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Time-based prospective memory in adults with developmental dyslexia

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Abstract

Prospective memory (PM) is memory for delayed intentions. Despite its importance to everyday life, the few studies on PM function in adults with dyslexia which exist have relied on self-report measures. To determine whether self-reported PM deficits can be measured objectively, laboratory-based PM tasks were administered to 24 adults with dyslexia and 25 age- and IQ-matched adults without dyslexia. Self-report data indicated that people with dyslexia felt that time-based PM (TBPM; requiring responses at certain times in the future) was most problematic for them and so this form of PM was the focus of investigation. Whilst performing the ongoing task from which they were required to break out every three minutes to make a PM-related response, the participants were allowed to make clock checks whenever they wished. The cognitive demands made on ongoing behaviour were manipulated to determine whether loading executive resources had a mediating role in dyslexia-related deficits in PM, resulting in three tasks with varying working memory load. A semi-naturalistic TBPM task was also administered, in which the participants were asked to remind the experimenter to save a data file 40 minutes after being given this instruction. Dyslexia-related differences were found across all three computerized tasks, regardless of cognitive load. The adults with dyslexia made fewer correct PM responses and also fewer clock checks. On the semi-naturalistic task, the participants with dyslexia were less likely to remember to remind the experimenter to save the file. This is the first study to document PM deficits in dyslexia using objective measures of performance. Since TBPM impairments were found under more naturalistic conditions as well as on computerized tasks, the results have implications for workplace support for adults with dyslexia.

Keywords: Developmental dyslexia; prospective memory; time-based prospective memory; executive functioning; adults

1. Introduction

Developmental dyslexia (henceforth, dyslexia) is the most commonly reported of the developmental disorders (e.g., Lyon, 1996; Shaywitz, 1998; Shaywitz & Shaywitz, 2003). Estimates place its prevalence in the population of the Western world at 5-17.5% (e.g., Badian, 1984; Katusic, Colligan, Barbaresi, Schaid, & Jacobsen, 2001; Lyon, 1996; Pennington et al., 1991; Shaywitz, 1998; Shaywitz, Shaywitz, Fletcher, & Escobar, 1990). Dyslexia is characterized by specific difficulties with decoding the written word, with these problems occurring despite adequate educational opportunities, intelligence, and socioeconomic status (e.g., World Federation of Neurology, 1968; Orton Dyslexia Research Committee, 1994). However, as well as reading and spelling problems, impairments with memory have also been documented in children and adults with dyslexia. Difficulties with short-term and working memory have featured chiefly amongst these (e.g., Booth, Boyle, & Kelly, 2010; Jorm, 1983; Palmer, 2000). One largely neglected area of memory with particular importance to everyday functioning is prospective memory (PM), also known as memory for delayed intentions (Winograd, 1988) or remembering to remember (Mäntylä, 1994). Despite its impact on daily life (e.g., McDaniel & Einstein, 2007), little research has been carried out on PM in dyslexia apart from a small amount of self-report evidence to suggest that PM is more frequently impaired (Khan, 2014; Smith-Spark, Zięcik, & Sterling, submitted, in preparation). Despite these indications of a PM deficit in dyslexia, self-reports of an increased susceptibility to PM failure have yet to be corroborated by objective measures of performance. The present study was, therefore, conducted in order to determine whether subjective reports of more frequent PM failures actually play out in poorer PM performance under laboratory-based conditions.

The function of two key memory components is required for PM to be successful, namely a prospective component and a retrospective component. The prospective component allows the intention to be recalled at the appropriate point in the future, whilst the retrospective component permits the nature of the intention itself to be remembered. Prospective memory can be divided into two main types. Event-based PM (EBPM) requires an individual to remember to perform an intention in response to a cue in the environment; for example, remembering to post a letter as intended when seeing a post box. Conversely, time-based PM (TBPM) requires an individual to remember to perform an intention at a particular time in the future, in the absence of salient environmental cues to guide performance; for example, remembering the intention to call a friend 30 minutes from now. In the absence of external props to aid memory, TBPM is argued to require much more in the way of self-initiated mental processes (e.g., Einstein, McDaniel, Richardson, Guynn, & Cunfer, 1995), with the individual having to rely on, for example, free recall to remember to make appropriate checks of the time.

This reliance on self-initiated processes has led to arguments that executive functioning is more closely related to TBPM than EBPM (Martin, Kliegel, & McDaniel, 2003; McDaniel & Einstein, 2000; although see Gonneaud et al., 2011, for a contrary view). Executive functioning relates to higher-order cognitive processes such as inhibiting habitual responses, shifting between cognitive sets, updating the contents of working memory, and accessing information held in long-term memory in a controlled, strategic manner (e.g., Fisk & Sharp, 2004; Miyake & Friedman, 2012; Miyake et al., 2000). Martin et al. (2003) have proposed that executive functioning is engaged during intention formation and intention execution but plays less of a role in retaining intentions over the intervening period between formation and execution. Van den

Berg, Aarts, Midden, and Verplanken (2004) argue that executive functions are called upon to enable the individual to break out from ongoing task activity to perform a PM task.

As previously stated, there is a small body of evidence to suggest that people with dyslexia experience greater problems with PM than those without dyslexia. Smith-Spark (2000) employed a diary study methodology in which age- an IQ-matched adults were asked to record their everyday cognitive failures and slips of action (Cohen, 1996; Norman, 1981). Employing Reason's (1979) methodology, he instructed participants to keep a diary of any slips of action that they made in their day-to-day lives over a two-week period, instructing them to note down the nature of the slip and the circumstances prevailing at the time of its occurrence (e.g., that the participant was feeling tired or was in a hurry). Whilst Smith-Spark's interest was predominantly in the types of error that occurred when habitual actions went awry, many of the errors which were recorded by the participants fell outside Reason's taxonomy of slips of action. Smith-Spark, therefore, adopted a broader categorization of everyday cognitive error alongside Reason's taxonomy. One of these categories was forgetfulness. These recorded acts of forgetfulness were often retrospective (or episodic) in nature (e.g., forgetting where possessions had been left or failing to remember previous actions), but many of these errors were prospective in nature (for example, forgetting to return library books as intended or taking off a wristwatch and then forgetting to put it back on again afterwards as intended). Smith-Spark found that the participants with dyslexia reported a greater propensity to forgetfulness in their day-to-day lives.

Further to this, Smith-Spark, Fawcett, Nicolson, and Fisk (2004) raised the possibility of impaired PM in adults with dyslexia when considering group differences on the Cognitive Failures Questionnaire (CFQ; Broadbent, Cooper, FitzGerald, & Parkes, 1982). The participants with dyslexia rated themselves as being significantly more prone to failures in everyday cognition than age- and IQ-matched controls on two CFQ items which could be construed as drawing on PM (c.f., Maylor, 1993).

Khan (2014), however, was the first to specifically investigate PM in dyslexia. He administered the Prospective and Retrospective Memory Questionnaire (PRMQ; Smith, Della Sala, Logie, & Maylor, 2000) to children across Classes 5 to 12, with a mean age of 12 years. He found that the children with dyslexia rated themselves as being significantly more susceptible to PM failures than children without dyslexia, especially when self-cued performance was required. Whilst this work was an important first step in documenting PM problems in dyslexia and indicating where exactly problems might lie, it should be noted that there are a number of methodological concerns related to this paper. Firstly, no background literacy measures were reported for either group. It is important to check the validity of the participant groupings and not simply rely on the reports of schools. Secondly, no data relating to IQ or other cognitive measures were presented (despite mention of IQ and a cognitive test battery in the Method) to allow a comparison of the relative ability levels across the participant groups, again potentially hindering interpretation of the results if there were to be group differences on these measures. Thirdly, the range of ages of the 115 children taking part in the study was large, spanning seven school years. The opportunities for a child to exercise his or her own PM independently of his or her parents will vary considerably with age, with older children having greater responsibility for their actions than younger children and, usually, having a more personally (rather than parentally) organized social life. Khan did not provide a breakdown of the relative ages of the groups with and without dyslexia. It is, thus, not possible to determine whether the children with dyslexia were older on average than those without dyslexia. If this were to be the case, it could provide an alternative, non-dyslexia-related explanation for the reported findings. Finally, the

PRMQ is designed for use with adult populations and the questionnaire items may, therefore, not be fully applicable to children, especially those at the younger end of the distribution of ages in Khan's study. These concerns may well explain the low effect size reported by Khan for the group difference on the PRMQ (.06). Furthermore, no independent check of the participants' responses, such as proxy ratings taken from parents or other close associates of the PRMQ respondents (i.e., the proxy-rating PRMQ; Crawford, Henry, Ward, & Blake, 2006), was undertaken. Given that dyslexia is often accompanied by problems with self-esteem (e.g., Alexander-Passe, 2006; McNulty, 2003; Riddick, Sterling, Farmer, & Morgan, 1999), it is very important to check whether responses reflect problems with lowered self-perception rather than problems with PM per se.

Smith-Spark, Zięcik, and Sterling (submitted) also administered Smith et al.'s (2000) PRMQ to people with and without dyslexia but the focus of their research was on PM in adults. Further to simply presenting the PRMQ to an age-appropriate sample, it should be recognized that adults with dyslexia are not simply children with dyslexia who have grown up but instead have distinct and different demands on their cognition, a point argued by McLoughlin, Fitzgibbon, and Young (1994). It is, therefore, important to study their cognition in its own right and not simply extrapolate from children, especially given the responsibilities placed on employers to support people with dyslexia in the workplace by making reasonable adjustments to their practices and expectations (e.g., Equality Act, 2010, in the UK).

The adult participant groups in Smith-Spark et al.'s (submitted) study were matched for short-form IQ (Turner, 1997) and differed significantly on measures of reading and spelling. Like Khan (2014), Smith-Spark et al. found that the participants with dyslexia reported significantly more frequent PM and retrospective memory failures than the participants without dyslexia. In their case, however, the overall effect size of the group difference was around .30. Comparison of group scores on the individual PRMQ subscales indicated that when PM tasks required longer-term responses (i.e., a greater delay between the formation of an intention and the opportunity to act upon that intention) or required more self-initiated processes (i.e., were time-based rather than allowing the individual to use the environment as cues to prompt the PM intention), the adults with dyslexia rated themselves as particularly prone to error compared with the age- and IQ-matched controls. Corroborative evidence in favour of increased PM problems in dyslexia was provided by proxy-PRMQ respondents (Crawford et al., 2006). These close associates of the PRMQ respondents also rated the adults with dyslexia as having experienced more frequent PM problems across different types of cue (self-initiated vs. environmental) and time-frame (short- vs. long-term), using exactly the same set of questions as the PRMQ respondents. The data from adults are consistent, therefore, with those of Khan in highlighting self-cued PM as being particularly prone to failure in dyslexia.

As well as this direct evidence of PM difficulties in dyslexia, there are also several indirect lines of evidence to suggest that PM is likely to be impaired in the condition. Anecdotal reports of greater absentmindedness have been reported by Augur (1985). Moreover, problems with organization (e.g., Levin, 1990), planning (Torgeson, 1977), and temporal sequencing (e.g., Miles, 1982) have also been reported, with these different areas of cognition likely to have an impact on the ability to remember to act at an appropriate point in the future. As stated previously in this section, executive functioning is argued to play a role in PM, particularly when responses need to be self-initiated or when performance is time-based (Martin et al., 2003; McDaniel & Einstein, 2000). Executive functioning deficits in dyslexia are well documented in both children (for a review, see Booth et al., 2010) and adults (e.g., Brosnan et al., 2002). Of particular relevance to the study of PM in dyslexia, individuals with dyslexia have been found to have deficits in inhibition (e.g., Brosnan et al., 2002; Everatt, Warner, Miles, & Thomson, 1997; McLean, Stuart, Coltheart, & Castles, 2011; Wang, Tasi, & Yang, 2012) and set shifting (Poljac et al., 2010; although see Stoet, Markey, & Lopez, 2007). Both inhibition and set shifting have been found to predict PM, although sometimes only in children (e.g., Altgassen, Vetter, Phillips, Akgün, & Kliegel, 2014; Bisiacchi, Schiff, Ciccola, & Kliegel, 2009; Gonneaud et al., 2011; Mahy & Moses, 2011; Mahy, Moses, & Kliegel, 2014; Schnitzspahn, Stahl, Zeintl, Kaller, & Kliegel, 2013).

From a theoretical perspective, a dyslexia-related impairment in the Supervisory Attentional System (SAS; Norman & Shallice, 1986) has been suggested by Smith-Spark and Fisk (2007; see also Varvara, Varuzza, Sorrentino, Vicari, & Menghini, 2014). Due to its role in the control, coordination, and integration of information from different sources, the SAS has been proposed by Baddeley (1986) as a candidate for the central executive of the working memory model (Baddeley & Hitch, 1974). Norman and Shallice have argued that the SAS is called upon when novel or poorly learned action sequences are required. The SAS has been argued to be involved in PM (Burgess & Shallice, 1997; Cockburn, 1995), with it being called upon to monitor for cues to break out from ongoing activity to perform the PM intention. Smith-Spark and Fisk (2007) discovered that a group of adults with dyslexia performed worse than age- and IQ-matched controls on the first half of a visuospatial working memory span task but recovered to perform at an equivalent level on the second half of the task. They interpreted this finding as reflecting a dyslexia-related difficulty in setting up cognitive schemata to deal with the task when it was at its most novel. An SAS impairment in dyslexia would, thus, be predicted to show itself on PM tasks, particularly when novelty is high and/or greater attentional resources are required.

Given its self-initiated nature and potential for drawing on EFs (Einstein et al., 1995; Martin et al., 2003; McDaniel & Einstein, 2000), it seemed that an exploration of TBPM in adults with dyslexia would be a good starting point for the laboratory-based investigation of PM in dyslexia. Computerized TBPM measures in which cognitive load was manipulated were, therefore, administered to two groups of adult participants, one group with dyslexia and the other group without dyslexia. There were three experimental conditions, all of which involved a primary ongoing task and a PM task. The PM task required the participants to press a key on a laptop computer positioned out of direct view every three minutes. The participants were permitted to check a clock on the same laptop computer as many times as they wished. The ongoing task involved semantic categorizations. The participants were shown an array of famous faces and were asked to indicate whether there were more living or deceased famous people displayed. Under two of the three conditions, the participants were asked to perform a further (or secondary) ongoing task which drew upon either phonological or visuospatial working memory.

On the basis of the subjective reports of PM difficulties (Khan, 2014; Smith-Spark et al., submitted), it was predicted that the participants with dyslexia would show poorer TBPM performance relative to the participants without dyslexia. Given that Nicolson and Fawcett (1990) have argued that people with dyslexia are able to mask deficits in their cognition by a process of conscious compensation (in which additional attentional resources are allocated to the task at hand), it was predicted that the additional cognitive load would lead to greater drops in PM performance in the group with dyslexia relative to the group without dyslexia. A similar prediction would also be made based on the dyslexia-related SAS deficit proposed by Smith-

Spark and Fisk (2007) and Varvara et al. (2014). By manipulating cognitive load using both phonological and visuospatial tasks, it was possible to assess (at least to an extent) whether PM deficits would be limited to ongoing tasks requiring performance in the phonological domain or would be indicative of a broader problem with the allocation of cognitive resources by an executive system such as the SAS model (Norman and Shallice, 1986).

The number of clock checks and their distribution over the course of the tasks was also expected to reveal group differences. Ceci and Bronfenbrenner (1985) argued that it is not the number of time checks itself which has a positive impact on performance of the PM task, but rather their effective and strategic allocation (i.e., they should increase in their frequency as the time at which a response is required is approached). There is some evidence to suggest that people with dyslexia will find it more difficult to identify and act upon strategic methods of going about the task. For example, Meltzer (1991) has argued that individuals with dyslexia have reduced levels of cognitive flexibility, meaning that they may not be able to gain access to metacognitive information effectively when problem-solving. Similarly, Bacon, Parmentier, and Barr (2013) have reported that adults with dyslexia lack the cognitive flexibility to shift to an advantageous strategy unless explicitly told to do so. Strategic deficits in dyslexia were, thus, predicted to reveal themselves in a reduced or different pattern of clock checks from those made by the group without dyslexia.

The final aim of the current study was to determine whether dyslexia-related PM deficits could be found on a more naturalistic, yet objective, measure of TBPM as well as on computerized tasks. Given that PM tasks require the formation of an intention, then a delay involving intervening activity, followed by the opportunity to remember to act upon the intention, they are well suited to study under naturalistic conditions. Studies of PM have required participants to mail postcards to the researchers on specified days (e.g., Meacham & Leiman, 1982) or to telephone the experimenter a certain number of days after a laboratory visit (e.g., Moscovitch, 1982). A further PM task was, therefore, presented under semi-naturalistic conditions, such that it was administered whilst the participants were in the laboratory but the task itself was one that might naturally occur in the workplace or at home. In this task, the participants were instructed to remind the experimenter to save some data to disk 40 minutes after having been given the instruction to do so. On the basis that this task required self-initiated PM after a fairly long time interval, it was predicted that dyslexia-related deficits would also be apparent on this task (cf. Smith-Spark et al., submitted). Fewer participants with dyslexia were expected to remember to remind the experimenter to save the data file 40 minutes after forming the intention to do so.

2. Method

2.1 Participants

A total of 49 university students acted as participants. All were native English speakers aged between 18 and 35 years. They received a small honorarium or course credit for taking part. The participants were split between two groups on the basis of their self-declared dyslexia status, resulting in a group of 24 participants with dyslexia (18 females, 6 males) and a group of 25 participants without dyslexia (19 females, 6 males). The two participant groups did not differ significantly in age, $t(47) < 1$, $p = .380$.

When investigating the cognition of people with dyslexia, it is important to ensure that general cognitive ability is matched with the group with which they are being compared (e.g., Goswami, 2003). To this end, four subscales from the Wechsler Adult Intelligence Scale- Fourth UK Edition (WAIS-IV; Wechsler, 2010) were presented to the participants. These were

Comprehension, Vocabulary, Block Design, and Picture Completion. According to Turner (1997), none of the four subscales are sensitive to the presence of dyslexia and, thus, provide a good indication of general ability level independent of the effects of dyslexia. A short-form IQ score was calculated from the scaled scores obtained from the four subscales, using the method set out by Turner. The two participant groups did not differ significantly in short-form IQ score, $t(47) < 1$, $p = .904$.

Nicolson and Fawcett (1997) have reported that people without dyslexia are highly accurate in reporting that they do not, in fact, have the condition. Despite this, however, measures of reading and spelling were obtained from all of the participants in order to validate the participant groupings.

The Nonsense Word Reading (NWR) Passage from the Dyslexia Adult Screening Test (DAST; Fawcett & Nicolson, 1998) was administered as a measure of reading ability. This test required the timed reading of a passage which contained a mixture of real words and orthographically legal nonsense words. Reading speed and accuracy were combined to provide a composite measure of reading performance, with scoring penalties incurred for particularly slow or inaccurate reading. Adults with dyslexia find the decoding of novel nonwords difficult, even when their reading level is otherwise compensated (Brachacki, Fawcett, & Nicolson, 1994; Finucci, Guthrie, Childs, Abbey, & Childs, 1976). The NWR is, thus, a powerful indicator of the presence of dyslexia. The group with dyslexia obtained significantly lower raw scores than the control group on the DAST NWR, $t(26.995) = 6.86$, $p < .001$, $d = 1.41$.

The spelling component of the Wechsler Objective Reading Dimensions (WORD; Wechsler, 1993) was presented to assess spelling ability. The participants were requested to spell words of increasing complexity, with testing being terminated after six successive incorrect spellings. The experimenter read the word to be spelled, then read a sentence containing the word, and then repeated the word. The participant then wrote down his or her response. Raw scores of 42/50 or more on the test indicate spelling in the adult age. Further to this, a spelling age was derived from the raw score, with the ceiling spelling age for the task being greater than 17 years. The participants with dyslexia were found to have a significantly lower mean WORD spelling raw score, $t(32.951) = 5.42$, $p < .001$, $d = 1.24$. All of the participants in the control group obtained spelling ages of greater than 17 years (the ceiling on the task), whilst 12 of the group with dyslexia were found to have spelling ages of less than 17 years, indicating that their spelling abilities were not in the typical adult range.

Table 1 shows the descriptive statistics for the background measures obtained from the two participant groups.

TABLE 1 ABOUT HERE

2.2 Materials

The experiment was programmed in E-Prime 2.0 (Psychology Software Tools, Inc., Sharpsburg, PA). A 19” VDU connected to an IBM-compatible PC was used to present the ongoing tasks. A laptop computer with a 15” display was positioned on a filing cabinet behind the participants to record the PM-related responses. A purpose-built push-button response box was used to log responses. Its eight buttons were positioned in three rows, with three buttons being located in each of the top two rows and two buttons being placed in the bottom row. These buttons were used to record the responses to the visuo-spatial additional ongoing task. The two buttons on the bottom row were labelled “LIVING” (colour-coded in green) and “DEAD” (colour-coded in red). The same colour-coding was used in the instruction screens. In order to synchronize the clocks of the two computers, the response box was connected to both the PC on which the ongoing task was run and to the laptop on which the PM responses had to be made. Responses on the laptop placed behind participants were recorded using its QWERTY keyboard.

The stimuli for the ongoing semantic categorization task were chosen on the basis of responses provided by a panel consisting of 26 native English speakers (21 females, five males, all of whom were university students and British Citizens aged between 18 and 35 years, mean age = 22 years, *SD* = 5). The characteristics of the panel with regards to age, gender, and occupation, therefore, matched closely the characteristics of the target participants for the experiment itself. Each panel member was asked to provide the names of five very well-known living and five very well-known dead celebrities whom they considered to be very well recognized by people in the United Kingdom. The responses from the panel were collected by means of an online survey (Qualtrics Research Suite; Qualtrics, Provo, UT). The 12 most frequently occurring names from each list of celebrities were selected to form the stimuli for the experimental task. A 256 x 256 pixel greyscale image was obtained of each celebrity so chosen. The same stimuli were used in all three tasks.

2.3 Design

The experiment consisted of three conditions which placed different demands on working memory. In the no additional load condition, the participants performed a simple ongoing task whilst also responding appropriately to the PM component. The two working memory load conditions employed a further ongoing task as well as the ongoing and PM tasks, which required the updating of either phonological working memory or visuospatial working memory.

Each trial consisted of six images presented on a computer screen in reverse video. The images were displayed in two parallel horizontal rows of three pictures with a 0.5cm gap separating each image. On any given trial, the number of images of living and deceased celebrities differed such that the trial contained either a split of 5:1 or 4:2 images in favour of one or other type of celebrity. Equal numbers of trials containing each split type were presented. The order of the pictures on the screen was assigned based on a random number allocation rule. The presentation of trials was also randomized. For each trial, there was a 30-second time limit in which to provide a response. If a response was provided before the 30 seconds had elapsed, the next trial was presented immediately. If no response was made before the 30-second cutoff, then the next trial was initiated at this point. Each condition was programmed to terminate after 14 minutes. The stimuli lists were looped so that if a participant completed all of the trials before the 14 minutes had elapsed, the list would start again from the beginning. In such cases, the trials were presented once again in random order. There were a total of 212 primary ongoing task trials in the no additional load condition and 150 in each of the two higher cognitive load conditions. The number of trials was lower in the additional working memory load tasks due to the additional time component involved in making responses to the memory recall prompts, rendering the generation of further trial stimulus sets unnecessarily time-consuming. For each condition, there were 12 practice trials with feedback. As part of the practice session for the additional working memory load conditions, two memory recall prompts were presented.

All three conditions involved a TBPM task which required the participants to press a key on the keyboard of the laptop placed behind them every three minutes (i.e., at three minutes, six minutes, nine minutes and 12 minutes from the start of the 14-minute experiment).

The phonologically-loaded condition involved the same primary ongoing and PM tasks as the lower load condition. Further to these tasks, there was a secondary phonologically-based memory updating task embedded within the primary ongoing task. This secondary ongoing task involved remembering the last four responses made to the primary ongoing task for recall in serial order when prompted (e.g., “living, dead, living, living”). This task engaged memory updating processes (e.g., Morris & Jones, 1990; although see Cowan et al., 2005, for an alternative interpretation of the way in which the task is performed), with the memory recall prompt screens appearing on the computer screen pseudo-randomly, after every four to eight ongoing trials. In total, the participants were presented with 25 memory recall prompt screens over the course of the task. Memory recall responses had to be made within a 40s time limit to be deemed correct. The memory recall screen consisted of a two x four table (one column was headed DEAD, the other headed LIVING). The top row was labelled “least recent” and the bottom row was labelled “most recent”.

The visuospatially-loaded condition used the same primary ongoing and PM tasks as the lower load condition. Further to these tasks, a visuo-spatial memory updating task was embedded in the primary ongoing task. In each trial of the primary ongoing task, one of the six celebrity images was surrounded by a red frame. The location of the frame changed pseudo-randomly between trials such that in each trial a picture in a different position had a red frame around it. The secondary ongoing task involved the serial order recall of the locations of the last four celebrity images to be framed in red. In order to enable the participants to record these responses, the six buttons on the push-button response box were designed to map onto the 2x3 grid in which the pictures were presented.

A similar method of scoring PM responses was used to that of the Memory for Intentions Test (MIST; Raskin, Buckheit, & Sherrod, 2010). Correct responses were given a score of two. A score of one was given to PM responses which were made at the correct time but with the wrong type of response (e.g., pressing the wrong response key on the laptop, e.g., the letter “B” instead of “A”). A score of zero was awarded to responses which were produced +/-10 seconds from the designated target time for making a specified PM response, thus creating a 20-second time window during which a PM response could be correctly made. This time window for correct TBPM responses was previously employed by Mioni and Stablum (2014).

The number of clock checks made in every 30s period of the 14-minute tasks was logged by the PC. The clock check data were analyzed using a 2 (participant group) x 3 (task load) x 28 (30s period) mixed-measures ANOVA.

The administration of the three TBPM conditions was counterbalanced over two testing sessions conducted on different days. In one session, two PM tasks were presented, interleaved with the dyslexia screening and short-form IQ measures in order to minimize task interference. The remaining PM task was presented in the remaining session.

On the semi-naturalistic PM task, responses were deemed incorrect if they fell more than five minutes earlier or later than the designated time to make the response.

2.4 Procedure

The participants gave informed consent to take part in the experiment. They were then seated in front of a desktop computer with a further laptop computer positioned directly behind them. The instructions about the ongoing semantic decision task were presented. For each stimulus array, the participants were requested to decide as quickly and as accurately as possible whether the majority of the six celebrities presented were living or dead, using one of two push-buttons. Prior to the start of each of the three experimental conditions, the participants were shown the famous faces to be presented as stimuli. In the phonologically-loaded and visuospatially-loaded conditions, the participants were then given the instructions concerning the additional ongoing tasks which they were to perform in addition to the semantic categorization task.

After being instructed in how to perform the ongoing task, the participants were presented with a two column display containing the photos of the 24 celebrities used in the task. Each column contained 12 images and was headed either “Living” or “Dead”. Prior to the start of the practice trials, the participants confirmed that they were familiar with all of the celebrities and that they were aware which celebrities were living and which were deceased. After this, the participants engaged in 12 practice trials (which, in the case of the additional ongoing task load conditions, included memory prompts for the last four presented items). Feedback was provided after each practice trial. The experimenter was present during the practice trials to further clarify instructions and to answer any questions.

After the practice trials, the participants were told that the actual experimental condition would involve them performing the same ongoing task on the PC placed in front of them, but that another task also needed to be performed on a laptop computer placed behind them. For this additional task, the participants were asked to press the “A” key on the keyboard of the laptop computer every three minutes. The participants were not allowed to have their personal wristwatches visible, but were permitted to check how much time had elapsed since the start of the experiment by pressing the space bar on the laptop computer placed behind them. They were told that the timer would started at 00:00 and that they could check the timer as many times as they wished. After the instructions had been presented, the experimenter synchronized the two computers and commenced the tasks. Each time the “A” key was pressed, the laptop display flashed green for 600ms to indicate that the response had been registered before returning to black.

In the phonologically-loaded condition, the participants were instructed to use the buttons labelled DEAD and LIVING on the push-button response box to enter the sequence of the last four correct responses in serial order, starting with the least recently produced response and finishing with the most recent answer. The boxes on the screen were highlighted as the participant entered the last four responses which they had made.

The additional ongoing task used in the visuospatially-loaded condition was similar to that presented in the phonologically-loaded condition, except that the participants had to indicate the positions of the last four pictures which appeared with red frames around them. The participants were told to start with the least recently presented position and to end with the most recently presented. These boxes were highlighted as each recall response was made.

The participants were given a written debrief at the end of the study.

3. Results

3.1 Prospective memory trials

Overall, the group with dyslexia (mean = 3.32, *SEM* = .35) made fewer correct PM responses than the control group (mean = 4.75, *SEM* = .35). The effect of participant group on PM accuracy was found to be statistically very significant, $F(1, 47) = 8.27$, $MSE = 9.046$, $p = .006$, $\eta_p^2 = .150$.

Whilst PM accuracy was slightly lower under the visuospatially-loaded condition (mean = 3.80, *SEM* = 0.36) than under both the low load condition (mean = 4.20, *SEM* = 0.33) and the phonologically-loaded condition (mean = 4.11, *SEM* = 0.33), cognitive load did not have a significant effect on PM accuracy, $F(2, 94) < 1$, $MSE = 3.967$, $p = .582$.

There was also no significant participant group x cognitive load interaction, $F(2, 94) < 1$, $MSE = 3.967$, $p = .383$. Table 2 shows the descriptive statistics for PM accuracy.

TABLE 2 ABOUT HERE

3.2 Ongoing primary task trials

The overall mean accuracy rates in response to the ongoing primary task were 94.58% (*SEM* = 0.92) for the group with dyslexia and 95.83% (*SEM* = 0.90) for the group without dyslexia. A 2 x 3 mixed-measures ANOVA indicated that there was no effect of participant group on ongoing task accuracy, $F(1, 47) < 1$, $MSE = 61.249$, $p = .337$.

On average, the accuracy of performance on the ongoing task was highest in the lower load condition (mean = 96.24%, *SEM* = 0.69), then the phonologically-loaded condition (mean = 94.74%, *SEM* = 0.75), and was lowest in the visuospatially-loaded condition (mean = 94.63%, *SEM* = 0.77). Task load was found to have a significant effect on accuracy, $F(1.512, 94) = 4.19$, $MSE = 12.538$, $p = .029$, $\eta_p^2 = .082$, with Greenhouse-Geisser epsilon-adjusted degrees of freedom being reported as Mauchly's Test of Sphericity was significant ($p < .001$). Post hoc Bonferroni comparisons indicated that the accuracy scores in the low load and phonologically-loaded conditions differed significantly ($p = .002$). The difference between the lower load and visuospatially-loaded conditions fell short of statistical significance ($p = .068$). There was no significant difference between the two higher load conditions ($p = 1$).

There was also a significant participant group x task load interaction, $F(2, 94) = 4.42$, $MSE = 12.538$, $p = .024$, $\eta_p^2 = .086$. The interaction is shown in Figure 1. Post hoc unrelated *t*-tests indicated that the performance of the group with dyslexia was significantly higher on the lower load task (mean = 95.70, SD = 5.38) than it was on the phonologically-loaded task (mean = 93.15, SD = 6.38), $t(23) = 3.99$, $p < .001$, $d = 0.82$. Once Bonferroni corrections had been applied (resulting in a corrected α-level of .008), no other pairwise comparisons were statistically significant, $t \leq 2.20$, $p \geq .038$.

FIGURE 1 ABOUT HERE

3.3 Ongoing secondary task trials

On average, the group with dyslexia (mean = 64.34%, *SEM* = 3.16) performed at a slightly lower overall accuracy than the group without dyslexia (mean = 66.57%, *SEM* = 3.09). However, a 2 x 2 mixed-measures ANOVA indicated that there was no significant effect of participant group on memory span accuracy, $F(1, 47) < 1$, $MSE = 478.056$, $p = .616$. Table 3 shows the mean scores for each participant group under the two secondary task load conditions.

TABLE 3 ABOUT HERE

The participants performed worse on the visuospatial memory updating task (mean = 56.97, *SEM* = 3.31) than on the phonological updating task (mean = 73.93, *SEM* = 1.62). The effect of task type was significant, $F(47) = 37.30$, $MSE = 188.828$, $p < .001$, $\eta_p^2 = .442$.

There was no significant participant group x task interaction, $F(1, 47) < 1$, $MSE = 188.828$, $p = .445$.

3.4 Time checks

A three-way ANOVA conducted on the number of clock checks made over the course of the tasks indicated that the group with dyslexia made significantly fewer clock checks than the group without dyslexia, $F(1, 47) = 4.08$, $MSE = 1.395$, $p = .049$, $\eta_p^2 = .080$.

There was no significant effect of task load on the number of clock checks made by the participants, $F(2, 94) = 1.50$, $MSE = 0.424$, $p = .228$.

The 30s period during which clock checks were made had a significant effect on the number of clock checks, $F(8.981, 422.116) = 25.33$, $MSE = 1.153$, $p < .001$, $\eta_p^2 = .350$. Greenhouse-Geisser epsilon-adjusted degrees of freedom are again reported since Mauchly's Test of Sphericity was significant ($p < .001$). Given that there were 177 significant Bonferroni post hoc comparisons (and that these differences were not the focus of the research), these are not reported here but the details are available from the first author on request. Overall, the trend was for higher numbers of checks to be made in the 30s period leading up to one of the specified PM responses. The number of clock checks made per 30s period is shown in Figure 2.

FIGURE 2

There were no significant interactions between either participant group and task load, $F(2, 94) < 1$, $MSE = 0.424$, $p = .780$, participant group and 30s period, $F(27, 1269) < 1$, $MSE = 0.383$, $p = .732$, or task load and 30s period, $F(54, 2538) < 1$, $MSE = 0.289$, $p = .919$. The three-way interaction was also not statistically significant, $F(54, 2538) = 1.13$, $MSE = 0.289$, $p = .238$.

3.5 Semi-naturalistic TBPM task

Three participants with dyslexia performed the PM task outside the 10-minute time window for making a response and were thus given a score of zero.

A Pearson Chi-square showed there to be a significant association between participant group and the type of response made to the semi-naturalistic TBPM task, $\chi^2(2) = 11.89$, $p = .003$. The adults with dyslexia were more likely not to remember to carry out the PM activity than to remember to perform it, whilst the adults without dyslexia were more likely to remember to perform the PM task and less likely not to remember to act upon the intention. Figure 3 shows the frequency counts for the two participant groups.

FIGURE 3 ABOUT HERE

4. Discussion

Time-based PM was found to be poorer in the group with dyslexia compared with the group without dyslexia. This is the first study to find evidence of PM problems in dyslexia using objective measures of performance. In finding objective evidence for impaired PM in dyslexia, the results of the computerized tasks are consistent with the self-report questionnaire data obtained from both children (Khan, 2014) and adults (Smith-Spark et al., submitted). The questionnaire data from adults had suggested that the participants with dyslexia would find tasks which drew on self-initiated, time-based PM particularly problematic. The data from the current study bear this out in finding deficits across all three computerized TBPM tasks, regardless of the cognitive load demanded by the ongoing task and whether or not the additional load on the ongoing task was phonological or visuospatial in nature.

The results of the semi-naturalistic task also indicated that the group with dyslexia had deficits in TBPM, in that they were less likely to remember to act upon an intention 40 minutes after it had been formed and more likely to forget it than the group without dyslexia. The semi-naturalistic findings indicate the way in which an increased susceptibility to TBPM problems can play out in real-life tasks, with TBPM failures having a potentially serious impact on an adult's ability to perform effectively in employment (where they may be instructed to do a certain thing at a certain time) or to deal with tasks in their lives, either privately (such as paying bills on time or remembering to pay a motor vehicle congestion charge) or socially (such as remembering to meet someone for a date or an appointment).

It would, therefore, appear that TBPM is impaired in dyslexia and that these impairments can be elicited using both computerized and more naturalistic measures of performance. In considering the findings of the computerized tasks in more depth, dyslexia-related PM deficits were found across all three tasks, suggesting that increased task load did not disproportionately affect the group with dyslexia. This may indicate that the problems that people with dyslexia experience with PM have their origin at encoding (and, more specifically, in encoding the verbal instructions relating to the task) rather than at the point of executing the intention and are, thus, pervasive and not vulnerable to further disruption through loading on executive resources. Such an explanation would sit well with the phonological processing problems which are central to dyslexia and on which the phonological deficit hypothesis of dyslexia is built (e.g., Vellutino, 1979; Vellutino, Fletcher, Snowling, & Scanlon, 2004). Less reliable encoding of phonologically-based instructions might result in a reduced likelihood of access at the point at which the information is needed in the future. However, it should be noted that executive functions are also argued to be needed most at intention formation and intention execution by Martin et al. (2003), with their playing less of a role in the retention of intentions.

Alternatively, it may be that the secondary ongoing task was not sufficiently taxing to induce performance decrements in the group with dyslexia. They may still, thus, have had sufficient attentional capacity to cope with the additional task demands (cf., Nicolson & Fawcett, 1990). Whilst performance of the visuospatially-loaded secondary task was lower than that for the phonologically-loaded secondary task for both groups, it did not lead to lowered TBPM performance. Furthermore, the ongoing task performance of the group with dyslexia was at a very similar level to the group without dyslexia in this condition. Smith-Spark, Fisk, Fawcett, and Nicolson (2003) found that adults with dyslexia performed at the same level as controls when 4, 6, or 8 updates were required in a visuospatial updating task involving serial positions in a 5x5 grid. Group differences only emerged when 10 updates were required. The use of four updates in the present study may not have been sufficiently taxing to elicit a group x task load interaction. Given that the participants were performing two ongoing tasks, it was thought that four updates would be enough to reveal differences. The data argue otherwise and this issue should be explored further with greater task loads and perhaps individual titration of task load to ensure that all participants are operating at span rather than below span level.

Overall, the participants with dyslexia made fewer time checks than the participants without dyslexia. There were no significant two- or three-way interactions involving participant group. Whether the reduced frequency of clock checking in the adults with dyslexia is due to a less strategic approach to the task, greater amounts of attention being demanded by the ongoing task(s), or a (possibly misplaced) confidence in their time-keeping abilities is open to question and, further to being discussed below, should be explored in future research.

Given reports of dyslexia-related deficits in temporal processing and time perception (e.g., Bruno & Maguire, 1993; Khan et al., 2014; Klein, 2002; Nicolson, Fawcett, & Dean, 1995; Tallal, 1980; Wolff, 2002), the reduced number of time checks might reflect difficulties with temporal processing or an awareness of how time was passing. Whilst such temporal processing problems have been recorded in the millisecond range which is associated with “internal clock” models of time perception (e.g., Wearden, 1999, 2001), they have not been explored over the longer durations which more cognitive processes to be involved (e.g., Block, George, & Reed, 1980; Thomas & Brown, 1975; Thomas & Weaver, 1975). It may be that dyslexia-related temporal processing difficulties influence performance over the durations typically involved in TBPM and this could be an avenue for future research to take. However, on the basis of the existing literature from the perspective of either dyslexia or TBPM, it is difficult to predict what would be found if such a research programme were undertaken. As well as there being a paucity of literature on time perception in dyslexia over longer durations, there are only a few studies which have explored the general relationship between time perception and TBPM. These have used differing measures of time perception and have obtained varied results. A positive relationship between time perception and PM accuracy has been reported by Mackinlay et al. (2009). Set against this, McFarland and Glisky (2009) found no relationship between time perception and PM accuracy. Labelle et al. (2009), too, found no relationship with accuracy but did find that time perception significantly predicted monitoring behaviour. A similar pattern has recently been reported by Mioni and Stablum (2014) who used a temporal reproduction task using stimuli in the range of 4-14s, finding that this particular measure of time perception predicted monitoring behaviour but not PM accuracy in young and old adults.

An alternative explanation to dyslexia-related temporal processing difficulties lies in an argument couched in terms of cognitive capacity. The participants with dyslexia may have fewer cognitive resources available to make time-checks. Under this account, the adults with dyslexia were able to allocate sufficient attentional resources to performing the PM task and the ongoing task(s) but did not have sufficient capacity left over to perform a number of clock checks comparable to that of the adults without dyslexia. Nicolson and Fawcett (1990) have argued that people with dyslexia are able to compensate for performance decrements by consciously allocating attentional resources towards the task at hand. They argue that it is when further stressors (such as secondary tasks, fatigue, or time pressures) are introduced that the deficits in performance of people with dyslexia become apparent. From this perspective, the reduced number of time-checks and its probable impact on TBPM performance would be a manifestation of Nicolson and Fawcett's hypothesis with the conscious allocation of attention to the ongoing and PM tasks leaving less spare capacity for clock checking. However, set against this, there was no participant group x task load interaction, meaning that the reduced number of time checks in the participants with dyslexia cannot be the result of stressing the cognitive system with secondary tasks. Furthermore, there was no interaction between participant group and 30s period in the number of clock checks made. This would suggest that there was no difference between the adults with and without dyslexia in the extent to which their approach to time-checking was strategic (c.f. Ceci & Bronfenbrenner, 1985).

5. Conclusion

Adults with dyslexia made both significantly fewer correct PM responses and fewer time-checks when performing computerized TBPM tasks. These deficits were found regardless of task load and irrespective of whether ongoing performance called upon a greater or lesser amount of phonological processing resources. This study is the first to demonstrate that self-reported deficits in PM (Khan, 2014; Smith-Spark et al., submitted) can be objectively measured under laboratory conditions. Further to this, the results of the semi-naturalistic task illustrate the way in which deficits in TBPM may have an impact on the day-to-day life of people with dyslexia. These findings should inform the provision of workplace support for people with the condition (e.g., the Equality Act 2010 in the UK), allowing them to maximize their potential to the benefit of employee and employer alike.

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Table 1

The descriptive statistics for the background measures taken from both participant groups. Standard deviations are shown in parentheses.

	Participants with dyslexia (N = 24)	Participants without dyslexia (N = 25)
Age (years)	24.67	23.44
	(5.16)	(4.52)
WAIS-IV short-form IQ	110.59	110.24
	(9.71)	(10.41)
DAST non-word reading score	78.88	93.20
	(9.81)	(2.96)
WORD spelling test raw score	40.88	45.36
	(3.66)	(1.78)

Table 2

The descriptive statistics for PM accuracy on the three computerized tasks. Standard deviations are shown in parentheses.

Condition	Participants with dyslexia	Participants without dyslexia
No additional load	4.64	3.75
	(2.22)	(2.38)
Phonologically-loaded	4.80	3.42
	(2.52)	(2.08)
Visuospatially-loaded	4.80	2.79
	(2.45)	(2.59)

Table 3

Group mean performance (% accuracy) on the secondary ongoing tasks under phonological and visuospatial working memory load conditions. Standard deviations are shown in parentheses.

Condition	Participants with dyslexia	Participants without dyslexia
Phonologically-loaded	72	76
	(10)	(12)
Visuospatially-loaded	57	57
	(24)	(22)

Figure 1

The participant group x task load condition interaction on the accuracy of ongoing task performance.

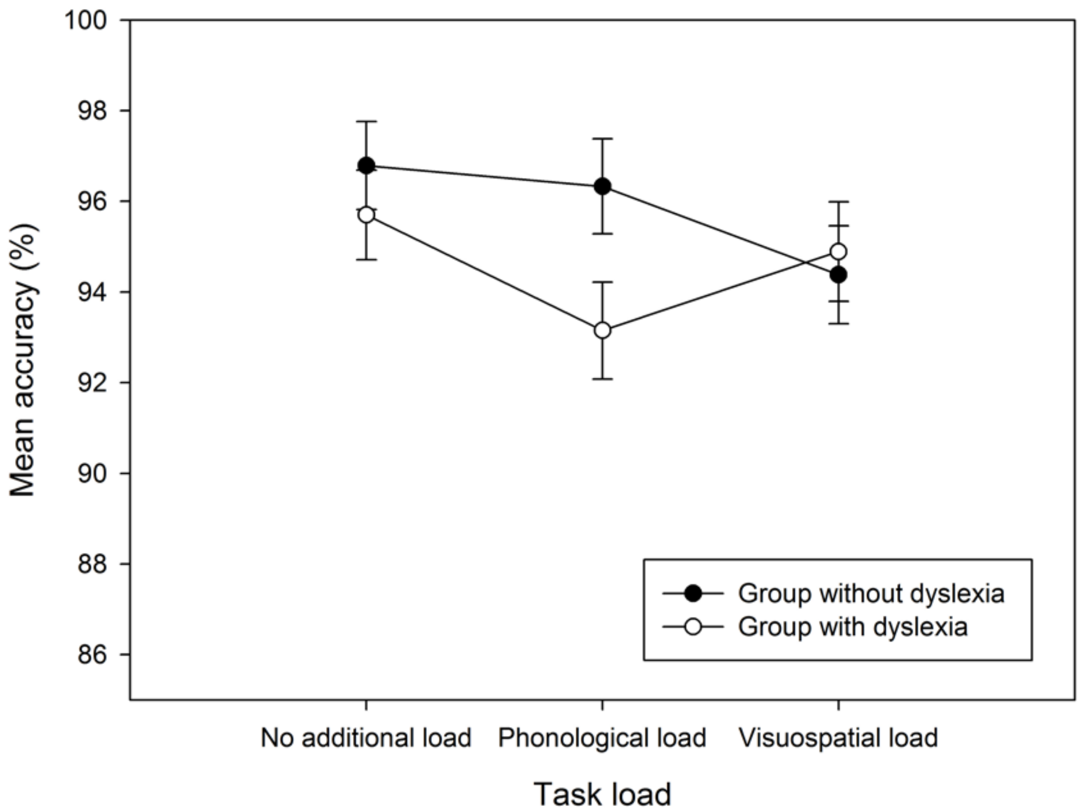

Figure 2

Mean number of clock checks per 30s period, collapsed across task condition. Prospective memory responses were required at the end of Time Points 6, 12, 18, and 24.

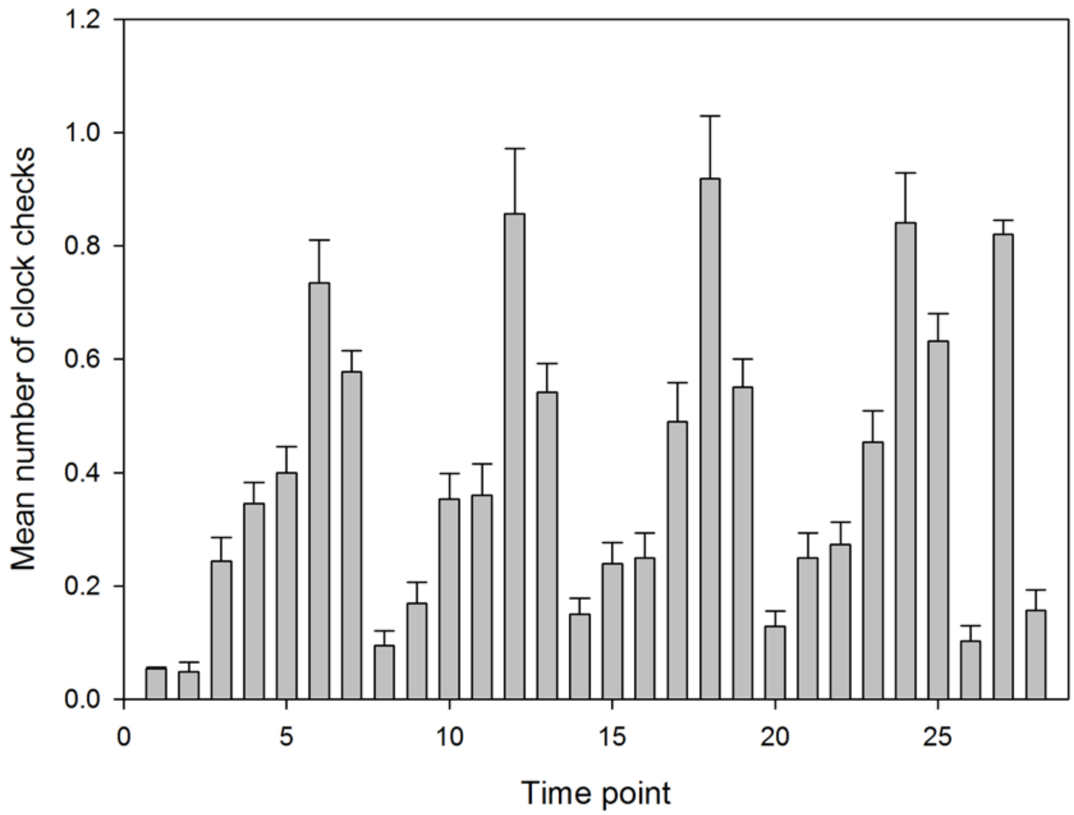

Figure 3

The frequency of each type of response on the semi-naturalistic TBPM task.