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Executive functions in adults with developmental dyslexia

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Abstract

Background: Executive functioning (EF) deficits are well recognized in developmental dyslexia, yet the majority of studies have concerned children rather than adults, ignored the subjective experience of the individual with dyslexia (with regard to their own EFs), and have not followed current theoretical perspectives on EFs. Aims and Methods: The current study addressed these shortfalls by administering a self-report measure of EF (BRIEF-A; Roth, Isquith & Gioia, 2005) and experimental tasks to IQ-matched groups of adults with and without dyslexia. The laboratory-based tasks tested the three factors constituting the framework of EF proposed by Miyake et al. (2000). Results: In comparison to the group without dyslexia, the participants with dyslexia self-reported more frequent EF problems in day-to-day life, with these difficulties centering on metacognitive processes (working memory, planning, task monitoring, and organization) rather than on the regulation of emotion and behaviour. The participants with dyslexia showed significant deficits in EF (inhibition, set shifting, and working memory). Conclusions and Implications: The findings indicated that dyslexia-related problems have an impact on the daily experience of adults with the condition. Further, EF difficulties are present in adulthood across a range of laboratory-based measures, and, given the nature of the experimental tasks presented, extend beyond difficulties related solely to phonological processing.

Keywords: Developmental Dyslexia; Executive Functions; Adult cognition

What this paper adds

Executive functioning (EF) deficits are well documented in children with dyslexia, but are less well explored in adults. Two studies addressed this issue, using the same participants: 30 adults with dyslexia and 30 age- and IQ-matched controls. Firstly, a self-report measure assessed the frequency of EF failure in everyday life in the last month. Secondly, EF tasks tapping the different facets of EF under a theoretically coherent account of EF were administered. Adults with dyslexia identified themselves as experiencing EF failures more frequently in day-to-day life. Particular difficulties emerged in working memory, task monitoring, and planning and organization. Whilst differences were found in metacognitive aspects of EF, the groups did not differ in emotional regulation. On the laboratory-based tasks, the group with dyslexia was less able to inhibit pre-potent responses, incurred a greater temporal cost in switching between cognitive operations, and was less able to update working memory. In the latter case, differences emerged on a non-phonological working memory task as well as on a phonologically-based measure. On the reflective level of cognition (Stanovich, 2009), the results show how EF failures affect everyday life in adults with dyslexia. These difficulties were also apparent when performance was measured in the laboratory, indicating similar problems on the algorithmic level of cognition. No previous work has considered both self-report and laboratory EF performance in the same sample of adults with dyslexia. The results thus offer a greater understanding of the EF problems facing adults with dyslexia.

Executive functions in adults with developmental dyslexia

1. General Introduction

Developmental dyslexia (henceforth, dyslexia) is a learning disorder typically defined in terms of persistent difficulties with reading or spelling, or both (Lyon, Shaywitz & Shaywitz, 2003; Siegel, 2006). Such problems with literacy have led to the phonological core deficit hypothesis of dyslexia being proposed (e.g., Stanovich, 1988; Vellutino, 1979), which assumes that phonological processing difficulties are at the root of the condition (for a review, see Vellutino, Fletcher, Snowling & Scanlon, 2004). However, evidence has indicated that there are wider cognitive deficits associated with dyslexia (e.g., Facoetti et al., 2000; Jorm, 1983; Tallal, 1985), and that its impact on cognition persists into adulthood (e.g., McLoughlin, Fitzgibbon & Young, 1994). Given that day-to-day demands on cognition are likely to be very different in adulthood to those in childhood, it is important to study the cognition of adults with dyslexia in its own right. The current paper used self-report and laboratory measures to investigate one problematic area of cognition, executive functioning (EF), in which deficits are well documented in children (see Booth, Boyle & Kelly, 2010, for a review) but less well explored in adults.

Executive functions allow self-regulation and the enactment of goal-directed behavior, permitting the coordination of different cognitive processes over time. They include such higher-order cognitive abilities as planning, problem solving, organizing behaviour, sequencing, self-monitoring, inhibiting verbal and motor responses, accessing information in long-term memory in a controlled and flexible manner, adapting responses to changes in task or environmental demands, dual-task management, and ensuring that task-relevant information is retained over the duration for which it is needed (e.g., Andrés, 2003; Barkley, 1997; Fisk & Sharp, 2004; Miyake & Friedman, 2012; Pennington & Ozonoff, 1996; Rabbitt, 1997; Stuss & Benson, 1997).

Previous research on EF in dyslexia has mainly concerned cognition in childhood (where general developmental evidence has indicated that the structure of EFs may differ from that of adults; Best, Miller & Jones, 2009; van der Ven, Kroesbergen, Boom & Leseman, 2013). Further, it has tended to use a range of EF measures in a piecemeal and theoretically ad hoc manner, often failing adequately to match participant groups for IQ, and ignoring the self-perspective of the individual with dyslexia on his or her own EFs. The current paper investigated EF in adults with dyslexia, taking into account their own views, and exploring EF in terms of an established theoretical framework (Miyake et al., 2000). Study 1 investigated where adults with dyslexia considered their problems with EF to lie in everyday life, whilst laboratory-based experimental work was conducted in Study 2, drawing on the components of EF identified within Miyake et al.'s three-factor structure. The specific predictions relating to Studies 1 and 2 are set out in Sections 2.1 and 3.1 respectively.

2. Study 1: Self-ratings of EF

2.1. Introduction

Some self-report measures have previously been used to assess the everyday cognitive performance of adults with dyslexia. For example, Smith-Spark, Fawcett, Nicolson, and Fisk (2004) administered the Cognitive Failures Questionnaire (CFQ; Broadbent, Cooper, Fitzgerald & Parkes, 1982) to compare the relative frequency with which errors were reported as occurring in the day-to-day cognition of university students with and without dyslexia. Smith-Spark et al. found that the group with dyslexia reported significantly more frequent cognitive failures than a control group matched for age and IQ (for similar findings, see Leather, Hogh, Seiss & Everatt, 2011). More particularly, respondents with dyslexia had problems with distractibility, over-focusing their attentional resources to the detriment of noticing peripheral information, and

word-finding. Significant others (such as relatives and housemates) corroborated these problems with distractibility, absentmindedness, and disorganization in the group with dyslexia. Some CFQ items may be interpreted as tapping into EF failure, but the CFQ is not sufficiently focused on particular aspects of EF for definitive conclusions to be drawn.

A more focused measure of EF, centered on everyday functioning, is the Behavior Rating Inventory of Executive Function (BRIEF; Gioia, Isquith, Guy & Kenworthy, 2000). The BRIEF uses ratings from parents, teachers and participants themselves to assess behaviour relating to EF in the home and school environments of five- to 18-year-old children. Locascio, Mahone, Eason, and Cutting (2010) administered the BRIEF to parents of children aged 10 to 14 years, finding that respondents whose children had poor word recognition skills rated their offspring as having significantly higher levels of executive dysfunction than both children with comprehension problems and controls. However, only scores on the Global Executive Composite (GEC) were reported. This overall summary score, collapsed as it is across different facets of EF, does not reveal the specific aspects of EF that parents of children with dyslexia rate as problematic.

McLoughlin et al. (1994) advocate studying adults with dyslexia in their own right, not treating them as children with dyslexia who have grown up. Indeed, the daily experiences and demands on cognition of adults with dyslexia are different to those of children and present unique challenges. For example, by making careful choices over the type of profession he or she enters, the adult with dyslexia may avoid dealing with most situations involving high demands on literacy, yet will still encounter day-to-day situations that draw on cognitive resources affected by the condition (e.g., following spoken instructions or working in the face of distraction).

The adult version of the BRIEF (BRIEF-A; Roth, Isquith & Gioia, 2005) was, therefore, used in Study 1 to gain an understanding of participants' own ratings of their EF under everyday conditions. Scores for the different indices and clinical scales making up the BRIEF-A were recorded and analyzed in order to gain a finer-grained understanding of any EF problems identified. Educational psychologists' reports were checked for all participants with dyslexia to ensure that there was no reported co-morbid Attention Deficit Hyperactivity Disorder (ADHD) in the sample. On the basis of Locasio et al. (2010), it was hypothesized that the participants with dyslexia would self-report more frequent failures of EF than a group of control adults, matched for age and IQ and with reading and spelling scores in the typical adult range. Higher GEC scores were, therefore, expected in the group with dyslexia. Beyond this, the general literature on EF in dyslexia (e.g., Booth et al., 2010) suggested that group-related differences might be found on the Metacognition Index; in particular, problems were expected with working memory, organization, and planning. Problems on the Behavioral Regulation Index were hypothesized to be less likely. Many of the scales making up the latter index are related to emotional control and, thus, it was not thought that there would be a group difference on this summative index given previous findings by Smith-Spark et al. (2004), who reported that the CFQ item relating to emotional control did not show a significant group difference.

2.2. Method

2.2.1. Participants

Sixty-one university students took part in the study (overall mean age = 24 years, SD = 5, range = 18-40 years). They were awarded a small honorarium or course credits for their participation. There were 31 participants in the group with dyslexia (23 female, 8 male), each of whom presented the experimenter with an educational psychologist's report prior to testing

confirming that they had a diagnosis of dyslexia, and 30 participants who did not have dyslexia in the control group (22 female, 8 male). The two groups did not differ significantly in age. Table 1 shows the mean ages for the two groups, together with their mean scores on the background measures described in the remainder of Section 2.2.1. Inferential statistics are also presented in the table.

TABLE 1 ABOUT HERE

None of the participants in the control group reported reading or writing problems. Whilst Nicolson and Fawcett (1997) have found that self-reports of not having dyslexia are highly accurate, reading and spelling measures were administered to both participant groups to provide a further check to ensure the validity of the participant groupings.

Reading was assessed by the Nonsense Word Reading passage from the Dyslexia Adult Screening Test (DAST; Fawcett & Nicolson, 1998), which requires the reading of a short passage containing both real words and orthographically legal nonsense words. Even adults with dyslexia whose reading is otherwise compensated are impaired in the ability to decode novel words (Brachacki, Fawcett & Nicolson, 1994; Finucci et al., 1976), so this task is highly sensitive to the presence of dyslexia. Accuracy and speed of reading are measured and combined to produce an overall score. The reading performance of the participants with dyslexia was significantly worse than that of the control group.

The spelling component of the Wechsler Objective Reading Dimensions (WORD; Wechsler, 1993) was administered in the standardized fashion, with participants being presented with a series of words to spell, each set in the context of a sentence. Testing was ended when six successive words were spelt incorrectly. Scores of 42/50 or greater on this measure indicated a spelling age in the adult range (being greater than 17 years and the ceiling spelling age on the

task). The group with dyslexia had significantly lower mean WORD spelling raw scores than the control group. Eighteen participants in the group with dyslexia had spelling ages falling below the normal adult range, whilst every participant in the control group obtained a spelling age greater than 17 years.

The Digit-Symbol subtest of the Wechsler Adult Intelligence Scale-III (WAIS-III; Wechsler, 1998) was used to assess processing speed, another area of impairment in dyslexia (see, for example, Booth et al., 2010). The group with dyslexia were significantly slower at processing information than the control group.

Four further subtests from the Wechsler Adult Intelligence Scale- Fourth UK Edition (WAIS-IV; Wechsler, 2010) were administered: Picture Completion, Block Design, Comprehension, and Vocabulary. As none of these subtests are sensitive to the presence of dyslexia, they can be combined to produce a short-form IQ independent of the effects of dyslexia (Turner, 1997). A one-way ANOVA indicated that there was no significant difference in short-form IQ between the two participant groups.

Finally, to screen for potential comorbid Attention Deficit (Hyperactivity) Disorder, the Test of Everyday Attention (TEA; Ward & Ridgeway, 1994) was presented to all participants. A one-way MANOVA conducted on the scales constituting the TEA indicated that there was no significant multivariate effect of participant group on performance, Wilks' $\Lambda = .857$, $F(8, 51) = 1.06$, $p = .406$. One participant with dyslexia failed to complete the TEA.

2.2.2. Materials

The BRIEF-A (Roth et al., 2005) was used to obtain self-ratings of EF. Participants responded to 75 questions on a three-point scale, indicating the frequency with which they felt that they had experienced a particular everyday problem related to EF over the past month (1 =

Never, 2 = Sometimes, and 3 = Often). Higher scores on the BRIEF-A indicated a greater frequency of self-reported problems. As well as providing a GEC score for each participant, questionnaire items also contributed scores towards different clinical scales, each reflecting a different area of EF. The clinical scales formed two indices, Metacognition and Behavioral Regulation.

The Metacognition Index reflected the ability to solve problems in an organized, planned, systematic way, using working memory. It consisted of five clinical scales: the Initiate scale addressed how easy individuals had found it to start tasks and activities or to generate ideas or problem-solving strategies independently of others; the Working Memory scale measured the ability to maintain information in memory in an active state, allowing the successful completion of a task or production of a response; the Plan/Organize scale assessed the ability to oversee current and future task demands; and Organization of Materials provided an indication of the orderliness of the respondent's everyday environment, across different personal spaces (e.g., home and work).

The Behavioral Regulation Index assessed how well an individual felt that he or she had controlled and regulated his or her emotional responses and behaviour. It consisted of four scales: the Inhibit scale provided a measure of inhibitory control, with the respondent rating how able he or she had been to resist acting on impulse and desist from behaviour at an appropriate point; the Shift scale indicated how able the respondent had been to move flexibly between situations, activities, or problem spaces; the Emotional Control scale measured how well the respondent had been able to temper emotional responses to events or situations; and the Self-Monitor scale indexed how well the respondent had been able to monitor his or her own behaviour and its effect on surrounding people.

2.2.3. Design

One-way unrelated analyses of variance (ANOVAs) were run on the three summary scores derived from the BRIEF-A raw scores (GEC, the Metacognition Index, and the Behavioral Regulation Index). Participant group was entered as the between-subjects factor (levels: group with dyslexia, group without dyslexia).

One-way multivariate analyses of variance (MANOVAs) were used to analyze the raw scores from the nine Clinical Scales, with participant group entered as the between-subjects factor. The dependent variables were the raw scores on the Initiate, Working Memory, Plan/Organize, Task Monitor, Organization of Materials, Shift, Emotional Control, Inhibit, and Self Monitor scales.

In addition to the clinical scales, three further scales were used to assess the validity of the participants' responses. The Negativity scale indicated the extent to which responses to certain BRIEF-A questions were answered negatively and provided a means of highlighting individuals who had an unusually negative view of themselves. The Infrequency scale provided an indication of atypical responses by respondents, drawing on five items which should usually be endorsed in only one direction by the majority of respondents. Finally, Inconsistency assessed how consistently an individual responded to ten sets of BRIEF-A items paired for similarity.

2.2.4. Procedure

The participants all gave written informed consent to take part in the study. The study was given ethical approval by London South Bank University's University Research Ethics Committee. Testing was conducted on an individual basis. The IQ and screening measures were administered in an initial hour-long session. The BRIEF-A was administered in a separate session, one day to a week after the initial screening session.

A verbal debriefing followed the administration of the BRIEF-A.

2.3. Results

Overall, the group with dyslexia (mean = 130.19, $SD = 20.35$) had a higher BRIEF-A GEC raw score than the group without dyslexia (mean = 113.97, $SD = 21.78$). A one-way ANOVA showed that the group difference in GEC raw scores was statistically significant, $F(1, 60) = 9.17$, $MSE = 444.263$, $p = .004$, $\eta_p^2 = .133$. The group with dyslexia (mean = 78.13, $SD = 14.17$) indicated more frequent problems on the Metacognition Index than the group without dyslexia (mean = 64.87, $SD = 12.10$). A one-way ANOVA indicated that there was a significant group difference in raw scores on the Metacognition Index, $F(1, 60) = 15.70$, $MSE = 173.549$, $p < .001$, $\eta_p^2 = .207$. Whilst the group with dyslexia (mean = 52.10, $SD = 8.81$) scored slightly higher on the Behavioral Regulation Index than the group without dyslexia (mean = 48.77, $SD = 10.70$), this difference was not statistically significant, $F(1, 60) = 1.78$, $MSE = 96.002$, $p = .187$.

The mean raw scores on the nine clinical scales making up the Metacognition and Behavioral Regulation indices are shown in Table 2. The group with dyslexia rated themselves as experiencing a greater frequency of problems than the group without dyslexia on all nine BRIEF-A scales. A MANOVA indicated a significant multivariate effect of participant group on mean raw scores, Wilks' $\Lambda = .653$, $F(9, 51) = 3.02$, $p = .006$, $\eta_p^2 = .347$. The univariate ANOVA results are also shown in Table 2 for each Clinical Scale score. After applying Bonferroni corrections (resulting in an adjusted α -level of .006), the group with dyslexia scored significantly lower than the group without dyslexia on three of the nine BRIEF-A clinical scales (Working Memory, Plan/Organize, and Task Monitor; all p -values $\leq .004$).

TABLE 2 ABOUT HERE

The Negativity score of the group with dyslexia (mean = 0.62, $SD = 1.02$) was slightly higher than that of the control group (mean = 0.56, $SD = 1.01$), but not significantly so, $t(54^1) < 1$, $p = .811$. The control group (mean = 0.19, $SD = 0.48$) had a slightly higher Infrequency score than the group with dyslexia (mean = 0.14, $SD = 0.35$), but not to a statistically significant extent, $t(54) < 1$, $p = .676$. The group with dyslexia had a higher Inconsistency score (mean = 4.31, $SD = 1.67$) than the group without dyslexia (mean = 3.74, $SD = 1.67$); again, this difference was not significant, $t(54) = 1.10$, $p = .277$.

2.4. Discussion

As predicted, the GEC scores on the self-report BRIEF-A (Roth et al., 2005) indicated that the adults with dyslexia rated themselves as having experienced more frequent problems with EF in the past month than a group of adults without dyslexia matched for IQ. In particular, the metacognitive aspects of EF were found to be more problematic than those relating to emotional control. On the Metacognition Index, the adults with dyslexia rated themselves as significantly more prone to problems with working memory, as having more problems managing current and future task demands, and having greater difficulty keeping track of successes and failures in problem solving. As expected, whilst everyday difficulties with EF were perceived as being prevalent on three out of five Metacognition subscales, the two participant groups did not differ significantly on the Behavioral Regulation Index, indicating no differences in their relative ability to regulate and control behaviour and emotional responses. The latter finding is consistent with Smith-Spark et al.'s (2004) results (which drew upon a more limited number of questions relating to the regulation of emotions). Zelazo and Müller (2002) have argued that EFs run along a continuum from “cool” to “hot”. Cool EFs tend to be used in abstract, decontextualized tasks such as those commonly employed in laboratory settings. Hot EFs, on the other hand, are

involved when tasks have motivational significance to the individual and are also engaged in the deliberate control of emotion. The two types of EF are typically brought together to bear on real-world problems (e.g., Zelazo, 2015). The Metacognition Index has been associated with “cool” EFs and the Behavioral Regulation Index with “hot” EFs by Giancola, Godlaski, and Roth (2012). The results of the BRIEF-A reported in Study 1 are, from this perspective, suggestive of selective problems with “cool” EFs in dyslexia, whilst “hot” EFs are unimpaired.

The significant problems with EF in everyday life found in Study 1 are consistent with the parental ratings of children with and without dyslexia obtained by Locascio et al. (2010). Problems with EF may be carried over into adulthood by individuals with dyslexia and are perceived as having a negative impact on day-to-day living. Study 1, therefore, provides finer grained evidence as to how perceived problems with EF affect higher-order cognitive functioning. The self-reported problems with monitoring and planning are similar to those identified by participants with dyslexia and their close friends and relatives in Smith-Spark et al.'s (2004) study. More broadly, the data highlight the way in which problems with working memory (e.g., Jorm, 1983; Palmer, 2000; Smith-Spark, Fisk, Fawcett & Nicolson, 2003) and planning (e.g., Gilroy & Miles, 1996; Levin, 1990; Torgeson, 1977) can have an impact on everyday situations. Diamond (2013) has highlighted the consequences of poor EFs across most, if not all, aspects of everyday life, from general quality of life through to marital harmony, job success, and public safety.

It is possible that the participants with dyslexia rated themselves as having more problems with EF due to the lowered self-esteem often associated with the condition (e.g., McNulty, 2003; Riddick, Sterling, Farmer & Morgan, 1999). However, the group with dyslexia did not produce Negativity scores that differed significantly from those of the controls (nor were

there differences on the other two measures of BRIEF-A validity, namely Inconsistency and Infrequency). Furthermore, one would expect an explanation rooted in lower self-esteem to apply equally to the Behavioral Regulation Index and the Metacognition Index, resulting in people with dyslexia reporting significantly more problems on both indices. Instead, the results of Study 1 indicate that statistically significant group differences emerged only on the Metacognition Index.

From these self-report data, problems with EF are experienced more frequently in the day-to-day lives of adults with dyslexia and these problems are related to systematic, organized behaviour (which tends to draw on working memory resources). However, the literature on EF in adults with dyslexia is limited and there can be discrepancies between questionnaire- and performance-based assessments of EF. Topiak, West, and Stanovich (2013) have argued that the BRIEF and laboratory-based measures assess different levels of higher-order cognition. In their comparison of 13 studies in which the BRIEF was correlated with a range of performance-based EF measures, less than one in five were significant. Drawing on the terminology of Stanovich (2009), Topiak et al. proposed that the BRIEF assesses the reflective level of cognition (relating to goals, beliefs which relate to those goals, and choices of action to best fit these goals and beliefs), whilst performance-based measures tap into the algorithmic level of cognition (relating to information processing mechanisms). On this basis, there might be little overlap between ratings-based measures of EF and performance-based measures. Topiak et al. emphasized the importance of collecting both types of data to understand EF performance under situations which require either optimal (assessed by laboratory or clinical measures) or typical performance (measured by self-report ratings). Higher-order cognition was, therefore, explored further using laboratory measures administered to the same participants tested in Study 1.

3. Study 2: Laboratory-based measures of executive function

3.1. Introduction

In order to select relevant EF tasks for Study 2, Miyake et al.'s (2000) three-factor structure of EF was adopted (set shifting, inhibition, and updating). The three-factor structure is hypothesized to reflect both the unity and diversity of EFs (Miyake et al., 2000): the constructs are correlated yet also separable as latent variables in young adults. More recently, Miyake and Friedman (2012) proposed that a common EF ability contributes to all three factors, and that a factor-specific ability contributes to updating and set-shifting, but not inhibition. This proposal has been influential, although different structures have been reported and differences may be due to variations in the tasks that have been employed (McCabe, Roediger, McDaniel, Balota & Hambrick, 2010; Salthouse, Atkinson & Berish, 2003). Our approach was to use the original formulation of this model.

Set shifting (or task switching; see Monsell, 2003, for a review) describes the ability to move back and forth flexibly between different tasks or operations, adapting to changes in task demands or environmental context. The cost incurred in switching between cognitive operations or sets (relative to performance when staying “in set”) provides an index of an individual's cognitive flexibility, measured in terms of accuracy or reaction time. Inhibition relates to the ability to prevent automatic, habitual, dominant responses to stimuli, in favour of more context-specific, task-appropriate responses (e.g., Diamond, 2013). Miyake et al.'s (2000) updating aspect of EF refers to the ability to refresh the contents of working memory in the light of new information. Updating is much like Baddeley's (1986) concept of executive-loaded working memory. Indeed, Chein, Moore, and Conway (2011) have argued that the two constructs are highly related and that complex span is the best measure of both.

Set shifting has been studied in dyslexia with varying results. Meltzer (1991) proposed that a lack of cognitive flexibility may prevent individuals with dyslexia from gaining access to metacognitive information in an effective manner when problem solving. Further, Poljac et al. (2010) argued for a specific task switching deficit in children with dyslexia, in addition to a general problem with information processing speed. When asked to match one of four stimuli to a reference figure on the basis of either colour or shape, 12- to 18-year-old participants with dyslexia showed a considerably greater switch cost when shifting between matching the colour and shape criteria than either typically-developing participants or children with autism. Poljac et al. proposed that children with dyslexia might be less able to activate a “now-relevant” task rule or inhibit instantiation of a “now-irrelevant” rule.

Conversely, Stoet, Markey, and Lopez (2007) found no evidence of a task shifting deficit in undergraduate students with dyslexia, using randomly interleaved colour and shape discrimination trials. They concluded that the task impairments that they did find were at a perceptual level, rather than affecting central cognitive processes. However, Poljac et al. (2010) have raised some methodological concerns over stimulus congruence which may explain the absence of a switch cost in Stoet et al.’s study. Nevertheless, several other studies have reported no dyslexia-related differences in task switching or set shifting (e.g., Kapoula et al., 2010; Närhi, Räsänen, Metsäpelto & Ahonen, 1997; Smith-Spark, 2000).

On the basis of the equivocal findings outlined in this section, dyslexia-related deficits in set shifting were considered possible, but not inevitable, in Study 2.

Dyslexia-related impairments in inhibition have been reported on several different tasks, for example, the Stroop test (e.g., Everatt, Warner, Miles & Thomson, 1997; Kapoula et al., 2010; Protopapas, Archonti & Skaloumbakas, 2007; Reiter et al., 2005), the Go/No Go task

(McLean, Stuart, Coltheart & Castles, 2011; although Reiter et al., 2005, found no dyslexia-related difference in either children or adults), and the Wisconsin Card Sorting Test (Kelly, Best & Kirk, 1989; although Smith-Spark, 2000, found no differences in adults). Further to this, Brosnan et al. (2002) used the Group-Embedded Figures Test as a measure of inhibition and found significantly poorer performance in a small sample of adults with dyslexia. They also administered an age-appropriate version of the task to children (the Children's Embedded Figures Test) and, again, found significant deficits in inhibition in the group with dyslexia. Similarly, Wang, Tasi, and Yang (2012) presented six different measures of inhibition to children with dyslexia (comparing them to controls and children with dyscalculia). Their factor analysis revealed that the inhibition tasks loaded onto three factors, namely word, number, and graphical inhibition. Wang et al. found that the group with dyslexia was significantly worse than the controls on both word and graphical inhibition but performed at an equivalent level on number inhibition. These consistent findings suggest that dyslexia-related impairments in inhibition are likely to be found in Study 2.

Working memory impairment has been identified as one of the most problematic areas of EF for children with dyslexia (Booth et al., 2010) and has been argued to be a defining characteristic of dyslexia in adults by McLoughlin et al. (1994). Given the severity of deficits in the phonological domain (e.g., Vellutino, 1979), most research on working memory in dyslexia has focused on identifying impairments in phonological loop function (e.g., Ackerman & Dykman, 1993; Cohen, Netley & Clarke, 1984; Gould & Glencross, 1990; Helland & Asbjørnsen, 2004; Jorm, 1983; Palmer, 2000; Roodenrys & Stokes, 2001). However, it has also been argued that the central executive is also impaired in dyslexia (e.g., Bacon, Parmentier & Barr, 2013; Jeffries & Everatt, 2004; Palmer, 2000; Smith-Spark et al., 2003; Smith-Spark &

Fisk, 2007), although central executive deficits have been claimed to be restricted to tasks drawing on phonological processing (e.g., Brosnan et al., 2002; Jeffries & Everatt, 2003, 2004; Kibby, Marks, Morgan & Long, 2004; Schuchardt, Maehler & Hasselhorn, 2008).

Whilst central executive problems may be most strongly expressed on tasks tapping the function of the phonological loop, there is a growing corpus of research indicating that central executive problems can also be found on visuospatial working memory tasks (e.g., Bacon et al., 2013; Menghini, Finzi, Carlesimo & Vicari, 2011; Olson & Datta, 2002; Swanson, 1992; Swanson, 1999; Varvara, Varuzza, Sorrentino, Vicari & Menghini, 2014), particularly when conditions are cognitively taxing or novel (e.g., Smith-Spark et al., 2003, Smith-Spark & Fisk, 2007). Therefore, it was predicted that executive-loaded working memory deficits would be found across both the phonological and visuospatial domains.

Study 2, therefore, compared the EF performance of a group of adults with dyslexia to a group of control participants without dyslexia. Set shifting was measured using Jersild's (1927) Plus-Minus task. Inhibition was tested using a task which employed a similar methodology to the Go/No Go task but required the inhibition of a pre-potent motor response in favour of a different response. Updating was assessed using executive-loaded working memory span measures. In order to explore the issue of central executive problems in dyslexia manifesting themselves on visuospatial as well as phonological working memory tasks (e.g., Smith-Spark & Fisk, 2007), tests were presented in both processing domains (using Conway et al.'s, 2005, Operation Span and Symmetry Span tasks).

3.2. Method

3.2.1. Participants

See Study 1, except that one participant with dyslexia did not complete all of the tasks.

3.2.2. Materials

Stimuli on the Plus-Minus task (Jersild, 1927) consisted of three printed lists of 30 two-digit numbers.

Two line drawings (a bear and a rabbit) were taken from the Snodgrass and Vanderwart (1980) picture set and used as stimuli in the inhibition task.

The automated versions of the Operation Span (Conway et al., 2005; Unsworth, Heitz, Schrock & Engle, 2005) and Symmetry Span tasks (Conway et al., 2005; Unsworth et al., 2009) were used as measures of executive-loaded working memory.

3.2.3. Design

The order of presentation of the EF tasks was counterbalanced. Participant group (group with dyslexia and group without dyslexia) was used as the between-subjects factor in all analyses.

For each participant, the mean time taken to perform the first two trials of the Plus-Minus task (Plus-3 and Minus-3) was calculated. This mean was then subtracted from the time taken to complete the Plus-Minus trial to give a measure of the cost associated with alternating between the two mathematical operations.

In the course of the inhibition task, a total of 200 stimuli were presented: 80% depicted the line drawing of the bear (the habituated stimulus) and 20% depicted the line drawing of the rabbit (the non-habituated stimulus, requiring the participant to break out from his or her customary response). In order to build up a dominant, pre-potent response (habituation phase), the initial 40 trials consisted entirely of presentations of the bear drawing. A further 160 trials were presented in the inhibition phase of the task (140 habituated stimuli and 20 non-habituated stimuli). The non-habituated stimuli were presented pseudo-randomly every 3-6 trials. The

transition between the two phases of the task was not evident to the participants. They simply responded to the 200 trials of the experiment presented seamlessly in succession.

Five different scores were obtained from the Operation Span (Ospan) task. The first, Ospan Score, was the sum of all the sets of letters that were recalled perfectly by the participant. The total number of letters recalled in the correct position was recorded by Ospan Total. Speed Errors indicated the number of occasions on which a participant ran out of time in attempting to solve a given mathematics operation. Accuracy Errors recorded the number of times that a participant made an incorrect response to the mathematical operation. Speed Errors and Accuracy Errors were combined to create Math Errors, which was the total number of processing task errors committed.

Like the Operation Span task, five scores were obtained from the Symmetry Span task. Symmetry Score was the sum of all perfectly recalled sets of red squares. Symmetry Span Total was the total number of squares recalled in the correct position. The number of occasions on which a participant had made an incorrect response in judging the symmetry of the figures was recorded by Accuracy Error. Speed Error Total indicated the number of times that a participant ran out of time in attempting to indicate whether or not a figure was symmetrical. Accuracy Error and Speed Error Totals were combined to give the Symmetry Error Total (the total number of processing task errors).

3.2.4. Procedure

The participants gave written informed consent to take part in the experiment.

For each list of the Plus-Minus task (Jersild, 1927), the participants were asked to work as quickly and as accurately as they could. Completion times were recorded using a stopwatch. The first list required the participants to add three to each presented number whilst progressing

through the 30 numbers sequentially. For the second list, the participants were instructed to subtract three from each number. On the third, “switching”, list, the participants alternated between adding and subtracting three from each of the sequence of two-digit numbers.

On the inhibition task, the participants were required to press one of two buttons in response to the presentation of two line drawings: the “s” key on the computer keyboard when a picture of a bear appeared on the monitor screen and the “k” key when a picture of a rabbit appeared.

The Operation Span task (Conway et al., 2005; Unsworth et al., 2005) required participants to solve a series of simple mathematical operations whilst also remembering a set of letters. The participants were first presented with practice sessions that focused on the two separate components of the task. Initially, they were presented with a letter span task requiring the recall of sequences of letters in the order in which they had been presented. Following this, the participants practised carrying out simple mathematical operations. The mean length of time required to solve the mathematics problems was calculated automatically by the program at the end of this phase. This mean duration plus 2.5 standard deviations was used as the time limit for the mathematical operations in the experimental phase before a trial was deemed to be incorrect. Unsworth et al. have argued that this individual titration process allows a control for individual differences in the time taken to solve mathematical problems (processing speed) and prevents participants from verbally rehearsing the letters when they should be solving the problems. Next, the letter span and mathematics components were combined in a final practice phase. During this final practice and the experiment itself, the participants were presented with a series of mathematical problems (e.g., $1*2$), with each problem being followed by the onscreen presentation of a further number. If the number was the answer to the preceding mathematical

problem, the participant was instructed to click on a TRUE box presented on the screen, but if the number was not the solution, the participant had to click on a FALSE box instead. After making this decision, the participants were presented with a letter of the alphabet for subsequent recall. At the end of the trial, the participants were asked to recall the letters in the order in which they had appeared. The number of arithmetic problems presented varied between three and seven and there were three trials at each set length.

On the Symmetry Span task (Conway et al., 2005; Unsworth et al., 2009), the participants were presented with a series of black and white figures. For each figure, they were asked to indicate whether or not it was symmetrical in shape. After each figure, the participants were shown a 5 x 5 matrix with one red square highlighted and were asked to remember the position of the highlighted square for subsequent recall. At the end of the trial, the participants recalled the positions of the highlighted squares in serial order. Trial length varied between two and five figures and there were three trials at each set size. The same timing parameters as used in the Operation Span task were used, with the participants carrying out the processing and storage components of the task individually prior to doing the Symmetry Span task itself.

A verbal debriefing concluded the experiment.

3.3. Results

3.3.1. Set shifting

The combined mean time to complete the Add-3 and Subtract-3 trials was 97s ($SD = 39$) for the group with dyslexia and 77s ($SD = 24$) for the group without dyslexia. The mean time to complete the Switching trial was 134s ($SD = 64$) for the group with dyslexia and 93s ($SD = 29$) for the group without dyslexia. The cost values showed that, on average, the group with dyslexia were slowed by 39s ($SD = 39.69$) whilst the group without dyslexia were slowed by 15s ($SD =$

13.25). A one-way ANOVA indicated that the cost attached to switching was significantly greater in the group with dyslexia, $F(1, 59) = 9.77$, $MSE = 887.415$, $p = .003$, $\eta_p^2 = .142$.

3.3.2. Inhibition

Separate two-way mixed measures ANOVAs were conducted on the mean RT and the accuracy data from the inhibition task, comparing group performance over the two phases of the experiment. These analyses were conducted separately for RT and accuracy of performance with the habituated and the non-habituated stimuli. Due to computer error, data were not logged for two participants (one from each participant group). The analyses are, thus, reported on an N of 29 per group.

3.3.2.1. Responses to the habituated stimulus

3.3.2.1. 1. Reaction time

Although the group with dyslexia (mean = 361ms, $SEM = 15.84$) was slightly faster than the group without dyslexia (mean = 377ms, $SEM = 15.84$) in response to the habituated stimulus, a 2 x 2 mixed-measures ANOVA indicated that there was no significant effect of participant group on RT, $F(1, 56) < 1$, $MSE = 14558.186$, $p = .473$.

Overall, faster responses were made by the participants in the initial habituation phase (mean = 352ms, $SEM = 13.93$) than in the inhibition phase of the experiment (mean = 386ms, $SEM = 9.75$). This slowing of performance when potential inhibition was required was highly significant, $F(1, 56) = 15.15$, $MSE = 2210.937$, $p < .001$, $\eta_p^2 = .213$.

There was no statistically significant participant group x phase interaction, $F(1, 56) < 1$, $MSE = 2210.937$, $p = .650$, with more-or-less equivalent slowing in both groups between the habituation and inhibitory phases of the task. Thus, for the “control” (habituated) stimuli no group differences in RT were identified.

3.3.2.1.2. Accuracy

Overall, the two participant groups scored at an equivalent level of accuracy in response to the habituated stimulus (mean = .955, $SEM = .002$ for both groups), with no significant effect of participant group on accuracy, $F(1, 56) < 1$, $MSE < .001$, $p = .781$.

Responses were, on average, more accurate to the habituated stimulus in the habituation phase of the experiment (mean = .997, $SEM = .001$) than in the inhibition phase (mean = .993, $SEM = .001$). The effect of phase on the proportion of correct responses was significant, $F(1, 56) = 7.52$, $MSE < 1$, $p = .008$, $\eta_p^2 = .118$, with more accurate performance in the habituation phase than in the inhibition phase.

Participant group and experimental phase did not interact significantly, $F(1, 56) < 1$, $MSE < 1$, $p = .820$.

3.3.2.2. Responses to the non-habituated stimulus

Separate one-way ANOVAs were performed on the RT and accuracy data in response to the non-habituated stimulus in the inhibition phase.

3.3.2.2.1. Reaction time

The responses of the group with dyslexia (mean = 380ms, $SD = 75.92$) were slightly faster than those of the group without dyslexia (mean = 392ms, $SD = 72.61$), however, this difference in RT was not statistically significant, $F(1, 56) < 1$, $MSE = 5518.299$, $p = .534$.

3.3.2.2.2. Accuracy

The group with dyslexia (mean = .87, $SD = 0.12$) were significantly less accurate in their responses to the non-habituated stimulus than the group without dyslexia (mean = .93, $SD = .07$), $F(1, 56) = 6.07$, $MSE = 0.010$, $p = .017$, $\eta_p^2 = .098$. This was the only significant group difference that was found in the data concerning inhibition.

3.3.3. Updating

3.3.3.1. Span scores (Span Score and Total Span Score)

The group mean scores for the operation span and symmetry span tasks are shown in Table 3. The means indicated that the group with dyslexia performed worse on average than the group without dyslexia on both the span and total score measures across both tasks.

TABLE 3 ABOUT HERE

There was a significant multivariate effect of participant group on performance on the Operation Span task, Wilks' $\Lambda = .867$, $F(2, 57) = 4.39$, $p = .017$, $\eta_p^2 = .133$. The univariate analyses (see Table 3) indicated that the group with dyslexia had both significantly lower span scores than the control group and significantly lower total scores.

There was a significant multivariate effect of participant group on the Symmetry Span task, Wilks' $\Lambda = .894$, $F(2, 57) = 3.37$, $p = .041$, $\eta_p^2 = .106$. Whilst the group with dyslexia had lower span sizes on average, the group difference fell short of statistical significance. However, the group with dyslexia produced significantly fewer correct total responses than the group without dyslexia.

3.3.3.2. Processing task scores (Accuracy, Speed and Symmetry Error)

Group performance on the processing component of the span tasks was also compared. The mean error scores are shown in Table 4, together with t -test statistics. No significant group differences were found for accuracy errors, speed errors, or total errors on either the Operation Span task or the Symmetry Span task.

TABLE 4 ABOUT HERE

To summarize, for updating, the significant group differences involved lower scores for the dyslexia group on operational span (span score and total span) and for symmetrical span (but only the total score).

3.3.4 Correlations between self-report and laboratory measures for the group with dyslexia

To determine whether those individuals reporting more problems in day-to-day life on the BRIEF-A (Roth et al., 2005) were also those performing most poorly on the laboratory-based measures, Pearson's correlations were run on the scores on the individual scales of the BRIEF-A Metacognition Index and the laboratory measures for the group with dyslexia only. The correlations are shown in Table 5. Of most interest to the research question, significant negative correlations were found between Go/No Go accuracy and two BRIEF-A scales, namely Plan/Organize ($p = .010$) and BRIEF-A Organization of Materials ($p = .011$).

TABLE 5 ABOUT HERE

3.4. Discussion

In Study 2, the performance of adults with and without dyslexia was compared on laboratory measures tapping the three factors identified under Miyake et al.'s (2000) conceptualization of EF. The participants with dyslexia showed impairments in all three EF components, namely, shifting, inhibition, and updating.

The cost of switching between cognitive operations on the Plus-Minus task (Jersild, 1927) was two-and-a-half times as great in the group with dyslexia as it was in the control group. The magnitude of the deficit in switching is similar to that reported in children with dyslexia by Poljac et al. (2010) and contrasts with the absence of group-related deficits on other tasks designed to assess set shifting (e.g., Kapoula et al., 2010; Närhi et al., 1997; Smith-Spark, 2000;

Stoet et al., 2007). The data from Study 2 suggest that, depending on the task and the design used, adults with dyslexia can exhibit greater switch costs when compared to control participants matched for IQ.

On the inhibition task, the presence of dyslexia did not influence responses to the habituated stimulus over either phase of the task, either in terms of mean RT or accuracy. Thus, both groups performed at equivalent levels when the customary response was required. However, there was an effect of dyslexia on responses to the non-habituated stimulus. Whilst the mean RT to the non-habituated stimulus did not differ between the two groups, the group with dyslexia was significantly less accurate than the control group in inhibiting the pre-potent response and responding correctly to the appearance of the non-habituated stimulus. These results reveal dyslexia-related problems with inhibition and to add to the range of tasks on which such impairments have previously been reported (e.g., Brosnan et al., 2002; Everatt et al., 1997; Kapoula et al., 2010; Reiter et al., 2005).

Whilst the participants with dyslexia were able to make fast responses to the onset of both habituated and non-habituated stimuli, their lower level of accuracy when confronted with the less frequently appearing stimulus suggests that their performance was less well adapted to changes in the environment than that of the controls. This is consistent with a dyslexia-related problem around task novelty (Smith-Spark & Fisk, 2007), considered in more depth in Section 4. On the habituation trials, the participants with dyslexia did not need to concern themselves with changing information in the environment; rather they had to respond rapidly to an unchanging stimulus. Fawcett and Nicolson (1994) have argued that people with dyslexia may excel at “closed” motor skills (p. 184), which require concentration solely on their own performance, rather than “open” skills where rapid adaptation to situational demands is needed for successful

responses. In contrast to this, Fawcett and Nicolson identify four general types of skill prone to disruption in dyslexia, namely complex skills requiring fluency in component sub-skills, time-dependent skills that call upon fast processing speed, multi-modality skills involving the monitoring of various modalities or sources of information, and vigilance tasks requiring concentration over time. In such cases, Fawcett and Nicolson argue that task demands are such as to prevent the use of conscious compensation to guide performance. The types of skill identified by Fawcett and Nicolson would seem highly likely to draw upon EF resources.

The working memory measures used to assess Miyake et al.'s (2000) updating aspect of EF also highlighted significant dyslexia-related deficits. In contrast to those authors who have argued that central executive impairments in dyslexia are yoked to the phonological loop (e.g., Brosnan et al., 2002; Jeffries & Everatt, 2003, 2004; Kibby et al., 2004; Schuchardt et al., 2008), poor working memory was not restricted solely to the Operation Span task (which draws on phonological processing resources). Performance of the group with dyslexia was also affected on the Symmetry Span task, a measure of visuospatial working memory, albeit to a lesser degree. Whilst the group difference on the span measure of the Symmetry Span task fell short of statistical significance, the performance of the participants with dyslexia was significantly more error-prone on the storage component of the task, resulting in a lower total number correct. Conway et al. (2005) have argued that due to the small range of span values over which performance can vary, absolute span is not a sensitive measure on which to base individual differences research. Garcia, Mammarella, Tripodi, and Cornoldi (2014) have made a similar point when investigating visuospatial working memory in children with dyslexia, and calculated the percentage of items recalled in the correct order per trial rather than using a simple span

measure. Given this, problems with updating memory were present for phonological and visuospatial working memory performance alike.

The results suggest a domain-general deficit in executive-loaded working memory in dyslexia, as proposed, for example, by Smith-Spark et al. (2003), Smith-Spark and Fisk (2007), and Swanson (e.g., 1992, 1999). Deficits on the executive-loaded visuospatial working memory span task are consistent with previous reports of dyslexia-related difficulties becoming apparent under more taxing conditions where central executive processes as well as the visuospatial sketchpad tend to be engaged (e.g., Bacon et al., 2013; Menghini et al., 2011; Smith-Spark et al., 2003; Smith-Spark & Fisk, 2007).

Whilst significant group differences were uncovered on the storage component of the working memory span tasks, the two groups did not differ in the number of errors that they made in response to the processing tasks (mathematical operations or symmetry judgements), neither in terms of speed nor accuracy. Since the executive-loaded span tasks were individually titrated for processing speed, these findings indicate that the dyslexia-related problems on these measures are not explicable in terms of a processing speed deficit.

In line with Topiak et al.'s (2013) findings, there were few significant correlations between the group with dyslexia's scores on the BRIEF-A Metacognition Index scales (Roth et al., 2005) and the laboratory measures administered in Study 2. Indeed, inhibition, as measured by the Go/No Go task, was the only one of the laboratory measures to correlate with self-reports on the BRIEF-A. Poorer inhibition of pre-potent responses was associated with a greater frequency of self-reported problems with organizing tasks and arranging the environment (Plan/Organize and Organization of Materials).

4. General Discussion

Whilst there is a large corpus of research highlighting the phonological processing deficits of children and adults with developmental dyslexia (e.g., Vellutino et al., 2004), the current findings identify EF problems that extend into non-linguistic/non-phonological domains.

In Study 1, the self-report BRIEF-A (Roth et al., 2005) identified self-reported problems for adults with dyslexia in the areas of EF measured by the Metacognition index (Working Memory, Plan/Organize, Task Monitor, Organization of Materials; with Initiate falling just short of significance). The lower scores of the group with dyslexia would not appear to be a result of differences in self-perception or self-esteem (e.g., Riddick et al., 1999), since there was no group difference in Negativity scores and self-ratings did not differ between the groups on the Behavioral Regulation index (as they would do if responses of the participants with dyslexia reflected a generally depressed profile). The findings provide further evidence for the continued impact of dyslexia on the day-to-day lives of adults with the condition, both complementing and supplementing work investigating everyday cognitive failures in adults with dyslexia (Smith-Spark et al., 2004; Leather et al., 2011), many of which also fell outside the types of error that would be predicted by purely phonologically-based accounts (e.g., Vellutino, 1979).

The results of Study 2 suggest that, in general terms, the self-reports of people with dyslexia are borne out in their performance on laboratory measures of EF, tasks that should arguably tap into some of the same underlying cognitive processes as assessed by the BRIEF-A, albeit at an algorithmic rather than reflective level (Stanovich, 2009). The group with dyslexia showed problems with inhibiting pre-potent responses, greater temporal costs in switching between cognitive operations, and more difficulty in updating the contents of working memory (both phonological and visuospatial). Dyslexia-related problems were, therefore, found in all three aspects of Miyake et al.'s (2000) conceptualization of EF tested under laboratory

conditions. Moreover, the nature of the EF tasks employed (tapping variously visuospatial and phonological processing as well as motor responses) indicate that impairments in EF are not limited to tests drawing on phonological processing but can be found across a range of modalities. The results present a challenge to accounts of dyslexia couched solely in terms of phonological processing deficits (e.g., Vellutino, 1979). Friedman and Miyake (2012) have suggested that the three EF components identified under their unity/diversity framework could be further decomposed to the level of subprocesses (e.g., for updating, they suggest monitoring, adding items, actively maintaining information, and deleting items) and studied at this finer-grained level (see also van der Ven et al., 2013). This could be an informative approach to adopt in further studies of EFs in dyslexia, contributing significantly to theoretical accounts of EF impairment in dyslexia by identifying specific subprocesses involved in deficits.

Despite EF deficits being well recognized in the dyslexia literature (e.g., Booth et al., 2010), there is little overarching theory to explain their prevalence. On a general level, a role for EFs in reading is well established (e.g., Sesma, Mahone, Levine, Eason, & Cutting, 2009) and, as a consequence, impairments in EFs are likely to lead to problems with reading comprehension. More specifically relating to dyslexia theory, Levin (1990) proposed dysfunction of the frontal lobes as the reason for planning and organizational problems that she uncovered in children with dyslexia, arguing that the same underlying frontal lobe impairment may be responsible for both reading and problem-solving deficits in dyslexia (see also Kelly et al., 1989; Hynd, 1995).

Nicolson and Fawcett (1990) proposed a general problem with the automatization of any skill in dyslexia, with reading ability being a particularly strong manifestation of this general difficulty. Whilst their Dyslexia Automatization Deficit hypothesis did not relate to EFs directly, they argued that people with dyslexia are able to mask deficits in a range of skills by a process of

conscious compensation, whereby extra attentional resources are allocated to the task at hand to make up for shortfalls in automatic skill. When task demands exceed spare attentional capacity (e.g., under fatigue or stress), dyslexia-related impairments emerge. Under this view, novel or dual-task conditions are highly likely to lead to decrements in performance. Executive functions have been argued to be required in order to respond to novelty (e.g., Shallice & Burgess, 1991), whilst dual-task performance is recognized as a salient EF ability (e.g., Logie, Cocchini, Della Sala & Baddeley, 2004; Salthouse et al., 2003).

Norman and Shallice (1986) argue that the Supervisory Attentional System (SAS) is responsible for the coordination, integration, and control of information and draws on attentional resources to modulate behaviour. It is called upon when task novelty is high or poorly learnt action sequences are demanded. Taking this perspective, Smith-Spark and Fisk (2007) downplay the role of automaticity deficits in dyslexia and instead consider problems with conscious compensation as one aspect of a larger problem with the executive allocation of attention. Smith-Spark and Fisk proposed an SAS impairment in dyslexia to explain problems in with dealing with novel task demands and setting up appropriate cognitive schemata to respond to a visuo-spatial working memory task. Varvara et al. (2014) have recently also made a similar claim regarding SAS dysfunction based on evidence from children.

Whilst not tested under laboratory conditions, the results of the BRIEF-A (Roth et al., 2005) suggest that it is “cool” EFs (e.g., Zelazo & Carlson, 2012), rather than “hot” EFs, which are impaired by dyslexia (a similar argument has been made in relation to ADHD by Zelazo & Carlson, 2012). Further research is needed to explore EFs in dyslexia along the continuum from “hot” to “cool”, perhaps using the knowledge gained to suggest the ways in which relative strengths could be used to benefit performance where EF skills are deficient.

Given the wide-ranging and persistent problems with EF uncovered in Studies 1 and 2, it is important to ensure that children and adolescents with dyslexia are supported not just in their reading and writing skills but also their EFs, especially given their self-reported impact on everyday life in both childhood (Locascio et al., 2010) and adulthood (in Study 2). Under certain conditions and with varying degrees of transferability, EFs can be improved during childhood (e.g., Diamond, 2014; Diamond & Lee, 2011; Jaeggi, Buschkuhl, Jonides & Shah, 2011), at a time when dyslexia can also be identified by classroom teachers and formally diagnosed. Although EFs have been found to develop at different rates (e.g., Best & Miller, 2010; Davidson, Amso, Anderson & Diamond, 2006; Huizinga, Dolan & van der Molen, 2006), this is likely to be the most effective point at which to target EF interventions in individuals either identified as being at risk of dyslexia or actually having a diagnosis of dyslexia.

However, there are also many adults with dyslexia for whom the time for such interventions has passed. In identifying dyslexia-related EF problems in adulthood, a responsibility rests on the researcher to move beyond simply cataloguing deficits to determining means by which those impairments can be ameliorated. Whilst there is less evidence related to improving WM and other EFs in early adulthood (see Diamond, 2013, for a review), some of the EF training methods which have been used (such as video game training; e.g., Dahlin, Nyberg, Bäckman & Stigsdottir Neely, 2008; Nouchi et al., 2013) might usefully be employed to benefit the higher-order cognition of young adults with dyslexia. Moreover, cognitive training for older adults might also be successfully adapted; for example, implementation intentions (e.g., Gollwitzer & Sheeran, 2006) have been shown to improve both prospective memory (dyslexia-related deficits in this area have been self-reported by children, Khan, 2014, and found experimentally in adults, Smith-Spark, Zięcik & Sterling, 2016) and inhibition in older adults by

Burkard et al. (2014). The beneficial role of reflection and the use of rules in improving EFs have been highlighted by Zelazo (2015). He has argued for the involvement of verbal processes in self-regulation and maintaining task information in memory; given the phonological problems associated with dyslexia (e.g., Vellutino et al., 2004), these processes may be underused or underdeveloped in dyslexia. Bacon et al. (2013) have found that adults with dyslexia are able to make use of rules and strategies when explicitly shown them but are less likely to find them independently. Indeed, a preference in dyslexia for visuo-spatial problem-solving strategies over verbal strategies (e.g., Bacon & Handley, 2010; Bacon, Handley & McDonald, 2007; Torgeson, 1977; von Károlyi, Winner, Gray & Sherman, 2003) may hinder the development of these key skills and have a negative impact on performance across a range of settings (Bacon & Handley, 2014). Explicitly directing people with dyslexia to these verbal regulatory reflective processes may prove beneficial to their EFs.

In conclusion, the current results add to research indicating the persistence of EF impairments in dyslexia into adulthood (e.g., Brosnan et al., 2002) and suggest that these deficits are perceived as affecting everyday life. By administering both self-report and laboratory measures to the same sample of participants, the findings provide convincing evidence that problems with EF are experienced by adults with dyslexia at a reflective cognitive level as well as at an algorithmic level (e.g., Stanovich, 2009). Dyslexia-related EF problems do not just manifest themselves under the artificial conditions of the laboratory environment, but have adverse consequences for day-to-day life. This needs to be recognized when providing support and remediation for adults with dyslexia in employment and educational settings.

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Footnote

¹ Due to experimenter error, the Negativity, Inconsistency, and Infrequency scores for a number of participants were not coded straight after testing (unlike the Clinical Scales). Unfortunately, the response forms belonging to five of these cases could not be located to obtain the values when this omission was discovered. The analyses reported for these three variables were therefore conducted on a slightly reduced sample size (N= 29 for the group with dyslexia and N = 27 for the group without dyslexia).

Table 1:

Mean scores and unrelated t-test results for the background measures taken in Study 1. Standard deviations are shown in parentheses.

Scale	Group with dyslexia	Group without dyslexia	Unrelated t-test			
			<i>t</i>	<i>df</i>	<i>p</i>	<i>d</i>
Age (years)	24.65 (5.35)	23.93 (5.13)	< 1	59	.598	-
WAIS-IV Short- form IQ	109.93 (9.80)	111.20 (9.57)	< 1	59	.609	-
DAST NWR score	78.27 (10.45)	92.83 (2.94)	7.35	33.558*	< .001	1.38
WORD spelling test raw score	41.06 (3.37)	45.57 (1.70)	6.63	44.621*	< .001	1.29
Number of participants with a WORD spelling age of ≤ 17 years	18	0	-	-	-	-
WAIS-III Digit- Symbol	73.35 (11.27)	82.37 (11.94)	3.03	59	.004	0.73

* Levene's test was significant so equal variances were not assumed.

Table 2:

Mean scores for the BRIEF-A Clinical scales (standard deviations in parentheses), together with MANOVA test statistics. MI = Metacognition Index; BRI = Behavioral Regulation Index.

Clinical Scale (Index)	Mean raw scores (<i>SD</i>)		MANOVA test statistics			
	Group with dyslexia	Group without dyslexia	<i>F</i> (1, 59)	<i>MSE</i>	<i>p</i>	η_p^2
Initiate (MI)	14.87 (3.21)	13.37 (2.81)	3.78	9.126	.057	.060
Working Memory (MI)	17.10 (3.41)	13.73 (3.42)	14.78	11.671	< .001	.200
Plan/Organize (MI)	18.58 (4.34)	15.57 (3.43)	9.01	15.371	.004	.132
Task Monitor (MI)	12.68 (2.29)	10.27 (2.24)	17.27	5.130	< .001	.226
Organization of Materials (MI)	14.87 (4.15)	12.30 (3.27)	7.18	14.030	.010	.109
Inhibit (BRI)	14.13 (3.12)	13.13 (3.04)	1.60	9.474	.212	.026
Shift (BRI)	10.58 (2.55)	10.00 (2.39)	< 1	6.130	.363	.014
Emotional Control (BRI)	16.84	16.73	< 1	18.204	.924	< .001

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	(3.95)	(4.57)				
Self-Monitor (BRI)	10.55	9.23	3.261	8.085	.076	.052
	(2.85)	(2.84)				

Table 3

Group mean (SD) span measures for the two working memory span tasks, together with univariate MANOVA test statistics.

Span measure	Mean scores (SD)		MANOVA test statistics			
	Group with dyslexia	Group without dyslexia	<i>F</i> (1, 58)	<i>MSE</i>	<i>p</i>	η_p^2
Operation Span span score	25.30 (14.97)	36.33 (16.25)	7.48	244.051	.008	.114
Operation Span total score	43.47 (15.49)	54.30 (12.80)	8.72	201.961	.005	.131
Symmetry Span span score	14.03 (7.94)	18.13 (9.56)	3.26	77.249	.076	.053
Symmetry Span total score	22.83 (7.40)	27.63 (8.00)	5.82	59.399	.019	.091

Table 4

Group mean (SD) processing performance measures for the two working memory span tasks, together with t-test statistics.

Span measure	Mean scores (SD)		t-test statistics		
	Group with dyslexia	Group without dyslexia	<i>t</i>	<i>df</i>	<i>p</i>
Operation Span Accuracy Error	9.03 (5.55)	8.67 (6.27)	< 1	58	.811
Operation Span Speed Error	2.03 (3.50)	1.03 (1.25)	1.48	36.231*	.149
Operation Span Math Error Total	11.07 (7.77)	9.70 (6.41)	< 1	58	.461
Symmetry Span Accuracy Error	3.33 (2.25)	3.67 (4.22)	< 1	44.237*	.704
Symmetry Span Speed Error	0.43 (0.94)	0.90 (1.54)	1.42	58	.161
Symmetry Span Error Total	3.77 (2.62)	4.57 (4.45)	< 1	58	.400

* Levene's test was significant so equal variances were not assumed.