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Evaluation of the Bangor Dyslexia Test (BDT) for use with Adults

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Abstract

The Bangor Dyslexia Test (BDT) is a short, easy-to-administer screener for use with a broad age range, which has been in use in the United Kingdom for over three decades. A distinctive feature of the battery is its focus on skills requiring aspects of verbal and phonological processing without, however, measuring literacy skills per se. Despite its longstanding existence and usage, there has been no evaluation of the psychometric properties of the battery as an adult dyslexia screener. We examined the psychometric properties of the BDT and evaluated its capacity to discriminate between adults with and without dyslexia. A large archival sample of university students with dyslexia (n = 193) and students with no reported literacy difficulties (n = 40) were compared on the BDT as well as on literacy and cognitive measures. Statistical analyses revealed the BDT to be a reliable (α = .72) and valid dyslexia screening tool with the capacity to effectively identify adults at risk of the disorder with an overall classification rate of 94% (sensitivity 96.4% and specificity 82.5%). In addition, higher indices of dyslexia risk on the BDT were associated with lower scores on standardized measures of literacy.

Keywords: dyslexia; adults; screening test; higher education; Bangor Dyslexia Test; evaluation

Practitioner Points:

- The BDT can be used by practitioners to effectively screen for dyslexia in adults

- Knowledge of the psychometric properties of screening tests is useful for the selection of the most appropriate tools
- Independent research is one method of confirming/validating the effectiveness of screening tests
- Continuing independent research ensures that screening tests remain appropriate in light of our increased knowledge and understanding of dyslexia

Introduction

The ability to detect dyslexia in adults presents a challenge to many employers and educational institutions. While the mechanisms and tools for the diagnosis of dyslexia, and support for those affected are quite well established for school children in many countries (e.g., Rose Review, 2009; Caravolas, Kirby, Fawcett, & Glendenning, 2012), they are less advanced for adults in the higher /further education sector and in the workplace. The need for reliable and valid diagnostic tools is pressing, because several acts of legislation in the United Kingdom, such as the Disability Discrimination Act of 2005, Special Education Needs and Disability Act (SENDA), 2001, and the Equality Act 2010 (also similar legislation and initiatives worldwide e.g., United States Department of Education Individuals with Disabilities Education Act, 2004; United Nations Educational Scientific and Cultural Organization Salamanca Statement on Special Needs Education, 1994), now exist to prevent discrimination against people with disability (including dyslexia) in access to services, education, and employment. Moreover, these laws call for education providers and employers to identify and support students and employees with dyslexia. The SENDA (2001) specifically requires that disabled students and employees are treated fairly, and that reasonable adjustments are made to alleviate obstacles to their learning and/or job performance.

Not coincidentally, the number of students with disabilities entering higher education in the United Kingdom, including a large proportion with dyslexia, is rapidly increasing (Higher Education Statistics Agency, 2008). This is true not only for the United Kingdom, but also in other countries such as France, Germany, Canada (Organization for Economic Co-operation and Development, 2003), and the United States of America (Raue & Lewis, 2011). In the United Kingdom, a significant percentage (approximately 43%) of students with dyslexia is only identified after admission to post secondary institutions (National Working Party on Dyslexia in Higher Education, 1999; Singleton, 2004). Nicolson, Fawcett, & Miles (1993) have furthermore suggested that in the wider work community, the number of adults with undiagnosed dyslexia may be high. Thus, both higher education institutions (HEIs) and employers require knowledge of and access to effective dyslexia screening and/or assessment tools in order to fulfill their legal and professional obligations. Screening tests (screeners) are broadly designed to be quick, cost effective, and easy-to-administer tools for identifying individuals most at-risk of a disease or disorder. While administrators should be trained to administer specific screeners in accordance with their published instructions, they do not require specific professional qualifications, as in Educational Psychology, Speech and Language Therapy, or Specialist Dyslexia Teaching (e.g., Singleton, Horne, & Simmons, 2009). Screeners may thus be useful for HEIs and employers, who lack the means and/or the access to full diagnostic assessment services, in the identification of individuals who may be at-risk of dyslexia.

Very few dyslexia screeners are available for adults, and, of these, there is no generally accepted or “gold standard” battery. In the UK, two frequently used paper based tests are the BDT (Miles, 1997) and the Dyslexia Adult Screening Test (DAST) (Fawcett & Nicolson, 1998). The main computerized screening tests include: Lucid Adult Dyslexia Screening Plus (LADS Plus) (Lucid Research Limited, 2010), QuickScan (Zdzienski, 1998), and Instines (Dyslexia Foundation http://www.dyslexia-check.com/instines01.htm). Although these tools have been in use for several years (the BDT for almost three decades), there is a still a paucity of published research evaluating them. HEIs and employers may therefore find it difficult to select the most appropriate batteries for their contexts. This paper presents an empirical evaluation of the psychometric properties of the BDT as a screener of dyslexia in a population of university students. We investigated the BDT because it is in use in the UK (not least Bangor University) and several other countries, having been widely translated and being easy to administer (Miles, 2006).

Manifestations of Dyslexia in Adulthood

To accurately identify adults at-risk of dyslexia, an understanding of how the disorder manifests in affected adults is important. Similar to children, adults with dyslexia exhibit specific deficits at the behavioural level, as well as differences at the brain and genetic levels (see Sun, Lee, & Kirby, 2010; Swanson & Hsieh, 2009; Wagner, 2005 for reviews). Over and above weaknesses in reading efficiency (accuracy and speed) and spelling, behavioural markers most typically include difficulties in the accuracy and/or speed of processing phonological (speech sound) information, and verbal memory (Nergard-Nilssen & Hulme, 2014; Vellutino, Fletcher, Snowling, & Scanlon, 2004). In addition, single or multiple deficits have sometimes been reported in the domains of language use and comprehension, auditory and speech perception, visual attention, motor coordination, and associative learning (Vellutino et al., 2004). The prevalence of each type of difficulty and their rates of co-occurrence have not yet been clearly established in the adult dyslexic population, however, deficits in phonological processing and verbal short term memory tend to predominate both in terms of severity and frequency (Bruck, 1992; Gathercole, Alloway, Willis, & Adams, 2006; Nergard-Nilssen & Hulme, 2014; Snowling, et al., 1997).

To date, few longitudinal studies have tracked dyslexic individuals from childhood into adulthood (e.g., Undheim, 2009; Snowling, Muter, & Carroll, 2007; Svensson, & Jacobson, 2006), however, it is clear that despite the persistence of underlying deficits in dyslexia, some changes in the behavioural manifestations of difficulties do occur. For example, by adulthood many English-speakers with dyslexia are able to close the gap in reading accuracy (though rarely also in fluency) relative to typical readers (Kemp, Parrila, & Kirby 2009). However, spelling accuracy as well as phonological processing *speed* tend to remain impaired into adulthood, and this across languages (Callens, Tops, & Brysbaert, 2012; Judge, Caravolas, & Knox, 2006). The mounting evidence of heterogeneity in the cognitive profiles of dyslexic individuals has led to recent (re)conceptualizing of dyslexia as a multidimensional disorder, which stems from the interaction of possibly multiple deficits, varying in severity (Pennington, 2006; Rose Review, 2009). In line with these current trends, Miles (1993) conceived of dyslexia very much as a complex of cognitive strengths and weaknesses, despite the disorder having its primary basis in the domain of language processing (Miles, 1961). The BDT was thus constructed to reflect this view.

The BDT: A Screener of Dyslexic Traits.

The BDT was one of the first dyslexia screening tests to be developed in the United Kingdom, designed by the late Tim R. Miles in 1983 as a battery of ten subtests for use across a wide age range, from 7 years to adulthood (Miles, 1993). Miles believed dyslexia to be a syndrome with a distinctive pattern of symptoms/difficulties resulting primarily from a lexical or verbal labelling deficit, which he considered to reflect an underlying phonological processing deficit (e.g., Miles, 2006; Miles, 1993; Payne, Miles, & Wheeler, 2007). The selection of subtests was mainly informed by observational evidence gathered during Miles' clinical work with dyslexic individuals, which he believed could identify their pattern of difficulties. The test is a non-threatening set of simple tasks, in which the test taker can engage confidently without time pressure (although the whole battery should take no longer than 30 minutes to complete).

A unique feature of the BDT, setting it apart from other dyslexia screening tools, is its emphasis on quick and easy-to-administer tests that do not directly assess reading and spelling skills. Thus, the BDT subtests were conceived as more distal markers of the array of difficulties in the oral language domain that may underlie dyslexics' literacy difficulties. This conceptualization has not gone without some criticism, with concerns being raised regarding both the objectivity of the scoring system and the specificity of the battery given its exclusion of literacy measures (Sutherland & Smith, 1991). Norms and validation for *some* subtests of the BDT were established from a large, nationally representative cohort of children aged 10-11 years, participating in the Child Health and Education Study (see Miles (1993), and Miles, Haslum, & Wheeler (1998) for details), but wider norms including adult populations have not been published. The validation study (Miles, 1993) focusing on three subtests Left-Right, Months Forwards, and Months Reversed, revealed that children with positive scores tended to be more educationally disadvantaged than those with negative or zero scores.

As is true of other screening tests, independent research on the BDT is very limited and there are no studies evaluating its psychometric properties. Cognizant of this lack, in the present study, we assessed whether the BDT possesses psychometric properties that are adequate for use with an adult student population. We made use of the archival database of screening and full assessment outcomes of students at Bangor University, where the BDT has long been in use by the Student Dyslexia Service. Specifically, we investigated its reliability and its construct and predictive validity. If the BDT is an adequate screening tool for adults, we expected the students' data on each subtest and on the battery as a whole to yield robust estimates of internal consistency. Additionally, we expected that if the (non-literacy) subtests of the BDT are valid indicators of literacy difficulties, then adults with dyslexia should obtain higher scores than those without the disorder. Moreover, we expected that: (1) BDT scores would correlate more strongly with standardized measures of literacy than with nonverbal cognitive measures, and (2) dyslexia-risk status as determined by the BDT would predict fully diagnosed (by EP) dyslexia status, and dyslexic versus non-dyslexic group membership in logistic regression.

Method

Participants

Two groups participated in the study: a dyslexic group selected from the Miles Dyslexia Centre's archived data, and a control group that was recruited from among Bangor University students who had no history of learning difficulties.

Dyslexic sample. Data were obtained from the archived records of 373 students who were screened and assessed at the Miles Dyslexia Centre of Bangor University between September 2004 and October 2008. Students self-referred to the Centre on a voluntary basis and data were collected and stored electronically for those who had given written consent for their data to be used for research purposes. The participants in question were studying in a wide range of disciplines including Psychology, Nursing, Sports Science, Zoology, Marine Biology and Social Work. The majority were undergraduates 337 (90%) and 38 (10%) were postgraduates; 325 (87%) were first language English speakers.

Of the original sample (N = 373), 348 students were referred for a full assessment because their screening outcomes (see Procedure) indicated risk of dyslexia or of other learning disorders. Of this referred group, 230 undertook the full assessment; the screening and assessment outcomes of these students are detailed in Table 1. The majority, n = 193, were diagnosed with dyslexia and comprised the dyslexic group in the ensuing analyses. Characteristics of the group are detailed in Table 2.

Table 1

Screening and Diagnostic Outcomes of Participants Undertaking Full Assessment (n = 230) with Totals for Each Category

Screening	Full Diagnostic Assessment Outcomes					
Indications of Risk of Specific Difficulties (*n*)	Dyslexia	Dyspraxia	Other Learning Disorders	Working/Short Memory	Others Specified Disorders	No Disability
Dyslexia (183)	156	8	10	1	4[a]	4
Dyspraxia (10)	4	2	2	1	1[b]	-
Attention Deficit Hyperactive Disorder (1)	1	-	-	-	-	-
Other Learning Disorders (4)	3	-	1	-	-	-
Disorder not Specified (32)[c]	29	1	-	1	1[d]	-
Total	193	11	13	3	6	4

Notes. For Other Learning Disorders the extra nature of these were not specific by the assessors.
[a]Disorders diagnosed were as follows: Attention and Concentration Difficulties – 1, Myalgic Encephalomyelitis – 1, General Learning Difficulties – 1, and Information Processing Weakness – 1.
[b]Disorder diagnosed Writing Speed Difficulty
[c]Assessor did not specify, however, primary risk of dyslexia is assumed.
[d]Disorder diagnosed Learning Weaknesses

Control sample. Control participants were 40 psychology undergraduates recruited through a student participation panel. All had English as their first language and reported no history of learning difficulties; they were compensated with course and printer credits. Characteristics of the group are detailed in Table 2. The groups differed statistically in age, $t(230.99)$ -7.22, $p < .001$.

Table 2

Characteristics of Participants for Dyslexic Sample and Sub-samples (participating in Different Statistical Analyses) and Control Sample

Characteristics	Dyslexic		Control
	Reliability and Logistic Regression	MANOVA	
N	193	97	40
Age			
M	24.5	24.93	19.50
SD	8.76	9.36	1.81
Gender			
Male	61	28	10
Female	132	69	30
First Language[a]			
English	164	79	40
Welsh	19	15	-
Other	2	1	-

Note. The difference between the numbers for the language groups and the total sample is due to missing data on language background for 8 participants.

Bangor Dyslexia Test

The BDT comprises ten subtests: eight skill-based tasks, and two anecdotal queries about persisting confusion of the letters *b* and *d*, and report of other family members with similar difficulties. Descriptions of these subtests are provided in Table 3. In the present paper, we do not take a position on the causal mechanisms that may (or may not) be measured by the subtests of the BDT, but rather our aim is to assess the battery's ability to discriminate between adult students with and without dyslexia. For example, reports of persistent confusions between similar-looking letters (e.g., *b* and *d*) may be more prevalent among individuals with dyslexia because they reflect one aspect of the well documented delays in letter learning and spelling skills in this population (e.g., Treiman et al., 2014), rather than a specific neurological impairment in discriminating letter-shape orientation, as has sometimes been proposed (e.g., Orton, 1937). Similarly, adults with dyslexia may experience greater difficulties responding to instructions in the Left-Right test due to verbal short term memory difficulties and not a core difficulty in telling left from right. Thus, it is conceivable that the test comprises a sensitive battery of behavioural markers of literacy difficulties, even though current thinking might provide somewhat different explanations for their sensitivity than were originally posited.

The scoring system as detailed in the manual (Miles, 1997) is deliberately simple allowing only three possible scores for each subtest: + (plus) a dyslexia positive response, - (minus) a dyslexia negative response, and 0 (zero) an ambiguous response, not clearly dyslexia-positive or negative. In addition to response accuracy for 8 of the subtests (excluding B-D Confusion and Familial Incidence), scoring is also based on the assessor's clinical judgement, taking into account any manifest difficulty experienced or explicit strategies used by the assessee to achieve the response. Indications of difficulties experienced by the test taker include hesitations, requests for repetitions of the question, repeating the question before answering, and other manifest difficulties. Therefore, a + score would be given not only for incorrect responses, but also for correct responses meeting the criteria of response difficulty. A score of – is awarded for correct responses with no indication of difficulties or strategies, and a score of 0 is awarded for correct responses in which the behavioural evidence of difficulty is ambiguous. These subtest scores are then assigned numerical values such that + = 1, 0 = .5, and - = 0, which are summed for a minimum of 0 and a maximum of 10 points. The BDT prescribes no unique cut off score for indicating risk of dyslexia. According to Miles (1997), the assessor should determine each individual's' at-risk score based on their performance on the BDT and other information (such as personal or educational history). For research purposes, however, he suggested that five or more pluses in children and four or more pluses in adults indicate the presence of dyslexia, and a score of three or less indicates its absence.

Procedure

Screening procedure for the dyslexic sample. All students were screened individually at the Miles Dyslexia Centre by trained professionals with qualifications in assessing and teaching individuals with Specific Learning Difficulty (SpLD). The screening procedure included: (1) the Bangor Dyslexia Test, administered and scored in accordance with published instructions (Miles, 1997); (2) a semi-structured interview probing information about prior and current academic difficulties, general background, medical history, and any post-secondary experience including educational or work activities; (3) a timed (3-minute) free writing test to assess writing speed; and (4) four subtests of the Dyslexia Adult Screening Test (DAST) (Fawcett & Nicolson, 1998), as follows: Nonsense Passage Reading, Two Minute Spelling, Phonemic Segmentation, and Verbal and Semantic Fluency.

Table 3

Description of the Subtests of the Bangor Dyslexia Test

Subtests	Descriptions	Skills Assessed
Left – Right	Tests the awareness of left and right using body parts. e.g. “Point to my right ear with your left hand”. Eight items.	Verbal working memory, spatial awareness, and mental rotation.
Polysyllabic Words	Tests the ability to repeat polysyllabic words such as ‘preliminary’ and ‘philosophical’. Five items.	Verbal/phonological short term memory and articulatory accuracy.
Subtraction	Tests the ability to complete verbally presented subtraction problems. e.g. “52 take away 9”. Six items	Verbal working memory and arithmetic skills.
Tables	Tests the ability to recite 6, 7 & 8 times tables. Three items.	Rote and verbal working memory, arithmetic skill, and executive functions for sequencing.
Months Forwards	Tests the ability to recite the months of year in the correct order. One item (trial).	Rote recall and executive function for sequencing.
Months Reversed	Tests the ability to recite the months of the year in reverse order. One item (trial).	Verbal working memory and executive function for sequencing.
Digits Forwards	Tests the ability to repeat digits in the order in which they were presented. Consists of two blocks of six items. Twelve items.	Verbal short-term memory.
Digits Reversed	Tests the ability to repeat digits in the reverse order of presentation. Consists of two blocks of three items. Six items.	Verbal working memory.
B – D Confusion	Question: “Is there any evidence that the subject confuses *‘b’* and *d’* or did so beyond the age of 8?”	Not applicable
Familial Incidence	Question: “Is there evidence of anyone else in the family having similar difficulties?”	Not applicable

The Nonsense Passage Reading subtest consists of a short passage of real and nonsense words to be read aloud for a maximum of three minutes (reported test-retest reliability *r* =

.92). The Two Minute Spelling subtest consists of up to 32 words graded in difficulty, and spelled to dictation for 2 minutes (reported test-retest reliability r = .93). The Phonemic Segmentation subtest includes 12 syllable/phoneme deletion items and 3 spoonerism items (reported test-retest reliability is r = .90). The Verbal and Semantic Fluency subtest requires the rapid generation of words on the basis of either alliteration or meaning for a duration of one minute (reported test-retest reliability is r = .81 for Verbal Fluency and r = .76 for Semantic Fluency). The DAST subtests were administered and scored according to published guidelines and followed the semi-structured interview and the administration of the BDT. Note that the present study aims to evaluate only the psychometric properties of the BDT, and not the validity of the full screening process.

Full assessment procedure for the dyslexic sample. Students whose screening outcomes, including their BDT performance, indicated that they were at risk of dyslexia or other learning disabilities were referred for full assessment. For the period under study (September 2004 to October 2008), all but two assessments (completed by Specialist Teachers) were carried out by Educational Psychologists (EPs). Students were assessed on a battery that included subtests of the Wechsler Adult Intelligence Scale III (WAIS III) (Wechsler, 1997), usually administered were Vocabulary, Block Design, Verbal Comprehension, Perceptual Organization, Working Memory and Processing speed. Literacy attainment (reading, spelling and reading comprehension) was assessed using the Wechsler Individual Achievement Test II (WIAT II) (Wechsler, 2005), Wide Range Achievement Test III (WRAT III) (Wilkinson & Robertson, 2004), and/or the Wechsler Objective Reading Dimensions (WORD) (Wechsler, 1993). The general practice among the EPs at that time for diagnosing dyslexia was based on a discrepancy between IQ and literacy attainments.

Testing procedure for control participants. All students were tested individually in a quiet room in a session lasting approximately 60 minutes. Students were assessed on the BDT as well as on measures of literacy attainment using the Word Reading, Spelling, and Sentence Completion subtests of the WRAT IV (Wilkinson & Robertson, 2004) and, verbal and non-verbal ability using the Vocabulary and Matrices subtests of the Wide Range Intelligence Test (WRIT) (Glutting, Adams, & Shelow, 2000). Ethical approval for the study was granted by the School of Psychology, Bangor University.

Results

Comparisons of Performance of Dyslexic and Control Groups on Background Measures

Prior to the main analyses of the BDT, we compared the two participant groups on cognitive ability and literacy measures. Although the dyslexic and control groups were assessed on different background measures, all are well established, standardised, and widely used for research and assessment purposes. In addition, the manuals of the WRAT IV and the WRIT report significant moderate to high correlations between their subtests and those of the WIAT II and WAIS III that were used with the dyslexic group, thus demonstrating acceptable convergent validity. On these grounds, we carried out direct between-group comparisons; nevertheless, the results are indicative only. Performances were compared by multivariate analysis of variance (MANOVA), followed up with univariate analyses (ANOVA) with Bonferroni-adjusted alpha level, where *group* was the independent variable and *background measures* were the dependent variables. This analysis included a smaller sample size for the dyslexic group (n = 97) due to some missing data from the other 96 participants, which resulted from differences in the number of tests used by different assessors (EPs) during the full assessment procedure. Importantly, across all key measures (i.e., all background measures, DAST measures, and BDT scores), the mean scores of the dyslexic subgroups (in and out of the MANOVA) did not differ statistically. The data were first checked for outliers (by group) and scores above or below 2.5 standard deviations from the mean were trimmed to 2.5 standard deviations. This affected one control participant on the spelling task and for one dyslexic participant on the reading and spelling tasks, respectively. The MANOVA assumption of equality of error variances was violated; therefore, a more conservative alpha of .01 was used for significance (Tabachnick & Fidell, 2007).

A significant multivariate difference emerged between the groups $F(5, 131) = 27.47$, $p < .001$; $V = 0.51$ (see descriptives in Table 4). A follow-up ANOVA (with

Bonferroni adjusted alpha of .01) revealed significant differences on all the measures except verbal ability, $F(1, 135) = 5.26$, $p = .023$. Overall, the dyslexic group performed less well than the control group, however, all scores were well within the average range, as would be expected with a population of university students. On the literacy measures, the effect sizes for reading accuracy and spelling were very large, respectively $d = 1.86$ and $d = 1.59$. We remind the reader that the exact magnitudes of these effects should be interpreted with some caution in light of the different standardized batteries used between groups. It is also notable in Table 4 that on both DAST measures, the group with dyslexia was clearly in the ‘at risk’ range. In the aggregate, the students with dyslexia experienced significant literacy difficulties relative to their own cognitive abilities and, in all likelihood, relative to those of the control group.

Table 4

Mean Standard Scores (Standard Deviation in Parenthesis) on Background Measures of Dyslexic and Control Groups, and Scores on DAST Nonsense Passage Reading and Two Minute Spelling Subtests of Dyslexic Group

Measures	Dyslexics (n = 97)	Controls (n = 40)	Cohen's d
Nonverbal Ability	103.04 (13.44)[a]	110.20 (8.89)[b]	0.64
Verbal Ability	105.44 (12.28)[c]	110.40 (8.93)[d]	0.47
Reading	95.94 (10.75)	114.83 (9.57)	1.86
Spelling	94.67 (12.68)	114.73 (12.59)	1.59
Comprehension	95.94 (13.93)	105.68 (8.18)	0.88
DAST Nonsense Passage Reading	74.26 (12.91)[e]	-	-
DAST Two Minute Spelling	25.40 (4.60)[f]	-	-

Note. For the dyslexic group literacy was assessed with one of the following: WIAT II, WRAT III, or WORD. For the control group literacy was assessed with the WRAT IV.
[a]Score derived from Block Design subtest of the WAIS III.
[b]Score derived from Matrices subtest of the WRIT.
[c]Score derived from Vocabulary subtest of the WAIS III.
[d]Score derived from Vocabulary subtest of the WRIT.
[e]Scores below 87 indicate a risk of dyslexia.
[f] Scores below 33 indicate a risk of dyslexia.

To assess whether the indicative group difference on nonverbal ability may have confounded performance on the literacy measures, additional analyses of covariance, controlling for nonverbal IQ, were conducted, and revealed that group differences on the literacy tasks remained significant (Reading $F(1, 160) = 67.24$ p <.001, Spelling $F(1, 160) =$ 52.51 p <.001, Comprehension $F(1, 134) = 11.42$ p =.001). These results are consistent with the growing evidence suggesting that IQ is not a critical correlate of literacy abilities in adults with dyslexia (Ferrer, Shaywitz, Holahan, Marchione, & Shaywitz, 2010).

We also considered the potential influences of age, gender, and language background on the background measure attainments. As reported earlier, the groups differed significantly in age, the controls being younger than the dyslexics. As age is factored into the scoring for the standardised background measures, it is unlikely to have affected those results. The number of females in our samples exceeded that of males (reflecting the gender demographics of the academic colleges of the participants), however, no effects of gender were found, with the exception of verbal ability where females, somewhat unexpectedly, had lower attainments $M = 105.76$ $SD = 11.59$, than males $M = 112.70$ $SD = 11.85$, $t(162) = -3.42$, $p = .001$. Across samples, 9% of participants had a first language other than English (8% Welsh, 1% other), and we explored whether language status affected performance. *T*-tests revealed all performances to be within the normal range, and importantly no differences on the BDT, spelling, or comprehension. Some differences in favour of English L1 speakers emerged on reading ($t(32.01) = 3.99$, $p < .001$), verbal $t(159) = 3.42$, $p = .001$) and nonverbal abilities ($t(159) = 2.72$, $p = .007$). However, the very large difference in the language group sizes (see Table 2) precludes any meaningful interpretation of these results.

Main Data Analysis

In the ensuing sections, we report analyses testing the reliability and validity of the BDT. Participants' total BDT scores were first checked for outliers (by group) and scores above or below 2.5 standard deviations from the mean were adjusted to 2.5 standard deviations. This led to two adjustments in the group with dyslexia. Next, we conducted an analysis of the BDT's internal consistency reliability using Cronbach's Alpha. Then, to assess the capacity of the BDT to discriminate between adults with and without dyslexia, the groups were compared on each subtest using Mann Whitney *U*, as the scores were not normally distributed; furthermore, the magnitude of any group difference on the battery as a whole was tested by a *t*-test with Cohen's *d*. Construct validity (convergent and divergent) was assessed with correlational analysis. Finally, to assess predictive validity, we conducted a logistic regression with the BDT total scores as predictor and group membership (dyslexic, control) as the dependent variable.

Reliability of the BDT

Internal consistency of the BDT. We estimated the internal consistency of the measure as a whole, as well as each of its subtests with Cronbach's coefficient alpha, based on the total sample of dyslexic and control participants (N = 233). The resulting overall coefficient α = .72 indicated that the subtests are consistent and are likely measuring the same underlying construct (see Table 5). Although adequate, its reliability is lower than what is considered ideal (i.e., $\alpha \geq .80$) (Field, 2009; Kline, 2000). The inter-item correlations of the subtests ranged from a low of r = .16 to a high of r = .47 with mean of r = .20, reflecting their heterogeneity. Item-total correlations ranged from .18 to .55 with Months Forwards and Tables having the lowest and highest correlations, respectively. With the exception of Months Forwards and Polysyllabic Words, the item-total correlations of all other subtests, were greater than .30 indicating that they contributed to the reliability of the measure (Field, 2009). The low correlation of the Months Forwards subtest, coupled with ceiling scores (see also ensuing analyses), indicated that it was not contributing to the reliability of the screener and is insensitive for this age group. The squared multiple correlations indicated that the Tables subtest made the greatest contribution to the internal consistency of the BDT (R^2 = .39), while the Months Forwards and Polysyllabic Words subtests, not surprisingly, contributed the least (R^2 = .14). The Cronbach's alpha-if-item-deleted figures indicated that the reliability of the measure could not be improved by deleting any of the subtests. However, deleting the Months Forwards and Polysyllabic Words subtests left alpha unchanged, revealing the redundancy of these subtests, at least for use with adults. Thus, with the exception of Months Forwards and Polysyllabic Words, all subtests were contributing to the BDT's reliability.

Table 5

Item-total Statistics for BDT Subtests (N = 233)

BDT Subtests	Corrected item-total correlation	Squared multiple correlation	Cronbach's alpha if item deleted
Left-right	.32	.15	.71
Polysyllabic Words	.27	.14	.72
Subtraction	.51	.32	.67
Tables	.55	.39	.67
Months Forwards	.18	.14	.72
Months Reversed	.36	.22	.70
Digits Forwards	.38	.23	.70
Digits Reversed	.43	.26	.69
B-D Confusion	.36	.20	.70
Familial Incidence	.43	.25	.69

Validation of the BDT

Comparison of performance of dyslexic and control groups on the BDT.

Given the age difference between the groups, we correlated age with BDT scores, using the pooled sample (*N* = 233). This yielded a low but significant correlation with the total score, *r*(233) = .13, *p* = .044, and similarly so for two of the subtests, B-D Confusion *r*(233) = .14, *p* = .037, and Familial Incidence *r*(233) = .14, *p* = .040. However, these dropped to non-significance when analysed within groups, suggesting that the foregoing significant correlations were likely due to the group differences and not a specific association between age and BDT scores.

The total dyslexic sample, *n* = 193, was included in ensuing group comparisons on the BDT. We hypothesized a priory that the dyslexics would perform less well than the controls on the BDT, obtaining higher total and individual subtest scores. Indeed, the dyslexics (*M* =

6.17, *SD* = 1.44) attained significantly higher (total BDT) index scores than the controls (*M* = 2.09, *SD* = 1.23), *t*(231) -16.69, *p* < .001. Moreover, this pattern was replicated on each subtest (see details in Table 6). For the total measure, Cohen's *d* = 3.06, indicated that the difference was very large. The effect sizes for most subtests were also large, ranging from *d* = 0.87 for Digits Forwards to *d* = 1.70 on the Subtraction and Familial Incidence subtests. No effect size was calculated for the Months Forwards and B-D Confusion subtests as the control group performed at ceiling on these. The control group also performed near ceiling on the Polysyllabic Words, Subtraction, Months Reversed, and Familial Incidence subtests.

Table 6

Results of Mann-Whitney U Test of Difference in Mean Ranks of Performance of Dyslexic and Control Groups on the BDT Subtests, and Effect Sizes (N = 233)

	Dyslexics (n = 193)		Controls (n = 40)				
BDT Subtests	Mean Rank	Mean score (*SD*)	Mean Rank	Mean score (*SD*)	Mann-Whitney *U*	*Z*	Cohen's *d*
Left/Right	125.88	.76 (.33)	74.16	.45 (.37)	2146.50	-4.94***	0.89
Polysyllabic Words	126.20	.47 (.41)	72.63	.13 (.22)	2085.00	-4.90***	1.08
Subtraction	128.79	.49 (.43)	60.10	.03 (.11)	1584.00	-6.35***	1.70
Tables	128.25	.85 (.30)	62.73	.41 (.41)	1689.00	-6.76***	1.24
Months Forwards	119.38	.08 (.22)	105.5	.00 (.00)	3400.00	-2.29*	-
Months Reversed	125.81	.43 (.43)	74.48	.09 (.22)	2159.00	-4.79***	1.03
Digits Forwards	124.38	.85 (.35)	81.41	.48 (.50)	2436.50	-5.00***	0.87
Digits Reversed	126.86	.83 (.35)	69.43	.35 (.48)	1957.00	-6.16***	1.16
B-D Confusion	131.20	.64 (.44)	48.50	.00 (.00)	1120.00	-7.80***	-
Familial Incidence	130.60	.77 (.37)	51.38	.15 (.36)	1235.00	-7.73***	1.70

* $p < .05$. *** $p < .001$.

To better understand the nature of the between-group differences, the percentage of participants in each group who obtained BDT scores respectively of: 1 (i.e., positive indicator, at risk), 0 (i.e., negative indictor, not at risk), and .5 (i.e., marginal, doubtful) was also examined (Table 7). Overall, the percentage obtaining positive scores was higher for the dyslexic than the control group. In fact, no control participant obtained a positive score on four subtests: Polysyllabic Words, Subtraction, Months Forwards and B-D Confusion. In contrast, the dyslexic group obtained positive scores on all the subtests. For both groups, the highest percentages of participants having positive scores occurred on Digits Forwards, Digits Reversed, and Tables; however, the percentages were two to three times higher among the dyslexic participants. Furthermore, the majority (68.9%) of dyslexic participants reported that other members of their family might be affected by similar difficulties compared to 14.5% for the controls. Although the nature of their family relationships was not probed, this result is broadly in line with research confirming increased risk of dyslexia for individuals with first-order family members having the disorder (Byrne et al., 2009; Snowling, et al., 2007). Generally, the performance of the control group indicated minimal difficulty with the BDT, while the opposite was true for the dyslexic group.

Table 7

Percentages of Dyslexic and Control Participants Falling in each of the Outcome Categories of the Subtests of the BDT (N = 233)

	Outcome Categories		
Subtests	Positive[a]	Marginal[b]	Negative[c]
		Dyslexics	
Left-Right	61.7	29.0	9.3
Polysyllabic Words	31.1	32.1	36.8
Subtraction	35.8	26.4	37.8
Tables	76.2	17.1	6.7
Months Forwards	3.1	8.8	88.1
Months Reversed	30.1	25.9	44.0
Digits Forwards	82.9	3.6	13.5
Digits Reversed	78.2	9.3	12.5
B-D Confusion	57.5	13.5	29.0
Familial Incidence	68.9	16.6	14.5
		Controls	
Left-Right	22.5	45.0	32.5
Polysyllabic Words	0.0	25.0	75.0
Subtraction	0.0	5.0	95.0
Tables	25.0	32.5	42.5
Months Forwards	0.0	0.0	100.0
Months Reversed	2.5	12.5	85.0
Digits Forwards	47.5	2.5	50.0
Digits Reversed	35.0	0.0	65.0
B-D Confusion	0.0	0.0	100.0
Familial Incidence	15.0	0.0	85.0

Note. Dyslexics *n* = 193. Controls *n* = 40.
[a]Positive outcome indicates a dyslexia positive response.
[b]Marginal outcome indicates an ambiguous response not clearly dyslexia positive or negative.
[c]Negative outcome indicates a dyslexia negative response.

Despite the group differences, there were also some similarities. Both groups obtained the highest number of positive indicators on the Digits Forwards, followed by Digits Reversed and Tables subtests. In addition, both groups had the lowest mean scores and the lowest percentage of plus scores on the Months Forwards subtest. Notwithstanding these similarities, the Mann-Whitney *U* analysis indicated that dyslexics consistently obtained significantly higher index scores than the controls.

Convergent and Divergent Validity. The convergent validity of the BDT was examined by correlating the BDT total scores with the standardised measures of literacy for the dyslexic and control samples separately and collectively, and the subtests of the DAST in the dyslexia group (see Table 8). For the groups combined, significant negative correlations obtained, with high scores on the BDT associated with lower scores on the other measures. However, some of these correlations reflected range effects, and they reduced (sometimes to nonsignificance) when considered separately within groups. Moreover, within the group with dyslexia, the associations between the BDT and the timed DAST measures were relatively stronger than those with the untimed standardized literacy tests, suggesting that by adulthood, timed measures provide a more sensitive literacy assessment even among those with dyslexia. Importantly, the correlations of the dyslexic group indicate that, although the BDT does not directly assess literacy skills, poorer performance on the BDT is associated with literacy difficulties, further supporting the construct validity of the screener. Divergent validity can also be inferred. In the group with dyslexia, the correlation between nonverbal ability and the BDT was not significant; this is again consistent with the view that among dyslexic adults, the association between (nonverbal) IQ and literacy (and related skills) tends to decouple (Ferrer et al., 2010). In contrast, among control participants, the *only* significant association was obtained between nonverbal abilities and the BDT (the remaining correlations with IQ ranging r = .04 to .08).

Table 8

Correlations between BDT, Standardized Measures of Literacy and Cognitive Skills, and the DAST for Each Group Separately and Combined

Group	Nonverbal Ability[a]	Verbal Ability[b]	Reading	Spelling	Compre-hension	DAST Nonsense Passage Reading[c]	DAST 2-Minute Spelling[d]
Dyslexic	-.14	-.22*	-.23**	-.26**	-.26**	-.30**	-.33**
Control	-.39*	-.26	-.11	-.27	-.01	--	--
Combined	-.27**	-.24**	-.55**	-.55**	-.39**	--	--

Note. For the dyslexic group literacy was assessed with one of the following: WIAT II, WRAT III, or WORD. For the control group literacy was assessed with the WRAT IV.
[a]Scores derived from Block Design subtest of the WAIS III for the dyslexic group and the Matrices subtest of the WRIT for the control group.
[b]Scores derived from Vocabulary subtest of the WAIS III for the dyslexic group and the Matrices subtest of the WRIT for the control group.
[e]Only the dyslexic group is included in this correlation $n = 191$.
[d]Only the dyslexic group is included in this correlation $n = 192$.
* $p < .05$. ** $p < .01$.

Predictive Validity. Logistic regression analysis was conducted to evaluate the predictive validity of the BDT. Here, the total score obtained on the BDT was the predictor and group membership (dyslexic or control) the dependent variable. Scores on the individual subtests (categorical variables) were not used as predictors because the ratio of cases to predictors was inadequate (Tabachnik & Fidell, 2007). The model was statistically significant χ^2 (1, N = 233) = 147.34, $p < .001$, indicating that the BDT score distinguished between the dyslexic and control participants, and it explained a large amount of variance in the groups .47 (Cox and Snell R^2) and .78 (Nagelkerke R^2). Also, the Hosmer-Lemeshow Goodness of Fit Test indicated that the model fitted the data well χ^2 (8, N = 233) = 4.15, p = .843. As detailed in Table 9, overall, the BDT correctly classified 94% of the participants with an excellent sensitivity rate of 96.4% and a specificity rate of 82.5%. Its positive predictive and negative predictive values were the same as its sensitivity and specificity rates, respectively.

The BDT's sensitivity rate was above the 80% minimum recommended, however, its specificity rate was lower than the 90% minimum recommend by Glascoe and Byrne (1993). Despite the less than ideal specificity, the BDT's overall ability to discriminate between adult dyslexics and non-dyslexics is clearly very good.

Table 9

Classification Results of the Logistic Regression for Dyslexics and Controls Groups

Participants	Predicted Group Membership		
	Dyslexics	Controls	% Correct
Dyslexics	186	7	96.4
Controls	7	33	82.5
Overall %			94.0

An examination of the BDT scores of the 14 misclassified participants (7 dyslexics and 7 controls, see Table 9) revealed that these individuals' scores deviated considerably from the mean scores of their respective groups. The BDT scores of the dyslexic participants classified as controls (false negatives) ranged from 2.5 to 3, being much lower than the mean score, 6.17, of the dyslexic group and outside its average variance *SD* = 1.44. The opposite pattern held for the misclassified control participants (false positives) whose scores ranged from 3.5 to 5, well above the mean of 2.09 and outside the average variance, *SD* = 1.23, of this group. The atypical scores of these 14 participants raised the possibility that setting a cut-off point for identifying at-risk individuals may help to improve the specificity rate (proportion of individuals without dyslexia correctly classified) of the BDT while not adversely affecting its sensitivity rate (proportion of individuals with dyslexia correctly classified). Importantly, a threshold score of 4 as the minimum for a positive indication of risk (as suggested by Miles (1997) for research purposes) would have increased the specificity rate from 82.5% to 92.5%, which is above the minimum recommended (Glascoe & Byrne, 1993). This cut-off could also be used for general screening purposes.

However, as is the case with all screening tools, misclassification can only be minimized and not totally eliminated and this is especially true for individuals who perform outside the norm. For example, of the 37 students who were screened at risk but not diagnosed with dyslexia on full assessment (Table 1, column 1), 28 (75.7%) obtained scores above 4 on the BDT, although their mean score of $M = 5.46$ ($SD = 2.22$) was lower than that of the confirmed dyslexic group. Moreover, all but four of these participants were later diagnosed with *other* specific learning disorders, which often co-occur with dyslexia and share some behavioural features (Table 1); only 2% of the 37 were found to have no learning difficulties.

We further examined the predictive validity of the BDT in an additional logistic regression that included, in the group with dyslexia, only those participants ($n = 183$) whose screening result *specifically* stated a risk of dyslexia (see Table 1). Here again, the total score obtained on the BDT was the predictor and group membership the dependent variable. For this analysis, the overall classification increased to 95.5%, with increased sensitivity 98.4% while the specificity 82.5% remained the same.

Together, the foregoing analyses provided empirical evidence of the construct (convergent and divergent) validity of the BDT. Its scores correlated more strongly with literacy than with other cognitive measures. Additionally, predictive validity was demonstrated as BDT scores predicted of group membership, and literacy performance.

Discussion

The main purpose of this study was to evaluate the BDT by examining its psychometric properties, especially its ability to discriminate between adult students with and without dyslexia. We used data from a large university sample of 193 students diagnosed with dyslexia (dyslexic group), and 40 with no history of literacy difficulties (control group). The cognitive profiles of the groups were in the average to above average range on standardised tests of ability and literacy. However, with the exception of the measure of verbal ability, where the groups were comparable, the controls attained significantly higher scores than the dyslexics, and this most notably on measures of reading (d = 1.86) and spelling (d = 1.59).

Reliability

The reliability analysis indicated that the internal consistency of the BDT (α = .72) is adequate, but not optimal (Field, 2009; Kline, 2000). Thus, although the items on the BDT are consistent and are likely measuring the same underlying construct, the magnitude of the coefficient alpha was probably affected by the heterogeneity of its subtests. The author of the BDT believed dyslexia to be a syndrome with a distinctive pattern of symptoms/difficulties, and the test was designed to reflect this heterogeneity.

The screener could usefully be shortened by omitting the Polysyllabic Words and the Months Forwards subtests, as deleting them leaves alpha unchanged, this poor sensitivity reflecting near-ceiling performances. Miles (1993) similarly found that on Months Forward, only 10.4% of 48 dyslexic adults (of diverse educational and socioeconomic backgrounds) obtained positive scores. In adult assessments, these subtests could certainly be replaced by age-appropriate and sensitive measures of phonological processing speed, a skill that was not assessed in the BDT. Nevertheless, the reliability of the BDT is comparable to that of the

DAST, which reports test-retest reliability for its subtests ranging from $r = .64$ to $r = .93$ (Fawcett & Nicolson, 1998), and with the York Adult Assessment-Revised (YAA-R), which reports internal consistency reliability ranging from $\alpha = .53$ to $\alpha = .81$ on its subtests (Warmington, Stothard, & Snowling, 2013).

Validity

As expected, dyslexic participants attained significantly higher index scores than the control group on the subtests and total of the BDT, the effect sizes being very large. Similar differences on the BDT were reported by Miles (1993) among boys aged 7 to 14 years with and without dyslexia, where the dyslexics performed less well (obtained higher scores) than both chronological and spelling age-matched controls. In our study of adults, 57.5% to 82.9% of participants with dyslexia obtained positive dyslexia indices across subtests and their performance contrasted greatly with that of the controls of whom only a minority obtained positive scores (2.5% to 47.5% of participants). In addition, the correlations indicated that, although the subtests of the BDT were created on the basis of observational evidence (and not their psychometric properties), most demonstrated face and construct validity in keeping with what is currently known about dyslexia, as a language-based disorder.

The overall capacity of the BDT to differentiate between adult students with and without dyslexia, however, obscures the weakness of several subtests which clearly are less appropriate for assessing adults. Both groups reached ceiling on the Months Forwards subtest, and, relatively few dyslexic participants obtained positive scores on the subtests Months Reversed (30.1%), Polysyllabic Words (31.1%), and Subtraction (35.8%). The latter results suggest that these subtests might add relatively little value to the battery as a whole (see reliability analysis); however, their inclusion in no way damaged the reliability of the battery. Moreover, these basic tests may be useful with adults in certain non-university settings, such as employment centres, and in work environments where literacy skills of the work force may be relatively weak.

Further evidence of the capacity of the BDT to discriminate between students with dyslexia and controls was provided by the main logistic regression analysis (p. 19-20), as well as a follow-up analysis including only those participants obtaining a clear ‘at-risk of dyslexia’ indication at screening (p. 21). The BDT correctly classified 94% of the participants, an excellent hit rate. It also had an excellent sensitivity rate, correctly classifying 96.4% of the dyslexic group, well above the minimum recommended, 80% (Glascoe & Byrne, 1993). This high sensitivity rate ensures that the number of false negatives is kept to a minimum and that most adults who are at risk of dyslexia will be correctly identified. The BDT also correctly classified 82.5% of the controls making its specificity rate lower than the 90% minimum recommended. This may result in a larger than acceptable proportion of non-dyslexics being incorrectly identified as being at risk of dyslexia (false positives). We were not able to investigate the causes of the weaker specificity in the present study, but expect that the addition of measures of phonological processing speed, as well as of reading and spelling efficiency would improve this aspect of the battery. Indeed, we are currently developing these supplementary measures, with a view to assessing their potential positive impacts on the screener.

On balance, the classification rate of the BDT compares favourably with other adult dyslexia screening tests. The DAST manual reports a sensitivity rate of 93% and a specificity rate of 100%; however, only 15 dyslexics were included in the validation study for that battery (Fawcett & Nicolson, 1998). What is more, independent research has reported lower rates for sensitivity (85%) and specificity (74%) for the DAST (Harrison & Nichols, 2005). The sensitivity rate of the BDT also compares favourably with other adult dyslexia screening tests, such as the Lucid Adult Dyslexia Screening Plus (91%), (Singleton et al., 2009), and the YAA-R (80%), (Warmington et al., 2013). However, the specificity rate of the BDT is lower than the rates reported for these tests, 90% and 97%, respectively. However, as shown earlier, the specificity rate of the test could be improved by clearly stipulating a cut-off score of 4 for classification decisions. This arguably makes the BDT a more effective screening test. As such, the BDT provides an alternative to other currently available screeners with its easily administered and scored measures of several distal markers of dyslexia, that may be appropriate for use with both children and adults in a variety of settings, including the non-academic.

Conclusion

Currently there is no gold standard dyslexia screening test for adults and there is a need for more empirical evidence on the effectiveness of the tests that are in use. This study provided empirical evidence that the BDT is a reliable and valid measure capable of discriminating between dyslexic and non-dyslexic adults. The study also highlighted some weaknesses or areas for improvement, and suggestions for how the measure may be enhanced. The BDT has been used effectively to screen for dyslexia in children and adults for almost three decades; it is affordable and relatively easily adapted and translated to other languages. In view of the rising need for simple-yet-sensitive screening tools for use with adults, the results of this study suggest that it deserves its place as a quick, engaging and adequately sensitive dyslexia screener, which may be particularly suited for non-academic settings of training and employment.

This paper is dedicated to the memory of Professor Tim R. Miles, founding editor of the journal Dyslexia, and co-founder of the Bangor Dyslexia Unit (now the Miles Dyslexia Centre).

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