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Statistical Support for QuickScreen Dyslexia Test

Diagnostic Accuracy Assessments 2020-21

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Executive Summary

Background

QuickScreen is an adult computerised screening test that assesses and delivers an indication of possible dyslexia without the need for users to undergo a costly professional assessment by an educational or occupational psychologist. In this study, Select provided an independent analysis of the diagnostic accuracy of QuickScreen based on the test's dyslexia quotient (degree of consistency with a dyslexia profile, based on established research). The data were provided by Pico Educational Systems and included all candidates who, between mid-December 2020 and January 2021, undertook a test via their university, college or workplace assessment process, along with members of the public who requested access to the test via the website. Therefore, the results reflect a cross-section of the public who accessed the service within this period, consistent with the normal age range of the test (17-55+). Participants with a previous positive assessment for dyslexia were considered in the dyslexic group for analysis. The non-dyslexic group included those without a previous assessment and who reported no life-long difficulties with literacy. A separate control group of non-dyslexics was also included, comprising self-selected volunteers without dyslexia. Candidates without a previous assessment but who reported life-long difficulties with literacy were considered "at risk" and explored in a separate exploratory analysis in the dyslexic group. Note: All participants' data was anonymised by Pico Educational Systems Ltd prior to being provided to Select for analysis and was handled in accordance with their current privacy policy.

Headline Results

An essential step in the evaluation process of any diagnostic/screening test is to assess its accuracy. The overall accuracy of a diagnostic test indicates how good it is at correctly identifying people with and without the condition in question. It is the probability that someone's status is correctly identified by the test. Based on the full sample of data for the dyslexic and non-dyslexic groups and to maximise the overall accuracy of the test, participants with a quotient greater than 4.25 (or equivalently a dyslexia percentile > 0.40) should be considered test positive (indicated to have dyslexia) and those ≤ 4.25 test negative (indicated to not have dyslexia). This cut-off aims to identify the quotient figure between the possible existence of dyslexia and a lack of symptoms, as a dyslexia screener. Based on this threshold, and assuming an estimated prevalence of dyslexia in the population of 10% (i.e., reflecting the results that we might expect if the test were applied to a random sample of the population), the QuickScreen test was estimated to have a high overall accuracy rate of 93% (95% confidence interval [CI]: 89 to 96%, reflecting sampling variability). The Receiver Operating Characteristic (ROC) area under the curve (AUC) was estimated to be 97% (95% CI: 95 to 99%). Given that the AUC represents the discrimination of the test where 100% is the best possible value (perfect classification), this illustrates that the QuickScreen test has strong predictive capacity for dyslexia.

We also analysed the link between speed of processing and dyslexia (a finding of a previous study), to further explore the extent to which slow processing might be an aggravating symptom for dyslexia and recognising the relevance of fast/efficient processing skills in high achievers. There was a statistically significant association between the QuickScreen general speed of processing result (Difficulties/Average/No Difficulties) and the non-dyslexic/dyslexic group; along with evidence of a better average speed of processing score for the non-dyslexics versus dyslexic participants. Therefore, speed of processing may be useful in identifying potential difficulties in learning profiles, as a standalone characteristic. Additionally, we found a statistically significant association between the speed of processing results and severity of dyslexia, measured as the dyslexia quotient minus the processing speed disparity factor, i.e., removing the speed of processing contribution from the quotient. For both dyslexics and non-dyslexics, participants with a worse speed of processing score tended to have a higher adjusted dyslexia quotient. A higher adjusted quotient was also observed on average for those with difficulties, followed by the average group, and then no difficulties with speed of processing. So, for participants in the dyslexic group, those with worse speed of processing results are associated with more severe dyslexia. Similarly, albeit at a lower level, for participants in the non-dyslexic group, those with worse speed of processing results are associated with more evidence of dyslexic symptoms (and equally those with better speed of processing results are associated with less of evidence of dyslexic symptoms).

Note: Slightly differing results for the quotient threshold and diagnostic accuracy measures are obtained if we alternatively choose the cut-off that maximises the sensitivity + specificity of the test, rather than the overall accuracy. There is a trade-off in the sensitivity vs specificity of the test for different thresholds which results in slight variation in the associated overall accuracy estimate. Furthermore, if we assume a higher prevalence of dyslexia, for example, that associated with those who might self-identify for a QuickScreen test (as opposed to the whole population), slightly differing estimates of the overall accuracy are obtained. These results are included in full in the body of this report.

Discussion/Context

The QuickScreen test results are almost entirely based on the candidates' current performance and a positive conclusion of Mild, Moderate or Strong indicators will have been adjusted in the light of attainment levels in verbal processing, literacy, and speed of processing. Whilst these can be seen as contributory elements, they are not necessarily the determining factors of dyslexia, and most likely not so when occurring in isolation in an otherwise consistent set of high-performance results. Therefore, it is possible to have a low result on one or more of these components but not be dyslexic.

Likewise, degrees of compensation are also taken into consideration by the QuickScreen test and may positively influence a dyslexia indication by reducing it to a Mild, Borderline or even None category where these other attainment levels are found to be satisfactory. To that extent the test result is not a diagnosis, but it is designed to act as a 'functional dyslexia screener' that provides immediate and detailed insights into an individual's current learning profile and upon which individual support programmes can be devised, reasonable adjustments put in place at work and where possible additional time in written examinations be considered.

Contents

Introduction

Following an initial study in 2016 and a subsequent study in 2018, Select were pleased to again be asked to help with the statistical analysis of Pico Educational Systems Ltd's QuickScreen dyslexia test[1], 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 our first 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 the second study, the aim was to support the development of the test by providing evidence that might inform adjustments to the existing QuickScreen indication category boundaries.

In this study, we provide an assessment of the diagnostic accuracy of the latest version of QuickScreen based on data from tests completed in December 2020 to January 2021. An essential step in the evaluation process of any diagnostic/screening test is to assess its accuracy via diagnostic accuracy measures. Rather than considering QuickScreen's categorical boundaries, we were asked to consider the test's dyslexia quotient (degree of consistency with a dyslexia profile, scored on a scale from 0 to 20), which is calculated by combining individual scores for various processes examined during the online assessments, such as visual, verbal, memory, reading, comprehension, etc. The cut-off values of the quotient score that best discriminate between those with and without a previous dyslexia diagnosis were first identified and then used in the subsequent accuracy assessments.

We were also asked to further explore the speed of processing component results available from the QuickScreen test and how these are associated with the presence or absence of a previous dyslexia diagnosis. The interest being in the potential connection between slow processing and dyslexia and whether speed of processing, as a standalone characteristic, may be useful in identifying potential difficulties in learning profiles. Additionally, we were asked to explore the association between the speed of processing component results with the QuickScreen dyslexia quotient minus the processing speed disparity factor, i.e., removing the speed of processing contribution from the quotient, to understand how the severity of dyslexia might correlate with slow processing.

Finally, further data from the QuickScreen test assessment were available for participants who were self-identified as having difficulties and therefore of being "at risk" of dyslexia but without a previous dyslexia diagnosis. We were also asked to conduct a repeat of the diagnostic accuracy assessments considering this group as dyslexia positive (though there was no way in which their presence or absence of dyslexia could be verified).

Data

The data for this study were compiled by Pico Educational Systems Ltd and provided to us for analysis. These included observational data collected from participants completing the online QuickScreen assessment from mid-December 2020 to mid-January 2021, including all candidates who came forward to do the test via their university, college or workplace assessment process and

[1] https://qsdyslexiatest.com/

members of the public who requested access via the website. Therefore, this study includes a cross-section of the public (aged 16 to 74) who accessed Pico's services within this time period.

The data received included results for participants on whether they did or did not have a previous dyslexia diagnosis. This information was used to subset the candidates into the following groups:

- A general non-dyslexic group, which comprised participants who had not been previously assessed for dyslexia and reported that they had not had life-long difficulties with literacy (n=69).
- A dyslexic group, which comprised participants who stated that they had been previously assessed as dyslexic (n=68).
- An "at risk" group, which comprised participants who had not been previously assessed for dyslexia but reported that they had experienced life-long difficulties with literacy (n=228).

Data from an additional control group of non-dyslexics were also provided, generating a further group:

- A "true control" group of non-dyslexics, which comprised self-selected volunteers who were known not to have dyslexia and were invited to participate in the study (n=25).

The QuickScreen dyslexia test results were provided in four Excel spreadsheets, for four separate weeks of data. These Excel files all had a consistent layout and were combined prior to analysis to create a single dataset. A separate Excel file was also provided of the data for the additional control group (i.e., "true control" group) of non-dyslexics, from which the IDs of these participants were extracted, allowing appropriate sub-setting of the data for analysis. The results for the "at risk" group who hadn't been previously assessed as having dyslexia but were self-referring for a test as they had experienced life-long difficulties with literacy were provided in separate sheets in the same Excel files, again in a similar format, and which were also combined ready for analysis.

The subsequent analysis of the study data was run for three different sets of these available data:

i. The "full" non-dyslexic group ("true control" group and general non-dyslexic group) vs the dyslexic group.
ii. The "true control" group of non-dyslexics only (excluding the general non-dyslexic group) vs the dyslexic group.
iii. The "full" non-dyslexic group vs the dyslexic group and "at risk" group (i.e., considering the "at risk" participants in the dyslexic group).

The aim of the subgroup analysis (ii.) was to help remove those with the potential for indications who were not aware of having problems from the analysis, that may have been in the general non-dyslexics group. The expectation being that the "true control" group explicitly identified themselves as non-dyslexics and were therefore less likely to have potentially undiagnosed dyslexia. Though, we note that this subgroup analysis has a more limited sample size than the primary analysis (i).

For the primary analysis (i), test results were available for 162 participants: 68 (42.0%) in the dyslexic group; and 94 (58.0%) in the non-dyslexic group. The 94 non-dyslexics included 25 "true controls", and 69 participants from the general non-dyslexic group. There were 228 "at risk" participants who were also considered in the dyslexic group in the additional exploratory analysis (iii).

Note: All participants' data was anonymised by Pico Educational Systems Ltd prior to being provided to Select for analysis and was handled in accordance with their current privacy policy.

Potential Limitations

We recognise that there are some potential limitations of the study, given the data available for analysis, that may affect its outcomes. In most cases, these are likely to lead to conservative estimates of the test accuracy, i.e., the reported results may underestimate the true performance of the test in practice.

Firstly, we note that some of those participants in the dyslexic group may have made improvements in their learning since their previous diagnosis was received, which may have not been very recently. Pico Educational Systems have highlighted that the QuickScreen test is only able to identify those with 'functional' dyslexia, i.e., those that are currently exhibiting problems. Any well-compensated individuals may be asymptomatic or more borderline in their dyslexia symptoms and this would therefore impact upon the accuracy assessments reported in this study as the test may find it more difficult to identify these lesser symptoms linked with dyslexia. 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, the graduated indications provided by QuickScreen in their presentation of the test results reflect this non-binary nature of dyslexia which is on a continuum of symptoms/severities, whereas the diagnostic accuracy summaries here are not able to account for this uncertainty.

We also acknowledge that those in the non-dyslexic group, particularly the general non-dyslexics as opposed to the "true control" group, may have unidentified learning problems which means that they may have indictors of dyslexia but be unaware of these issues. This will again have the potential to reduce the apparent accuracy of the QuickScreen test, as reported in this study. Furthermore, it is recognised that though participants in the non-dyslexic group may not have previously received a formal dyslexia diagnosis, it is possible that this group may in fact contain a small number of previously 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. The effect of this potential misclassification of participants is known as classification bias. The implication of which is that it may not be possible to achieve perfect diagnostic accuracy in this case.

Similar to our previous studies, it should also be noted when interpreting the results of this analysis that their validity depends upon 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".

Methods

Receiver Operating Characteristic (ROC) Curve Analysis

A Receiving Operating Characteristic (ROC) curve[2,3] is a useful tool that allows us to examine the trade-off between the QuickScreen test's sensitivity (i.e., the proportion of dyslexic participants that are identified as having dyslexia by the test) and specificity (i.e., the proportion of non-dyslexics that are identified as not having dyslexia by the test). We plot the true positive rate (TPR; or sensitivity) against the false positive rate (FPR; or 1 minus the specificity) for a variety of different classification thresholds based on the QuickScreen dyslexia quotient. Each point on the ROC curve represents a different threshold for classification, ranging from all quotients classified as non-dyslexic in the bottom left-hand corner (i.e., 0% TPR and FPR) and all quotients classified as dyslexics in the top right-hand corner (i.e., 100% TPR and FPR). The best possible predictive model would be one with a 100% TPR and 0% FPR (equivalently 100% sensitivity and specificity), which corresponds with the top left-hand corner of the figure for the ROC curve, though seldom is this achievable.

We considered two potential options for the choice of optimal threshold to give the best discrimination between the dyslexic/non-dyslexic groups:

i. To maximise the TPR + (1–FPR), i.e., the maximum sensitivity + specificity.
ii. To maximise the overall accuracy, i.e., the proportion of results that are correctly identified by the test.

The ROC curve is also a useful indicator of how well the test is able to perform classification. If the ROC curve follows the diagonal y=x line (i.e., TPR = FPR), then any classifications are no better than predicting at random, e.g., by tossing a coin for assigning participants as dyslexic or not. Ideally, we want the curve to lie above this line as this indicates that the test is better than if we were to classify the outcome randomly. We can formalise this by calculating the Area Under the Curve (AUC)[4]. The AUC represents the accuracy of the test in terms of its capacity for discrimination, where 100% is the best possible value (perfect classification), 50% is equivalent to predicting at random and a value of less than 50% is even worse. The AUC estimate can also be interpreted as the probability that the test will assign a higher score to a randomly chosen dyslexic individual than to a randomly chosen non-dyslexic participant example. An estimate of the AUC based upon a sample of data such as the data in this study, like all estimates, is subject to a sampling error. To account for this and express our uncertainty in the estimated AUC due to sampling variability, we also calculated a 95% confidence interval for the AUC (using the DeLong[5] method).

Diagnostic Accuracy Assessments

As described above, the sensitivity (or TPR) of a diagnostic test indicates how good it is at finding people with the condition in question. It is the probability that someone who has the condition is identified as such by the test. Whereas the specificity (1–FPR) of a diagnostic test indicates how good

[2] https://select-statistics.co.uk/resources/glossary-page/#receiver-operating-characteristic-roc-curve
[3] https://select-statistics.co.uk/blog/classifying-binary-outcomes/
[4] https://select-statistics.co.uk/resources/glossary-page/#roc-area-curve-auc
[5] Elisabeth R. DeLong, David M. DeLong and Daniel L. Clarke-Pearson (1988) "Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach". Biometrics 44, 837–845.

it is at identifying people who do not have the condition. It is the probability that someone who does not have the condition is identified as such by the test.

The predictive values of the test, also termed the “post-test probabilities”, provide the probability of a positive or negative diagnosis given the test result. The predictive values therefore provide important information on the diagnostic accuracy of the test for a particular participant, answering the question “How likely is it that I have or don’t have dyslexia given the test result that I have received?”

To assess the performance of the current QuickScreen test based on the dyslexia quotient cut-offs, as described above, we produced a number of diagnostic accuracy assessment summaries, including estimates of the sensitivities, specificities, and predictive values.

A similar approach to these calculations was applied to that used in our original project for QuickScreen. The method to calculate these values is described in our previous report (ref: PICO001) and therefore not repeated in full here. We again assumed an estimated prevalence of dyslexia in the population of 10% when calculating the predictive values. In screening situations, the prevalence is almost always small and the positive predictive value low, even for a fairly sensitive and specific test. This reflects the results for the predictive values that we might expect if the test were applied to a random sample of the population, for whom the prevalence is approximately 10%. However, the prevalence in those that have self-selected to take the QuickScreen dyslexia test is likely to be considerably higher. Therefore, the results were also considered for a higher estimate of the prevalence in line with this alternative population, using the rate of dyslexia observed in our original study of QuickScreen (ref: PICO001), i.e., 78.8%, which included participants where an independent assessment of their dyslexia diagnosis was available. (In this study, the observed prevalence will be arbitrarily affected by the number of control group participants that have been included and therefore cannot be used as a reliable estimate of the prevalence in this alternative population.)

In addition to the diagnostic accuracy measures described above and provided previously, estimates of the overall accuracy of the test were also calculated, i.e., the overall proportion of correctly classified participants, which was the key outcome of interest in this study. To express our uncertainty in the overall accuracy, 95% bootstrapped confidence intervals were also calculated. We note that, similar to the predictive values, the overall accuracy also depends upon the assumed prevalence of dyslexia and is therefore provided for the two populations and corresponding prevalence estimates considered (10% and 78.8%).

Alongside the diagnostic accuracy measures, we have again carried out a statistical test to assess whether there is evidence of an association between the QuickScreen test outcome and the independent dyslexia diagnosis. This would be expected if the test is useful in discriminating between dyslexic and non-dyslexic individuals. Fisher’s exact test was applied (rather than a large sample test such as the Chi-square test, for example) to account for the fact that we have relatively low sample sizes, which can bias the results in asymptotic tests (as the normal approximation of the multinomial distribution can fail).

General Speed of Processing Exploration

Another area of interest, highlighted by Dr Dee Walker, was to explore the QuickScreen speed of processing results and their association with dyslexia, expanding on some initial work carried out in our initial analysis for QuickScreen (ref: PICO001).

Therefore, in this study, we again looked at the association between the speed of processing categories (No Difficulties/Average/Difficulties) and the dyslexic/non-dyslexic groups and carried out a statistical test (again via a Fisher's exact test) of their independence. We also explored the relationship between the numeric speed of processing scores and the previous dyslexia diagnosis groups, via summary statistics and visualisations, and a statistical (Mann-Whitney U) test to compare their distributions.

Furthermore, we considered whether the extent of other dyslexic symptoms might be associated with the QuickScreen speed of processing results. We looked at the speed of processing results versus the dyslexia quotient minus the processing speed disparity component, calculating the correlation between these values and comparing the average adjusted dyslexia quotient across the general speed of processing groups (No Difficulties, Average, Difficulties) (via a Kruskal-Wallis rank sum test). Note: We didn't use the unadjusted QuickScreen quotient here as this incorporates the speed of processing disparity component and therefore will intrinsically be correlated with the speed of processing results.

Full Non-Dyslexic Group versus True Control Group Only

As discussed in the Data section above, the analysis described here was repeated for the full non-dyslexic (versus dyslexic) group, followed by the subgroup analysis whereby only the "true control" non-dyslexic (versus dyslexic) group was included.

At Risk Group Exploration

A further exploratory analysis was also carried out, considering the "at risk" group as dyslexics.

Results

The results of the analysis outlined in the Methods section are presented below, first for the primary analysis considering the full non-dyslexic group (general and true control group non-dyslexics), then for the true control group only for the non-dyslexics (but again including all dyslexics with a previous diagnosis), and finally an additional exploratory analysis considering the "at risk" group.

Full Non-Dyslexic Group

The ROC curve for the full non-dyslexic group analysis is shown in Figure 1. The ROC curve AUC is estimated to be 97.12%, with 95% confidence interval from 94.87% to 99.37%. Given that the AUC of a perfect model would be 100%, this illustrates that the QuickScreen test has strong predictive capacity for dyslexia and may be useful when screening for dyslexia.

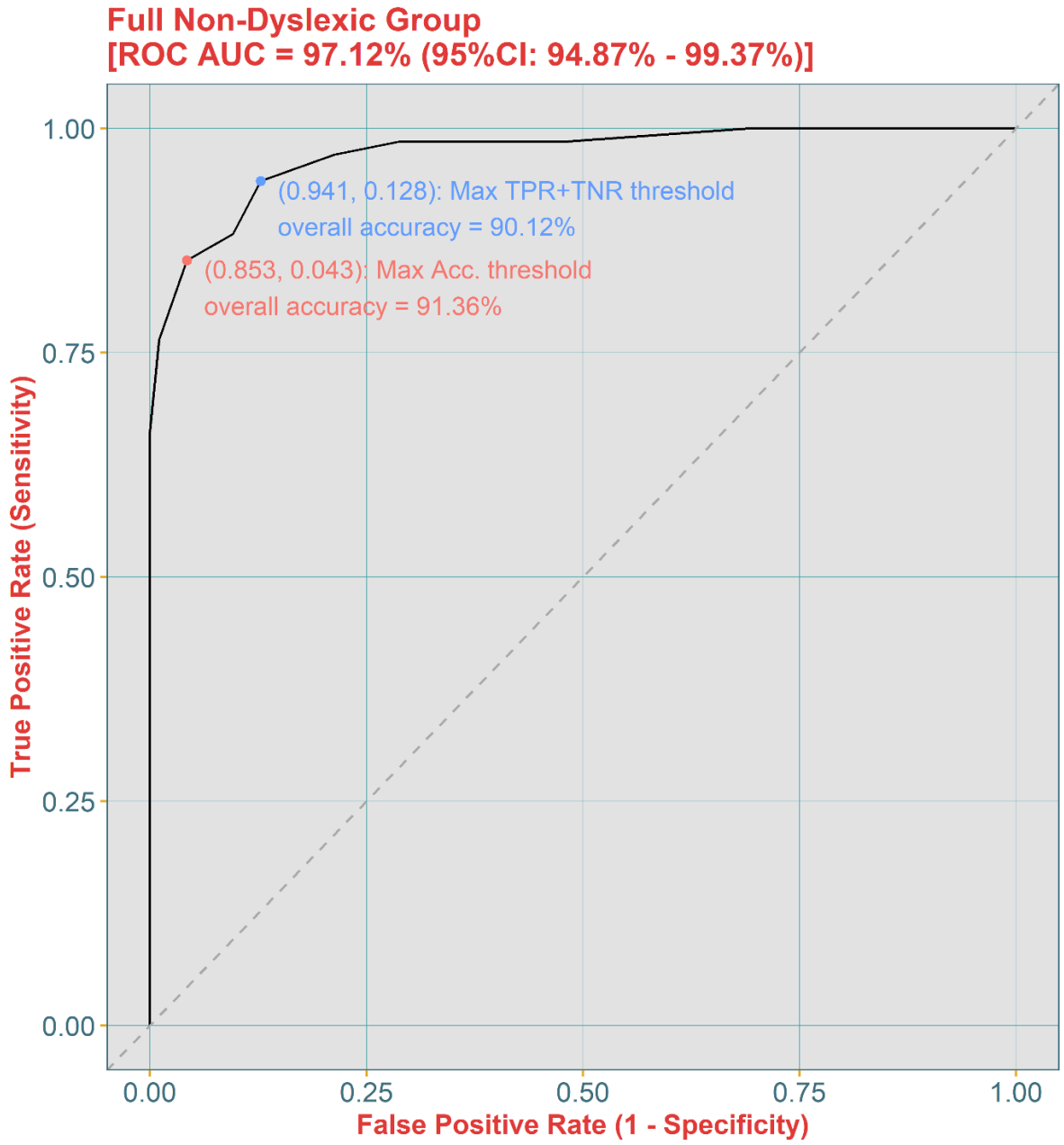

Figure 1: ROC Curve for the full non-dyslexic versus dyslexic group, with points (TPR, FPR) showing the thresholds associated with maximising the sensitivity + specificity (in blue) and maximising the overall accuracy (in red).

Overall Accuracy Threshold

The dyslexia quotient cut-off associated with maximising the overall accuracy (red point on Figure 1) was 4.25 (or equivalently a dyslexia percentile > 0.40). Therefore, to maximise the overall accuracy of the test, participants with a quotient greater than 4.25 should be considered test positive (indicated to have dyslexia) and those ≤ 4.25 test negative (indicated to not have dyslexia).

The distribution of the QuickScreen dyslexia quotient values observed in the non-dyslexic (previous diagnosis negative) and dyslexic (previous diagnosis positive) groups, along with this optimal threshold are visualised in Figure 2.

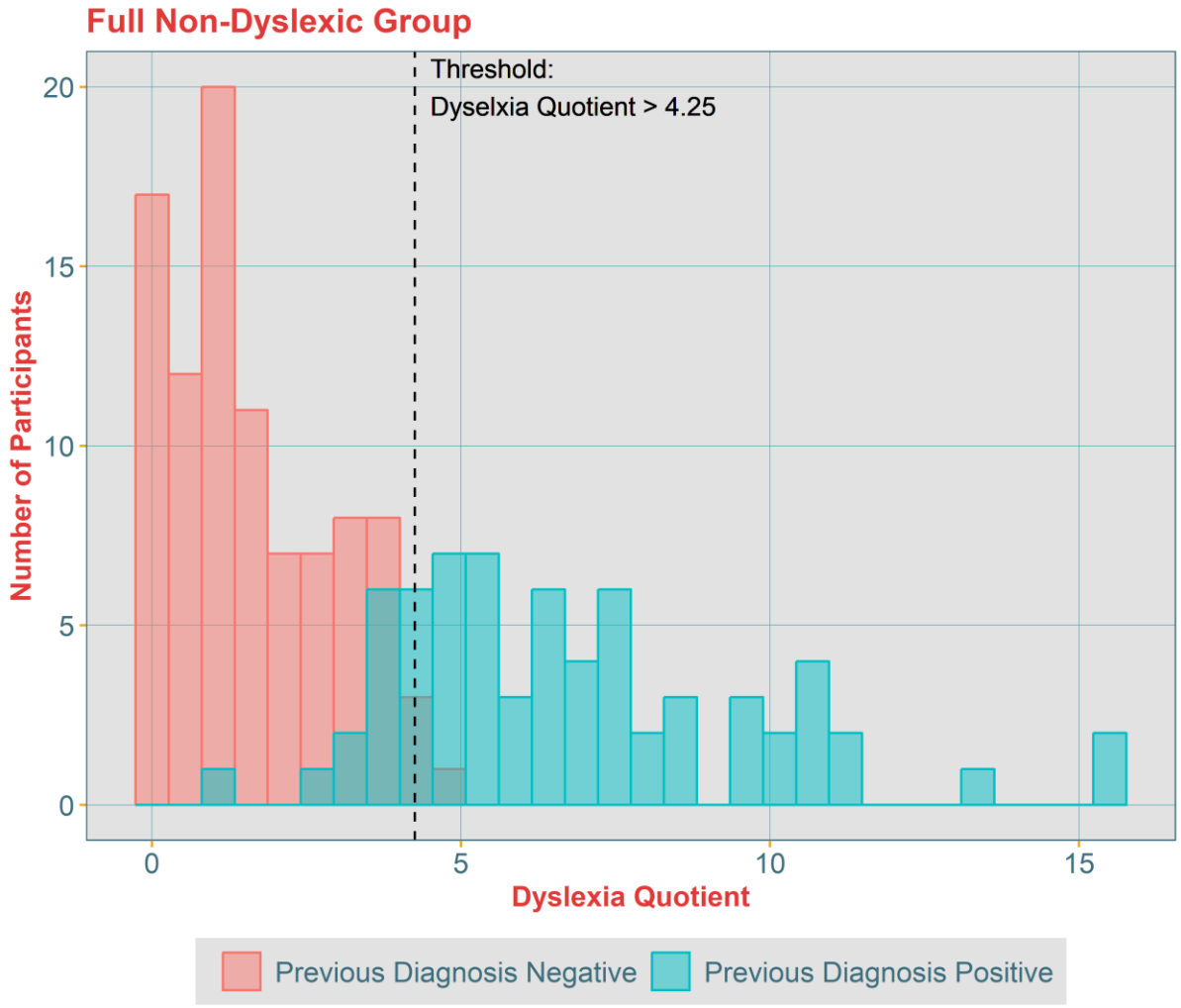

Figure 2: Histograms of the QuickScreen dyslexia quotients for the participants in the non-dyslexic (previous diagnosis negative) and dyslexic (previous diagnosis positive) groups, for the full non-dyslexic group. The vertical, dashed line shows the dyslexia quotient threshold associated with maximising the overall accuracy.

Applying this threshold, 100 (61.7%) of participants were test negative and 62 (38.3%) test positive, compared with 94 (58%) in the non-dyslexic group and 68 (42.0%) in the dyslexic group (as shown in the cross-tabulation in Table 1). 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 QuickScreen test result.

	QuickScreen Test Negative	QuickScreen Test Positive	Total
Non-Dyslexic Group	90	4	94 (58.0%)
Dyslexic Group	10	58	68 (42.0%)
Total	100 (61.7%)	62 (38.3%)	162 (100%)

Table 1: Cross-tabulation of the dyslexia group (non-dyslexics/dyslexics) versus the QuickScreen test result (negative/positive) based on the threshold associated with maximising the overall accuracy, for the full non-dyslexic group.

The proportion of participants in the non-dyslexic group who received a negative QuickScreen test result (i.e., sample specificity) and the proportion of participants in the dyslexic group who received a positive QuickScreen test result (i.e., sample sensitivity), based on this threshold, are shown in Table 2.

	QuickScreen Test Negative	QuickScreen Test Positive
Non-Dyslexic Group	95.7%	4.3%
Dyslexic Group	14.7%	85.3%

Table 2: Raw sample specificity (non-dyslexic group row) and sensitivity (dyslexic group row) values for the QuickScreen test negative and positive results, based on the threshold associated with maximising the overall accuracy, for the full non-dyslexic group.

Ninety-five-point-seven percent (95.7%) of participants in the non-dyslexic group received a negative test result, and 85.3% of those in the dyslexic group received a positive test result.

Of those participants who received negative QuickScreen test outcome, the proportion who were in the non-dyslexic group (i.e., sample negative predictive value); and of those participants who received a positive QuickScreen test outcome, the proportion who were in the dyslexic group (i.e., sample positive predictive value), are shown in Table 3. Overall 91.4% ([90+58]/162) of the QuickScreen test results were correct according to the non-dyslexic/dyslexic groups. These are the raw sample predictive values and overall accuracy, based on the observed sample prevalence, and do not reflect estimates for a random sample of the population nor those self-selecting for a QuickScreen test.

	QuickScreen Test Negative	QuickScreen Test Positive
Non-Dyslexic Group	90.0%	6.5%
Dyslexic Group	10.0%	93.5%

Table 3: Raw sample predictive values (negative for the non-dyslexic group and positive for the dyslexic group) for the QuickScreen test negative and test positive outcomes, based on the threshold associated with maximising the overall accuracy, for the full non-dyslexic group.

Ninety percent (90%) of those participants with a negative QuickScreen test result were in the non-dyslexic group, and 93.5% with a positive QuickScreen test result were in the dyslexic group.

The diagnostic accuracy measures, estimated using the adjusted method (with adjusted logit confidence intervals) and assuming a 10% prevalence of dyslexia, based on the threshold associated with maximising the overall accuracy, are shown in Table 4.

QuickScreen Test Result	Diagnostic Measure	Estimate	95% Confidence Interval
Positive	Sensitivity	83.4%	(73.0%, 90.3%)
	PPV	60.5%	(41.1%, 77.1%)
Negative	Specificity	93.9%	(87.1%, 97.3%)
	NPV	98.1%	(96.8%, 98.8%)
Overall	Accuracy	92.9%	(88.9%, 96.0%)

Table 4: Estimates of the diagnostic accuracy measures using the adjusted logit method, based on the threshold associated with maximising the overall accuracy, for the full non-dyslexic group (with 10% prevalence). PPV = Positive Predictive Value; NPV = Negative Predictive Value.

So, assuming an estimated prevalence of dyslexia in the population of 10%:

- The overall accuracy of the QuickScreen test (proportion of test results that are correct) is estimated to be 92.9%, with a 95% confidence interval [CI] expressing our uncertainty in this estimate of 88.9% to 96.0%).
- The sensitivity (proportion of those with dyslexia that test positive) of the Quickscreen test is estimated to be 83.4% (95% CI: 73.0% to 90.3%).
- The specificity (proportion of those without dyslexia that test negative) is estimated to be 93.9% (95% CI: 87.1% to 97.3%).
- The positive predictive value (proportion of those with a positive test that have dyslexia) is estimated to be 60.5% (95% CI: 41.1% to 77.1%).
- The negative predictive value (proportion of those with a negative test that don't have dyslexia) is estimated to be 98.1% (95% CI: 96.8% to 98.8%).

We note that, in screening situations, the prevalence is almost always small and the positive predictive value low, even for a fairly sensitive and specific test. This is reflected in the estimated positive predictive value of 60.5% here, which is impacted by the assumed prevalence of dyslexia in the population. We'll see in the subsequent results below, that for a higher assumed prevalence of dyslexia, the positive predictive value is higher.

The diagnostic accuracy measures, again estimated using the adjusted method (with adjusted logit confidence intervals) but assuming a 78.8% prevalence of dyslexia, based on the threshold associated with maximising the overall accuracy, are shown in Table 5.

QuickScreen Test Result	Diagnostic Measure	Estimate	95% Confidence Interval
Positive	Sensitivity	83.4%	(73.0%, 90.3%)
	PPV	98.1%	(95.9%, 99.1%)
Negative	Specificity	93.9%	(87.1%, 97.3%)
	NPV	60.4%	(47.5%, 71.9%)
Overall	Accuracy	85.6%	(78.9%, 91.6%)

Table 5: Estimates of the diagnostic accuracy measures using the adjusted logit method, based on the threshold associated with maximising the overall accuracy, for the full non-dyslexic group (with 78.8% prevalence). PPV = Positive Predictive Value; NPV = Negative Predictive Value.

The estimates of the sensitivity and specificity are unaffected by the change in assumed prevalence of dyslexia. However, based on this higher estimate of dyslexia for participants who have self-identified to take the test:

- The overall accuracy of the QuickScreen test (proportion of test results that are correct) is estimated to be 85.6% (95% CI: 78.9% to 91.6%).
- The positive predictive value (proportion of those with a positive test that have dyslexia) is estimated to be 98.1% (95% CI: 95.9% to 99.1%).
- The negative predictive value (proportion of those with a negative test that don't have dyslexia) is estimated to be 60.4% (95% CI: 47.5% to 71.9%).

We note that for this higher assumed prevalence the positive predictive value is estimated to be much higher at over 98%. However, the negative predictive value has correspondingly decreased to 60.4%.

Sensitivity + Specificity Threshold

Alternatively, choosing the threshold that maximises the sensitivity + specificity, rather than the overall accuracy, the dyslexia quotient cut-off (blue point on Figure 1) was 3.25 (or equivalently a dyslexia percentile > 0.34). Therefore, to maximise the sensitivity + specificity of the test, participants with a quotient greater than 3.25 should be considered test positive (indicated to have dyslexia) and those ≤ 3.25 test negative (indicated to not have dyslexia).

The distribution of the QuickScreen dyslexia quotient values observed in the non-dyslexic (previous diagnosis negative) and dyslexic (previous diagnosis positive) groups, along with this optimal threshold are visualised in Figure 3.

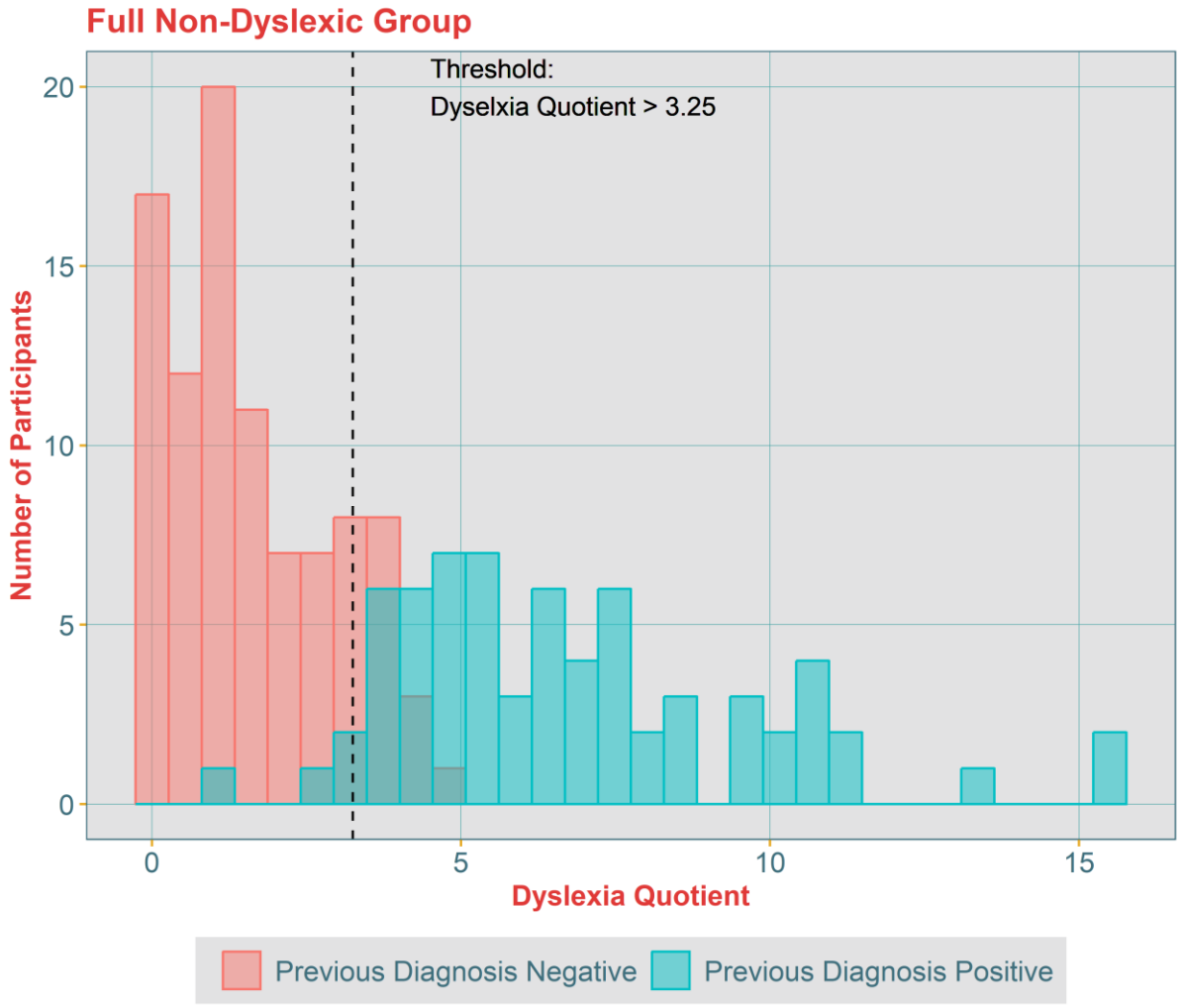

Figure 3: Histograms of the QuickScreen dyslexia quotients for the participants in the non-dyslexic (previous diagnosis negative) and dyslexic (previous diagnosis positive) groups, for the full non-dyslexic group. The vertical, dashed line shows the dyslexia quotient threshold associated with maximising the sensitivity + specificity.

Applying this threshold, 86 (53.1%) of participants were test negative and 76 (46.9%) test positive, compared with 94 (58.0%) in the non-dyslexic group and 68 (42.0%) in the dyslexic group (as shown in the cross-tabulation in Table 6). A Fisher's exact test (on the data in Table 6) finds strong statistical evidence (p-value < 0.0001) of an association between the dyslexia group and the QuickScreen test result.

	QuickScreen Test Negative	QuickScreen Test Positive	Total
Non-Dyslexic Group	82	12	94 (58.0%)
Dyslexic Group	4	64	68 (42.0%)
Total	86 (53.1%)	76 (46.9%)	162 (100%)

Table 6: Cross-tabulation of the dyslexia group (non-dyslexics/dyslexics) versus the QuickScreen test result (negative/positive) based on the threshold associated with maximising the sensitivity + specificity, for the full non-dyslexic group.

The proportion of participants in the non-dyslexic group who received a negative QuickScreen test result (i.e., sample specificity) and the proportion of participants in the dyslexic group who received

a positive QuickScreen test result (i.e., sample sensitivity), based on this threshold, are shown in Table 7.

	QuickScreen Test Negative	QuickScreen Test Positive
Non-Dyslexic Group	87.2%	12.8%
Dyslexic Group	5.9%	94.1%

Table 7: Raw sample specificity (non-dyslexic group row) and sensitivity (dyslexic group row) values for the QuickScreen test negative and positive results, based on the threshold associated with maximising the sensitivity + specificity, for the full non-dyslexic group.

Eighty-seven-point-two percent of participants in the non-dyslexic group received a negative test result, and 94.1% of those in the dyslexic group received a positive test result.

Of those participants who received negative QuickScreen test outcome, the proportion who were in the non-dyslexic group (i.e., sample negative predictive value); and of those participants who received a positive QuickScreen test outcome, the proportion who were in the dyslexic group (i.e., sample positive predictive value), are shown in Table 8. Overall 90.1% ([82+64]/162) of the QuickScreen test results were correct according to the non-dyslexic/dyslexic groups. These are the raw sample predictive values and overall accuracy, based on the observed sample prevalence, and do not reflect estimates for a random sample of the population nor those self-selecting for a QuickScreen test.

	QuickScreen Test Negative	QuickScreen Test Positive
Non-Dyslexic Group	95.3%	15.8%
Dyslexic Group	4.7%	84.2%

Table 8: Raw sample predictive values (negative for the non-dyslexic group and positive for the dyslexic group) for the QuickScreen test negative and test positive outcomes, based on the threshold associated with maximising the sensitivity + specificity, for the full non-dyslexic group.

Ninety-five-point-three percent (95.3%) of those participants with a negative QuickScreen test result were in the non-dyslexic group, and 84.2% with a positive QuickScreen test result were in the dyslexic group.

The diagnostic accuracy measures, estimated using the adjusted method (with adjusted logit confidence intervals) and assuming a 10% prevalence of dyslexia, based on the threshold associated with maximising the sensitivity + specificity, are shown in Table 9.

QuickScreen Test Result	Diagnostic Measure	Estimate	95% Confidence Interval
Positive	Sensitivity	91.8%	(82.8%, 96.3%)
	PPV	41.7%	(30.5%, 53.9%)
Negative	Specificity	85.8%	(77.4%, 91.4%)
	NPV	98.9%	(97.7%, 99.5%)
Overall	Accuracy	86.4%	(79.9%, 91.8%)

Table 9: Estimates of the diagnostic accuracy measures using the adjusted logit method, based on the threshold associated with maximising the sensitivity + specificity, for the full non-dyslexic group (with 10% prevalence). PPV = Positive Predictive Value; NPV = Negative Predictive Value.

So, assuming an estimated prevalence of dyslexia in the population of 10%:

- The overall accuracy of the QuickScreen test (proportion of test results that are correct) is estimated to be 86.4%, with a 95% confidence interval [CI] expressing our uncertainty in this estimate of 79.9% to 91.8%).
- The sensitivity (proportion of those with dyslexia that test positive) of the Quickscreen test is estimated to be 91.8% (95% CI: 82.8% to 96.3%).
- The specificity (proportion of those without dyslexia that test negative) is estimated to be 85.8% (95% CI: 77.4% to 91.4%).
- The positive predictive value (proportion of those with a positive test that have dyslexia) is estimated to be 41.7% (95% CI: 30.5% to 53.9%)
- The negative predictive value (proportion of those with a negative test that don't have dyslexia) is estimated to be 98.9% (95% CI: 97.7% to 99.5%).

We note that, in screening situations, the prevalence is almost always small and the positive predictive value low, even for a fairly sensitive and specific test. This is reflected in the estimated positive predictive value of 41.7% here, which is impacted by the assumed prevalence of dyslexia in the population. We'll see in the subsequent results below, that for a higher assumed prevalence of dyslexia, the positive predictive value is higher.

The diagnostic accuracy measures, again estimated using the adjusted method (with adjusted logit confidence intervals) but assuming a 78.8% prevalence of dyslexia, based on the threshold associated with maximising the sensitivity + specificity, are shown in Table 10.

QuickScreen Test Result	Diagnostic Measure	Estimate	95% Confidence Interval
Positive	Sensitivity	91.8%	(82.8%, 96.3%)
	PPV	96.0%	(93.6%, 97.5%)
Negative	Specificity	85.8%	(77.4%, 91.4%)
	NPV	73.7%	(56.3%, 85.9%)
Overall	Accuracy	90.5%	(85.6%, 94.4%)

Table 10: Estimates of the diagnostic accuracy measures using the adjusted logit method, based on the threshold associated with maximising the sensitivity + specificity, for the full non-dyslexic group (with 78.8% prevalence). PPV = Positive Predictive Value; NPV = Negative Predictive Value.

The estimates of the sensitivity and specificity are unaffected by the change in assumed prevalence of dyslexia. However, based on this higher estimate of dyslexia for participants who have self-identified to take the test:

- The overall accuracy of the QuickScreen test (proportion of test results that are correct) is estimated to be 90.5% (95% CI: 85.6% to 94.4%).
- The positive predictive value (proportion of those with a positive test that have dyslexia) is estimated to be 96.0% (95% CI: 93.6% to 97.5%).
- The negative predictive value (proportion of those with a negative test that don't have dyslexia) is estimated to be 73.7% (95% CI: 56.3% to 85.9%).

We note that for this higher assumed prevalence the positive predictive value is estimated to be much higher at approximately 96%. However, the negative predictive value has correspondingly decreased to 73.7%.

True Control Group Only

The results of the subgroup analysis outlined in the Methods section for the "true control" non-dyslexic (versus dyslexic) group are presented below.

The ROC curve for the true control subgroup analysis is shown in Figure 4. The ROC curve AUC is estimated to be 96.97%, with 95% confidence interval from 94.04% to 99.9%. Given that the AUC of a perfect model would be 100%, this illustrates that the QuickScreen test has strong predictive capacity for dyslexia and may be useful when screening for dyslexia.

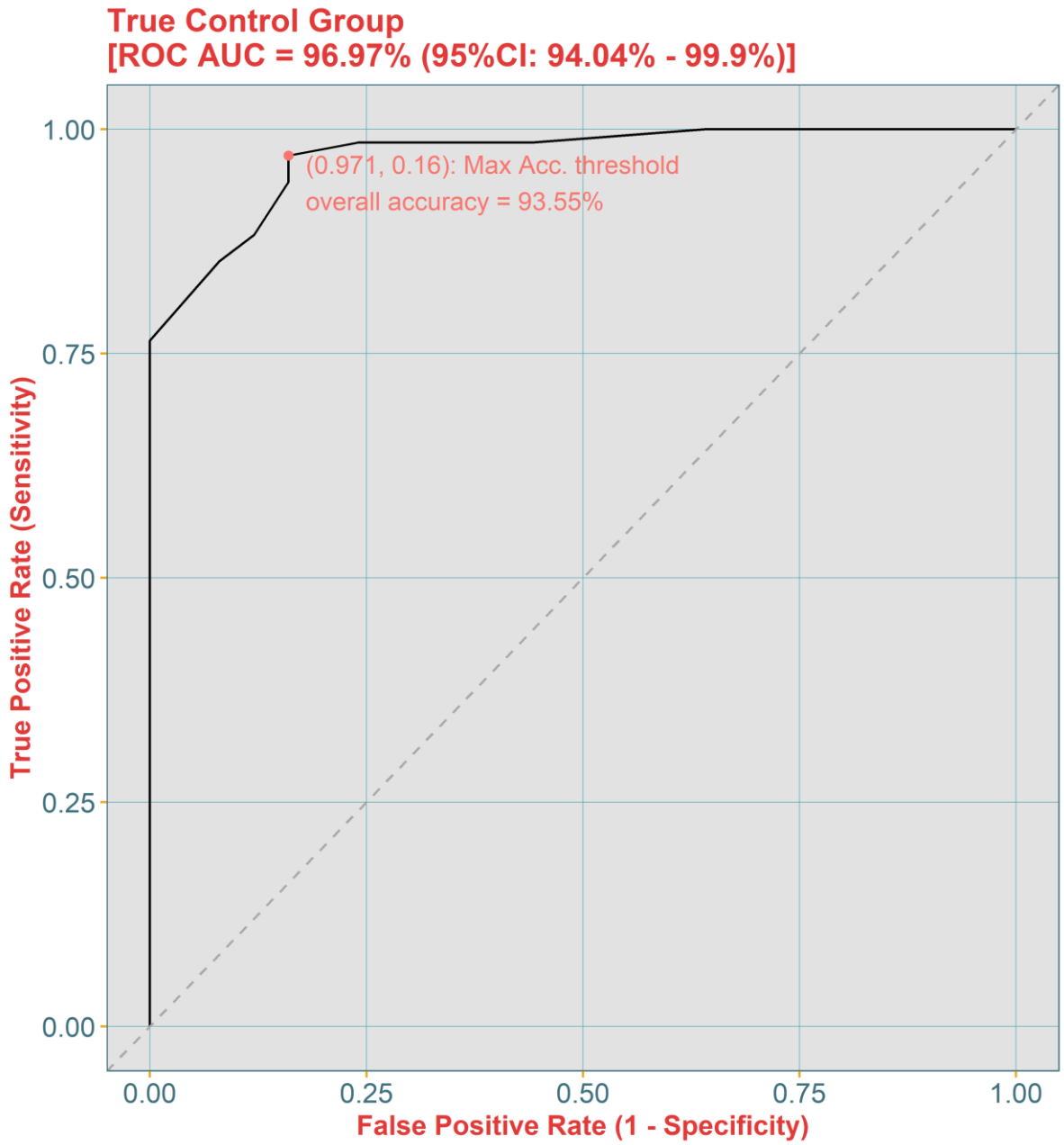

Figure 4: ROC Curve for the true control non-dyslexic versus dyslexic group, with point (TPR, FPR) showing the threshold associated with maximising the overall accuracy, which also corresponds with maximising the sensitivity + specificity.

Overall Accuracy and Sensitivity + Specificity Threshold

The dyslexia quotient cut-off associated with maximising the overall accuracy (red point on Figure 4), which was also found to maximise the sensitivity + specificity, was 2.75 (or equivalently a dyslexia percentile > 0.30). Therefore, to maximise the overall accuracy and sensitivity + specificity of the test, participants with a quotient greater than 2.75 should be considered test positive (indicated to have dyslexia) and those ≤ 2.75 test negative (indicated to not have dyslexia).

The distribution of the QuickScreen dyslexia quotient values observed in the true control non-dyslexic (previous diagnosis negative) and dyslexic (previous diagnosis positive) groups, along with this optimal threshold are visualised in Figure 5.

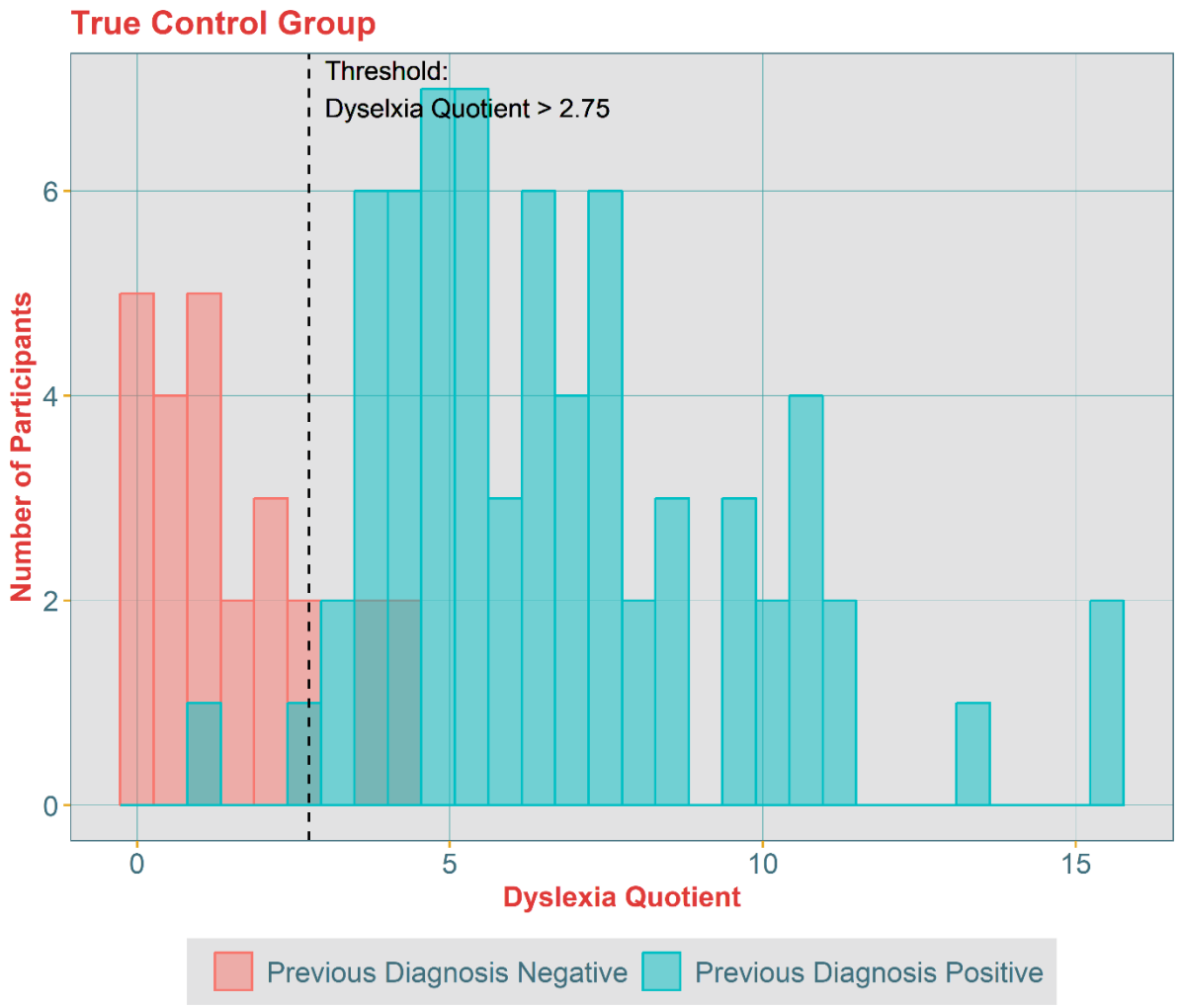

Figure 5: Histograms of the QuickScreen dyslexia quotients for the participants in the non-dyslexic (previous diagnosis negative) and dyslexic (previous diagnosis positive) groups, for the true control non-dyslexic group. The vertical, dashed line shows the dyslexia quotient threshold associated with maximising the overall accuracy and the sensitivity + specificity.

Applying this threshold, 23 (24.7%) of participants were test negative and 70 (75.3%) test positive, compared with 25 (26.9%) in the non-dyslexic group and 68 (73.1%) in the dyslexic group (as shown in the cross-tabulation in Table 11). A Fisher's exact test (on the data in Table 11) finds strong statistical evidence (p-value < 0.0001) of an association between the dyslexia group and the QuickScreen test result.

	QuickScreen Test Negative	QuickScreen Test Positive	Total
Non-Dyslexic Group	21	4	25 (26.9%)
Dyslexic Group	2	66	68 (73.1%)
Total	23 (24.7%)	70 (75.3%)	93 (100%)

Table 11: Cross-tabulation of the dyslexia group (non-dyslexics/dyslexics) versus the QuickScreen test result (negative/positive) based on the threshold associated with maximising the overall accuracy and sensitivity + specificity, for the true control non-dyslexic group.

The proportion of participants in the non-dyslexic group who received a negative QuickScreen test result (i.e., sample specificity) and the proportion of participants in the dyslexic group who received a positive QuickScreen test result (i.e., sample sensitivity), based on this threshold, are shown in Table 12.

	QuickScreen Test Negative	QuickScreen Test Positive
Non-Dyslexic Group	84.0%	16.0%
Dyslexic Group	2.9%	97.1%

Table 12: Raw sample specificity (non-dyslexic group row) and sensitivity (dyslexic group row) values for the QuickScreen test negative and positive results, based on the threshold associated with maximising the overall accuracy and sensitivity + specificity, for the true control non-dyslexic group.

Eighty-four percent (84.0%) of participants in the non-dyslexic group received a negative test result, and 97.1% of those in the dyslexic group received a positive test result.

Of those participants who received negative QuickScreen test outcome, the proportion who were in the non-dyslexic group (i.e., sample negative predictive value); and of those participants who received a positive QuickScreen test outcome, the proportion who were in the dyslexic group (i.e., sample positive predictive value), are shown in Table 13. Overall 93.5% ([21+66]/93) of the QuickScreen test results were correct according to the non-dyslexic/dyslexic groups. These are the raw sample predictive values and overall accuracy, based on the observed sample prevalence, and do not reflect estimates for a random sample of the population nor those self-selecting for a QuickScreen test.

	QuickScreen Test Negative	QuickScreen Test Positive
Non-Dyslexic Group	91.3%	5.7%
Dyslexic Group	8.7%	94.3%

Table 13: Raw sample predictive values (negative for the non-dyslexic group and positive for the dyslexic group) for the QuickScreen test negative and test positive outcomes, based on the threshold associated with maximising the overall accuracy, for the true control non-dyslexic group.

Ninety-one-point-three percent (91.3%) of those participants with a negative QuickScreen test result were in the non-dyslexic group, and 94.3% with a positive QuickScreen test result were in the dyslexic group.

The diagnostic accuracy measures, estimated using the adjusted method (with adjusted logit confidence intervals) and assuming a 10% prevalence of dyslexia, based on the threshold associated with maximising the overall accuracy and sensitivity + specificity, are shown in Table 14.

QuickScreen Test Result	Diagnostic Measure	Estimate	95% Confidence Interval
Positive	Sensitivity	94.5%	(86.2%, 98.0%)
	PPV	33.8%	(19.9%, 51.3%)
Negative	Specificity	79.5%	(61.1%, 90.5%)
	NPV	99.2%	(98.0%, 99.7%)
Overall	Accuracy	81.0%	(68.4%, 91.1%)

Table 14: Estimates of the diagnostic accuracy measures using the adjusted logit method, based on the threshold associated with maximising the overall accuracy and sensitivity + specificity, for the true control non-dyslexic group (with 10% prevalence). PPV = Positive Predictive Value; NPV = Negative Predictive Value.

So, assuming an estimated prevalence of dyslexia in the population of 10%:

- The overall accuracy of the QuickScreen test (proportion of test results that are correct) is estimated to be 81.0%, with a 95% confidence interval [CI] expressing our uncertainty in this estimate of 68.4% to 91.1%).
- The sensitivity (proportion of those with dyslexia that test positive) of the Quickscreen test is estimated to be 94.5% (95% CI: 86.2% to 98.0%).
- The specificity (proportion of those without dyslexia that test negative) is estimated to be 79.5% (95% CI: 61.1% to 90.5%).
- The positive predictive value (proportion of those with a positive test that have dyslexia) is estimated to be 33.8% (95% CI: 19.9% to 51.3%).
- The negative predictive value (proportion of those with a negative test that don't have dyslexia) is estimated to be 99.2% (95% CI: 98.0% to 99.7%).

We note that, in screening situations, the prevalence is almost always small and the positive predictive value low, even for a fairly sensitive and specific test. This is reflected in the estimated positive predictive value of 33.8% here, which is impacted by the assumed prevalence of dyslexia in the population. We'll see in the subsequent results below, that for a higher assumed prevalence of dyslexia, the positive predictive value is higher.

The diagnostic accuracy measures, again estimated using the adjusted method (with adjusted logit confidence intervals) but assuming a 78.8% prevalence of dyslexia, based on the threshold associated with maximising the overall accuracy and sensitivity + specificity, are shown in Table 15.

QuickScreen Test Result	Diagnostic Measure	Estimate	95% Confidence Interval
Positive	Sensitivity	94.5%	(86.2%, 98.0%)
	PPV	94.5%	(89.3%, 97.2%)
Negative	Specificity	79.5%	(61.1%, 90.5%)
	NPV	79.7%	(59.5%, 91.3%)
Overall	Accuracy	91.3%	(86.9%, 94.9%)

Table 15: Estimates of the diagnostic accuracy measures using the adjusted logit method, based on the threshold associated with maximising the overall accuracy and sensitivity + specificity, for the true control non-dyslexic group (with 78.8% prevalence). PPV = Positive Predictive Value; NPV = Negative Predictive Value.

The estimates of the sensitivity and specificity are unaffected by the change in assumed prevalence of dyslexia. However, based on this higher estimate of dyslexia for participants who have self-identified to take the test:

- The overall accuracy of the QuickScreen test (proportion of test results that are correct) is estimated to be 91.3% (95% CI: 86.9% to 94.9%).
- The positive predictive value (proportion of those with a positive test that have dyslexia) is estimated to be 94.5% (95% CI: 89.3% to 97.2%).
- The negative predictive value (proportion of those with a negative test that don't have dyslexia) is estimated to be 79.7% (95% CI: 59.5% to 91.3%).

We note that for this higher assumed prevalence the positive predictive value is estimated to be much higher at over 94%. However, the negative predictive value has correspondingly decreased to 79.7%.

At Risk Group

The results of the exploratory analysis noted in the Methods section for the "at risk" group are presented below. In this analysis, we repeated the steps carried out to analyse the diagnostic accuracy measures for the full non-dyslexic versus dyslexic group analysis presented above, but including the "at risk" group as dyslexics.

As shown in the histograms in Figure 6, the dyslexia quotients for the "at risk" group have a somewhat similar distribution to those in the positive previous dyslexia diagnosis group, though with slightly more overlap with the non-dyslexic (previous diagnosis negative) group. This is perhaps not surprising as these "at risk" participants do not have a previous positive dyslexia diagnosis, but have self-identified as having difficulties with their learning.

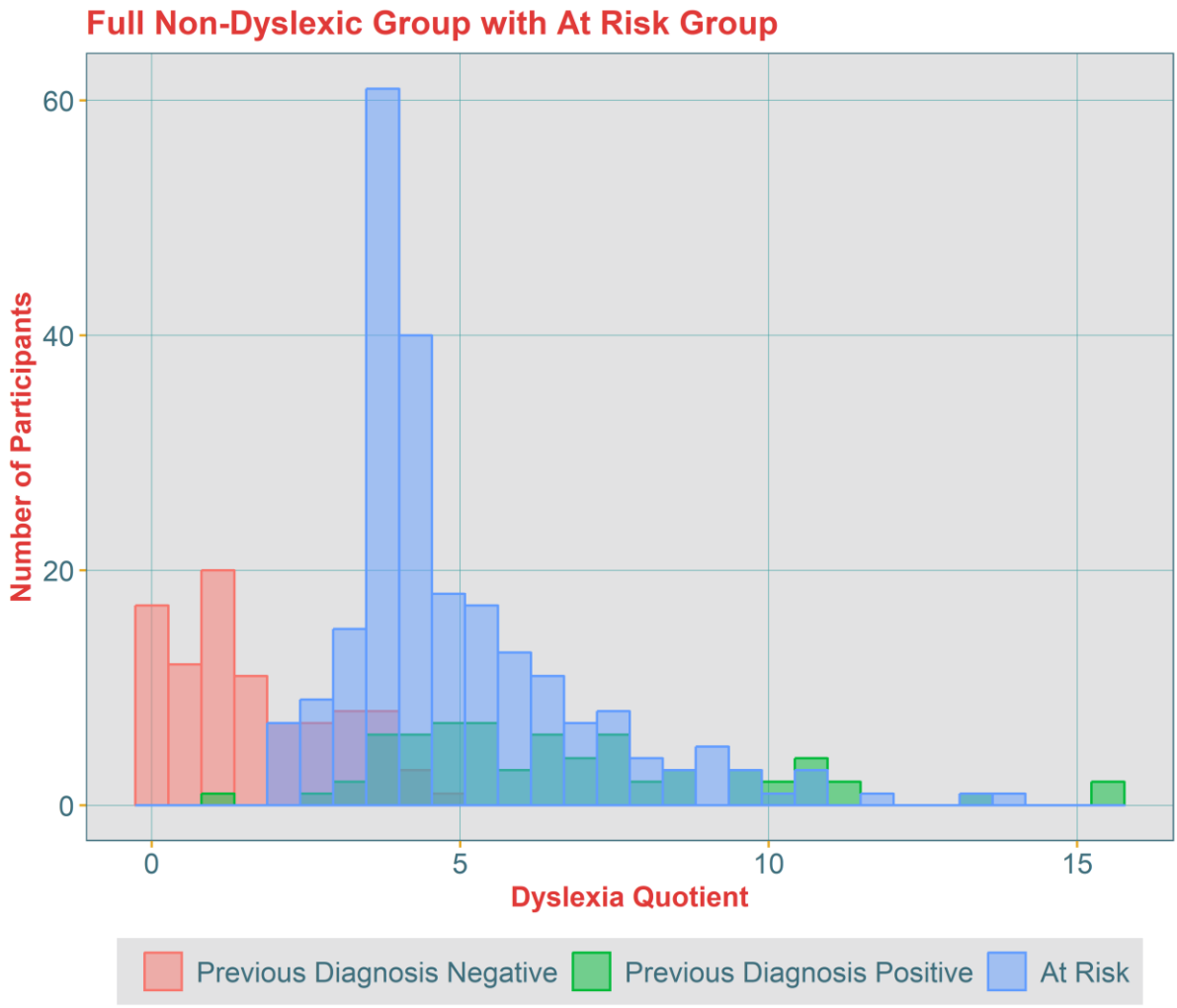

Figure 6: Histograms of the QuickScreen dyslexia quotients for the participants in the non-dyslexic (previous diagnosis negative), dyslexic (previous diagnosis positive) and "at risk" groups, for the full non-dyslexic group including "at risk" participants. The vertical, dashed line shows the dyslexia quotient threshold associated with maximising the overall accuracy.

Ultimately, these additional data boost the sample size available for analysis, but we find that the diagnostic accuracy measures are not dramatically different if these are included. For completeness, the results including these additional "at risk" data are presented below.

The ROC curve for the full non-dyslexic group analysis including the "at risk" group is shown in Figure 7. The ROC curve AUC is estimated to be 94.77%, with 95% confidence interval from 92.36% to 97.19%. Given that the AUC of a perfect model would be 100%, this illustrates that the QuickScreen test has strong predictive capacity for dyslexia and may be useful when screening for dyslexia.

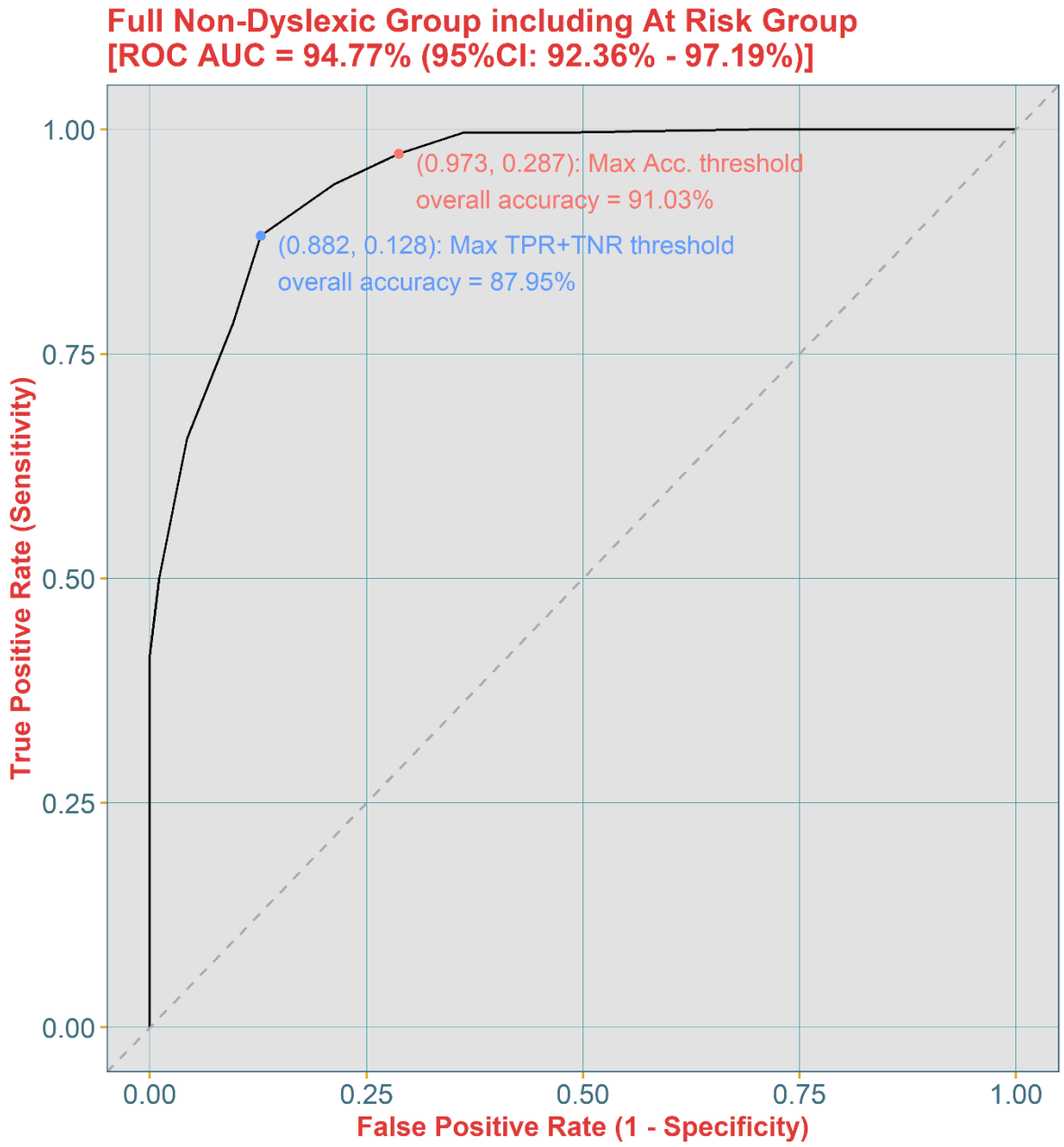

Figure 7: ROC Curve for the full non-dyslexic versus dyslexic group including the "at risk" participants, with points (TPR, FPR) showing the thresholds associated with maximising the sensitivity + specificity (in blue) and maximising the overall accuracy (in red).

Overall Accuracy Threshold

The dyslexia quotient cut-off associated with maximising the overall accuracy (red point on Figure 7) was 2.25 (or equivalently a dyslexia percentile > 0.27). Therefore, to maximise the overall accuracy of the test, participants with a quotient greater than 2.25 should be considered test positive (indicated to have dyslexia) and those ≤ 2.25 test negative (indicated to not have dyslexia).

The distribution of the QuickScreen dyslexia quotient values observed in the non-dyslexic (previous diagnosis negative) and dyslexic (previous diagnosis positive and "at risk") groups, along with this optimal threshold are visualised in Figure 8.

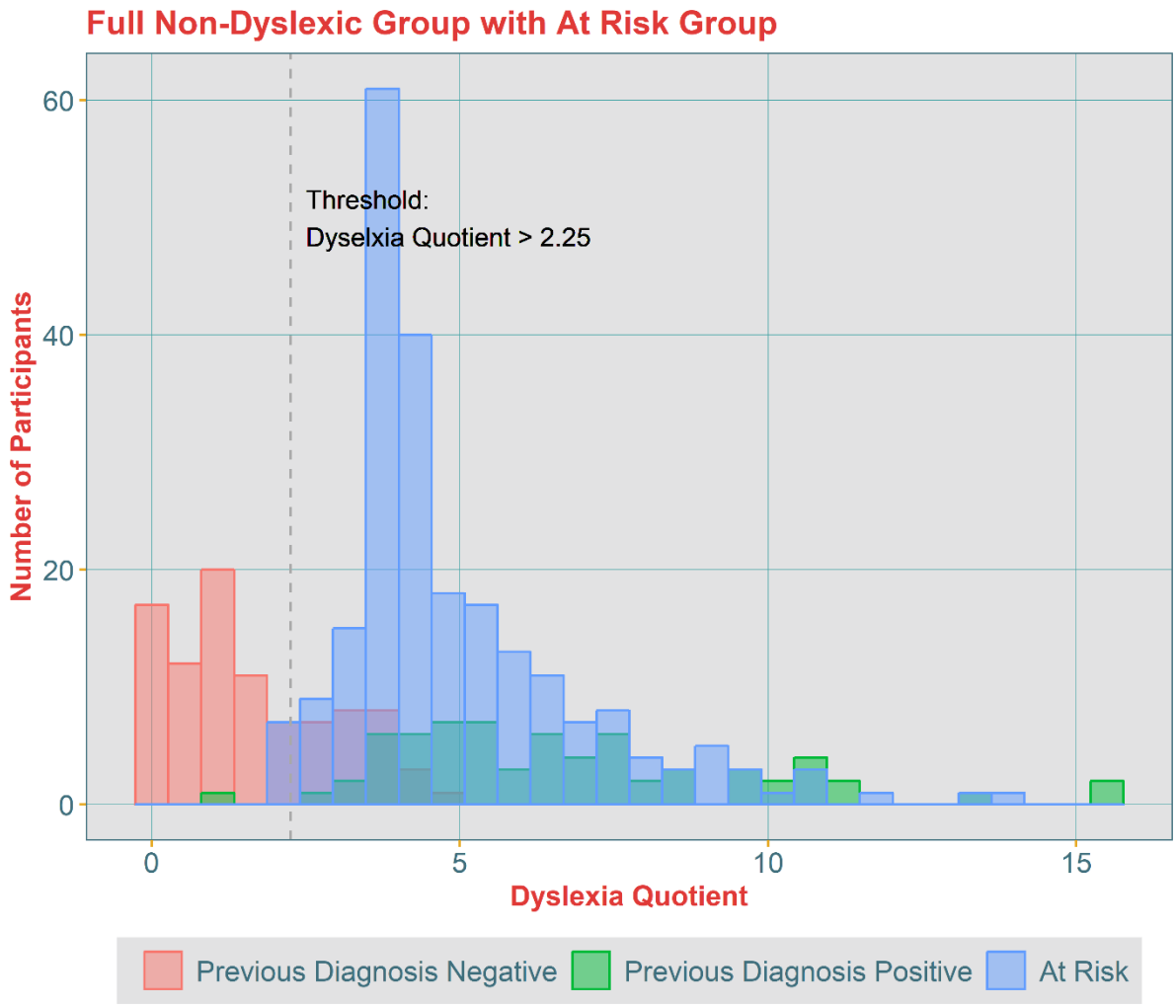

Figure 8: Histograms of the QuickScreen dyslexia quotients for the participants in the non-dyslexic (previous diagnosis negative) and dyslexic (previous diagnosis positive and "at risk") groups, for the full non-dyslexic group including "at risk" participants. The vertical, dashed line shows the dyslexia quotient threshold associated with maximising the overall accuracy.

Applying this threshold, 75 (19.2%) of participants were test negative and 315 (80.8%) test positive, compared with 94 (24.1%) in the non-dyslexic group and 296 (75.9%) in the dyslexic group, including "at risk" participants (as shown in the cross-tabulation in Table 16). A Fisher's exact test (on the data in Table 16) finds strong statistical evidence (p-value < 0.0001) of an association between the dyslexia group and the QuickScreen test result.

	QuickScreen Test Negative	QuickScreen Test Positive	Total
Non-Dyslexic Group	67	27	94 (24.1%)
Dyslexic Group	8	288	296 (75.9%)
Total	75 (19.2%)	315 (80.8%)	390 (100%)

Table 16: Cross-tabulation of the dyslexia group (non-dyslexics/dyslexics) versus the QuickScreen test result (negative/positive) based on the threshold associated with maximising the overall accuracy, for the full non-dyslexic group including "at risk" participantss.

The proportion of participants in the non-dyslexic group who received a negative QuickScreen test result (i.e., sample specificity) and the proportion of participants in the dyslexic group who received a positive QuickScreen test result (i.e., sample sensitivity), based on this threshold, are shown in Table 17.

	QuickScreen Test Negative	QuickScreen Test Positive
Non-Dyslexic Group	71.3%	28.7%
Dyslexic Group	2.7%	97.3%

Table 17: Raw sample specificity (non-dyslexic group row) and sensitivity (dyslexic group row) values for the QuickScreen test negative and positive results, based on the threshold associated with maximising the overall accuracy, for the full non-dyslexic group including "at risk" participants.

Seventy-one-point-three percent (71.3%) of participants in the non-dyslexic group received a negative test result, and 97.3% of those in the dyslexic group received a positive test result.

Of those participants who received negative QuickScreen test outcome, the proportion who were in the non-dyslexic group (i.e., sample negative predictive value); and of those participants who received a positive QuickScreen test outcome, the proportion who were in the dyslexic group (i.e., sample positive predictive value), are shown in Table 18. Overall 91.0% ([67+288]/390) of the QuickScreen test results were correct according to the non-dyslexic/dyslexic groups. These are the raw sample predictive values and overall accuracy, based on the observed sample prevalence, and do not reflect estimates for a random sample of the population nor those self-selecting for a QuickScreen test.

	QuickScreen Test Negative	QuickScreen Test Positive
Non-Dyslexic Group	89.3%	8.6%
Dyslexic Group	10.7%	91.4%

Table 18: Raw sample predictive values (negative for the non-dyslexic group and positive for the dyslexic group) for the QuickScreen test negative and test positive outcomes, based on the threshold associated with maximising the overall accuracy, for the full non-dyslexic group including "at risk" participants.

Eighty-nine-point-three percent (89.3%) of those participants with a negative QuickScreen test result were in the non-dyslexic group, and 91.4% with a positive QuickScreen test result were in the dyslexic group.

The diagnostic accuracy measures, estimated using the adjusted method (with adjusted logit confidence intervals) and assuming a 10% prevalence of dyslexia, based on the threshold associated with maximising the overall accuracy, are shown in Table 19.

QuickScreen Test Result	Diagnostic Measure	Estimate	95% Confidence Interval
Positive	Sensitivity	96.7%	(93.9%, 98.2%)
	PPV	26.7%	(21.1%, 33.1%)
Negative	Specificity	70.4%	(60.7%, 78.6%)
	NPV	99.5%	(99.0%, 99.7%)
Overall	Accuracy	73.1%	(65.0%, 80.7%)

Table 19: Estimates of the diagnostic accuracy measures using the adjusted logit method, based on the threshold associated with maximising the overall accuracy, for the full non-dyslexic group including "at risk" participants (with 10% prevalence). PPV = Positive Predictive Value; NPV = Negative Predictive Value.

So, assuming an estimated prevalence of dyslexia in the population of 10%:

- The overall accuracy of the QuickScreen test (proportion of test results that are correct) is estimated to be 73.1%, with a 95% CI of 65.0% to 80.7%.
- The sensitivity (proportion of those with dyslexia that test positive) of the Quickscreen test is estimated to be 96.7% (95% CI: 93.9% to 98.2%).
- The specificity (proportion of those without dyslexia that test negative) is estimated to be 70.4% (95% CI: 60.7% to 78.6%).
- The positive predictive value (proportion of those with a positive test that have dyslexia) is estimated to be 26.7% (95% CI: 21.1% to 33.1%).
- The negative predictive value (proportion of those with a negative test that don't have dyslexia) is estimated to be 99.5% (95% CI: 99.0% to 99.7%).

We note that, in screening situations, the prevalence is almost always small and the positive predictive value low, even for a fairly sensitive and specific test. This is reflected in the estimated positive predictive value of 26.7% here, which is impacted by the assumed prevalence of dyslexia in the population. We'll see in the subsequent results below, that for a higher assumed prevalence of dyslexia, the positive predictive value is higher.

The diagnostic accuracy measures, again estimated using the adjusted method (with adjusted logit confidence intervals) but assuming a 78.8% prevalence of dyslexia, based on the threshold associated with maximising the overall accuracy, are shown in Table 20.

QuickScreen Test Result	Diagnostic Measure	Estimate	95% Confidence Interval
Positive	Sensitivity	96.7%	(93.9%, 98.2%)
	PPV	92.4%	(89.9%, 94.3%)
Negative	Specificity	70.4%	(60.7%, 78.6%)
	NPV	85.1%	(75.4%, 91.5%)
Overall	Accuracy	91.1%	(88.7%, 93.4%)

Table 20: Estimates of the diagnostic accuracy measures using the adjusted logit method, based on the threshold associated with maximising the overall accuracy, for the full non-dyslexic group including "at risk" participants (with 78.8% prevalence). PPV = Positive Predictive Value; NPV = Negative Predictive Value.

The estimates of the sensitivity and specificity are unaffected by the change in assumed prevalence of dyslexia. However, based on this higher estimate of dyslexia for participants who have self-identified to take the test:

- The overall accuracy of the QuickScreen test (proportion of test results that are correct) is estimated to be 91.1% (95% CI: 88.7% to 93.4%).
- The positive predictive value (proportion of those with a positive test that have dyslexia) is estimated to be 92.4% (95% CI: 89.9% to 94.3%).
- The negative predictive value (proportion of those with a negative test that don't have dyslexia) is estimated to be 85.1% (95% CI: 75.4% to 91.5%).

We note that for this higher assumed prevalence the positive predictive value is estimated to be much higher at over 92%. However, the negative predictive value has correspondingly decreased to 85.1%.

Sensitivity + Specificity Threshold

Alternatively, choosing the threshold that maximises the sensitivity + specificity, rather than the overall accuracy, the dyslexia quotient cut-off (blue point on Figure 7) was 3.25 (or equivalently a dyslexia percentile > 0.34). Therefore, to maximise the sensitivity + specificity of the test, participants with a quotient greater than 3.25 should be considered test positive (indicated to have dyslexia) and those ≤ 3.25 test negative (indicated to not have dyslexia).

The distribution of the QuickScreen dyslexia quotient values observed in the non-dyslexic (previous diagnosis negative), dyslexic (previous diagnosis positive) and "at risk" groups, along with this optimal threshold are visualised in Figure 9.

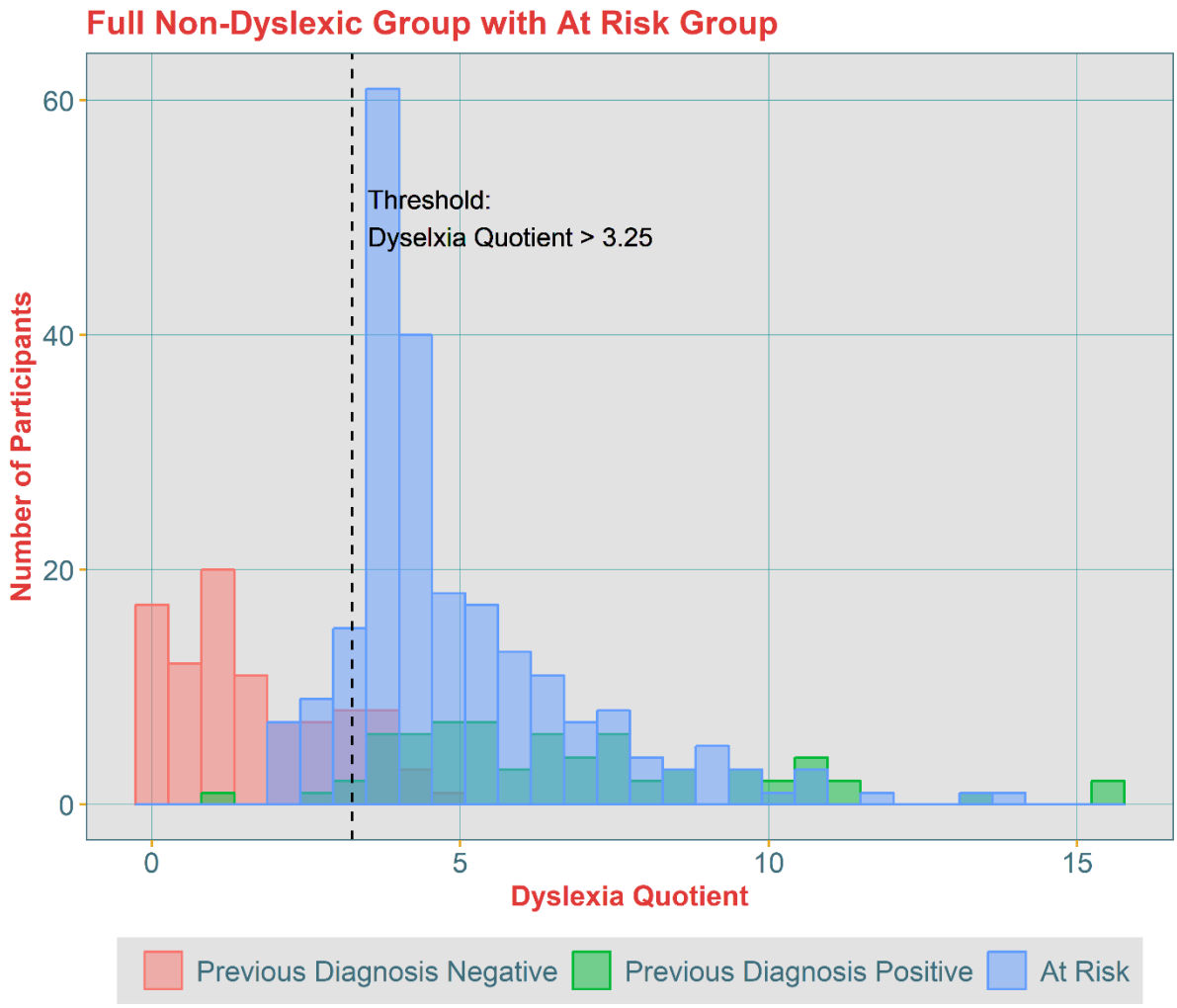

Figure 9: Histograms of the QuickScreen dyslexia quotients for the participants in the non-dyslexic (previous diagnosis negative), dyslexic (previous diagnosis positive) and "at risk" groups, for the full non-dyslexic group including "at risk" participants. The vertical, dashed line shows the dyslexia quotient threshold associated with maximising the sensitivity + specificity.

Applying this threshold, 117 (30.0%) of participants were test negative and 273 (70.0%) test positive, compared with 94 (24.1%) in the non-dyslexic group and 296 (75.9%) in the dyslexic group (as shown in the cross-tabulation in Table 21). A Fisher's exact test (on the data in Table 21) finds strong statistical evidence (p-value < 0.0001) of an association between the dyslexia group and the QuickScreen test result.

	QuickScreen Test Negative	QuickScreen Test Positive	Total
Non-Dyslexic Group	82	12	94 (24.1%)
Dyslexic Group	35	261	296 (75.9%)
Total	117 (30.0%)	273 (70.0%)	390 (100%)

Table 21: Cross-tabulation of the dyslexia group (non-dyslexics/dyslexics) versus the QuickScreen test result (negative/positive) based on the threshold associated with maximising the sensitivity + specificity, for the full non-dyslexic group including "at risk" participants.

The proportion of participants in the non-dyslexic group who received a negative QuickScreen test result (i.e., sample specificity) and the proportion of participants in the dyslexic group who received

a positive QuickScreen test result (i.e., sample sensitivity), based on this threshold, are shown in Table 22.

	QuickScreen Test Negative	QuickScreen Test Positive
Non-Dyslexic Group	87.2%	12.8%
Dyslexic Group	11.8%	88.2%

Table 22: Raw sample specificity (non-dyslexic group row) and sensitivity (dyslexic group row) values for the QuickScreen test negative and positive results, based on the threshold associated with maximising the sensitivity + specificity, for the full non-dyslexic group including "at risk" participants.

Eighty-seven-point-two percent (87.2%) of participants in the non-dyslexic group received a negative test result, and 88.2% of those in the dyslexic group received a positive test result.

Of those participants who received negative QuickScreen test outcome, the proportion who were in the non-dyslexic group (i.e., sample negative predictive value); and of those participants who received a positive QuickScreen test outcome, the proportion who were in the dyslexic group (i.e., sample positive predictive value), are shown in Table 23. Overall 87.9% ([82+261]/390) of the QuickScreen test results were correct according to the non-dyslexic/dyslexic groups. These are the raw sample predictive values and overall accuracy, based on the observed sample prevalence, and do not reflect estimates for a random sample of the population nor those self-selecting for a QuickScreen test.

	QuickScreen Test Negative	QuickScreen Test Positive
Non-Dyslexic Group	70.1%	4.4%
Dyslexic Group	29.9%	95.6%

Table 23: Raw sample predictive values (negative for the non-dyslexic group and positive for the dyslexic group) for the QuickScreen test negative and test positive outcomes, based on the threshold associated with maximising the sensitivity + specificity, for the full non-dyslexic group including "at risk" participants.

Seventy-point-one percent (70.1%) of those participants with a negative QuickScreen test result were in the non-dyslexic group, and 95.6% with a positive QuickScreen test result were in the dyslexic group.

The diagnostic accuracy measures, estimated using the adjusted method (with adjusted logit confidence intervals) and assuming a 10% prevalence of dyslexia, based on the threshold associated with maximising the sensitivity + specificity, are shown in Table 24.

QuickScreen Test Result	Diagnostic Measure	Estimate	95% Confidence Interval
Positive	Sensitivity	87.7%	(83.5%, 91.0%)
	PPV	40.6%	(29.6%, 52.7%)
Negative	Specificity	85.8%	(77.4%, 91.4%)
	NPV	98.4%	(97.9%, 98.8%)
Overall	Accuracy	86.0%	(79.7%, 91.5%)

Table 24: Estimates of the diagnostic accuracy measures using the adjusted logit method, based on the threshold associated with maximising the sensitivity + specificity, for the full non-dyslexic group including "at risk" participants (with 10% prevalence). PPV = Positive Predictive Value; NPV = Negative Predictive Value.

So, assuming an estimated prevalence of dyslexia in the population of 10%:

- The overall accuracy of the QuickScreen test (proportion of test results that are correct) is estimated to be 86.0%, with a 95% CI of 79.7% to 91.5%).
- The sensitivity (proportion of those with dyslexia that test positive) of the Quickscreen test is estimated to be 87.7% (95% CI: 83.5% to 91.0%).
- The specificity (proportion of those without dyslexia that test negative) is estimated to be 85.8% (95% CI: 77.4% to 91.4%).
- The positive predictive value (proportion of those with a positive test that have dyslexia) is estimated to be 40.6% (95% CI: 29.6% to 52.7%).
- The negative predictive value (proportion of those with a negative test that don't have dyslexia) is estimated to be 98.4% (95% CI: 97.9% to 98.8%).

We note that, in screening situations, the prevalence is almost always small and the positive predictive value low, even for a fairly sensitive and specific test. This is reflected in the estimated positive predictive value of 40.6% here, which is impacted by the assumed prevalence of dyslexia in the population. We'll see in the subsequent results below, that for a higher assumed prevalence of dyslexia, the positive predictive value is higher.

The diagnostic accuracy measures, again estimated using the adjusted method (with adjusted logit confidence intervals) but assuming a 78.8% prevalence of dyslexia, based on the threshold associated with maximising the sensitivity + specificity, are shown in Table 25.

QuickScreen Test Result	Diagnostic Measure	Estimate	95% Confidence Interval
Positive	Sensitivity	87.7%	(83.5%, 91.0%)
	PPV	95.8%	(93.4%, 97.4%)
Negative	Specificity	85.8%	(77.4%, 91.4%)
	NPV	65.2%	(57.8%, 71.9%)
Overall	Accuracy	87.3%	(84.0%, 90.3%)

Table 25: Estimates of the diagnostic accuracy measures using the adjusted logit method, based on the threshold associated with maximising the sensitivity + specificity, for the full non-dyslexic group including "at risk" participants (with 78.8% prevalence). PPV = Positive Predictive Value; NPV = Negative Predictive Value.

The estimates of the sensitivity and specificity are unaffected by the change in assumed prevalence of dyslexia. However, based on this higher estimate of dyslexia for participants who have self-identified to take the test:

- The overall accuracy of the QuickScreen test (proportion of test results that are correct) is estimated to be 87.3% (95% CI: 84.0% to 90.3%).
- The positive predictive value (proportion of those with a positive test that have dyslexia) is estimated to be 95.8% (95% CI: 93.4% to 97.4%).
- The negative predictive value (proportion of those with a negative test that don't have dyslexia) is estimated to be 65.2% (95% CI: 57.8% to 71.9%).

We note that for this higher assumed prevalence the positive predictive value is estimated to be much higher at approximately 96%. However, the negative predictive value has correspondingly decreased to 65.2%.

General Speed of Processing

Another area of potential further research, highlighted by Dr Dee Walker, was to explore how the QuickScreen general speed of processing results vary between non-dyslexic/dyslexics participants. We conducted this analysis with the main dataset corresponding with the primary analysis, including the full non-dyslexic group.

Table 26 below shows a cross-tabulation of the non-dyslexic/dyslexic group versus the general speed of processing results available from the QuickScreen test data.

	No Difficulties	Average	Difficulties	Total
Non-Dyslexic Group	33	47	14	94 (58.0%)
Dyslexic Group	6	33	29	68 (42.0%)
Total	39 (24.1%)	80 (49.4%)	43 (26.5%)	162 (100%)

Table 26: Cross-tabulation of the non-dyslexic/dyslexic group versus the QuickScreen general speed of processing result (No Difficulties/Average/Difficulties) for the full non-dyslexic group.

A Fisher's exact test (on the data in Table 26) finds strong statistical evidence (p-value < 0.0001) of an association between the dyslexia group and the QuickScreen test result.

We observe that of those 94 participants in the non-dyslexic group 33 (35.1%), 47 (50.0%) and 14 (14.9%) have No Difficulties, Average and Difficulties general speed of processing results, respectively. Whereas of those 68 with a positive previous dyslexia diagnosis 6 (8.8%), 33 (48.5%) and 29 (42.6%) have No Difficulties, Average and Difficulties general speed of processing results, respectively. So, 35.1% of those without a previous diagnosis have no speed of processing difficulties compared with 8.8% for those with a previous diagnosis; and 42.6% of those with a previous diagnosis have difficulties, compared with 14.9% without a previous diagnosis (as show in Table 27).

	No Difficulties	Average	Difficulties
Non-Dyslexic Group	35.1%	50.0%	14.9%
Dyslexic Group	8.8%	48.5%	42.6%

Table 27: Raw sample specificity (non-dyslexic group row) and sensitivity (dyslexic group row) values for the QuickScreen general speed of processing results, for the full non-dyslexic group.

Conversely, of those with no speed of processing difficulties 84.6% were in the non-dyslexic group, whereas of those with difficulties 67.4% were in the dyslexic group (as shown in Table 28).

	No Difficulties	Average	Difficulties
Non-Dyslexic Group	84.6%	58.8%	32.6%
Dyslexic Group	15.4%	41.2%	67.4%

Table 28: Raw sample predictive values (negative for the non-dyslexic group and positive for the dyslexic group) for the QuickScreen general speed of processing results, for the full non-dyslexic group.

Furthermore, rather than using the categorical general speed of processing result, the numerical score for general speed of processing is also associated with the non-dyslexic/dyslexic grouping. There is strong statistical evidence of a higher average general speed of processing score being associated with the non-dyslexic subjects compared to those with dyslexia (non-dyslexic mean=13.20 and median=14 versus dyslexic mean=10.06 and median=11; $p<0.0001$) as shown in Table 29.

General Speed of Processing Score	Minimum	Lower Quartile (Q1)	Median	Mean	Upper Quartile (Q3)	Maximum
Non-Dyslexic Group	4	11	14	13.20	15	19
Dyslexic Group	1	8	11	10.06	13	17

Table 29: Summary statistics for the general speed of processing scores for the non-dyslexic/dyslexic groups, for the full non-dyslexic group.

These results are also visualised in Figure 10, showing the distribution of the general speed of processing scores for the non-dyslexics and dyslexics.

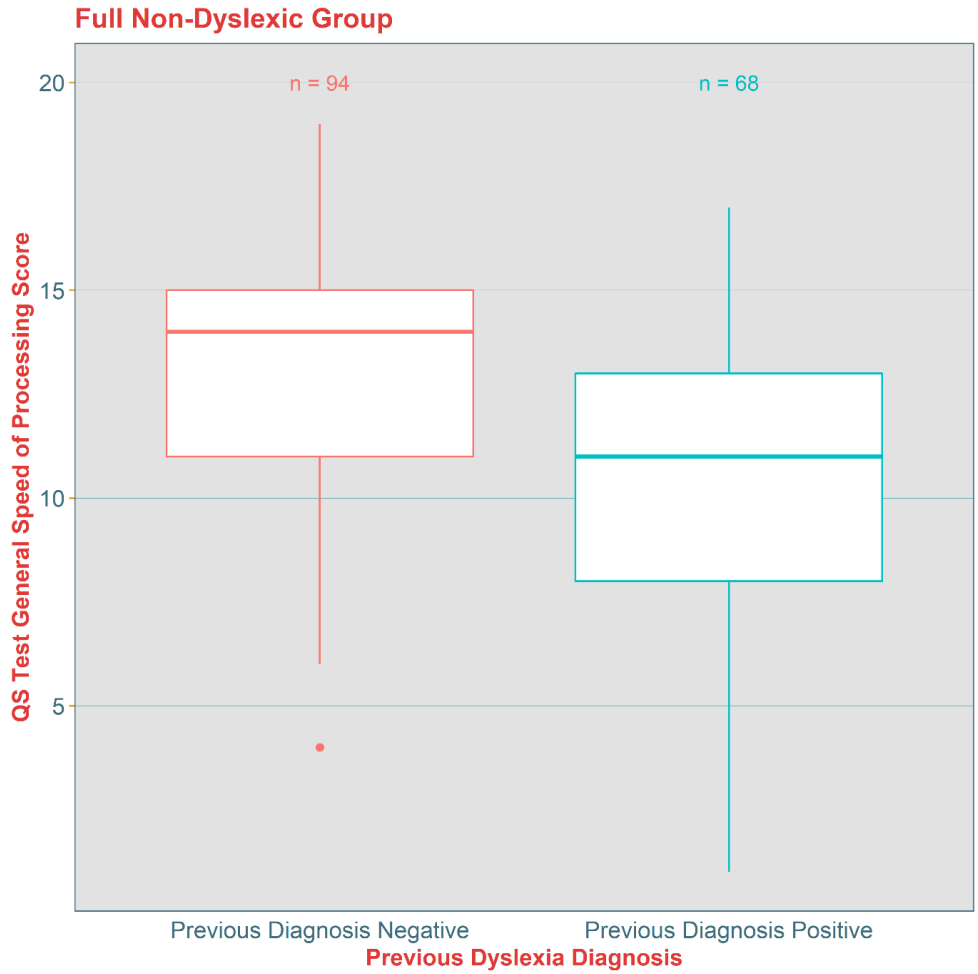

Figure 10: Boxplots of the general speed of processing scores by non-dyslexic/dyslexic group, for the full non-dyslexic group. (The bold horizontal line shows the median value, the box shows the middle 50% of the data, the top of the box shows the upper quartile [75th percentile] and the bottom of the box the lower quartile [25th percentile], the lines extend to the largest and smallest observed values that are no further than 1.5xIQR [interquartile range] from the upper and lower quartiles.)

Exploring the speed of processing results in some more detail, analysing how these relate with the dyslexia quotient minus the processing speed disparity component, we find clear evidence of an association. As shown in the scatterplot in Figure 11, for both those with and without a previous dyslexia diagnosis, the participants with a worse speed of processing score tend to have a higher dyslexia quotient (having removed the specific speed of processing component from the quotient itself) – in each case we find evidence of negative correlation that is statistically significantly different from zero ($p<0.0001$ in the dyslexic group; $p=0.0003$ in the non-dyslexic group).

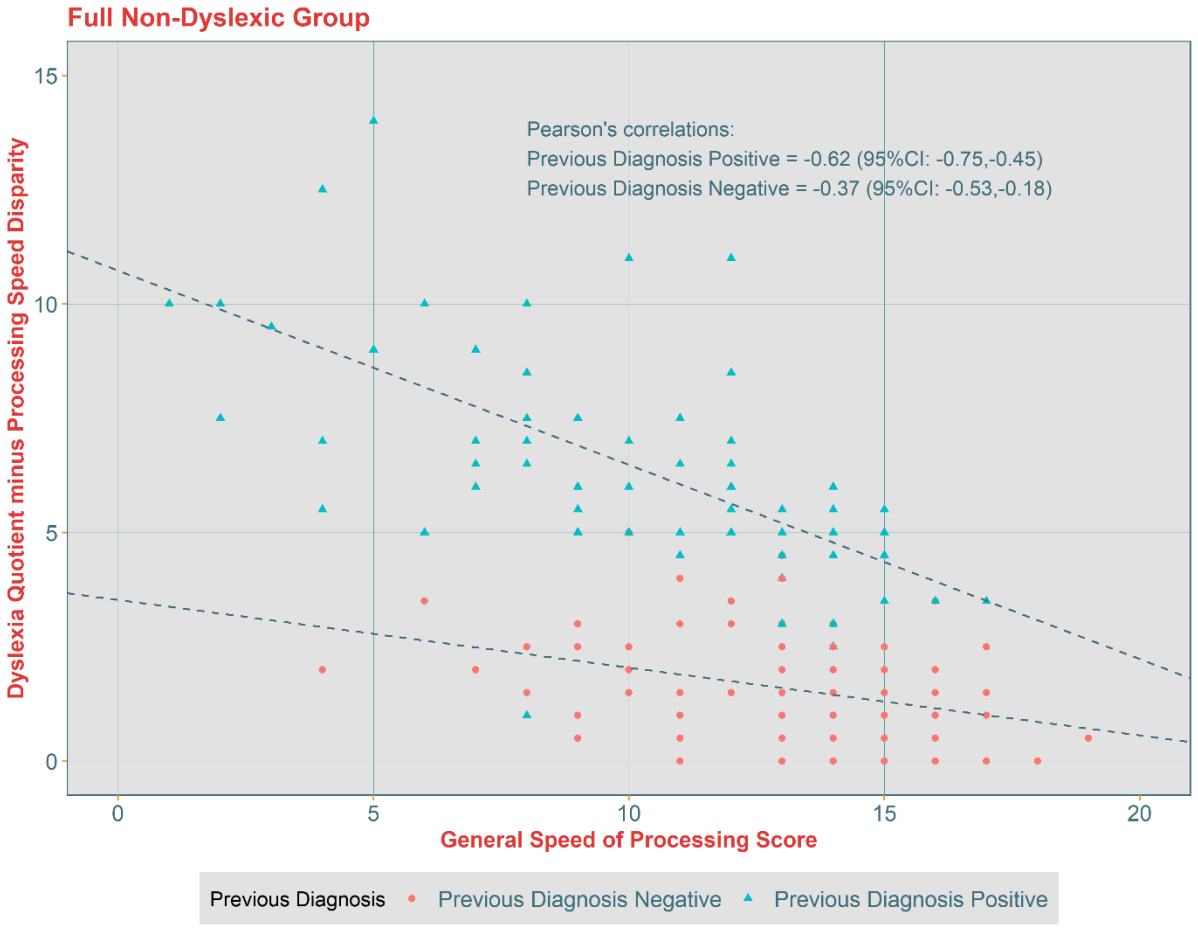

Figure 11: Scatterplot of the dyslexia quotient minus processing speed disparity versus general speed of processing score, for the full non-dyslexic group, with fitted simple regression lines.

We also find evidence of a difference in the average dyslexia quotient minus processing speed disparity across the grouped general speed of processing results (No Difficulties, Average, Difficulties), overall and by non-dyslexic/dyslexic group. A higher quotient was observed on average for those with difficulties, followed by the average group, and then those with no difficulties (overall $p<0.0001$; dyslexic group $p<0.001$; non-dyslexic group $p=0.0195$). Summary statistics for the dyslexia quotient minus processing speed disparity values by the dyslexic/non-dyslexic group and general speed of processing result are shown in Table 30. For example, overall, the median value for those with no processing speed difficulties was 1.5 compared with 6 for those with difficulties.

Dyslexia Quotient minus Processing Speed Disparity	General Speed of Processing Result	Min.	Lower Quartile (Q1)	Median	Mean	Upper Quartile (Q3)	Max.
Overall	No difficulties	0	0.5	1.5	1.76	2.5	5.5
	Average	0	1	3	3.25	5	11
	Difficulties	0.5	2.75	6	6	8.5	14
Non-Dyslexic Group	No difficulties	3.5	3.5	4	4.25	4.875	5.5
	Average	2.5	4.5	5	5.67	6.5	11
	Difficulties	1	6	7.5	7.81	9.5	14
Dyslexic Group	No difficulties	0	0.5	1	1.30	2	4.5
	Average	0	0.5	1.5	1.55	2.25	5
	Difficulties	0.5	1.625	2.5	2.25	2.875	3.5

Table 30: Summary statistics for the dyslexia quotient minus processing speed disparity overall and for the non-dyslexic/dyslexic groups by general speed of processing result, for the full non-dyslexic group.

These results are also visualised in Figure 12 and Figure 13, which show the distributions of the dyslexia quotient minus processing speed disparity values overall, and for the dyslexic and non-dyslexic groups, by general speed of processing result.

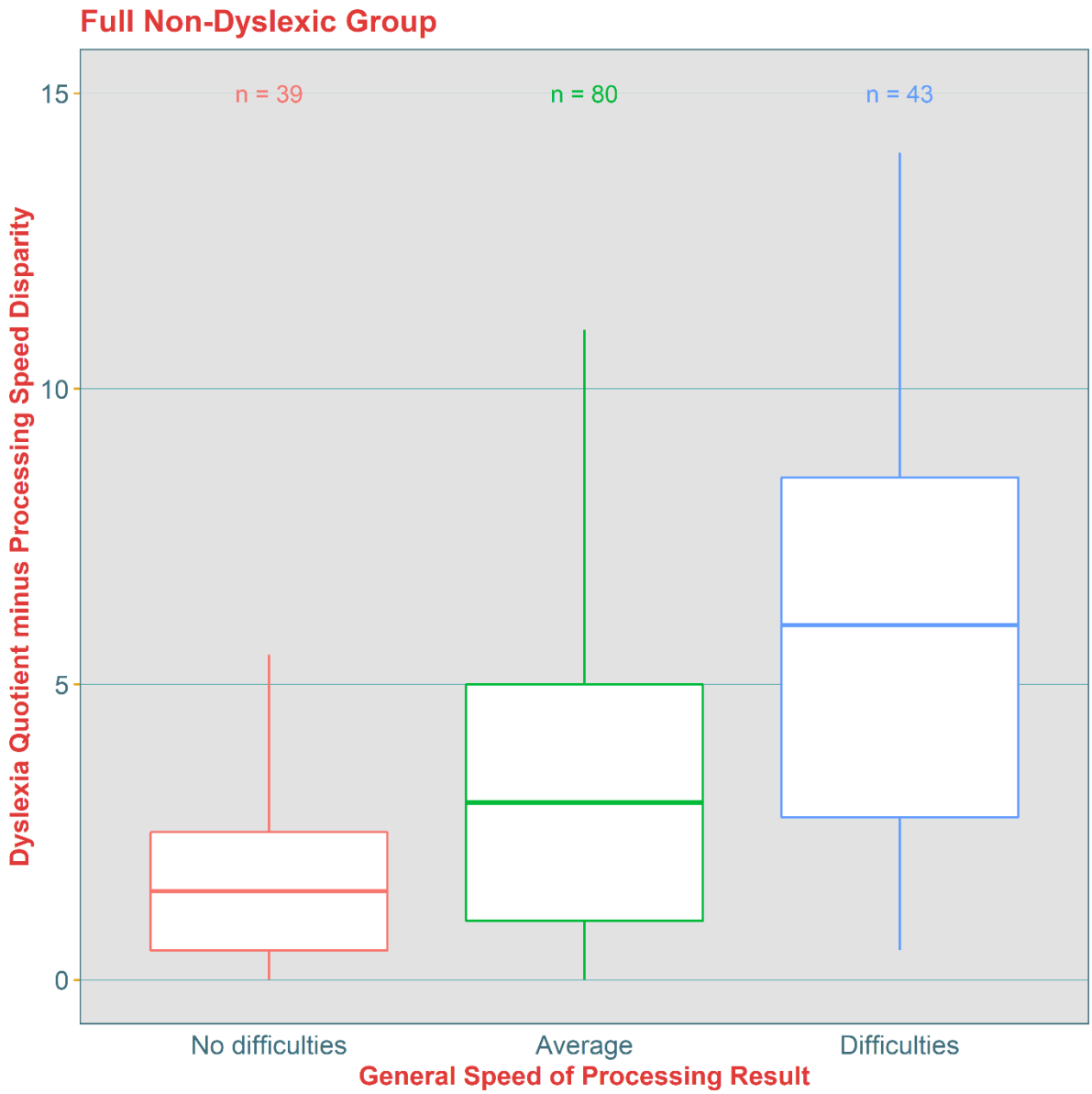

Figure 12: Boxplots of the dyslexia quotient minus processing speed disparity by general speed of processing result, for the full non-dyslexic group. (The bold horizontal line shows the median value, the box shows the middle 50% of the data, the top of the box shows the upper quartile [75th percentile] and the bottom of the box the lower quartile [25th percentile], the lines extend to the largest and smallest observed values that are no further than 1.5xIQR [interquartile range] from the upper and lower quartiles.)

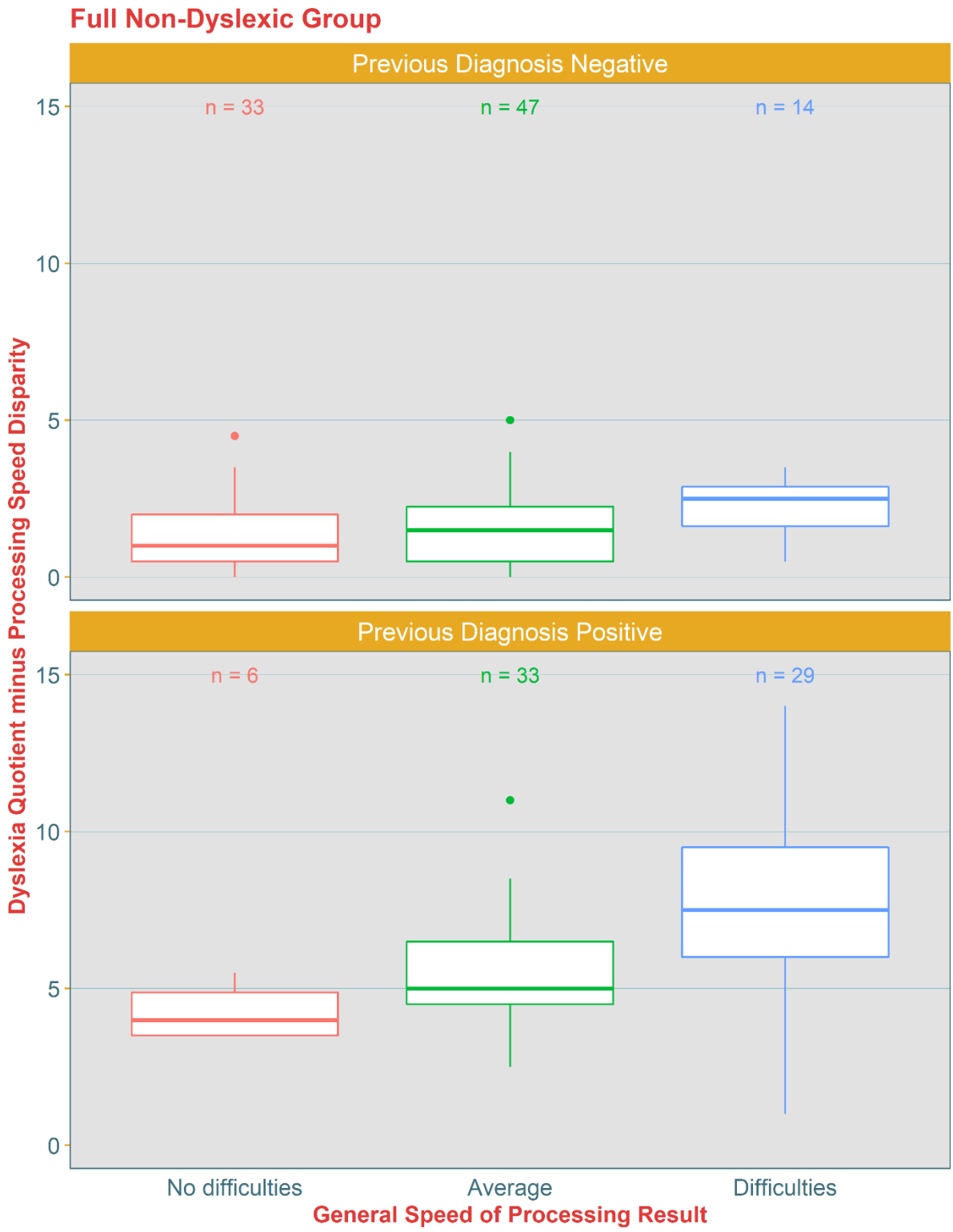

Figure 13: Boxplots of the dyslexia quotient minus processing speed disparity by non-dyslexic/dyslexic group and general speed of processing result, for the full non-dyslexic group. (The bold horizontal line shows the median value, the box shows the middle 50% of the data, the top of the box shows the upper quartile [75th percentile] and the bottom of the box the lower quartile [25th percentile], the lines extend to the largest and smallest observed values that are no further than 1.5xIQR [interquartile range] from the upper and lower quartiles.)

Potential Further Work

The analysis presented in this report provides an assessment of the current diagnostic accuracy of the QuickScreen dyslexia test and finds evidence of a high overall accuracy (93%). Further work could potentially be undertaken to expand upon this analysis to, for example, explore the performance achieved for different groups of participants who take the QuickScreen test. This might be splitting the participants into particular user-groups, for providing specific estimates to different customers that use the test, or into groups that are perhaps expected to be more or less well compensated, and therefore more or less challenging in which to detect the symptoms of dyslexia.