select statistical services
Oxygen House
Grenadier Road
Exeter Business Park
Exeter, Devon, EX1 3LH
tel: 01392 440426
email: info@select-statistics.co.uk
web: www.select-statistics.co.uk

Statistical Support for QuickScreen Dyslexia Test

Further Analysis

Author: Sarah Littler (née Marley)
Reviewed by: Lynsey McColl
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Executive Summary

As in the previous study, we again find strong statistical evidence (p-value < 0.0001) of an association between the dyslexia group (previously diagnosed vs control) and the current QuickScreen test indication.

Exploring the QuickScreen test's diagnostic accuracy, we find a high specificity with 92.4% (95% confidence interval [CI] = 84.0%, 96.6%) of those in the control group estimated to receive an indication of "None" or "Borderline". Furthermore, we find evidence of a high Negative Predictive Value (NPV) for these indications, with 95.8% (95% CI = 94.7%, 96.7%) of control participants estimated to be predicted as "None" or "Borderline". We also note that whilst there may be subjects in the control group who show some symptoms linked with dyslexia (perhaps leading to a "Borderline" indication), when presenting the results of the test to participants, QuickScreen provides a caveat/explanation that in the absence of other key indicators (e.g., deficiencies in literacy levels) a dyslexia diagnosis is unlikely. Furthermore, it is recognised that though participants in the control group may not have previously received a formal dyslexia diagnosis, it is possible that this group may contain a small number of previously undiagnosed dyslexics. It is also acknowledged that those in the dyslexia diagnosed group may have received their diagnosis a number of years previously, and may now potentially be well-compensated and therefore asymptomatic despite having a positive diagnosis. For these reasons, and as dyslexia is a condition with a spectrum of symptoms and severities, we recognise that it may not necessarily be possible to achieve perfect diagnostic accuracy in this context. The graduated indications provided by QuickScreen reflect this non-binary nature of dyslexia which is on a continuum of symptoms/severities, and these provide a means of communicating this uncertainty to participants.

Considering the individual components of the QuickScreen test: We find strong statistical evidence (p-value <0.0001) of a difference in the distribution of the Dyslexia Quotient scores between the dyslexia diagnosed and control groups (with a median score of 5.5 vs 0.2 and a mean score of 5.4 vs 0.9, respectively). Similarly, the data provide strong statistical evidence of a difference in the distributions between the dyslexia diagnosed and control participants for the majority of the other QuickScreen test components (p-values between <0.0001 and 0.0007).

Furthermore, for each of the QuickScreen test components, there is statistical evidence (based on a univariate classification tree [CART] approach) of there being cut-off values that are informative in discriminating between the dyslexia diagnosed vs control participants. For example, 142.1 and 185.65 words per minute (wpm) were determined as discriminating cut-offs for reading speed, with 97.3% of participants in the 'high' indication group (<142.1 wpm) being dyslexia diagnosed, 73.0% in the 'middle' group (142.1 to 185.65 wpm), and 19.1% in the 'low' group (>185.65 wpm).

Considering the QuickScreen test components in combination, the data provide statistical evidence (via multiple variable CARTs) of the combination of the Reading Speed (wpm), Spelling Score (%), General Speed of Processing Score minus Literacy Score, and Sequencing Scaled Score QuickScreen test components discriminating between the dyslexia diagnosed and control participants. In the 'high' group, for example, all participants with a Reading Speed of less than 185.65 wpm, a Spelling Score of less than 76.25%, a General Speed of Processing minus Literacy Score of less than 9.25 were in the dyslexia diagnosed group.

The results of these univariate and multiple variable CARTs may be useful in helping to inform the adjustments to the indications that we understand are currently being explored internally by Pico to refine the QuickScreen test.

Some areas of possible further exploration for the analysis are also presented in this report.

Introduction

Following an initial study in 2016, Select were pleased to again be asked to help with the statistical analysis of Pico Educational Systems Ltd's QuickScreen dyslexia test, on behalf of Dr Dee Walker.

QuickScreen is an adult computerised screening test, developed with the aim of providing a reasonably in-depth assessment of dyslexia. The test delivers an indication of possible dyslexia without the need for users to undergo a costly professional assessment by an educational or occupational psychologist.

The focus of the previous study was to provide an initial assessment of the diagnostic accuracy of the QuickScreen dyslexia test, based on the test's banded outcomes (None, Borderline, Mild, Moderate, or Strong). In this study, using new observational data compiled by Pico Educational Systems Ltd, the aim was to support the development of the test by providing evidence that might inform adjustments to the current QuickScreen indication category boundaries. The boundaries are currently defined with respect to a dyslexia quotient score, which is calculated by combining individual scores for various processes examined during the online assessment, such as visual, verbal, memory, reading, comprehension, etc.

In the previous study, we carried out an initial exploration of the speed of processing component results available from the QuickScreen test and found a clear association with dyslexia diagnosis. This initial analysis focussed on the categorical, banded speed of processing results (No Difficulties, Average, or Difficulties). In this study, we take this further, exploring the continuous speed of processing scores (scored from 0 to 20) and identifying the cut-off values that best discriminate between those with and without a previous dyslexia diagnosis, as well as extending this process to the other QuickScreen component assessments.

An essential step in the evaluation process of any diagnostic/screening test is to assess its accuracy via diagnostic accuracy measures. We also agreed to produce these measures for the QuickScreen test outcomes, based on the new data provided, as well as exploring the performance of the alternative predicted dyslexia indications developed as part of the analysis.

Data

The QuickScreen dyslexia test results were provided in two separate spreadsheets. The files had a consistent layout and were combined prior to analysis to create a single dataset.

The data received included one set of results for participants with a previous independent dyslexia diagnosis (a "dyslexia diagnosed" group) and a separate set of results for a group of "control" participants for whom no previous independent dyslexia diagnosis was available. The control group participants were all students from the psychology department of a leading UK university. The dyslexia diagnosed group included all participants who had completed the online QuickScreen test since January 2018 and had indicated that they had a previous positive dyslexia diagnosis. This included a

combination of students from various universities, employees of public sector organisations and members of the general public (accessed via the British Dyslexia Association [BDA] website). Note: One participant in the control group spreadsheet was recorded as having previously been diagnosed with dyslexia and was therefore omitted from our analysis.

QuickScreen test results were available for analysis for 185 participants; 111 (60.0%) in the dyslexia diagnosed group and 74 (40.0%) in the control group. The QuickScreen test reports the overall possibility of dyslexia assessment outcome in terms of one of five possible indications: None, Borderline, Mild, Moderate, or Strong. Of the 185 participants included in the analysis, 54 (29.2%) received an indication of None; 56 (30.3%) an indication of Borderline; 31 (16.8%) Mild; 42 (22.7%) Moderate; and 2 (1.1%) Strong (as shown in the cross-tabulation in Table 1 below).

	None	Borderline	Mild	Moderate	Strong	Total
Control	44	26	4	0	0	74 (40.0%)
Diagnosed	10	30	27	42	2	111 (60.0%)
Total	54 (29.2%)	56 (30.3%)	31 (16.8%)	42 (22.7%)	2 (1.1%)	185 (100%)

Table 1: Cross-tabulation of the dyslexia group (control/dyslexia diagnosed) versus the QuickScreen test result (None/Borderline/Mild/Moderate/Strong) for the 185 participants included in the study.

In addition to the test's banded outcomes (None, Borderline, Mild, Moderate, or Strong), scores for various QuickScreen component assessments, of processes that are thought to be associated with dyslexia, were also provided in the data. For some components, as well as a "raw" mark on the original scale (such as words per minute [wpm]), a scaled score (between 0 and 20; calculated following standard procedures for these tests) and a percentile version with reference to national norms were also supplied. For a number of the component assessments, 'Disparity' and 'Factor' variables were also provided, capturing unevenness in performance between the various components and additional symptoms over and above a main indication of dyslexia, respectively.

Prior to analysis, we also calculated a combined result (categorical grouping) and score (continuous variable) for the General Speed of Processing and Literacy components. This allowed us to directly explore potential interactions between these two processes which, following discussion with Dr Walker, we understand are expected to be associated with dyslexia. When combining the scores, as high literacy scores appeared to be associated with the dyslexia diagnosed group whereas high speed of processing scores appeared to be associated with the control group, we computed the General Speed of Processing Score minus the Literacy Score to contrast these rather than simply sum them. Note: There were some sparse categories for the Literacy Result that were excluded from the analysis, these were – "significantly below expectation", "significantly less well developed than general ability", and "somewhat less well developed than general ability".

Finally, a dyslexia quotient variable (scored on a scale from 0 to 20), combining the other component assessments was also provided in the datasets received. The current banded outcomes for the QuickScreen test (None, Borderline, Mild, Moderate, or Strong) are based on the dyslexia quotient score with, prior to September 2018, e.g., quotients of less than 0.5 being associated with an indication

of “None”. Note: We understand that further work is also currently being undertaken internally on the QuickScreen indications to refine the cut-offs used in banding these, e.g., adjusting the boundaries so that quotients of less than 0.5 correspond with an indication of “None”. The aim of this work, which we hope the results of this study will feed in to, is to help narrow-down some of the categories, such as “Borderline” and “Mild” as these were perceived to previously be too broad.

Table 2, below, provides a complete list of the QuickScreen component variables considered in the analysis.

QuickScreen Test Component Variable	Number (%) of Missing Values
Literacy Score	0 (0.0%)
Literacy Result ***(Commensurate with or better than general ability/ slightly below expectation/ somewhat below expectation/ significantly below expectation/ significantly less well developed than general ability/ somewhat less well developed than general ability)***	0 (0.0%)
General Speed of Processing Score	0 (0.0%)
General Speed of Processing Result ***(No difficulties/ Average/ Difficulties)***	0 (0.0%)
General Speed of Processing Score - Literacy Score (Difference in scores)	0 (0.0%)
Literacy & General Speed of Processing Result ***(Combined categories for Literacy Result & General Speed of Processing Result)***	0 (0.0%)
Spelling Score (%)	0 (0.0%)
Spelling Scaled Score	0 (0.0%)
Reading Speed (wpm)	7 (3.8%)
Reading Speed Scaled Score	7 (3.8%)
Memory Scaled Score	0 (0.0%)
Memory Score (%)	0 (0.0%)
Memory Span Scaled Score	10 (5.4%)
Memory Span (words)	0 (0.0%)
Sequencing Scaled Score	0 (0.0%)
Sequencing Score (%)	0 (0.0%)
Visual Score (%)	0 (0.0%)
Visual Scaled Score	0 (0.0%)
Verbal Score (%)	0 (0.0%)
Verbal Scaled Score	0 (0.0%)
Vocabulary Score (%)	0 (0.0%)
Vocabulary Scaled Score	0 (0.0%)
Processing Score (%)	0 (0.0%)
Processing Scaled Score	0 (0.0%)
Comprehension Score (%)	0 (0.0%)
Comprehension Scaled Score	0 (0.0%)
Writing Speed (wpm)	170 (91.9%)
Writing Speed Scaled Score	170 (91.9%)
Typing Speed (wpm)	1 (0.5%)

Typing Speed Scaled Score	1 (0.5%)
Accuracy Score (%)	0 (0.0%)
Accuracy Scaled Score	0 (0.0%)
Punctuation Score (%)	0 (0.0%)
Punctuation Scaled Score	0 (0.0%)
Ability Score (%)	0 (0.0%)
Ability Scaled Score	0 (0.0%)
Memory Disparity	0 (0.0%)
Sequencing Disparity	0 (0.0%)
Processing Disparity	0 (0.0%)
Processing Speed Disparity	0 (0.0%)
Reading Speed Disparity	0 (0.0%)
Literacy Factor	0 (0.0%)
Spelling Factor	0 (0.0%)
Writing/Typing Speed Factor	0 (0.0%)
Visual/Verbal Factor	0 (0.0%)
Dyslexia Quotient	0 (0.0%)

Table 2: QuickScreen test component variables available for analysis.

There were a number of missing values in the data for some of the component variables, as detailed in Table 2 above. These were primarily due to two reasons: timed tests as part of the QuickScreen assessment have a ceiling such that if a participant takes unduly long on an item the result is recorded as missing; and the writing component of the QuickScreen test is optional and so those participants choosing not to complete this component will have missing values for the corresponding variables. These missing values were retained within the analysis where possible.

In the following sections, we describe the statistical methods applied to the data provided followed by the corresponding results of these analyses.

We start by describing the assessments applied to the current QuickScreen test banded outcome.

Diagnostic Accuracy Assessments

Methods

To assess the performance of the current QuickScreen test banded outcome, we produced a number of diagnostic accuracy assessment summaries, including the sensitivities, specificities, and predictive values associated with each outcome indication. A similar approach was applied to that used in our original project for QuickScreen (again assuming an estimated prevalence of dyslexia in the population of 10%, when calculating the predictive values). The method to calculate these values is described in our previous report (ref: PICO001) and therefore not repeated here.

We note that 'Diagnostic Likelihood Ratios', whilst not explicitly given in the results of this project, can also be calculated from the Sensitivity and Specificity measures provided as follows.

- Likelihood Ratio Positive = Sensitivity / (1 − Specificity)
- Likelihood Ratio Negative = (1 − Sensitivity) / Specificity

Results

A Fisher's exact test (on the data in Table 1) finds strong statistical evidence (p-value < 0.0001) of an association between the dyslexia group and the current QuickScreen test indication.

The proportion of participants without dyslexia who received each QuickScreen test result (i.e., sample specificity) and the proportion of participants with dyslexia who received each QuickScreen test result (i.e., sample sensitivity) are shown in Table 3.

	None	Borderline	Mild	Moderate	Strong
Control	59.5%	35.1%	5.4%	0.0%	0.0%
Diagnosed	9.0%	27.0%	24.3%	37.8%	1.8%

Table 3: Raw sample specificity (Control row) and sensitivity (Diagnosed row) values for each QuickScreen test category.

For example, 59.5% of participants in the control group received a QuickScreen indication of "None", and 37.8% of participants in the dyslexia diagnosed group received a QuickScreen indication of "Moderate".

The proportion of participants in the control and dyslexia diagnosed groups in each QuickScreen test category are shown in Table 4. These are the raw sample predictive values, based on the observed sample prevalence, and do not reflect estimates for the population.

	None	Borderline	Mild	Moderate	Strong
Control	81.5%	46.4%	12.9%	0.0%	0.0%
Diagnosed	18.5%	53.6%	87.1%	100.0%	100.0%

Table 4: Raw sample predictive values (Negative and Positive, associated with the Control and Diagnosed groups, respectively) for each QuickScreen test category.

For example, 81.5% of those participants with a QuickScreen test result of "None" were in the control group, and 100% of those participants with a QuickScreen test result of "Moderate" or "Strong" were in the dyslexia diagnosed group.

The diagnostic accuracy measures for each QuickScreen test category, estimated using the adjusted method (with adjusted logit confidence intervals) and assuming a 10% prevalence of dyslexia are shown in Table 5.

QuickScreen Test Result	Diagnostic Measure	Estimate	Confidence Interval
None	Sensitivity	10.4%	(6.0%, 17.4%)
	PPV	1.9%	(1.1%, 3.3%)
	Specificity	59.0%	(47.8%, 69.3%)
	NPV	98.1%	(96.7%, 98.9%)

Borderline	Sensitivity	27.8%	(20.4%, 36.7%)
	PPV	7.9%	(5.4%, 11.6%)
	Specificity	35.9%	(26.0%, 47.1%)
	NPV	92.1%	(88.4%, 94.6%)
Mild	Sensitivity	25.2%	(18.1%, 33.9%)
	PPV	26.9%	(13.8%, 45.9%)
	Specificity	7.6%	(3.4%, 16.0%)
	NPV	73.1%	(54.1%, 86.2%)
Moderate	Sensitivity	38.2%	(29.8%, 47.4%)
	PPV	63.3%	(29.5%, 87.6%)
	Specificity	2.5%	(0.6%, 9.6%)
	NPV	36.7%	(12.4%, 70.5%)
Strong	Sensitivity	3.4%	(1.3%, 8.8%)
	PPV	13.3%	(2.7%, 45.7%)
	Specificity	2.5%	(0.6%, 9.6%)
	NPV	86.7%	(54.3%, 97.3%)
Moderate or Strong	Sensitivity	40.0%	(31.4%, 49.2%)
	PPV	64.3%	(30.4%, 88.1%)
	Specificity	2.5%	(0.6%, 9.6%)
	NPV	35.7%	(11.9%, 69.6%)
Mild, Moderate or Strong	Sensitivity	63.5%	(54.3%, 71.8%)
	PPV	48.1%	(29.7%, 67.1%)
	Specificity	7.6%	(3.4%, 16.0%)
	NPV	51.9%	(32.9%, 70.3%)
Borderline, Mild, Moderate or Strong	Sensitivity	89.6%	(82.6%, 94.0%)
	PPV	19.5%	(15.6%, 24.2%)
	Specificity	41.0%	(30.7%, 52.2%)
	NPV	80.5%	(75.8%, 84.4%)
None or Borderline	Sensitivity	36.5%	(28.2%, 45.7%)
	PPV	4.2%	(3.3%, 5.3%)
	Specificity	92.4%	(84.0%, 96.6%)
	NPV	95.8%	(94.7%, 96.7%)

Table 5: Estimates of the diagnostic accuracy measures for each QuickScreen test category using the adjusted logit method (with 10% prevalence). PPV = Positive (i.e., Diagnosed) Predictive Value; NPV = Negative (i.e., Control) Predictive Value.

So, for example, where the QuickScreen test predicted "None", we estimate that 98.1% (95% Confidence Interval [CI] = 96.7%, 98.9%) of those candidates will not be in the dyslexia diagnosed group (this is the 'Negative Predictive Value [NPV]'). Of those in the control group, we estimate that the QuickScreen test will predict 59.0% (95% CI = 47.8%, 69.3%) of these candidates to be in the "None" group (Specificity).

Note that the figures for the "None" group do not take account of the borderline cases. In addition to considering each category in isolation, the measures for some combinations of the QuickScreen test result are also provided above. The table includes a row, for example, for "None or Borderline" together. In this case (including the borderlines), of those in the control group, we estimate that the QuickScreen test will predict 92.4% (95% CI = 84.0%, 96.6%) of these candidates to be in the "None or Borderline" groups (this is the test Specificity for these groups when considering them in

combination). So by including the borderlines with the nones, we're expected to detect a much higher proportion of the control group. In this case, the Negative Predictive Value (NPV) for the "None or Borderline" group remains high, with 95.8% (95% CI = 94.7%, 96.7%) of control candidates estimated to be predicted as either in the "None" or "Borderline" group.

Including the borderline cases in this way helps to address the fact that there may be subjects in the control group who show some symptoms linked with dyslexia (perhaps leading to a "Borderline" indication). When presenting the results of the test to participants, QuickScreen provides a caveat/explanation that in the absence of other key indicators (e.g., deficiencies in literacy levels) a dyslexia diagnosis is unlikely. Furthermore, it is recognised that though participants in the control group may not have previously received a formal dyslexia diagnosis, it is possible that this group may contain a small number of previously undiagnosed dyslexics. Please see the Validity section of this report for further discussion of the potential for so-called classification bias. The implication of which is that it may not be possible to achieve perfect diagnostic accuracy in this case. The graduated indications provided by QuickScreen reflect the non-binary nature of dyslexia which is on a continuum of symptoms/severities and help communicate this uncertainty to participants.

In the following sections, we move on to describing the methods applied to the QuickScreen test component variables.

Exploratory Data Analysis

Methods

It is standard practice when undertaking a statistical analysis to begin with some exploratory analyses. In this case, we produced a boxplot[1] and summary statistics (calculating the mean, standard deviation [SD], median and range) for each continuous QuickScreen test component variable (i.e., excluding the categorical variables: Literacy Result, General Speed of Processing Result, Literacy + General Speed of Processing Result), split by group. These summaries help to provide an indication as to which variables might be most informative in discriminating between those in the dyslexia diagnosed and control groups, by comparing the distributions of the scores observed between these groups. A statistical hypothesis test[2] was also performed to assess the evidence available for a difference in the distributions between the groups for each QuickScreen component.

Note: Missing values were excluded from the corresponding summaries for the relevant variables.

Results

The boxplots, comparing the distributions of the QuickScreen test component variables between the dyslexia diagnosed and control groups are presented in an Appendix to this report. The summary statistics by dyslexia diagnosed versus control group are presented in Table 6 below.

[1] The box includes the upper and lower quartiles and therefore the middle 50% of the data and the horizontal line within the box is the median (https://select-statistics.co.uk/resources/glossary-page/#median). The whiskers extend to 1.5 times the interquartile range (https://select-statistics.co.uk/resources/glossary-page/#interquartile-range-iqr) and data points outside this range are marked as dots.

[2] A non-parametric, two-sample Mann–Whitney U test was applied, which does not rely on the assumption of normally distributed data, as for some variables there was evidence of a deviation from normality in the corresponding boxplots.

QuickScreen Test Component Variable	Dyslexia Group	Mean (SD)	Median (Range)	Mann-Whitney U test p-value
Literacy Score	Control	0.7 (1.22)	0 (0 to 5)	
	Dyslexia Diagnosed	2.4 (1.74)	2 (0 to 7.5)	<0.0001
General Speed of Processing Score	Control	15.6 (2.12)	16 (8 to 20)	
	Dyslexia Diagnosed	10.2 (3.71)	10 (1 to 17)	<0.0001
General Speed of Processing Score - Literacy Score	Control	14.9 (2.73)	15 (4 to 20)	
	Dyslexia Diagnosed	7.7 (4.78)	8 (-3 to 17)	<0.0001
Spelling Score (%)	Control	82.8 (19.67)	87.5 (1 to 100)	
	Dyslexia Diagnosed	48 (27.96)	55 (1 to 95)	<0.0001
Spelling Scaled Score	Control	13.1 (3.19)	14 (3 to 16)	
	Dyslexia Diagnosed	7.5 (3.78)	8 (3 to 16)	<0.0001
Reading Speed (wpm)	Control	232.8 (58.89)	231.5 (51.8 to 349)	
	Dyslexia Diagnosed	137.2 (52.89)	128.6 (18.7 to 335.2)	<0.0001
Reading Speed Scaled Score	Control	12.9 (2.66)	14 (3 to 16)	
	Dyslexia Diagnosed	8.5 (2.66)	8 (3 to 16)	<0.0001
Memory Scaled Score	Control	11.5 (2.81)	12 (3 to 16)	
	Dyslexia Diagnosed	8.2 (2.51)	8 (3 to 14)	<0.0001
Memory Score (%)	Control	63.7 (18.12)	64.3 (21.4 to 100)	
	Dyslexia Diagnosed	40.2 (15.32)	39.3 (3.6 to 78.6)	<0.0001
Memory Span Scaled Score	Control	10.7 (1.41)	10 (7 to 14)	
	Dyslexia Diagnosed	8.9 (2.93)	10 (3 to 16)	<0.0001
Memory Span (words)	Control	5.7 (2.54)	6.3 (-1 to 9.3)	
	Dyslexia Diagnosed	5.1 (2.2)	5 (-1 to 14.3)	<0.0001
Sequencing Scaled Score	Control	11.2 (2.53)	11 (7 to 16)	
	Dyslexia Diagnosed	7.7 (2.41)	8 (3 to 14)	<0.0001
Sequencing Score (%)	Control	69.3 (13.51)	67.7 (41.9 to 100)	
	Dyslexia Diagnosed	51.6 (12.26)	52.7 (14 to 88.2)	<0.0001
Visual Score (%)	Control	77 (15.19)	80 (25 to 100)	
	Dyslexia Diagnosed	58.3 (26.22)	60 (0 to 100)	<0.0001
Visual Scaled Score	Control	14.8 (2.45)	16 (3 to 16)	
	Dyslexia Diagnosed	11.3 (4.83)	12 (3 to 16)	<0.0001
Verbal Score (%)	Control	69 (14.25)	72 (40 to 100)	
	Dyslexia Diagnosed	53.7 (17.46)	52 (16 to 88)	<0.0001
Verbal Scaled Score	Control	12.7 (2.05)	14 (9 to 16)	
	Dyslexia Diagnosed	10.8 (2.32)	10 (7 to 16)	<0.0001
Vocabulary Score (%)	Control	82.1 (12.44)	85 (30 to 100)	
	Dyslexia Diagnosed	65.5 (22.28)	70 (0 to 100)	<0.0001
Vocabulary Scaled Score	Control	15.4 (1.55)	16 (7 to 16)	
	Dyslexia Diagnosed	12.9 (4.04)	14 (3 to 16)	<0.0001
Processing Score (%)	Control	76.8 (15.8)	80 (40 to 100)	
	Dyslexia Diagnosed	68 (16.5)	70 (30 to 100)	0.0005
Processing Scaled Score	Control	13 (1.77)	14 (7 to 14)	
	Dyslexia Diagnosed	8.7 (3.07)	10 (3 to 14)	<0.0001
Comprehension Score (%)	Control	76.8 (15.8)	80 (40 to 100)	
	Dyslexia Diagnosed	68 (16.5)	70 (30 to 100)	0.0005
Comprehension Scaled Score	Control	12.8 (2.39)	14 (7 to 16)	
	Dyslexia Diagnosed	11.5 (2.65)	12 (7 to 16)	0.0007
Writing Speed (wpm)*	Control	27.8 (9.54)	26.7 (19.5 to 42.9)	

	Dyslexia Diagnosed	19.6 (6.39)	16.7 (10.4 to 27.5)	0.0753
Writing Speed Scaled Score*	Control	12.4 (2.61)	12 (10 to 16)	
	Dyslexia Diagnosed	9.4 (2.27)	8 (7 to 12)	0.0674
Typing Speed (wpm)	Control	30.7 (7.14)	30.7 (12.9 to 49.8)	
	Dyslexia Diagnosed	19.3 (8.64)	19.1 (1.7 to 43.4)	<0.0001
Typing Speed Scaled Score	Control	13.1 (2.42)	14 (7 to 16)	
	Dyslexia Diagnosed	8.9 (3.35)	10 (3 to 16)	<0.0001
Accuracy Score (%)	Control	87.2 (22.58)	96 (1 to 100)	
	Dyslexia Diagnosed	66.5 (31.64)	80 (1 to 100)	<0.0001
Accuracy Scaled Score	Control	14.4 (3.18)	16 (3 to 16)	
	Dyslexia Diagnosed	11.2 (4.62)	12 (3 to 16)	<0.0001
Punctuation Score (%)	Control	80.4 (21.22)	85.4 (1 to 100)	
	Dyslexia Diagnosed	42.6 (30.27)	41.7 (1 to 100)	<0.0001
Punctuation Scaled Score	Control	13.9 (3.28)	15 (3 to 16)	
	Dyslexia Diagnosed	7.9 (4.71)	8 (3 to 16)	<0.0001
Ability Score (%)	Control	76.3 (11.61)	77.5 (37 to 99)	
	Dyslexia Diagnosed	59 (20.24)	61.5 (8 to 95.8)	<0.0001
Ability Scaled Score	Control	12.7 (1.68)	14 (9 to 16)	
	Dyslexia Diagnosed	10.7 (2.22)	10 (7 to 16)	<0.0001
Memory Disparity	Control	0.4 (0.62)	0 (0 to 3)	
	Dyslexia Diagnosed	1.2 (0.91)	1 (0 to 3)	<0.0001
Sequencing Disparity	Control	0.3 (0.64)	0 (0 to 3)	
	Dyslexia Diagnosed	1.4 (1.11)	2 (0 to 4)	<0.0001
Processing Disparity	Control	0.1 (0.42)	0 (0 to 3)	
	Dyslexia Diagnosed	0.8 (1.15)	0 (0 to 4)	<0.0001
Processing Speed Disparity	Control	0 (0.06)	0 (0 to 0.5)	
	Dyslexia Diagnosed	0.5 (0.61)	0 (0 to 2)	<0.0001
Reading Speed Disparity	Control	0 (0.17)	0 (0 to 1)	
	Dyslexia Diagnosed	0.4 (0.49)	0.5 (0 to 2)	<0.0001
Literacy Factor^	Control	0 (0)	0 (0 to 0)	
	Dyslexia Diagnosed	0 (0.21)	0 (0 to 2)	0.2501
Spelling Factor	Control	0 (0.16)	0 (0 to 1)	
	Dyslexia Diagnosed	0.6 (0.57)	0.5 (0 to 2)	<0.0001
Writing/Typing Speed Factor	Control	0 (0.16)	0 (0 to 1)	
	Dyslexia Diagnosed	0.4 (0.61)	0 (0 to 2)	<0.0001
Visual/Verbal Factor	Control	0 (0.1)	0 (0 to 0.5)	
	Dyslexia Diagnosed	0.2 (0.32)	0 (0 to 1.5)	0.0002
Dyslexia Quotient	Control	0.9 (1.13)	0.2 (0 to 4)	
	Dyslexia Diagnosed	5.4 (3.73)	5.5 (0 to 20)	<0.0001

Table 6: Summary statistics showing the mean (SD = standard deviation) and median (range) of the values of each continuous QuickScreen component variable, split by control versus dyslexia diagnosed group. The Mann-Whitney U test p-value is for a comparison of the distribution of values between the control and dyslexia diagnosed groups, for each continuous QuickScreen component variable. *Note: There are a large proportion of missing values (91.9%) for the Writing Speed variables and therefore little data on which these summaries are based. ^Note: Only two participants in the study were observed to have a non-zero Literacy Factor.

From these summaries, we note for example that there appears to be clear evidence of:

- Lower General Speed of Processing Scores being associated with the dyslexia diagnosed group compared with the control group.
    - On average (based on the mean values), the dyslexia diagnosed group participants achieve a score of 10.2, whereas the control group participants achieve a score of 15.6.
- Lower Memory Score (%) results being associated with the dyslexia diagnosed group compared with the control group.
    - On average (based on the mean values), the dyslexia diagnosed group participants achieve a score of 40.2%, whereas the control group participants achieve a score of 63.7%.
- Lower Reading Speed (wpm) results being associated with the dyslexia diagnosed group compared with the control group.
    - On average (based on the mean values), the dyslexia diagnosed group participants achieve a wpm of 137.2, whereas the control group participants achieve a wpm of 232.8.
- Lower Spelling Score (%) results being associated with the dyslexia diagnosed group compared with the control group.
    - On average (based on the mean values), the dyslexia diagnosed group participants achieve a score of 48.0%, whereas the control group participants achieve a score of 82.8%.
- Higher Dyslexia Quotient scores being associated with the dyslexia diagnosed group compared with the control group.
    - On average (based on the mean values), the dyslexia diagnosed group participants achieve a score of 5.4, whereas the control group participants achieve a score of 0.9.

Furthermore, based on the Mann-Whitney U test (Table 6), we find strong statistical evidence ($p<0.0001$) of a difference in the distribution of the Dyslexia Quotient scores between the dyslexia diagnosed and control groups (with a median score of 5.5 versus 0.2, respectively).

Similarly, the data provide strong statistical evidence of a difference in the distributions between the dyslexia diagnosed and control participants for the following QuickScreen test components: Literacy Score, General Speed of Processing Score, General Speed of Processing Score minus Literacy Score, Spelling Score (%), Spelling Scaled Score, Reading Speed (wpm), Reading Speed Scaled Score, Memory Scaled Score, Memory Score (%), Memory Span Scaled Score, Memory Span (words), Sequencing Scaled Score, Sequencing Score (%), Visual Score (%), Visual Scaled Score, Verbal Score (%), Verbal Scaled Score, Vocabulary Score (%), Vocabulary Scaled Score, Processing Scaled Score, Typing Speed (wpm), Typing Speed Scaled Score, Accuracy Score (%), Accuracy Scaled Score, Punctuation Score (%), Punctuation Scaled Score, Ability Score (%), Ability Scaled Score, Memory Disparity, Sequencing Disparity, Processing Disparity, Processing Speed Disparity, Reading Speed Disparity, Spelling Factor, Writing/Typing Speed Factor ($p<0.0001$, for each of the preceding variables), Visual/Verbal Factor ($p=0.0002$), Processing Score (%) ($p=0.0005$), Comprehension Score (%) ($p=0.0005$), and Comprehension Scaled Score ($p=0.0007$).

CART Modelling

Following the exploratory analysis described above, we applied some more formal modelling to further explore the association between each QuickScreen test component variable and the participants' dyslexia group.

Univariate Models

Methods

For each QuickScreen component variable, individually, we applied a tree-based modelling[3] approach (also known as "CART" [Classification And Regression Tree]). We fit a classification tree to the dyslexia group (control versus dyslexia diagnosed) as the outcome, with each component considered as the only explanatory variable, one-by-one. This is helps to identify the thresholds/groups of values for each explanatory variable that are associated with the outcome. A final set of tree groups are produced corresponding with distinct values of the explanatory variable that have an associated proportion/probability of being dyslexia diagnosed, which are as different as possible between the groups.

The classification tree is fit using a process called binary recursive partitioning. The algorithm starts with all of the participants at the top of the tree, then as we progress down to the first "branch", we identify the threshold, i.e., cut-off, in the QuickScreen test component variable under consideration that is the 'best' at discriminating between the dyslexia diagnosed and control group participants (splitting these as far as possible into separate groups). The participants are then broken down into two splits based upon the differing values of the QuickScreen variable (compared with the threshold identified), with one group going down the left-hand branch and the other the right-hand branch. The classification tree algorithm checks to see that the difference in the proportion of dyslexia diagnosed vs control participants between these groups is sufficiently discriminatory (based on a stopping rule with given tuning parameters) and, if it is, we retain these new branches. At the next step, for each of the new branches, we then consider whether they can be further split into subgroups so that there is a difference in the proportion of dyslexia diagnosed vs control participants, with the most discriminating split chosen as the next branch, and so on.

The algorithm measures the value of a potential split in terms of the 'deviance'. This is based on viewing the tree as a probability model and considering the likelihood of observing the data given the model that we are proposing. Introducing an additional split will reduce the deviance, and the split that results in the greatest reduction in the deviance is considered the optimal choice.

To help avoid spurious results that may occur due to small numbers of participants showing an apparent effect by chance, we included a condition in the tree algorithm so that the smallest number of participants that could contribute to a final group (at the bottom of the tree) was 20.

For each univariate classification tree, we produced a table summarising the results of the corresponding tree, giving details of the splits and the associated proportions of dyslexia diagnosed vs

[3] Hastie, R. Tibshirani, and J. Friedman. The Elements of Statistical Learning: Data Mining, Inference, and Prediction (2nd Edition). Springer, 2009. Download-able from http://web.stanford.edu/~hastie/ElemStatLearn. Cited on page 305; Section 9.2.

control candidates in the final groups formed. The tables also detail the number (and proportion) of participants in each final group out of all of the subjects included in the study.

Furthermore, we provide summaries of the "Residual Mean Deviance" and "Misclassification Rate" associated with each tree. These can be used to compare the predictive performance of the trees to understand which may be 'best' at discriminating between the dyslexia diagnosed and control participants. The misclassification rate, is simply calculated by predicting/classifying all participants within a tree group with a dyslexia diagnosed proportion higher than 50% as being in the dyslexia group, and those less than 50% as being in the control group. The proportion of candidates misclassified (as being in the wrong group according to the observed data) then gives the misclassification rate. The residual mean deviance is simply the average deviance across the final groups in the tree, and can be interpreted as the lower the value the better the model performance.

This tree-based approach helps to identify the cut-off values, looking at each variable in isolation, that best discriminate between those with and without a previous dyslexia diagnosis. The thresholds indicated, which have been identified in an objective manner, could then help to potentially redefine the current QuickScreen bandings, with a view to narrowing down the classifications and hopefully improving the predictive accuracy of the QuickScreen test.

Note: Missing values were excluded from the corresponding univariate tree for the relevant variables.

All analyses were performed in the statistical software package R version 3.4.3 (2017-11-30)[4]. The *tree* package[5] was used to implement the classification tree models.

Results

Summaries of the results of the univariate trees for each of the QuickScreen test component variables are shown in Table 7 overleaf. The table is ordered by the tree misclassification rates, where the lowest rate (closest to zero) indicates the 'best' performance. Based on this metric, we find that the following variables are most informative:

i. Reading speed (wpm),
ii. Literacy + General Speed of Processing Result,
iii. General Speed of Processing Result,
iv. Processing Scaled Score,
v. General Speed of Processing Score - Literacy Score,
vi. Reading Speed Scaled Score,
etc.

[4] R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.
[5] Brian Ripley (2016). tree: Classification and Regression Trees. R package version 1.0-37. https://CRAN.R-project.org/package=tree

QuickScreen Test Component Variable	CART Splits	Number of Participants	Proportion of Participants	Control Group Probability	Dyslexia Group Probability	Residual Mean Deviance	Misclassification Rate
Reading Speed (wpm)	x < 142.1	73	41.0%	2.7%	97.3%	0.7307	14.0%
	142.1 < x < 185.65	37	20.8%	27.0%	73.0%		
	185.65 < x	68	38.2%	80.9%	19.1%		
Literacy & General Speed of Processing Result	slightly below expectation + Average, Difficulties	76	42.2%	6.6%	93.4%	0.7752	15.6%
	Commensurate with or better than general ability, somewhat below expectation + Average, Difficulties	38	21.1%	31.6%	68.4%		
	slightly below expectation, somewhat below expectation + No difficulties	24	13.3%	66.7%	33.3%		
	Commensurate with or better than general ability + No difficulties	42	23.3%	92.9%	7.1%		
General Speed of Processing Result	Difficulties	46	24.9%	2.2%	97.8%	0.8141	15.7%
	Average	72	38.9%	23.6%	76.4%		
	No difficulties	67	36.2%	83.6%	16.4%		
Processing Scaled Score	x < 10.5	84	45.4%	7.1%	92.9%	0.7856	15.7%
	10.5 < x < 11.5	24	13.0%	29.2%	70.8%		
	11.5 < x < 13	20	10.8%	55.0%	45.0%		
	13 < x	57	30.8%	87.7%	12.3%		
General Speed of Processing Score - Literacy Score	x < 8.75	63	34.1%	3.2%	96.8%	0.7148	16.2%
	8.75 < x < 11.75	28	15.1%	14.3%	85.7%		
	11.75 < x < 14.25	40	21.6%	47.5%	52.5%		
	14.25 < x	54	29.2%	90.7%	9.3%		
Reading Speed Scaled Score	x < 9	75	42.1%	5.3%	94.7%	0.8227	16.3%

	9 < x < 11	39	21.9%	30.8%	69.2%		
	11 < x	64	36.0%	79.7%	20.3%		
General Speed of Processing Score	x < 7.5	29	15.7%	0.0%	100.0%	0.7665	17.3%
	7.5 < x < 11.5	41	22.2%	7.3%	92.7%		
	11.5 < x < 14.5	45	24.3%	33.3%	66.7%		
	14.5 < x < 16.5	40	21.6%	67.5%	32.5%		
	16.5 < x	30	16.2%	96.7%	3.3%		
Spelling Scaled Score	x < 9	79	42.7%	7.6%	92.4%	0.8697	18.9%
	9 < x < 11	23	12.4%	30.4%	69.6%		
	11 < x < 15	61	33.0%	65.6%	34.4%		
	15 < x	22	11.9%	95.5%	4.6%		
Dyslexia Quotient	4.25 < x	63	34.1%	0.0%	100.0%	0.7771	19.5%
	2.25 < x < 4.25	30	16.2%	30.0%	70.0%		
	0.75 < x < 2.25	38	20.5%	55.3%	44.7%		
	x < 0.75	54	29.2%	81.5%	18.5%		
Punctuation Scaled Score	x < 7.5	55	29.7%	7.3%	92.7%	0.9337	19.5%
	7.5 < x < 13	48	25.9%	20.8%	79.2%		
	13 < x < 15	37	20.0%	62.2%	37.8%		
	15 < x	45	24.3%	82.2%	17.8%		
Punctuation Score (%)	x < 39.6	55	29.7%	7.3%	92.7%	0.9187	19.5%
	39.6 < x < 72.9	48	25.9%	20.8%	79.2%		
	72.9 < x < 93.75	58	31.4%	65.5%	34.5%		
	93.75 < x	24	13.0%	91.7%	8.3%		
Spelling Score (%)	18.75 < x < 53.75	31	16.8%	0.0%	100.0%	0.8238	20.0%

	53.75 < x < 66.25	24	13.0%	8.3%	91.7%		
	x < 18.75	28	15.1%	14.3%	85.7%		
	66.25 < x < 83.75	43	23.2%	46.5%	53.5%		
	83.75 < x < 93.75	37	20.0%	73.0%	27.0%		
	93.75 < x	22	11.9%	95.5%	4.6%		
Literacy Result	slightly below expectation	92	51.1%	15.2%	84.8%	1.0015	20.6%
	somewhat below expectation	27	15.0%	37.0%	63.0%		
	Commensurate with or better than general ability	61	33.9%	78.7%	21.3%		
Typing Speed (wpm)	x < 12.75	29	15.8%	0.0%	100.0%	0.9102	20.7%
	12.75 < x < 20.8	42	22.8%	11.9%	88.1%		
	20.8 < x < 25.15	28	15.2%	28.6%	71.4%		
	25.15 < x < 29.15	30	16.3%	56.7%	43.3%		
	29.15 < x	55	29.9%	78.2%	21.8%		
Literacy Score	2.25 < x	61	33.0%	11.5%	88.5%	1.0100	21.1%
	0.25 < x < 2.25	63	34.1%	30.2%	69.8%		
	x < 0.25	61	33.0%	78.7%	21.3%		
Typing Speed Scaled Score	x < 7.5	40	21.7%	5.0%	95.0%	0.9640	21.2%
	7.5 < x < 11	56	30.4%	17.9%	82.1%		
	11 < x < 13	36	19.6%	58.3%	41.7%		
	13 < x	52	28.3%	76.9%	23.1%		
Memory Score (%)	x < 37.5	56	30.3%	7.1%	92.9%	0.9605	22.2%
	37.5 < x < 48.2	39	21.1%	25.6%	74.4%		
	48.2 < x < 55.35	29	15.7%	44.8%	55.2%		
	55.35 < x < 73.2	36	19.5%	66.7%	33.3%		

	73.2 < x	25	13.5%	92.0%	8.0%		
Sequencing Scaled Score	x < 7.5	57	30.8%	7.0%	93.0%	0.9798	22.2%
	7.5 < x < 10.5	75	40.5%	36.0%	64.0%		
	10.5 < x	53	28.6%	81.1%	18.9%		
Sequencing Score (%)	x < 48.95	48	25.9%	4.2%	95.8%	0.9583	22.2%
	48.95 < x < 56.45	27	14.6%	22.2%	77.8%		
	56.45 < x < 66.15	57	30.8%	40.4%	59.7%		
	66.15 < x	53	28.6%	81.1%	18.9%		
Memory Disparity	0.75 < x	98	53.0%	17.4%	82.7%	1.1066	25.4%
	x < 0.75	87	47.0%	65.5%	34.5%		
Sequencing Disparity	1.75 < x	63	34.1%	7.9%	92.1%	1.0550	25.4%
	0.25 < x < 1.75	37	20.0%	35.1%	64.9%		
	x < 0.25	85	45.9%	65.9%	34.1%		
Memory Scaled Score	x < 8.5	81	43.8%	11.1%	88.9%	1.0200	25.9%
	8.5 < x < 13	74	40.0%	54.1%	46.0%		
	13 < x	30	16.2%	83.3%	16.7%		
Accuracy Score (%)	15.5 < x < 61	20	10.8%	0.0%	100.0%	1.0997	26.5%
	x < 15.5	20	10.8%	20.0%	80.0%		
	61 < x < 95.5	90	48.6%	33.3%	66.7%		
	95.5 < x	55	29.7%	72.7%	27.3%		
Memory Span (words)	2.75 < x < 5.05	46	24.9%	6.5%	93.5%	1.0840	26.5%
	5.05 < x < 5.85	39	21.1%	33.3%	66.7%		
	x < 2.75	22	11.9%	36.4%	63.6%		
	7.15 < x	29	15.7%	44.8%	55.2%		

	5.85 < x < 7.15	49	26.5%	75.5%	24.5%		
Spelling Factor	0.25 < x	66	35.7%	3.0%	97.0%	0.9705	26.5%
	x < 0.25	119	64.3%	60.5%	39.5%		
Accuracy Scaled Score	x < 9	40	21.6%	10.0%	90.0%	1.1663	29.2%
	9 < x < 15	67	36.2%	31.3%	68.7%		
	15 < x	78	42.2%	62.8%	37.2%		
Verbal Score (%)	x < 46	39	21.1%	5.1%	94.9%	1.1239	30.3%
	46 < x < 78	112	60.5%	41.1%	58.9%		
	78 < x	34	18.4%	76.5%	23.5%		
Vocabulary Score (%)	x < 62.5	45	24.3%	8.9%	91.1%	1.1481	30.3%
	62.5 < x < 72.5	27	14.6%	29.6%	70.4%		
	72.5 < x < 87.5	71	38.4%	45.1%	54.9%		
	87.5 < x	42	22.7%	71.4%	28.6%		
Ability Score (%)	x < 55	48	25.9%	4.2%	95.8%	1.0810	30.8%
	55 < x < 63.9	24	13.0%	29.2%	70.8%		
	63.9 < x < 82.25	73	39.5%	50.7%	49.3%		
	82.25 < x	40	21.6%	70.0%	30.0%		
Reading Speed Disparity	0.25 < x	60	32.4%	5.0%	95.0%	1.0644	30.8%
	x < 0.25	125	67.6%	56.8%	43.2%		
Verbal Scaled Score	x < 9.5	29	15.7%	3.5%	96.6%	1.1731	31.4%
	9.5 < x < 13	96	51.9%	36.5%	63.5%		
	13 < x	60	32.4%	63.3%	36.7%		
Ability Scaled Score	x < 9.5	37	20.0%	5.4%	94.6%	1.1381	31.9%
	9.5 < x < 10.5	33	17.8%	21.2%	78.8%		

	10.5 < x	115	62.2%	56.5%	43.5%		
Visual Scaled Score	x < 10.5	47	25.4%	6.4%	93.6%	1.1573	33.5%
	10.5 < x < 15	44	23.8%	40.9%	59.1%		
	15 < x	94	50.8%	56.4%	43.6%		
Visual Score (%)	32.5 < x < 52.5	23	12.4%	0.0%	100.0%	1.1403	33.5%
	x < 32.5	24	13.0%	12.5%	87.5%		
	52.5 < x < 72.5	44	23.8%	40.9%	59.1%		
	72.5 < x	94	50.8%	56.4%	43.6%		
Vocabulary Scaled Score	x < 13	45	24.3%	8.9%	91.1%	1.1835	34.1%
	13 < x < 15	27	14.6%	29.6%	70.4%		
	15 < x	113	61.1%	54.9%	45.1%		
Memory Span Scaled Score	x < 9	55	31.4%	5.5%	94.6%	1.0945	34.3%
	9 < x	120	68.6%	52.5%	47.5%		
Comprehension Score (%)	x < 65	59	31.9%	23.7%	76.3%	1.2973	36.2%
	65 < x < 85	87	47.0%	42.5%	57.5%		
	85 < x	39	21.1%	59.0%	41.0%		
Processing Score (%)	x < 65	59	31.9%	23.7%	76.3%		
	65 < x < 85	87	47.0%	42.5%	57.5%		
	85 < x	39	21.1%	59.0%	41.0%		
Processing Speed Disparity	0.75 < x	44	23.8%	0.0%	100.0%	1.0662	36.2%
	x < 0.75	141	76.2%	52.5%	47.5%		
Writing/Typing Speed Factor	0.25 < x	43	23.2%	4.7%	95.4%	1.1640	38.9%
	x < 0.25	142	76.8%	50.7%	49.3%		
Comprehension Scaled Score	x < 11	59	31.9%	23.7%	76.3%	1.3062	40.0%

	11 < x	126	68.1%	47.6%	52.4%		
Processing Disparity	0.75 < x	38	20.5%	5.3%	94.7%	1.1989	40.0%
	x < 0.75	147	79.5%	49.0%	51.0%		
Visual/Verbal Factor	0.25 < x	30	16.2%	10.0%	90.0%	1.2748	40.0%
	x < 0.25	155	83.8%	45.8%	54.2%		

Table 7: Results of the univariate CART models.

A tree diagram, visualising these results for the reading speed univariate CART model (as presented in Table 7) is shown in Figure 1 below, for illustration.

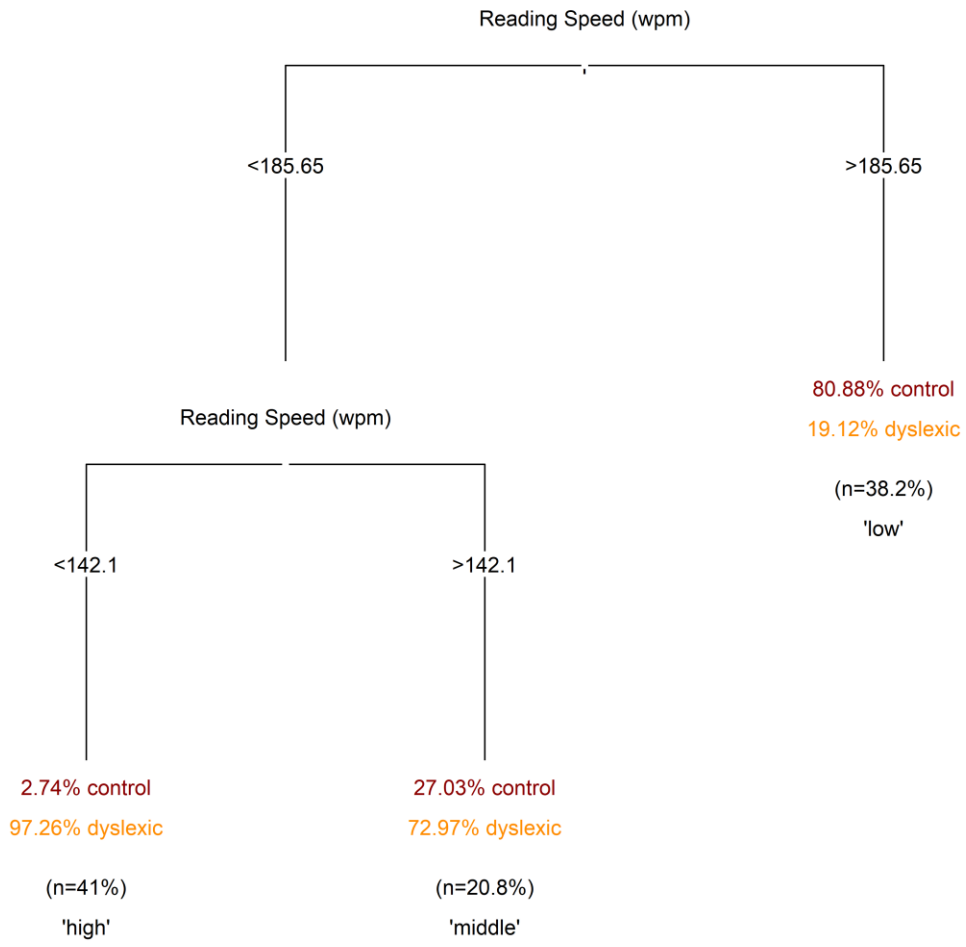


Figure 1: Tree diagram, for the univariate Reading Speed (wpm) CART model. The final tree groups are labelled 'high', 'middle' and 'low' in decreasing order of the predicted dyslexia diagnosed vs control group probabilities/proportions, respectively.

We see, for example, that the participants are split into those with a reading speed of:

- Words per minute (wpm) less than 142.1, for which 97.26% of the candidates in this group are dyslexia diagnosed vs. control (labelled 'high'),
- wpm between 142.1 and 185.65, for which 72.97% of the candidates in this group are dyslexia diagnosed (labelled 'middle'); and
- wpm greater than 185.65, for which 19.12% of the candidates in this group are dyslexia diagnosed (labelled 'low').

So, the data provide statistical evidence of reading speed cut-offs of 142.1 and 185.65 wpm providing discrimination between participants in the dyslexia diagnosed vs control groups.

For the processing scaled score QuickScreen component, there is statistical evidence that cut-offs of 10.5, 11.5 and 13 provide a means of discriminating between participants in the dyslexia groups (diagnosed vs control).

Similar results were found for the other QuickScreen components, so there was statistical evidence that cut-offs (as shown in Table 7) in each of these variables were informative in discriminating between the dyslexia diagnosed and control participants.

This analysis should be helpful in indicating which scores, associated with each variable, might be useful potential cut-off points for informing a dyslexia diagnosis prediction. For example, we find evidence that candidates with a reading speed of less than 142.1 wpm are very likely to be in the dyslexia diagnosis group (as described above). These results may be useful in informing the refinements to the QuickScreen test indications that we understand are currently being explored by Pico.

We note that for the dyslexia quotient score (which is currently used to define the QuickScreen test indication boundaries), cut-offs of less than 0.75, 0.75-2.25, 2.25-4.25, and greater than 4.25 are identified, corresponding with 18.5%, 44.7%, 70.0% and 100% of the participants in each group being in the dyslexia diagnosed (as opposed to the control group), respectively (as shown in Table 7). So, there is statistical evidence of dyslexia quotient score cut-offs of 0.75, 2.25 and 4.25 discriminating between the dyslexia diagnosed vs control groups.

Multiple Variable Models

Methods

CART

In the univariate trees described above, each variable is considered individually in isolation, whereas we recognise that some of the variables will likely be capturing/explaining similar information and that combinations of variables may interact, i.e., their combined effects may be greater or less than the sum of their individual effects. Therefore, to understand the combined effects of the QuickScreen test component variables, we explored fitting multiple variable classification tree models to the data, including combinations of the QuickScreen components as explanatory variables in one tree. This multiple variable approach also helps to identify which variables are the most important/discriminatory (out of the large number of QuickScreen test components recorded). Those variables that are chosen by the tree algorithm as the preferred ones to split on (and those that are split on higher up the tree) are those found to be the most informative.

This statistical framework allows us to consider different ways of combining the individual scores to create an overall assessment of the likelihood of being in the dyslexia diagnosed group. The aim being to improve upon the performance of the current approach to combining the components, corresponding with the current QuickScreen test indication bandings.

Following discussion with Dr Walker, we agreed to consider three different multiple variable trees, where the following subsets of variables were offered as explanatory variables to each.

- Tree 1: Speed of processing, spelling and reading speed (all versions)
- Tree 2: Speed of processing, spelling and reading speed (scaled scores only)
- Tree 3: All QuickScreen test component variables (corresponding with the 46 variables listed in Table 2)

The first two trees above focus on three of the QuickScreen component processes understood to be linked with dyslexia, with the former considering all versions of these variables and the latter only considering the scaled scores (for comparability). Whereas the final model is more flexible in offering all of the QuickSreen test component variables to the tree.

These results should hopefully be useful in actively improving how the scores provided by the test can be best used to generate a dyslexia assessment, as part of the process of refining the QuickScreen test indications that we understand is already underway internally at Pico.

Note: Participants with missing values are included where possible in the multiple variable CART models (i.e., up to the point at which the variable that is split upon in the tree is the one that contains the missing values). This way, these participants still contribute to the evidence of which variables are most discriminating (between the dyslexia diagnosed and control groups) where possible, so we retain as much data as possible to inform the analysis. These participants with missing values are also then included in the overall CART summaries, i.e., Residual Mean Deviance and Misclassification Rate results.

Out-of-sample Model Performance

To further explore the predictive performance of the multiple variable classification trees, we produced a similar set of diagnostic accuracy summaries as described above (for the QuickScreen test banded indications) for each model (again using an estimated prevalence of dyslexia of 10% in calculating the predictive values). These summaries help to demonstrate the ability of the combination of these QuickScreen test components to distinguish between the dyslexia diagnosed and control groups (over and above the misclassification and mean residual deviance summaries already noted).

The summaries are calculated by labelling the CART model predictions, associated with the final groups at the bottom of each tree, as ‘low’, ‘midlow’, ‘middle’, ‘midhigh’, and ‘high’, in order of the lowest to highest predicted probability of being in the dyslexia group, respectively. These groups are then used in place of the QuickScreen test banded indications as the predicted diagnosis for comparing with the observed dyslexia diagnosed vs control group outcome.

However, if we were to calculate these performance assessments using the complete set of data available, which were the observations used to construct the CART trees, these figures may potentially overestimate how well the model will perform in practice, i.e., for subsequent participants. This is because there is the potential for the CART models to be “overfitted” to the data used to train them.

Therefore, to get a more reliable estimate of the performance of the CART models for use in practice, we can explore what’s called the “out-of-sample” model performance. This means that we produce the performance assessments for data not used to train the model. Ideally, we would use a completely new and independent dataset to do this. However, given the available data, we can alternatively use an approach called ‘*cross-validation’* to similar effect.

We randomly sample a subset of the data to obtain a new training dataset which can be used to refit the CART model. The remaining data not included in the training dataset is then our "hold-out" (a.k.a. out-of-sample) test dataset which we can use to independently assess the performance of the refitted model. We repeat this process lots of times (1,000 times for each model) for different random training (and corresponding test) samples, and then explore the distribution/average of the performance results to derive a more accurate estimate of the model performance. Note: We use a consistent method to fit the training trees, but they are pruned to ensure that they have the same number of final groups as the final models, for consistency.

To help ensure that the trees fit to the training datasets reflect the final model as closely as possible, we use bootstrapping, i.e., sampling with replacement. This allows us to sample a training dataset of the same size as the complete dataset used to fit the final tree (where some observations will be included in the training data multiple times). We recognise however that these bootstrapped, training data samples will not have the same coverage of the QuickScreen test component variables as the full dataset, as not all of the original participants (with varying characteristics) will be included. Therefore the out-of-sample model performance summaries may be somewhat conservative, i.e., underestimating the performance of the final trees in practice.

Results

Tree 1: Speed of processing, spelling and reading speed (all versions)

The results of the multiple variable CART model for the speed of processing, spelling and reading speed (all versions) QuickScreen component variables are presented in Table 8 and Figure 2 below.

Reading Speed (wpm)	Spelling Score (%)	Number of Participants	Proportion of Participants	Control Group Probability	Dyslexia Group Probability	Residual Mean Deviance	Misclassification Rate
x < 185.65	x < 61.25	66	37.1%	0.0%	100.0%	0.5771	17.3%
x < 185.65	61.25 < x < 76.25	21	11.8%	9.5%	90.5%		
x < 185.65	76.25 < x	23	12.9%	43.5%	56.5%		
185.65 < x	x < 83.75	30	16.9%	66.7%	33.3%		
185.65 < x	83.75 < x	38	21.3%	92.1%	7.9%		

Table 8: Results of the multiple variable CART model for speed of processing, spelling and reading speed (all versions).

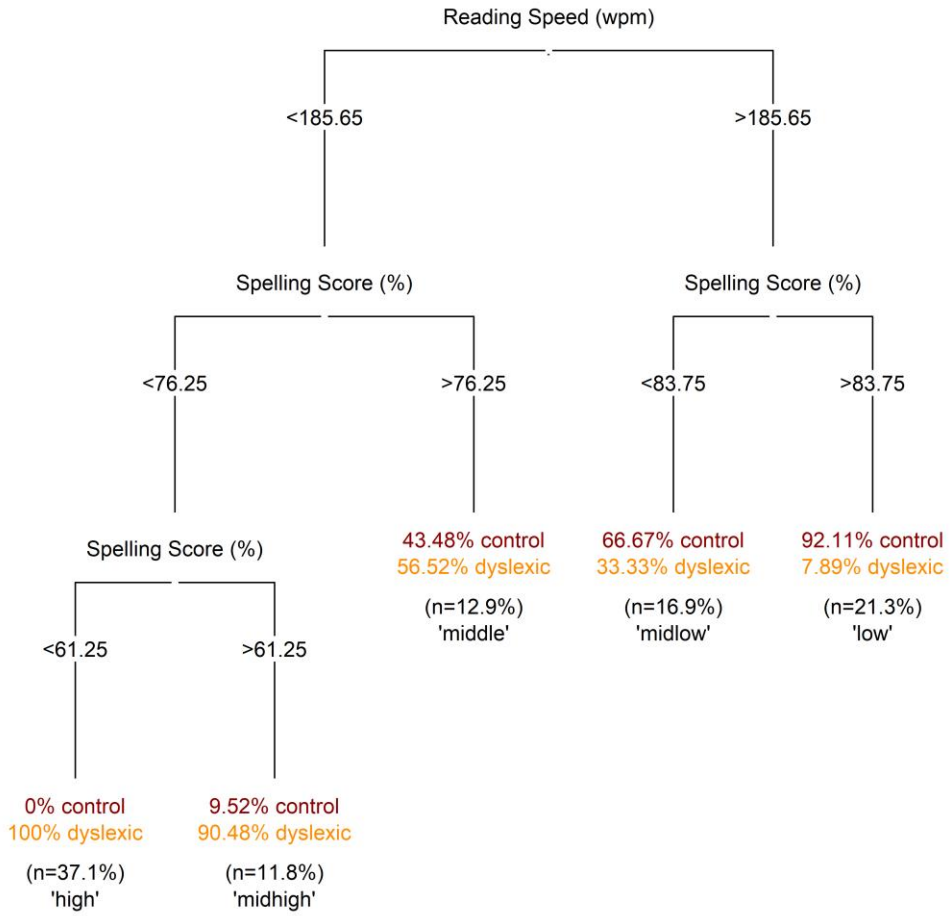


Figure 2: Tree diagram, for the multiple variable CART model for speed of processing, spelling and reading speed (all versions). The final tree groups are labelled 'high', 'midhigh', 'middle', 'midlow' and 'low' in decreasing order of the predicted dyslexia diagnosed vs control group probabilities/proportions, respectively.

We find that both the reading speed and spelling score components add to one another in discriminating between those with a dyslexia diagnosis and those in the control group, so they are not necessarily each explaining the same underlying effect (as both are retained within the model).

Having offered both versions of each of these variables (i.e., score and result for General Speed of Processing, percentile and scaled score for Spelling Score, and wpm and scaled score for Reading Speed), and we find that the reading speed wpm and spelling score percentile versions (and corresponding splits as shown in the table above) are most informative. The top two (labelled 'High' and 'MidHigh') and bottom (labelled 'Low') final tree groups, for example, are defined as:

- ‘High’: A reading speed slower than 185.65 wpm and a spelling score percentile less than 61.25%; for which 100% of the participants in this group are dyslexia diagnosed (as opposed to being in the control group).
- ‘MidHigh’: A reading speed slower than 185.65 wpm and a spelling score percentile between 61.25% and 76.25%; for which 90.5% of the participants in this group are dyslexia diagnosed (as opposed to being in the control group).
- ‘Low’: A reading speed faster than 185.65 wpm and a spelling score percentile greater than 83.75%; for which 92.1% of the participants in this group and in the control group (i.e., not dyslexia diagnosed).

The out-of-sample performance assessments for the CART model for speed of processing, spelling and reading speed (all versions) are shown in Table 9.

CART Category	Diagnostic Measure	Mean Estimate	95% Confidence Interval Mean Estimates
High	NPV	59.1%	(31.5%, 82.6%)
	PPV	40.9%	(17.4%, 68.5%)
	Sensitivity	58.0%	(43.4%, 71.2%)
	Specificity	9.8%	(3.2%, 27.3%)
Low or MidLow	NPV	97.6%	(94.9%, 98.9%)
	PPV	2.4%	(1.1%, 5.1%)
	Sensitivity	14.6%	(7.1%, 28.1%)
	Specificity	65.9%	(47.5%, 80.3%)
Low	NPV	97.8%	(93.2%, 99.3%)
	PPV	2.2%	(0.7%, 6.8%)
	Sensitivity	7.8%	(2.8%, 20.2%)
	Specificity	40.6%	(25.0%, 58.6%)
Middle	NPV	91.8%	(80.2%, 96.8%)
	PPV	8.2%	(3.2%, 19.8%)
	Sensitivity	16.3%	(8.4%, 29.9%)
	Specificity	22.7%	(11.2%, 41.1%)
Middle, MidHigh or High	NPV	76.7%	(65.4%, 85.4%)
	PPV	23.3%	(14.6%, 34.6%)
	Sensitivity	85.4%	(71.9%, 92.9%)
	Specificity	34.1%	(19.7%, 52.5%)
MidHigh or High	NPV	66.4%	(46.5%, 82.7%)
	PPV	33.6%	(17.3%, 53.5%)
	Sensitivity	73.5%	(59.0%, 84.1%)
	Specificity	18.2%	(8.3%, 36.4%)
MidHigh	NPV	85.5%	(65.9%, 94.9%)
	PPV	14.5%	(5.1%, 34.1%)
	Sensitivity	19.9%	(10.8%, 34.0%)
	Specificity	15.2%	(6.4%, 33.1%)
MidLow	NPV	95.9%	(89.2%, 98.5%)
	PPV	4.1%	(1.5%, 10.8%)
	Sensitivity	11.2%	(4.9%, 24.2%)

MidLow, Middle, MidHigh or High	Specificity	32.1%	(18.1%, 50.5%)
	NPV	84.7%	(79.9%, 88.6%)
	PPV	15.3%	(11.4%, 20.1%)
	Sensitivity	92.2%	(79.8%, 97.2%)
	Specificity	59.4%	(41.4%, 75.0%)

Table 9: Out-of-sample, mean estimates of the diagnostic accuracy measures for each tree category using the adjusted logit method (with 10% prevalence) for the CART model for speed of processing, spelling and reading speed (all versions). PPV = Positive (i.e., Diagnosed) Predictive Value; NPV = Negative (i.e., Control) Predictive Value.

So, where the CART model predicts a 'Low' or 'MidLow' probability of being in the dyslexia diagnosed group (corresponding with a reading speed of > 185.65 wpm), we estimate that 97.6% of those candidates will not be in the dyslexia diagnosed group (this is the "Negative Predictive Value [NPV]"). Of those in the control group, we estimate that the model will predict 65.9% of these candidates to be in the 'Low' or 'MidLow' group (this is the Specificity).

Tree 2: Speed of processing, spelling and reading speed (scaled scores only)

The results of the multiple variable CART model for the speed of processing, spelling and reading speed (scaled scores only) QuickScreen component variables are presented in Table 10 and Figure 3 below.

General Speed of Processing Score	Spelling Scaled Score	Number of Participants	Proportion of Participants	Control Group Probability	Dyslexia Group Probability	Residual Mean Deviance	Misclassification Rate
x < 11.5	x < 13	67	36.2%	1.5%	98.5%	0.6645	16.2%
11.5 < x < 14.5	x < 13	26	14.1%	19.2%	80.8%		
x < 14.5	13 < x	22	11.9%	54.5%	45.5%		
14.5 < x	x < 13	33	17.8%	60.6%	39.4%		
14.5 < x	13 < x	37	20.0%	97.3%	2.7%		

Table 10: Results of the multiple variable CART model for speed of processing, spelling and reading speed (scaled scores only).

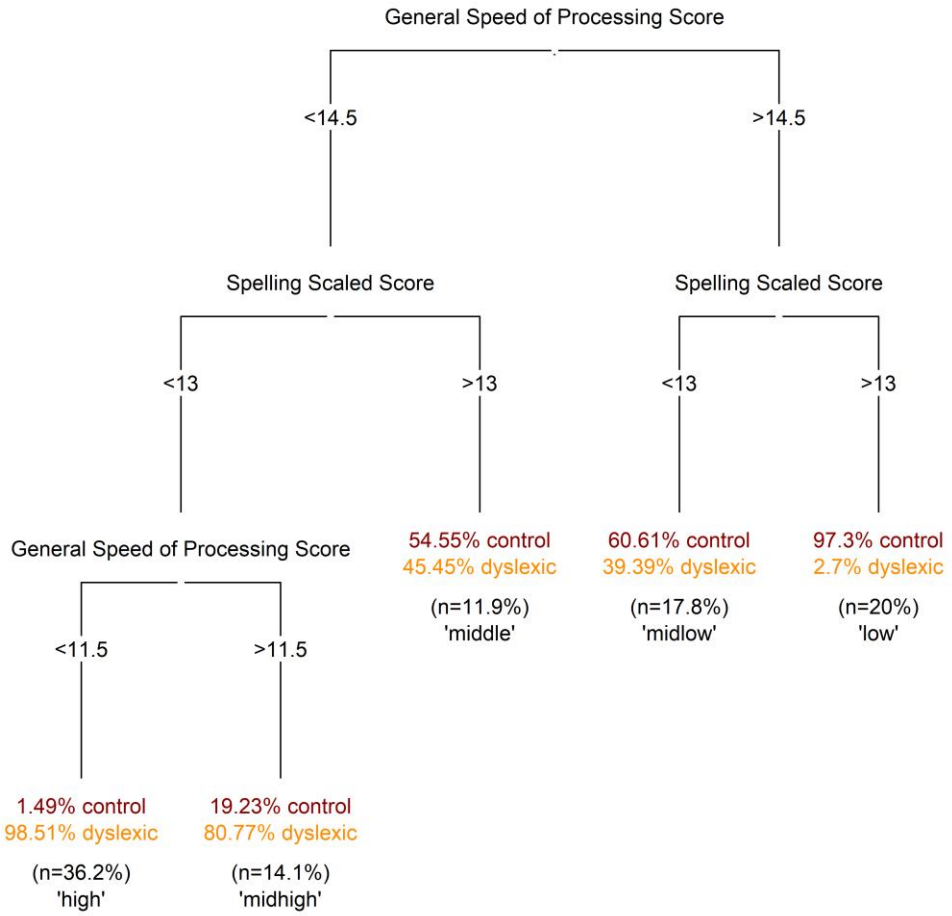


Figure 3: Tree diagram, for the multiple variable CART model for speed of processing, spelling and reading speed (scaled scores only). The final tree groups are labelled 'high', 'midhigh', 'middle', 'midlow' and 'low' in decreasing order of the predicted dyslexia diagnosed vs control group probabilities/proportions, respectively.

Here, for example, the first group (labelled 'High') is defined by participants with:

- A general speed of processing score of less than 11.5 and a spelling scaled score of less than 13.

In this group, 98.5% of the participants are in the dyslexia diagnosed group (as opposed to in the control group).

The corresponding out-of-sample performance assessments for the CART model for speed of processing, spelling and reading speed (scaled scores only) are shown in Table 11.

CART Category	Diagnostic Measure	Mean Estimate	95% Confidence Interval Mean Estimates
High	NPV	62.6%	(34.7%, 84.7%)
	PPV	37.4%	(15.3%, 65.3%)
	Sensitivity	56.1%	(41.5%, 69.6%)
	Specificity	11.3%	(3.6%, 31.0%)
Low or MidLow	NPV	97.3%	(94.2%, 98.7%)
	PPV	2.7%	(1.3%, 5.8%)
	Sensitivity	16.0%	(8.1%, 29.8%)
	Specificity	62.7%	(43.0%, 78.8%)
Low	NPV	97.6%	(92.6%, 99.2%)
	PPV	2.4%	(0.8%, 7.4%)
	Sensitivity	8.9%	(3.5%, 21.7%)
	Specificity	41.3%	(24.6%, 60.7%)
Middle	NPV	92.4%	(81.3%, 97.0%)
	PPV	7.6%	(3.0%, 18.7%)
	Sensitivity	16.6%	(8.7%, 30.4%)
	Specificity	24.4%	(11.7%, 44.6%)
Middle, MidHigh or High	NPV	78.7%	(67.9%, 86.7%)
	PPV	21.3%	(13.3%, 32.1%)
	Sensitivity	84.0%	(70.2%, 91.9%)
	Specificity	37.3%	(21.2%, 57.0%)
MidHigh or High	NPV	69.8%	(50.5%, 84.6%)
	PPV	30.2%	(15.4%, 49.5%)
	Sensitivity	71.9%	(57.1%, 82.9%)
	Specificity	21.0%	(9.5%, 41.0%)
MidHigh	NPV	87.0%	(68.9%, 95.4%)
	PPV	13.0%	(4.6%, 31.1%)
	Sensitivity	20.3%	(11.1%, 34.5%)
	Specificity	17.7%	(7.4%, 37.6%)
MidLow	NPV	95.6%	(87.5%, 98.4%)
	PPV	4.4%	(1.6%, 12.5%)
	Sensitivity	11.5%	(5.2%, 24.7%)
	Specificity	29.5%	(15.5%, 49.6%)
MidLow, Middle, MidHigh or High	NPV	84.8%	(79.4%, 88.9%)
	PPV	15.2%	(11.1%, 20.6%)
	Sensitivity	91.1%	(78.3%, 96.5%)
	Specificity	58.7%	(39.3%, 75.4%)

Table 11: Out-of-sample, mean estimates of the diagnostic accuracy measures for each tree category using the adjusted logit method (with 10% prevalence) for the CART model for speed of processing, spelling and reading speed (scaled scores only). PPV = Positive (i.e., Diagnosed) Predictive Value; NPV = Negative (i.e., Control) Predictive Value.

So, where the CART model predicts a 'Low' probability of being in the dyslexia diagnosed group (corresponding a general speed of processing score of greater than 14.5 and a spelling scaled score of greater than 13), we estimate that 97.6% of those candidates will not be in the dyslexia diagnosed group (this is the "Negative Predictive Value [NPV]"). Of those in the control group, we estimate that the model will predict 41.3% of these candidates to be in the 'Low' group (this is the Specificity).

Tree 3: All QuickScreen test component variables

The results of the multiple variable CART model for all of the QuickScreen test component variables are presented in Table 12 and Figure 4 below.

Reading Speed (wpm)	Spelling Score (%)	General Speed of Processing Score - Literacy Score	Sequencing Scaled Score	Number of Participants	Proportion of Participants	Control Group Prob.	Dyslexia Group Prob.	Residual Mean Deviance	Misclass. Rate
x < 185.65	x < 76.25	x < 9.25	NA	67	37.6%	0.0%	100.0%	0.5512	17.3%
x < 185.65	x < 76.25	9.25 < x	NA	20	11.2%	10.0%	90.0%		
x < 185.65	76.25 < x	NA	NA	23	12.9%	43.5%	56.5%		
185.65 < x	NA	NA	x < 10.5	36	20.2%	66.7%	33.3%		
185.65 < x	NA	NA	10.5 < x	32	18.0%	96.9%	3.1%		

Table 12: Results of the multiple variable CART model for all QuickScreen test component variables.

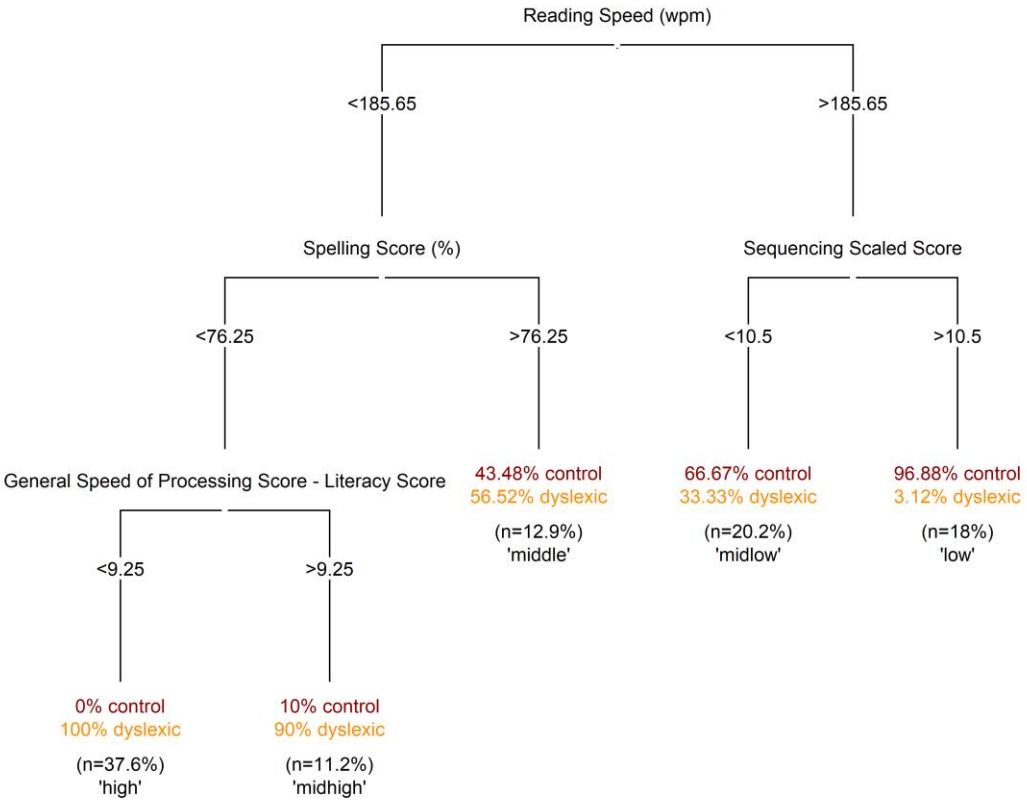


Figure 4: Tree diagram, for the multiple variable CART model for all QuickScreen test component variables. The final tree groups are labelled 'high', 'midhigh', 'middle', 'midlow' and 'low' in decreasing order of the predicted dyslexia diagnosed vs control group probabilities/proportions, respectively.

In this case, we find that the General Speed of Processing Score minus the Literacy Score variable, and the Sequencing Scaled Score variable are also found to be informative (in addition to the Reading Speed and Spelling Score variables) in discriminating between the dyslexia diagnosed and control groups.

For example, the first group (labelled 'High') is defined by participants with:

- A reading speed of less than 185.65 wpm, a spelling score of less than 76.25% and a general speed of processing minus literacy score of less than 9.25.

In this group, 100% of the candidates are dyslexia diagnosed (as opposed to in the control group).

This tree also appears to be promising in picking out the control candidates. For example, the 'Low' group defined by a reading speed of greater than 185.65 wpm and a sequencing scaled score of greater than 10.5, are made up of 96.9% control candidates.

So, there is statistical evidence that the combination of the Reading Speed (wpm), Spelling Score (%), General Speed of Processing Score minus Literacy Score, and Sequencing Scaled Score QuickScreen test components are informative in discriminating between the dyslexia diagnosed and control participants.

The out-of-sample performance assessments for the CART model for all QuickScreen test component variables are shown in Table 13.

CART Category	Diagnostic Measure	Mean Estimate	95% Confidence Interval Mean Estimates
High	NPV	61.5%	(35.6%, 83.0%)
	PPV	38.5%	(17.0%, 64.4%)
	Sensitivity	59.4%	(44.8%, 72.5%)
	Specificity	11.4%	(4.1%, 29.0%)
Low or MidLow	NPV	97.6%	(94.9%, 98.8%)
	PPV	2.4%	(1.2%, 5.1%)
	Sensitivity	14.4%	(7.0%, 27.9%)
	Specificity	64.2%	(45.8%, 78.9%)
Low	NPV	97.8%	(93.7%, 99.3%)
	PPV	2.2%	(0.7%, 6.3%)
	Sensitivity	8.3%	(3.1%, 20.9%)
	Specificity	43.9%	(27.6%, 61.6%)
Middle	NPV	91.9%	(80.3%, 96.9%)
	PPV	8.1%	(3.1%, 19.7%)
	Sensitivity	16.0%	(8.1%, 29.7%)
	Specificity	22.2%	(10.9%, 40.6%)
Middle, MidHigh or High	NPV	77.7%	(67.1%, 85.8%)
	PPV	22.3%	(14.2%, 32.9%)
	Sensitivity	85.6%	(72.1%, 93.0%)
	Specificity	35.8%	(21.1%, 54.2%)
MidHigh or High	NPV	69.2%	(51.0%, 83.5%)
	PPV	30.8%	(16.5%, 49.0%)
	Sensitivity	73.9%	(59.4%, 84.5%)
	Specificity	20.4%	(9.7%, 38.7%)
MidHigh	NPV	87.2%	(69.4%, 95.4%)
	PPV	12.8%	(4.6%, 30.6%)
	Sensitivity	18.8%	(10.1%, 32.8%)
	Specificity	15.8%	(6.7%, 33.8%)
MidLow	NPV	95.5%	(87.5%, 98.4%)
	PPV	4.5%	(1.6%, 12.5%)
	Sensitivity	10.5%	(4.5%, 23.4%)
	Specificity	27.0%	(14.3%, 45.5%)
MidLow, Middle, MidHigh or High	NPV	84.1%	(78.8%, 88.3%)
	PPV	15.9%	(11.7%, 21.2%)
	Sensitivity	91.7%	(79.1%, 96.9%)
	Specificity	56.1%	(38.4%, 72.4%)

Table 13: Out-of-sample, mean estimates of the diagnostic accuracy measures for each tree category using the adjusted logit method (with 10% prevalence) for the CART model for all QuickScreen test component variables. PPV = Positive (i.e., Diagnosed) Predictive Value; NPV = Negative (i.e., Control) Predictive Value.

So, where the CART model predicts a 'Low' probability of being in the dyslexia diagnosed group (corresponding with a reading speed of > 185.65 wpm and a Sequencing Scaled Score of > 10.5), we estimate that 97.8% of those candidates will not be in the dyslexia diagnosed group (this is the "Negative Predictive Value [NPV]"). Of those in the control group, we estimate that the model will predict 43.9% of these candidates to be in the 'Low' group (this is the Specificity).

Validity

Similar to our original study, it should be noted when interpreting the results of this analysis that their validity depends on the applicability of the sample participants to the population of interest. This includes the spectrum of severity of dyslexia in the sample. Where this might not reflect the target population, a study is sometimes said to suffer from "spectrum bias". We note for example that the 'control' group are all students from a leading university. Whereas the 'test' group (with a previous dyslexia diagnosis) are a mixture of students and members of the public.

The potential for other biases such as classification bias, where misclassification of participants in their dyslexia diagnosed group may have occurred, should also be considered. We note that this is particularly relevant in this study where it is recognised that the control group participants may include a small number of undiagnosed dyslexics. Therefore, where QuickScreen may report a positive albeit weak indication of dyslexia (not "None", for example) for a participant in the control group, it is understood that this subject could in fact have undiagnosed dyslexia. It is also acknowledged that those in the dyslexia diagnosed group may have received their diagnosis a number of years previously, and may now potentially be well-compensated and therefore asymptomatic despite having a positive diagnosis. The graduated indications provided by QuickScreen reflect this non-binary nature of dyslexia which is on a continuum of symptoms/severities.

A more formal, prospective cohort study may provide a more reliable assessment of the diagnostic test accuracy, by helping to eliminate potential sources of bias such as those described above. Though, we recognise that due to the challenges of obtaining a reliable, independent diagnosis and as dyslexia is a condition with a spectrum of severities, it may not necessarily be possible to achieve perfect diagnostic accuracy in this context.

Potential Further Work

In this section, we note some possible extensions that could be made to the analyses conducted to date to further support the ongoing refinement of the QuickScreen test indications that we understand is being undertaken internally at Pico.

An alternative approach to the multiple variable CART modelling could be explored. For example, a logistic regression model could be applied to predict the dyslexia group based on the QuickScreen test component variables.

Similar to the classification tree models already explored, the logistic regression model would give us a formula that could then be applied going forwards to obtain the predicted probability for new participants. This would provide a different way of combining the individual scores to create an overall assessment of the likelihood of dyslexia. A logistic regression model would estimate effects on the probability of being a dyslexia diagnosed vs control participant for linear changes in the QuickScreen test component variables. So, rather than grouping scores into splits with different effects, this

assumes that each unit change in a score (increasing it by one), say, has a given effect on the odds of being in the dyslexia diagnosed group.

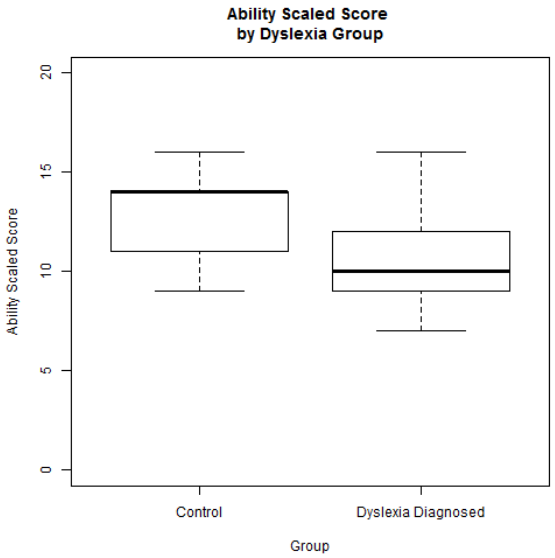
This is a different approach from the CART modelling, where one method is not necessarily better or worse than the other. Though, the classification trees arguably provide more intuitively interpretable results. We could potentially explore both modelling approaches and compare their performance to see which might work best (i.e., give the most accurate predictions) in this context.

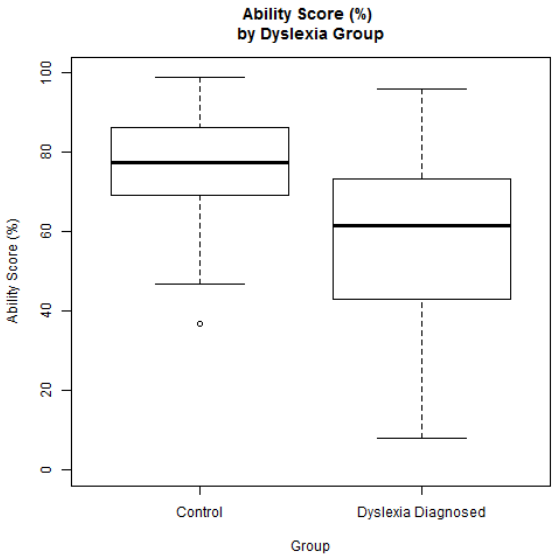
Based on the results of the analyses conducted in this study, consideration could be given to amending the current QuickScreen test indication category boundaries. For example, where the CART models appear to discriminate well between the dyslexia diagnosed and control groups, inclusion of the corresponding QuickScreen component variables (and/or refinements to the thresholds currently used) could be considered, adjusting the current process for calculating the dyslexia quotients and resulting QuickScreen dyslexia indications. The Negative (i.e., Control) Predictive Value for the multiple variable CART model for all QuickScreen test component variables may offer some improvement over the current "None" and "Borderline" bandings (combined), when considering the combination of the 'Low' and 'MidLow' tree groups (97.6% versus 95.8%). The 'Low' and 'MidLow' groups correspond with a reading speed of greater than 185.65 wpm. Similarly, the 'High' or 'High' and 'MidHigh' groups for the multiple variable CART model for all QuickScreen test component variables appears to offer improved Sensitivity values compared with the current "Strong" or "Strong" and "Moderate" QuickScreen indications (59.4% or 73.9%, versus 3.4% or 40.0%, respectively). These groups correspond with a reading speed of less than 185.65 wpm, a spelling score of less than 76.25% and a general speed of processing minus literacy score of less than 9.25 (for the 'High' group), or a reading speed of less than 185.65 wpm and a spelling score of less than 76.25% (for the 'High' or 'MidHigh' group).

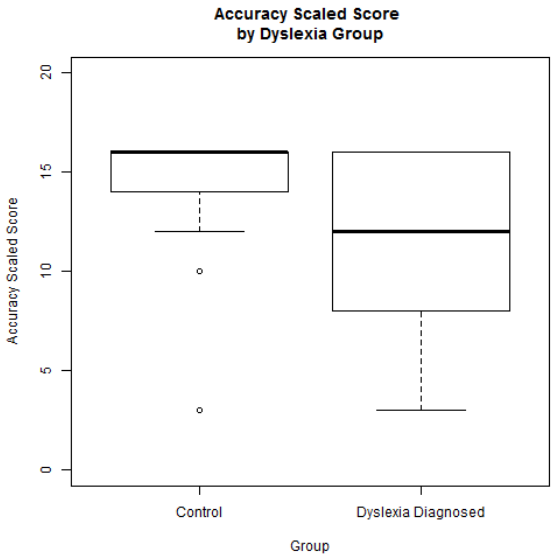
Ultimately, following any updates that might be made to the QuickScreen test indications bandings, ideally additional data would be collected to carry out a further, independent assessment of if and how the diagnostic performance has improved.

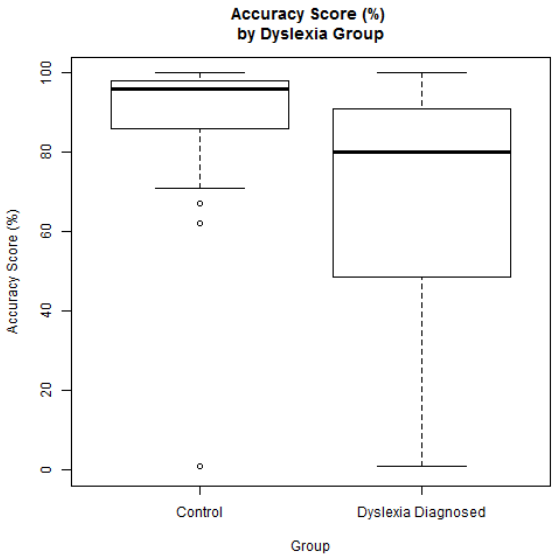
Appendix

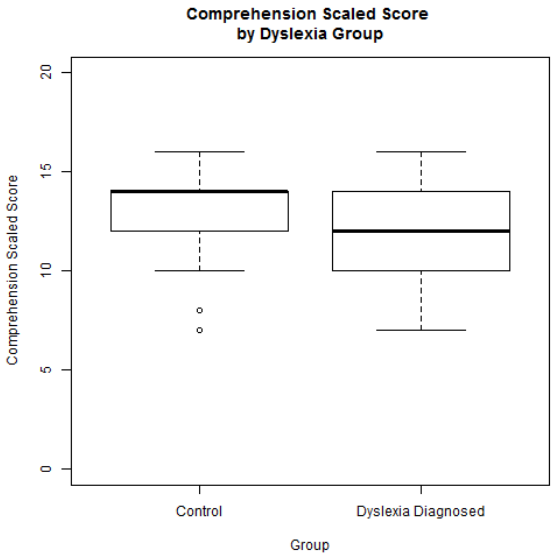
Boxplots

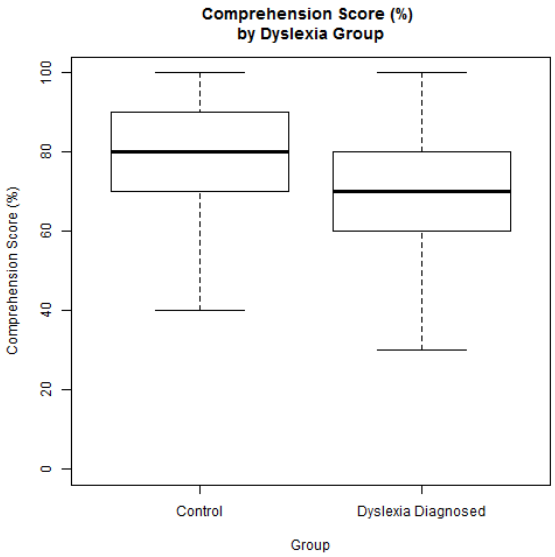


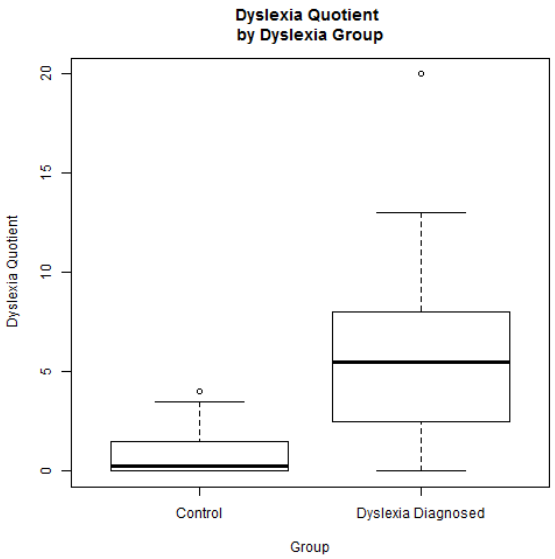


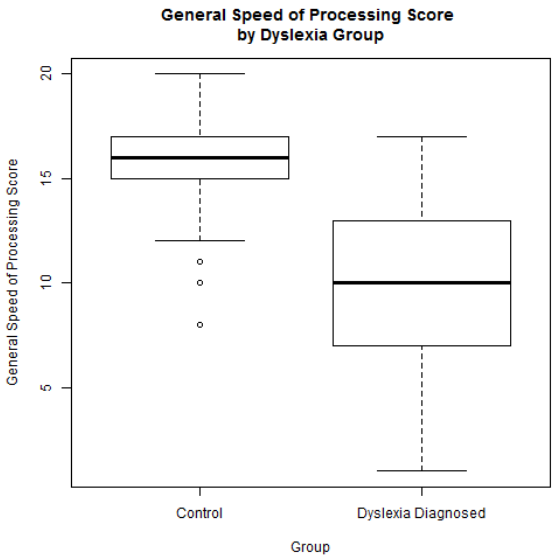


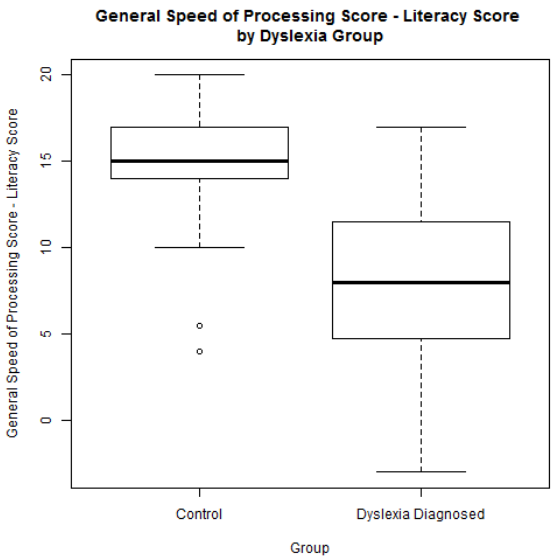


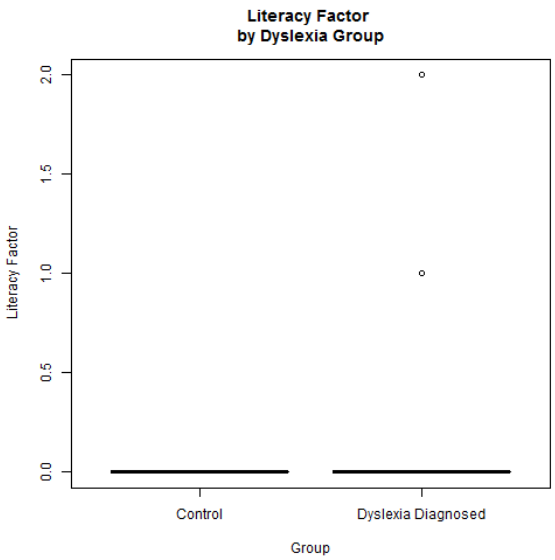

Comprehension Scaled Score
by Dyslexia Group
Comprehension Scaled Score
0
5
10
15
20
Control
Dyslexia Diagnosed
Group

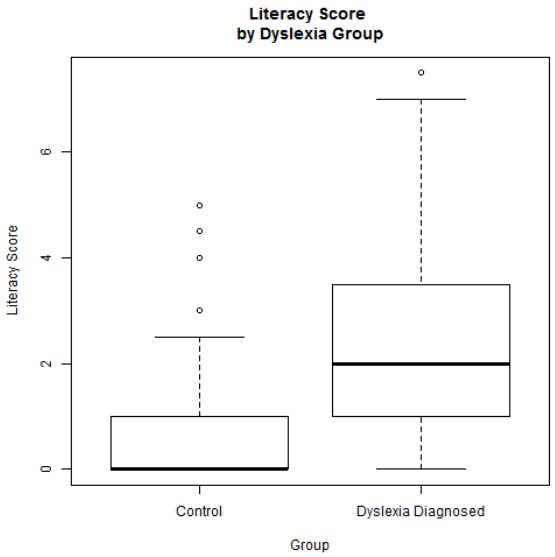

Comprehension Score (%)
by Dyslexia Group
Comprehension Score (%)
0
20
40
60
80
100
Control
Dyslexia Diagnosed
Group

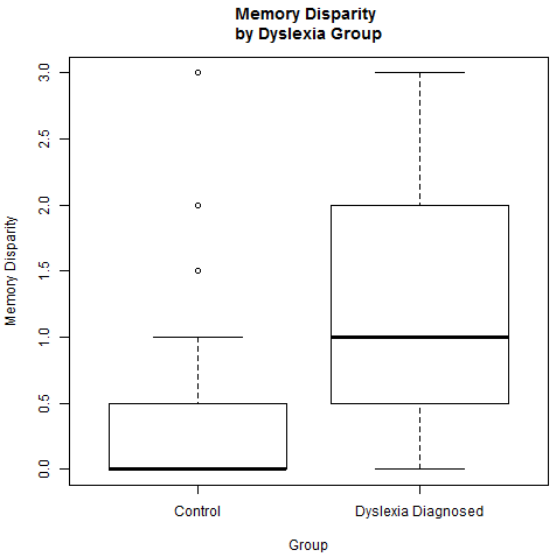

Dyslexia Quotient
by Dyslexia Group
Dyslexia Quotient
0
5
10
15
20
Control
Dyslexia Diagnosed
Group

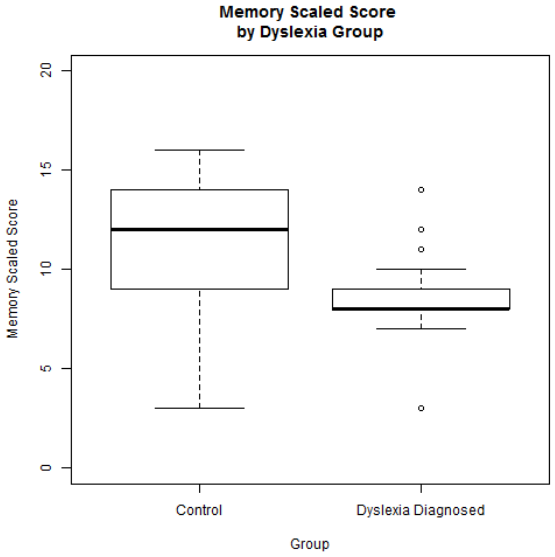

General Speed of Processing Score
by Dyslexia Group
General Speed of Processing Score
5
10
15
20
Control
Dyslexia Diagnosed
Group

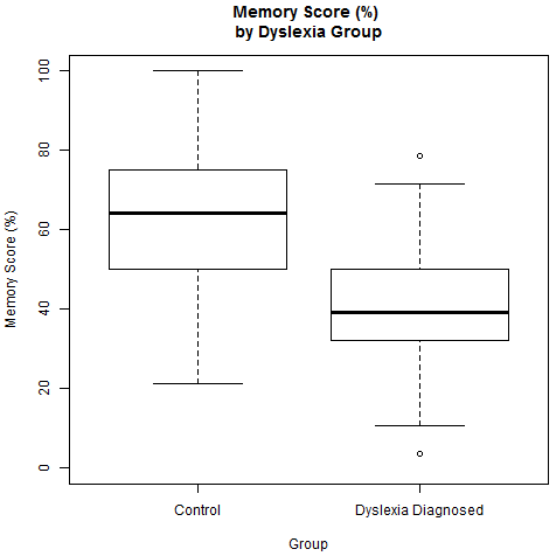

General Speed of Processing Score - Literacy Score
by Dyslexia Group
General Speed of Processing Score - Literacy Score
0
5
10
15
20
Control
Dyslexia Diagnosed
Group

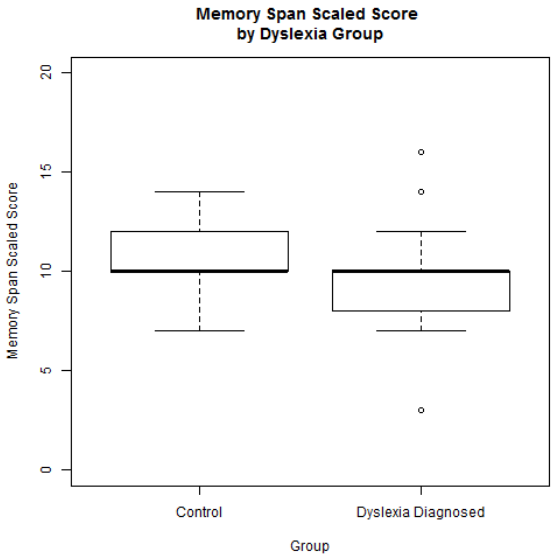

Literacy Factor
by Dyslexia Group
Literacy Factor
0.0
0.5
1.0
1.5
2.0
Control
Dyslexia Diagnosed
Group

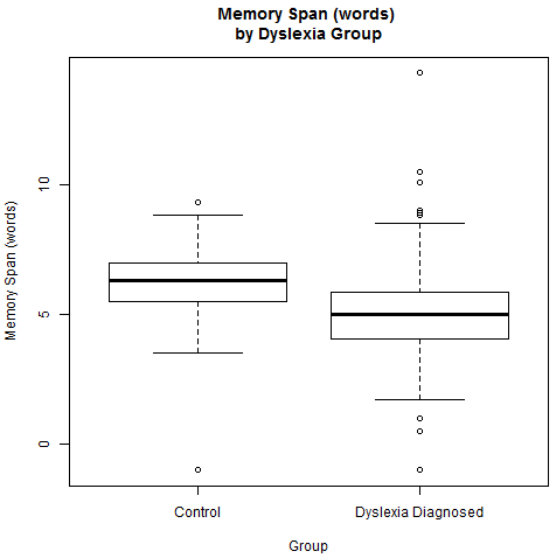

Literacy Score
by Dyslexia Group
Literacy Score
0
2
4
6
Control
Dyslexia Diagnosed
Group

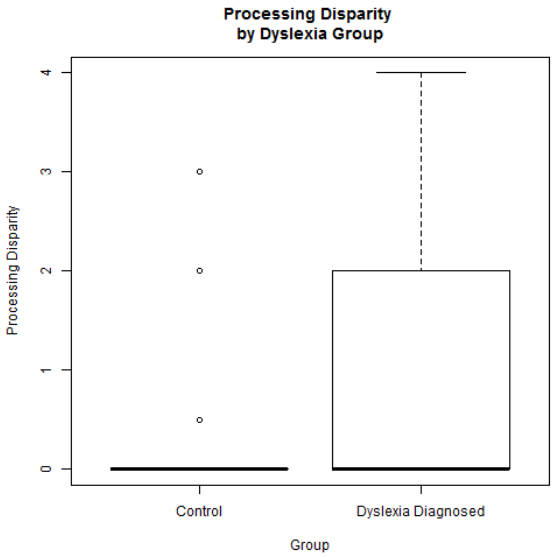

Memory Disparity
by Dyslexia Group
Memory Disparity
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Control
Dyslexia Diagnosed
Group

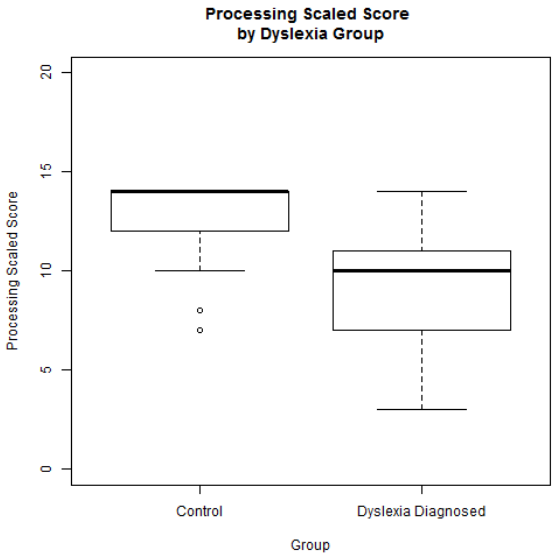

Memory Scaled Score
by Dyslexia Group
Memory Scaled Score
0
5
10
15
20
Control
Dyslexia Diagnosed
Group

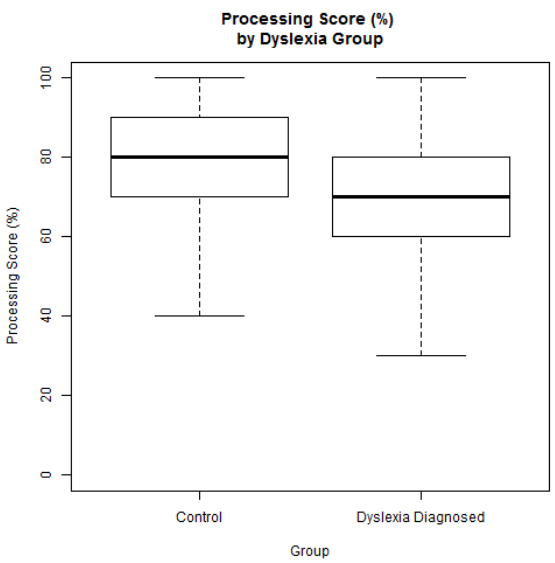

Memory Score (%)
by Dyslexia Group
Memory Score (%)
0
20
40
60
80
100
Control
Dyslexia Diagnosed
Group

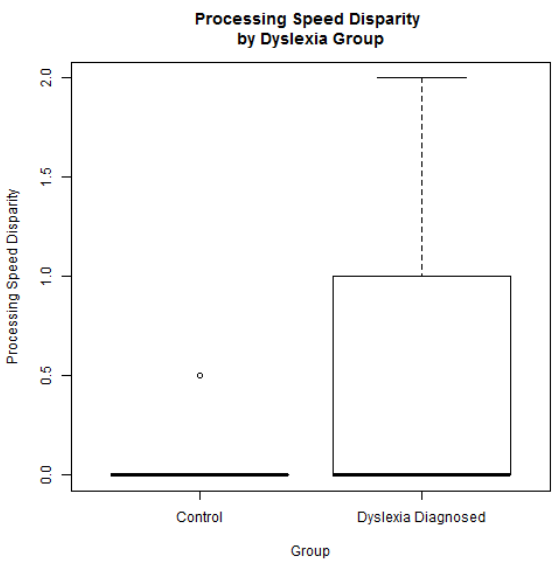

Memory Span Scaled Score
by Dyslexia Group
Memory Span Scaled Score
0
5
10
15
20
Control
Dyslexia Diagnosed
Group

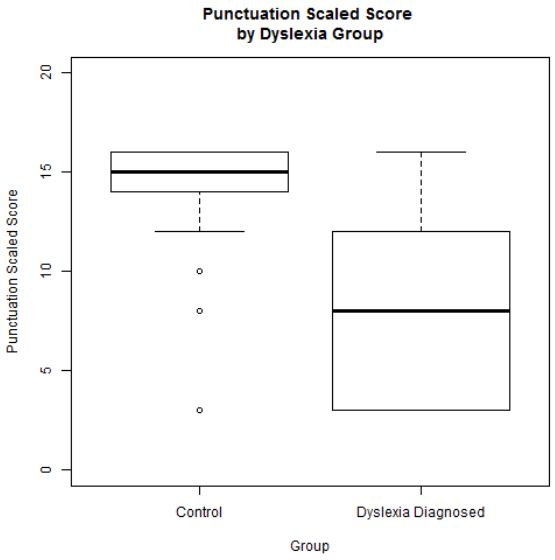

Memory Span (words)
by Dyslexia Group
Memory Span (words)
0
5
10
Control
Dyslexia Diagnosed
Group

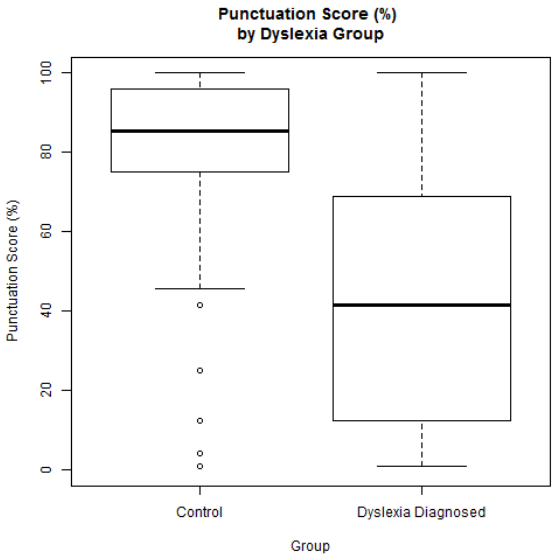

Processing Disparity
by Dyslexia Group
Processing Disparity
0
1
2
3
4
Control
Dyslexia Diagnosed
Group

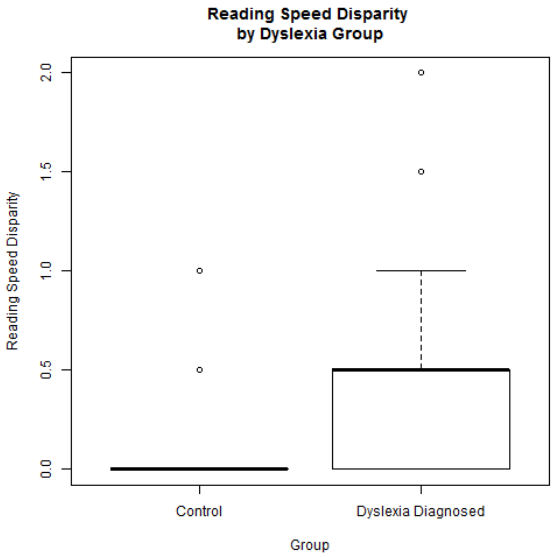

Processing Scaled Score
by Dyslexia Group
Processing Scaled Score
0
5
10
15
20
Control
Dyslexia Diagnosed
Group

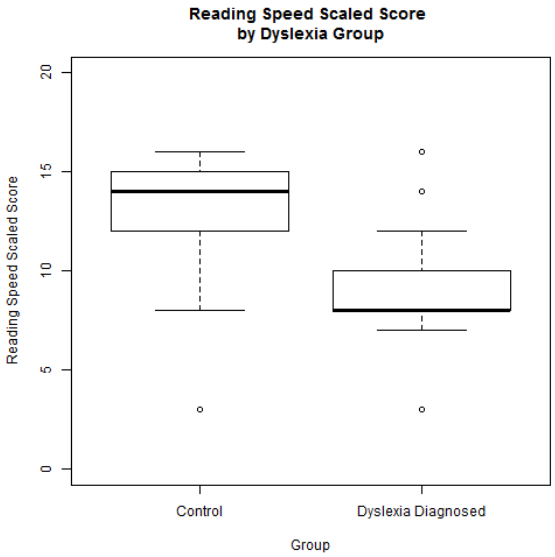

Processing Score (%)
by Dyslexia Group
Processing Score (%)
0
20
40
60
80
100
Control
Dyslexia Diagnosed
Group

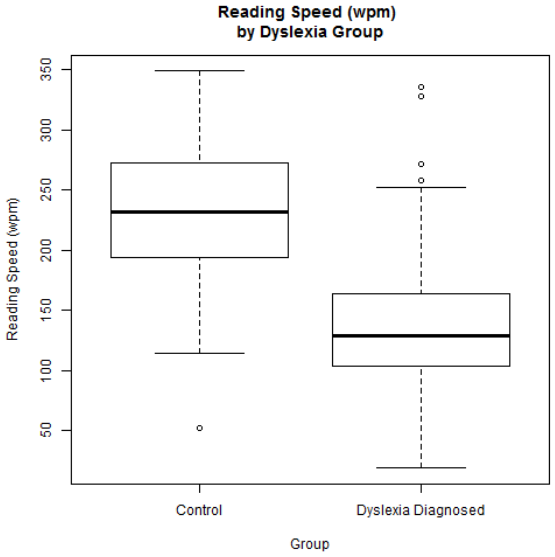

Processing Speed Disparity
by Dyslexia Group
Processing Speed Disparity
0.0
0.5
1.0
1.5
2.0
Control
Dyslexia Diagnosed
Group

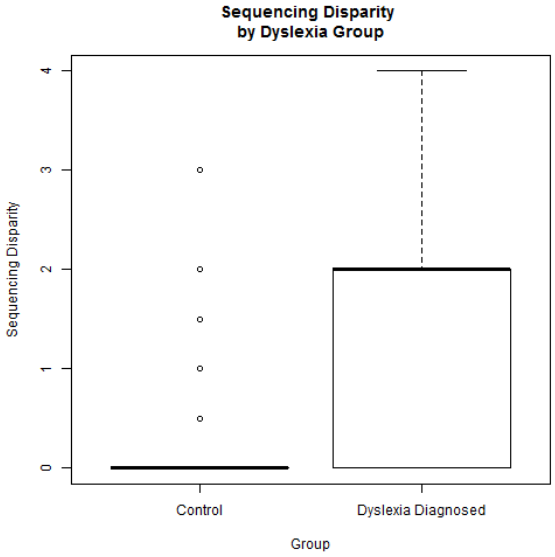

Punctuation Scaled Score
by Dyslexia Group
Punctuation Scaled Score
0
5
10
15
20
Control
Dyslexia Diagnosed
Group

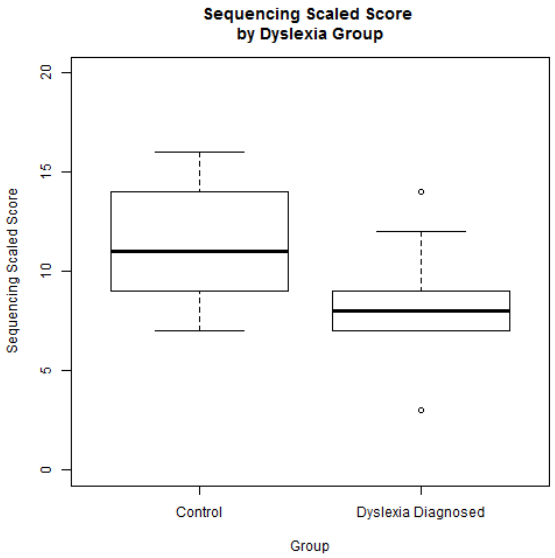

Punctuation Score (%)
by Dyslexia Group
Punctuation Score (%)
0
20
40
60
80
100
Control
Dyslexia Diagnosed
Group

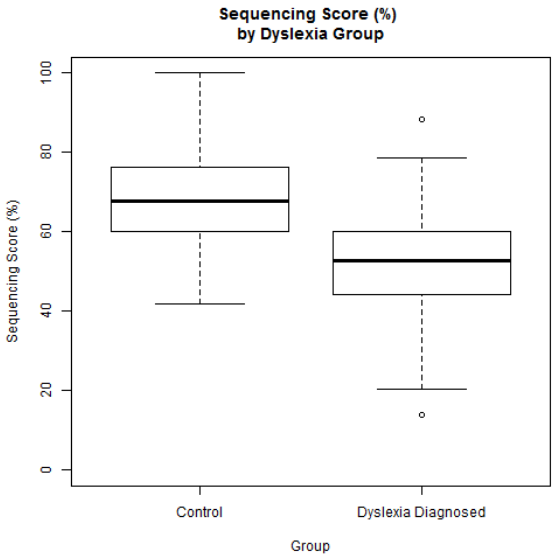

Reading Speed Disparity
by Dyslexia Group
Reading Speed Disparity
0.0
0.5
1.0
1.5
2.0
Control
Dyslexia Diagnosed
Group

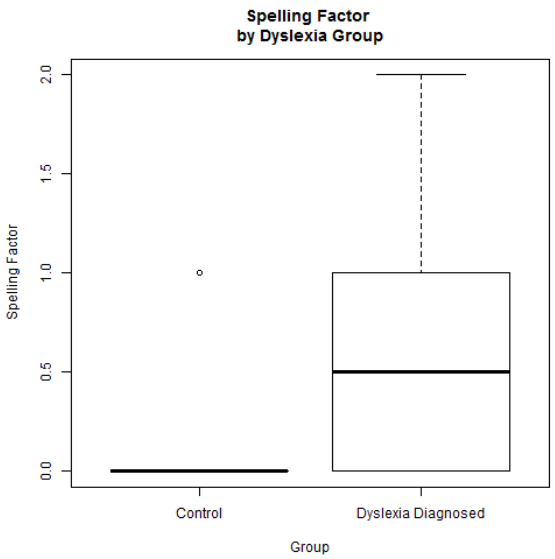

Reading Speed Scaled Score
by Dyslexia Group
Reading Speed Scaled Score
0
5
10
15
20
Control
Dyslexia Diagnosed
Group

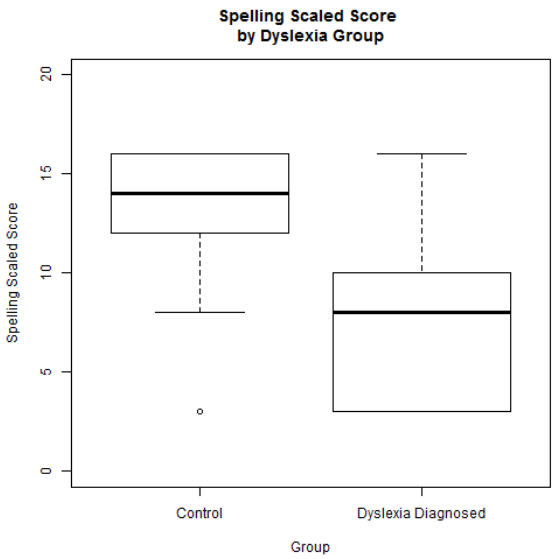

Reading Speed (wpm)
by Dyslexia Group
Reading Speed (wpm)
50
100
150
200
250
300
350
Control
Dyslexia Diagnosed
Group

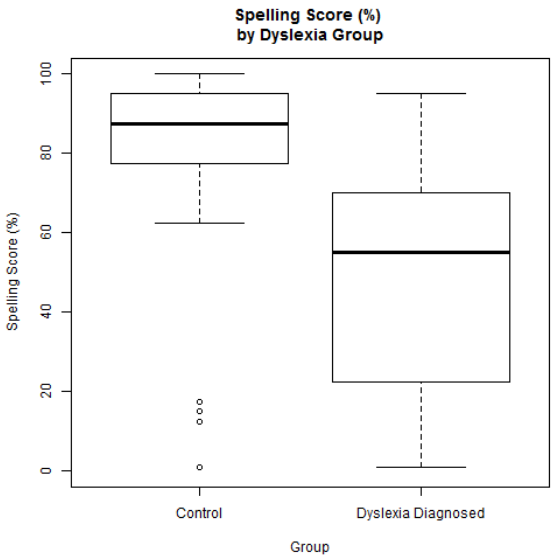

Sequencing Disparity
by Dyslexia Group
Sequencing Disparity
0
1
2
3
4
Control
Dyslexia Diagnosed
Group

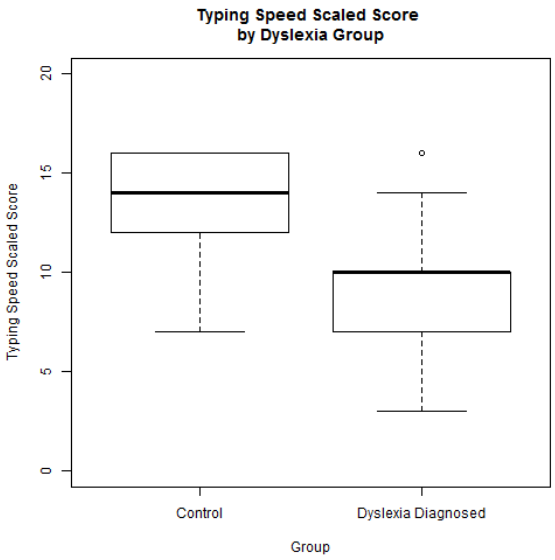

Sequencing Scaled Score
by Dyslexia Group
Sequencing Scaled Score
0
5
10
15
20
Control
Dyslexia Diagnosed
Group

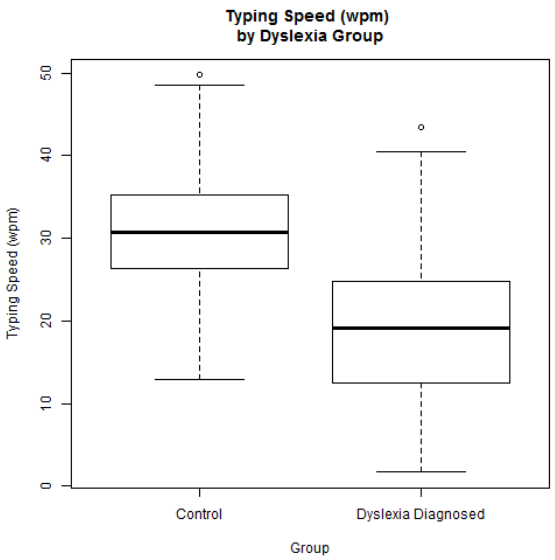

Sequencing Score (%)
by Dyslexia Group
Sequencing Score (%)
0
20
40
60
80
100
Control
Dyslexia Diagnosed
Group

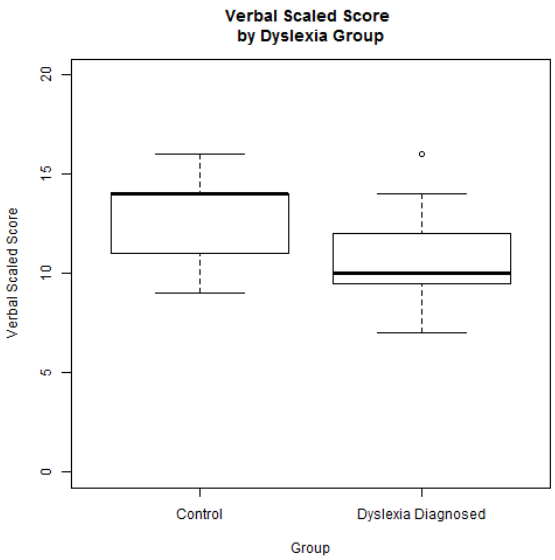

Spelling Factor
by Dyslexia Group
Spelling Factor
0.0
0.5
1.0
1.5
2.0
Control
Dyslexia Diagnosed
Group

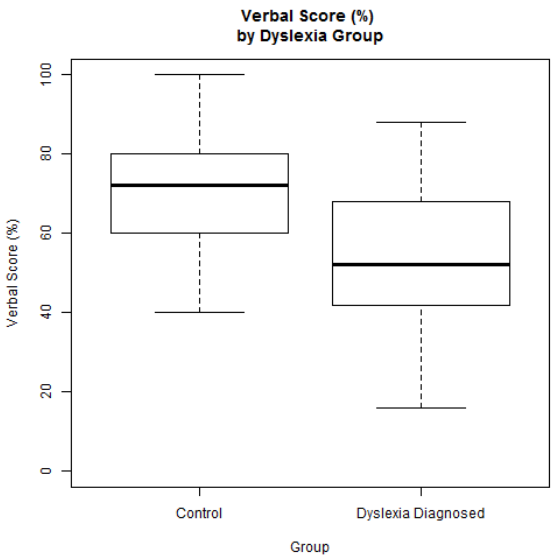

Spelling Scaled Score
by Dyslexia Group
Spelling Scaled Score
0
5
10
15
20
Control
Dyslexia Diagnosed
Group

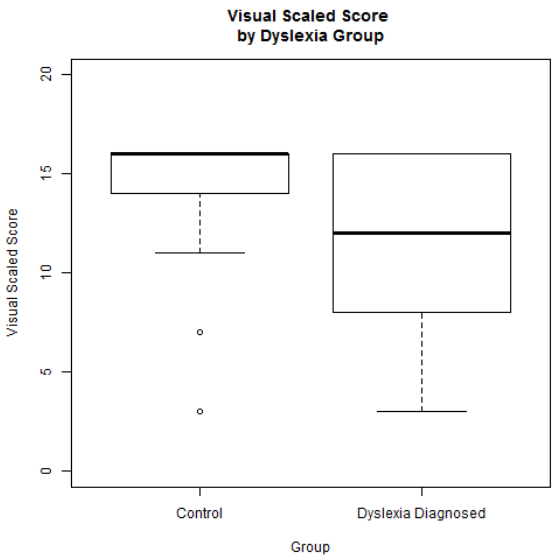

Spelling Score (%)
by Dyslexia Group
Spelling Score (%)
0
20
40
60
80
100
Control
Dyslexia Diagnosed
Group

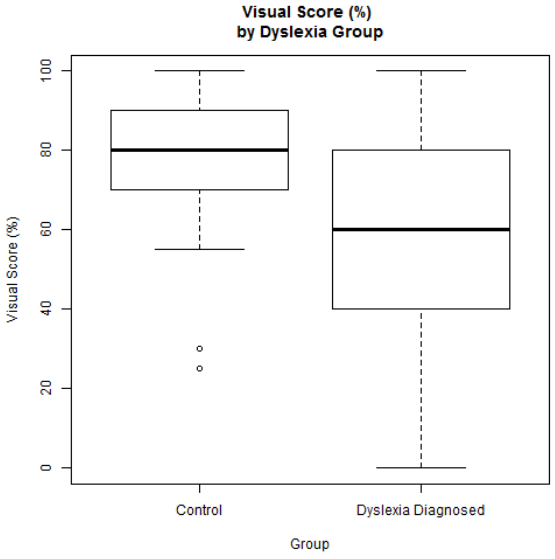

Typing Speed Scaled Score
by Dyslexia Group
Typing Speed Scaled Score
0
5
10
15
20
Control
Dyslexia Diagnosed
Group

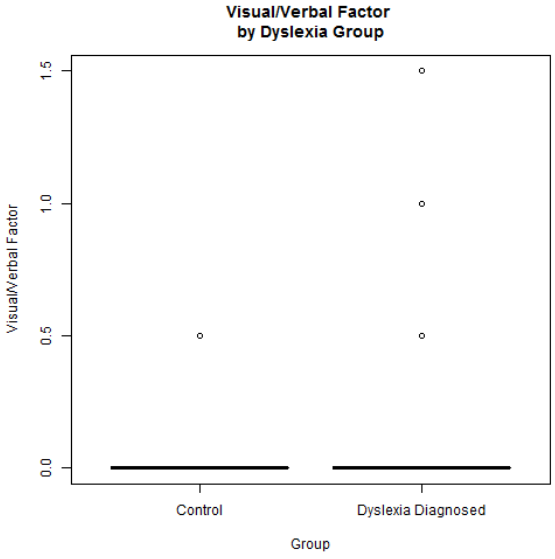

Typing Speed (wpm)
by Dyslexia Group
Typing Speed (wpm)
0
10
20
30
40
50
Control
Dyslexia Diagnosed
Group

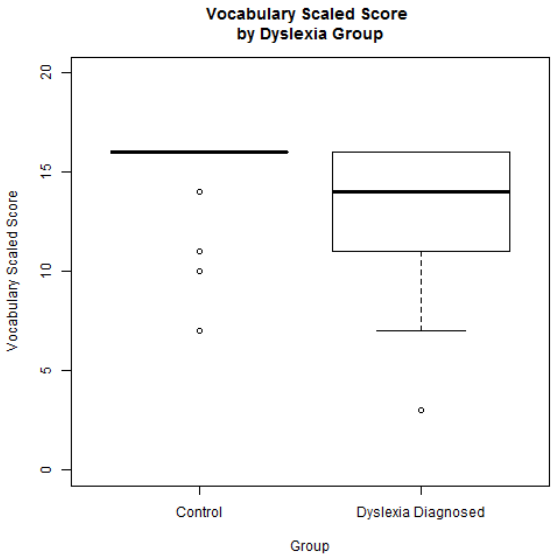

Verbal Scaled Score
by Dyslexia Group
Verbal Scaled Score
0
5
10
15
20
Control
Dyslexia Diagnosed
Group

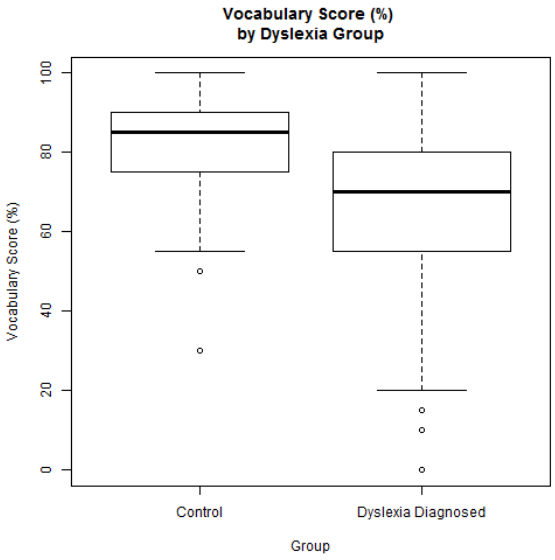

Verbal Score (%)
by Dyslexia Group
Verbal Score (%)
0
20
40
60
80
100
Control
Dyslexia Diagnosed
Group

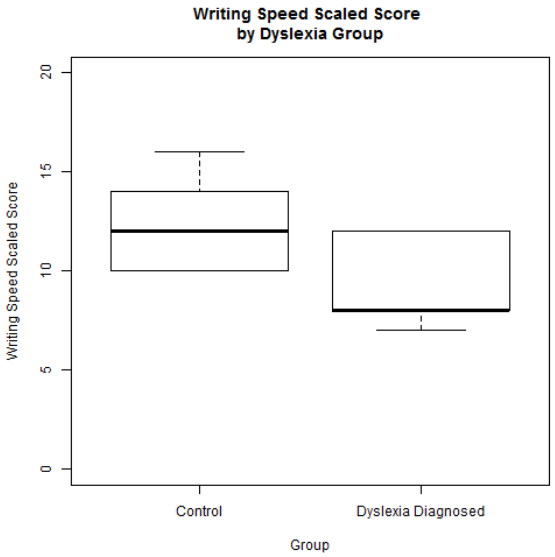

Visual Scaled Score
by Dyslexia Group
Visual Scaled Score
0
5
10
15
20
Control
Dyslexia Diagnosed
Group

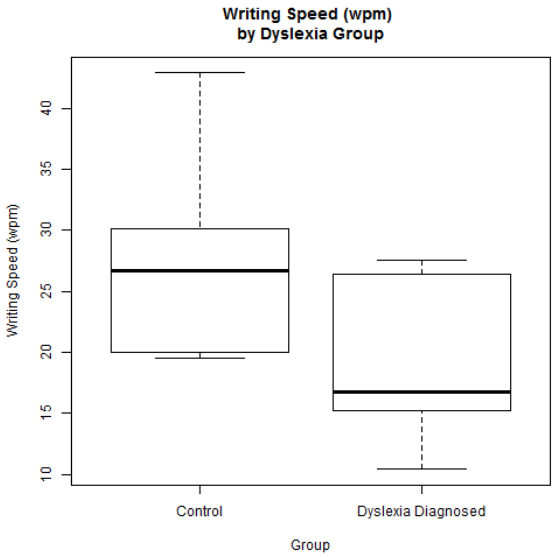

Visual Score (%)
by Dyslexia Group
Visual Score (%)
0
20
40
60
80
100
Control
Dyslexia Diagnosed
Group

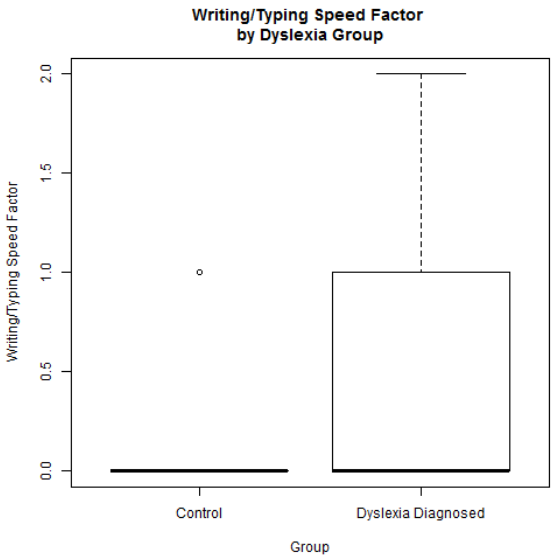

Visual/Verbal Factor
by Dyslexia Group
Visual/Verbal Factor
0.0
0.5
1.0
1.5
Control
Dyslexia Diagnosed
Group


Vocabulary Scaled Score
by Dyslexia Group
Vocabulary Scaled Score
0
5
10
15
20
Control
Dyslexia Diagnosed
Group


Vocabulary Score (%)
by Dyslexia Group
Vocabulary Score (%)
0
20
40
60
80
100
Control
Dyslexia Diagnosed
Group


Writing Speed Scaled Score
by Dyslexia Group
Writing Speed Scaled Score
0
5
10
15
20
Control
Dyslexia Diagnosed
Group


Writing Speed (wpm)
by Dyslexia Group
Writing Speed (wpm)
10
15
20
25
30
35
40
Control
Dyslexia Diagnosed
Group


Writing/Typing Speed Factor
by Dyslexia Group
Writing/Typing Speed Factor
0.0
0.5
1.0
1.5
2.0
Control
Dyslexia Diagnosed
Group