79 (0.92)
Number of switches	.047#	.015	.199	-.122	13.04 (4.59)	13.75 (3.15)
Words per cluster	.021#	.011	.087	.104	1.97 (0.75)	1.83 (0.42)
Quartile 1	.024#	.024	.140	-.156	16.00 (3.17)	17.07 (3.71)
Quartile 2	.001#	.001	.175	-.023	10.43 (3.61)	10.57 (2.57)
Quartile 3	.113	.030	.315 *	-.176	8.36 (2.71)	9.07 (2.92)
Quartile 4	.149	.043	.358 **	-.219	7.25 (3.04)	8.18 (2.96)

Key: *$p < .05$; **$p < .01$; ***$p < .001$. # Overall regression model was not significant.

Table 4:

Summaries of the hierarchical multiple regression analyses conducted on the Design Fluency task. See Table 2 for explanations of the analyses.

Design Fluency measure	Total R^2	ΔR^2 Block 2	β Short-form IQ	β Presence of Dyslexia	Mean score (SD) of the group with dyslexia	Mean score (SD) of the group without dyslexia
Total responses	.258	.003	.513 ***	-.054	31.57 (9.65)	31.14 (8.71)
Valid responses	.276	.012	.530 ***	-.109	27.29 (8.36)	27.75 (8.00)
Total errors	.079 #	.035	.180	.190	2.39 (2.22)	1.57 (1.48)
Switching total correct	.210	.017	.459 ***	-.132	38.50 (8.89)	38.79 (11.76)
Number of correct switching responses	.224	.007	.479 ***	-.086	8.04 (2.50)	8.36 (2.67)

Key: *$p < .05$; **$p < .01$; ***$p < .001$. # Overall regression model was not significant.

Table 5:

Summaries of the hierarchical multiple regression analyses conducted on the Swiching Fluency trials of the Category and Design Fluency tasks. See Table 2 for explanations of the analyses.

Switching Fluency measure	Total R^2	ΔR^2 Block 2	β Short-form IQ	β Presence of Dyslexia	Group with dyslexia mean score (SD)	Group with dyslexia mean score (SD)
Category Switching total correct responses	.124 *	.037	.324	-.195	13.64 (2.04)	14.36 (2.83)
Category Switching total switching accuracy	.106 #	.040	.287	-.202	11.93 (2.57)	12.82 (3.07)
Design Switching total correct	.210 **	.017	.459 ***	-.132	38.50 (8.89)	38.79 (11.76)
Design Switching number of correct switching responses	.224 ***	.007	.479 ***	-.086	8.04 (2.50)	8.36 (2.67)

Key: *$p < .05$; **$p < .01$; ***$p < .001$. [#] Overall regression model was not significant.