The computerised-based Lucid Rapid Dyslexia Screening for the identification of children at risk of dyslexia: A Singapore study

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The computerised-based Lucid Rapid Dyslexia Screening (Lucid Rapid) used for the speedy identification of children at risk of literacy difficulties or dyslexia has been employed as part of the dyslexia awareness drive organised by the Dyslexia Association of Singapore (DAS) to identify Singapore children who may be at risk of literacy difficulties or dyslexia. In view of a lack of research on the Lucid Rapid, this study explored the effectiveness of the Lucid Rapid in the screening of children at risk of literacy difficulties or dyslexia in the Singaporean context. In this exploratory study, a sample of 127 children aged between 6 years to 12 years 2 months was each administered the Lucid Rapid. This was followed by formal assessments conducted at the DAS or external agencies, comprising of cognitive and literacy assessments as well as phonological tests. As part of the formal assessment, a full background history was taken of each child including educational history and teachers' reports. Data from this sample showed that children found to be at risk of dyslexia on the Lucid Rapid were likely to be diagnosed to be dyslexic. However, concerns were raised on the large number of children who were misclassified falling within the false positive (misclassifying children to be at risk of dyslexia when they are not dyslexic) and false negative (misclassifying children to be at low risk of dyslexia when they are dyslexic) groups. In this sample, phonological processing, auditory sequential memory and phonic decoding, but not visual-verbal integration memory, on the Lucid Rapid positively correlated with comparable measures in formal assessments. As compared to the true negative group (children classified to be at low risk of dyslexia and not diagnosed to be dyslexic), the false negative group showed lower phonic decoding and auditory sequential memory scores. Risk levels on the Lucid Rapid have been found to be negatively correlated with a number of cognitive, literacy and phonological measures. The children's home language usage might also affect the Lucid Rapid results to some extent.

Keywords: *dyslexia screening; multilingual; computer-based assessment; Singapore; DAS.*

ACCURATE identification is an important first step to helping children with specific learning difficulties such as dyslexia. While screening tools are not typically used to diagnose dyslexia, an effective dyslexia screening tool can help identify at risk children in the population who need further attention, in terms of intervention or formal psychological assessments (Protopapas, Skaloumbakas & Bali, 2008). Dyslexia screening tests are generally brief and simple to administer relative to full psychological assessments and do not require the services of psychologists, thus making them applicable for widespread use. Learning support officers or teachers can be trained to screen children for dyslexia.

Currently, a number of conventional and computerised screening tools are available to assist the identification of children at risk of dyslexia. Among the ones most widely used in the UK are the Dyslexia Early Screening Test, 2nd edition (DEST-II) for pre-school aged children (Fawcett & Nicolson, 1996) and the Dyslexia Screening Test – Junior (DST-J) for primary and secondary-school aged children (Fawcett & Nicolson, 2004). In recent years, however, there has been a growing trend towards the use of computer-based assessments (CBA) for the identification of children with specific learning difficulties (Protopapas et al., 2008; Singleton, Horne & Simmons, 2009).

Computer-based assessment for dyslexia

Singleton (2001) outlined various advantages of CBA over conventional assessments. Relative to subjective judgments inherent in individual administrators, test delivery in CBA is standardised. Because most of the test delivery and scoring is performed by the computer, it is reported to be more efficient and cost-effective to administer. In addition, the technology allows the tests to be presented in more appealing formats for children, whom have displayed greater preference and motivation toward CBA over conventional assessments (Singleton, 2001).

Nevertheless, CBA programmes would not be able to take into account various additional factors that could impact test performance, such as the child's concentration, environmental factors that could occur during test administration, or background factors, which would usually be taken into consideration in conventional assessments. Thus, it is important for administrators to take note of the child's behaviour during testing as well as gather relevant background information if possible, and consider the information together with test scores when interpreting the screening results. In addition, Singleton (2001) highlighted that the ease and greater accessibility of CBA creates risk of abuse by those who do not properly understand the nature and administration of the assessment, and they might use the CBA erroneously or misinterpret findings.

Lucid Rapid Dyslexia Screening

Lucid Research Limited (Lucid Research) has produced among the most widely used dyslexia assessment software in the UK and in the world. The Cognitive Profiling System (CoPS) is a diagnostic assessment system designed for the early identification of children with special needs (including dyslexia) between ages 4 to 8 years. CoPS has been used in over 8000 primary schools in the UK and elsewhere in the world (*Lucid Research Fact Sheet 4*, 2007). Apart from the CoPS, two other systems were developed for the identification of special education needs and dyslexia in other age groups, namely the Lucid Assessment Systems for Schools (LASS) Junior (ages 8 to 11 years) and LASS Secondary (ages 11 to 15 years).

Based on selected tests from their more comprehensive assessment systems, Lucid Research has produced a brief screening tool to identify children at risk of dyslexia. Taking only 15 minutes to administer, Lucid Rapid Dyslexia Screening (Lucid Rapid) is a computerised-based test designed to screen children at risk of dyslexia between ages 4 to 15 years. Due to its ease of administration and interpretation, the Lucid Rapid can be utilised by teachers or other individuals with some training.

To date, there has not been any known validation study dedicated to the Lucid Rapid. The tests within Lucid Rapid which were selected from the CoPS, LASS Junior and LASS Secondary had been individually validated and normed on 2000 children in the UK. The CoPS, LASS Junior and LASS Secondary are in widespread use in over 8000 schools (*Lucid Research Fact Sheet 4*, 2007). Validation studies on the CoPS, LASS Junior and LASS Secondary were used to support the validity of Lucid Rapid. The authors reported that CoPS showed a 96 per cent accuracy rate in predicting poor reading skills, with 17 per cent false negative and 2.3 per cent false positive rates. LASS Secondary reportedly showed strong correlations between its measures and widely used equivalent conventional tests for the assessment of dyslexia (*Lucid Research Fact Sheet 4*, 2007). More recently, Singleton et al. (2009) conducted a study examining the validity of an adult screening tool. The measures were reported to satisfactorily discriminate between dyslexic and non-dyslexic adults, with sensitivity and specificity rates of 90.6 per cent and 90.0 per cent, respectively.

Use of Lucid Rapid in Singapore

Outside the UK, the Lucid Rapid has been used in various countries. In Singapore, it has been utilised by the Dyslexia Association of Singapore (DAS) since May 2009 to screen children potentially at risk of dyslexia at awareness talks organised by the DAS and at various DAS open houses. The screenings were conducted by DAS psychologists and educational therapists who had been trained in the administration and interpretation of the Lucid Rapid. Results of the screening, as well as information gathered during parent and teacher feedback sessions, were used to aid the decision on whether to refer each child for a formal psychological assessment. To date, DAS has screened over 400 children between the ages of 5 to 15 years in Singapore using the Lucid Rapid.

Applicability of Lucid Rapid in Singapore's multilingual context

As the current dyslexia screening and assessment tools have mostly been developed in the UK or the US, they were typically developed based on predominantly monolingual, English-speaking children (Everatt et al., 2000). There appears to be a consensus in the literature that traditional assessment and screening approaches for dyslexia tend to disadvantage children who speak English as a Second Language (ESL) as well as bilingual or multilingual children (Cline & Frederickson, 1999; Woolley, 2010).

Singapore possesses a multi-ethnic population of close to five million consisting of 74.1 per cent Chinese, 13.4 per cent Malays, 9.2 per cent Indians, while 3.3 per cent are classified as Others (Singapore Department of Statistics, 2010). While English is the official language and the main language of instruction in schools, Mandarin, Malay, Tamil and various dialects are widely spoken and are the predominant language for many families. Thus, it is common for Singaporean children to be able to speak one or more languages other than English.

While English is the formal language of instruction in schools and is widely used in social settings, it is not the predominant language spoken at home for the majority of the population (77 per cent). However, it is the predominant language for a substantial portion of the population (23 per cent), particularly the more educated (Singapore Department of Statistics, 2000). It is thus a concern whether the wide variation in English proficiency among children in Singapore would impact on their test performance on the Lucid Rapid. English proficiency is likely to play a role in the understanding of task instructions, which is verbally mediated by the computer in British English which may significantly differ from Singapore colloquial English both in terms of accent and distinct rules in grammar, syntax and pragmatics (Gupta, 1992). In view of the possible linguistic differences within the Lucid Rapid, there is a need to examine the appropriateness of using the Lucid Rapid in Singapore's multilingual context.

Purpose of the current study

To date, there is no known dedicated study on the validity of the Lucid Rapid as a screening tool for dyslexia. There is also a need to investigate the applicability of Lucid Rapid for children in Singapore in this current exploratory study. It examined a sample of children who had been screened on the Lucid Rapid and had also undergone formal psychological assessments at the DAS or other agencies; it aimed to explore the effectiveness of the Lucid Rapid in the screening of children at risk of literacy difficulties or dyslexia in the Singaporean context. The study compared measures on the Lucid Rapid with comparable measures obtained in formal assessments and examined the relationship between cognitive and literacy skills with results on the Lucid Rapid. The study also explored if the children's home language usage could affect their scores on the Lucid Rapid.

Method

Participants

The assessment results of 127 children were collated for the purpose of this study. The children were tested on the Lucid Rapid between March 2009 and June 2010 to provide an indication of their risk of dyslexia. These children had also undergone full psychological assessments within six months from the date of the screening test to ascertain dyslexia. One-hundred-and-twenty-two children were assessed by DAS psychologists and five children were assessed by educational psychologists at hospitals and external agencies. These children were from the ages of 6 years to 12 years 2 months. The mean age of the children was 8.39 years (*SD*=1.68) during the computerised screening test and 8.48 years (*SD*=1.69) during formal psychological assessments. There were 87 boys and 40 girls in this sample.

Materials

Computer-based assessment

The Lucid Rapid provides an indication of a child's risk of dyslexia and an estimate of a child's performance in three dyslexia sensitive measures (Singleton et al., 2003). These measures were based on the phonological deficit model of dyslexia (Snowling, 1998) and comprised phonological processing, auditory sequential memory, and visual-verbal integration memory/phonic decoding. The three measures yield three scores and the tests administered varied with the age of the children as shown in Table 1. In this current study, the visual-verbal integration memory test was administered to 49 children, while the phonic decoding test was administered to 78 children.

The scores on the three measures were combined to derive an overall probability of dyslexia and the children were classified into one of four categories: very high probability of dyslexia (>95 per cent chance of dyslexia), high probability of dyslexia (>90 per cent chance of dyslexia), moderate probability of dyslexia (>75 per cent chance of dyslexia) and low probability of dyslexia (<10 per cent chance of dyslexia). For further information on the Lucid Rapid Dyslexia Screening, see Singleton et al. (2004).

Conventional formal assessment

The children were assessed on their cognitive, literacy and phonological abilities. The cognitive tests administered were obtained from the Differential Abilities Scale – 2nd edition, (DAS-II) (Elliott, 2007); the British Abilities Scale – 2nd edition, (BAS-II) (Elliott, Smith & McCulloch, 1997); and the Wechsler Intelligence Scale for Children – 4th edition (United States), (WISC-IV) (Wechsler, 2003). The specific cognitive measures which were used in the formal assessments are listed as shown in Table 2.

Table 1: Description of tests on the Lucid Rapid.

Phonological processing	Children who were younger than 8-years-old were assessed on their speed and accuracy in performing rhyming and alliteration tasks. Older children above 8-years-old were assessed on their accuracy in segmenting words into syllables and phonemes.
Auditory sequential memory (working memory)	Children who were younger than 8-years-old were tested on their ability to remember sequences of animal names. Older children above 8-years-old were tested on their ability to recall sequences of digits.
Phonic decoding and Visual-verbal integration memory	Children younger than 8-years-old were tested on their ability to integrate visual and auditory information in a short-term memory task involving sequences of colours. Children above 8-years-old were tested on their phonic skills in decoding nonsense words.

Table 2: Cognitive abilities measured in formal assessments.

General Conceptual Ability and the Full Scale Intelligence Quotient	These measure general cognitive ability.
Non-Verbal Reasoning Cluster	This measures the child's non-verbal inductive reasoning abilities.
Special Non-Verbal Composite	This measures the child's non-verbal reasoning and spatial abilities.
Verbal Cluster/ Verbal Comprehension Index	These measure the child's vocabulary knowledge, verbal reasoning and expressive language abilities as well as knowledge of general information.
Spatial Cluster	This measures the child's visual-spatial processing ability.
Vocabulary /Word Definition Subtests	These measure the child's vocabulary knowledge and expressive language abilities.
Verbal Similarities Subtest	This measures the child's ability to reason with verbal concepts.
Speed of Information Processing Subtest/Processing Speed Index	This measures the child's mental processing speed.
Recall of Digits Forward Subtest	This measures the child's short-term auditory memory.
Recall of Digits Backward Subtest	This measures the child's auditory working memory.
Recall of Sequential Order Subtest	This measures the child's auditory working memory requiring some degree of visualisation.
Working Memory Cluster/Index	This measures the child's auditory working memory.
Recall of Objects Subtest/ Recall of Objects Verbal-Immediate	This measures the child's visual-verbal memory.
Recall of Objects Spatial-Immediate Subtest	This measures the child's visual-spatial memory.

The literacy tests administered were obtained from the Wechsler Individual Achievement Test – 2nd Edition (WIAT-II) (Wechsler, 2001); the Wechsler Objective Reading and Language Dimensions, Singapore (WORLD^{singapore}) (Rust, 2000); and the BAS-II Achievement Scales (Elliott, Smith & McCulloch, 1997). The specific literacy tests used in the formal assessments are listed as shown in Table 3.

The phonological tests were obtained from the Phonological Assessment Battery (PhAB), (Frederickson, Frith & Reason, 1997); and the DAS-II (Elliott, 2007). The phonological tests used in the formal assessments are listed as shown in Table 4.

Procedure

The study was conducted in two phases. In Phase 1, each child was administered the Lucid Rapid by trained Psychologists and Educational Therapists at the DAS. In Phase 2, each child underwent full psychological assessments conducted by Psychologists at the DAS or Educational Psychologists at external agencies. Although the time interval between each phase varied with different children, Phase 2 mostly occurred within six months of Phase 1.

Not all tests were used by the various professionals in the diagnosis of children with dyslexia, accounting for the varying sample numbers for the different tests.

Table 3: Literacy skills tested in formal assessments.

Spelling Test	This measures the child's ability to spell single words.
Word Reading Test	This measures the child's ability to read single words.
Non-Word Subtest/ Pseudoword Subtest	These measure the child's phonological decoding skills.
Listening Comprehension Subtest	This measures the child's receptive vocabulary and language.
Reading Comprehension Subtest	This measures the child reading comprehension skills which include the child's ability to understand as well as to draw conclusion and make inferences of text read.

Table 4: Phonological tests used in formal assessments.

Phonological Processing Subtest	This measures the child's ability to perform rhyming tasks as well as blend phonemes into words, delete phonemes in words and segment words into their phonemes.
Alliteration Subtest	This measures the child's ability to identify words that start with the same sound.
Alliteration Fluency Subtest	This measures the child's ability to generate words that start with the same sound.
Rhyme Subtest	This measures the child's ability to identify words that end with the same sound.
Rhyme Fluency Subtest	This measures the child's ability to generate words that end with the same sound.
Naming Speed (Digit) Subtest	This measures the child's word retrieval fluency for digit sequences.
Naming Speed (Pictures) Subtest/ Rapid Naming Subtest	These measure the child's word retrieval fluency.

The sample numbers on which analyses were carried out will be specified in the reporting of the results.

Conventional formal assessments (the set 'gold standard' used in this study for the diagnosis of dyslexia) included tests of cognitive ability and literacy skills as well as tests of phonological processing and decoding abilities. The criteria used by the DAS Psychologists for the diagnosis of dyslexia were based on the DAS definition of dyslexia, *'Dyslexia is a neurologically-based specific learning difficulty which is characterised by difficulties in one or more of reading, spelling and writing. Accompanying weaknesses may be identified in the areas of language acquisition, phonological processing, working memory and sequencing. Some factors which are associated with, but do not cause dyslexia are poor motivation, impaired attention and academic frustration'* (Smith et al., 2003, no page number).

The diagnosis of dyslexia at the DAS was based on an integrative approach incorporating the principles of the discrepancy-achievement model and the symptomatic approach. The tests used in the formal assessments provided an indication of the children's cognitive, literacy and phonological processing skills. With the discrepancy-achievement model, the children's literacy skills were compared in relation to their ages as well as their cognitive and verbal abilities. However, given the limitations of the discrepancy-achievement model (for which discussion is beyond the scope of this paper), the symptomatic approach was used to provide further diagnostic information regarding the children's difficulties. Diagnostic tests were used to identify if the children showed weaknesses associated with dyslexia, such as difficulties with working memory, speed of information processing, sequencing and phonological processing. A formal diagnosis was made based on the test results, together with information gathered on the children's medical, familial and educational background.

The British Psychological Society (1999, p.18) suggests that *'Dyslexia is evident when accurate and fluent word reading and/or spelling develops very incompletely or with great difficulty. This focuses on literacy learning at the 'word level' and implies that the problem is severe and persistent despite appropriate learning opportunities. It provides the basis for a staged process of assessment through teaching.'* In recent years there has been much debate on the need to move away from the traditional classification-based approach in the identification of children with possible learning difficulties to one which focuses on a dynamic assessment approach which is based on the children's response to intervention (Restori, Katz & Lee, 2009). Notwithstanding the merits of this approach, conventional testing continues to be a requirement in Singapore to allow children with learning difficulties to access remediation and intervention. However, Singapore is developing its own initiatives with regards to a staged approach to assessment.

Results

Diagnostic accuracy of the Lucid Rapid Dyslexia Screening

The Lucid Rapid provides probabilistic categories of the probabilities of dyslexia and not a binary categorisation. Hence, for the purpose of this study, children catergorised as having 'low probability' of dyslexia were classified as having low risk of dyslexia and children categorised as having 'very high probability', 'high probability' and 'moderate probability' of dyslexia were classified as children who were at risk of dyslexia. Based on the screening results of the Lucid Rapid and results obtained based on conventional formal assessments, the children were classified accordingly to the different groups (i.e. true positives, true negatives, false positives, false negatives) in the contingency table (see Table 5). A chi square test performed to examine the relationship between the results obtained on the Lucid Rapid and formal psychological assessments showed that the number of observations in each cell of the contingency table is not independent, χ^2 (1, N=127)=9.71, p<.002, and the phi coefficient computed from the 2 x 2 contingency table is 0.28. This suggests that there is a 0.28 correlation between the results of screening on the Lucid Rapid and the results obtained from conventional formal assessments. An odds ratio analysis showed that children who were found to be at risk of dyslexia on the Lucid Rapid were 3.77 times more likely to be diagnosed as dyslexic in formal assessments.

In order to assess the effectiveness of the Lucid Rapid, the following measures were computed: (a) sensitivity rate, which measures the proportion of correctly identified dyslexics; (b) specificity rate, which measures the proportion of correctly identified non-dyslexics; (c) positive predictive value, which measures the proportion of children identified to be at risk for dyslexia and were diagnosed as dyslexic; and (d) negative predictive value, which measures the proportion of children identified to be at low risk for dyslexia and not diagnosed to be dyslexic.

The Lucid Rapid demonstrated a sensitivity of 81.9 per cent (95 per cent C.I.: 76.7 per cent, 86.9 per cent), specificity of 45.5 per cent (95 per cent C.I.: 30.7 per cent, 59.6 per cent), a positive predictive value of 81.1 per cent (95 per cent C.I.: 75.9 per cent, 86.0 per cent) and a negative predictive value of 46.9 per cent (95 per cent C.I.: 31.7 per cent, 61.5 per cent). Overall, the results suggest that when compared to the 'gold standard' in the diagnosis of dyslexia in a conventional full psychological assessment, the Lucid Rapid is somewhat sensitive in identifying dyslexia (i.e. picking out true positives from true positives and false negatives), but it is not very specific (i.e. picking out true negatives out of true negatives and false positives).

Comparison of the false negative and true negative groups

While the Lucid Rapid demonstrates a relatively high positive predictive value at 81.1 per cent, it is of concern that it misses approximately 20 per cent of children with dyslexia or for every five children with dyslexia, one will show low risk of dyslexia on the Lucid Rapid (false negative). Thus, it is important to identify the false negatives amongst the children in the low risk group.

To examine possible differences between the true negative and false negative groups, the test scores on the Lucid Rapid were compared with those on conventional assessments in the true negative and false negative groups using independent sample t tests. There were no differences between the true negative and false negative groups on the phonological processing test, $t(30)$=0.68, p=.50, and visual-verbal integration memory test, $t(4)$=1.58, p=.19 on the Lucid Rapid. However, the false negative group scored lower on the phonic decoding test (mean (M)=39.36, standard deviation (SD)=13.09) than the true negative group (M=52.08, SD=16.61), $t(24)$=2.18, p=.039. The difference on the auditory sequential memory test scores between the false negative group (M=70.35, SD=20.41) and the true negative group (M=81.73, SD=11.29) also approached significance, $t(30)$=1.91, p=.065. In conventional assessments, there were no significant differences between the false negative and true negative groups for all tests with the exception of the spelling and word reading tests. On the spelling test, the false negative group tended to score lower (M=99.12, SD=11.11) than the true negative group (M=110.67, SD=12.95), $t(30)$=2.72, p=.011. On the word reading test, the false negative group also tended to score lower (M=99.88, SD=9.43) than the true negative group (M=111.60, SD=13.71), $t(30)$=2.84, p=.0079. However, these scores were nevertheless within the average range.

The above analysis showed that the false negative group in this sample tended to have lower auditory sequential memory and phonic decoding test scores on the Lucid Rapid compared with the true negative group. The false negative group in this sample also tended to score lower on the spelling and word reading tests in formal assessments, although it should be noted that their scores on these tests were within the average range for the age group.

Correlational analysis

The Kendall Rank Correlations were computed on the centile test scores of the Lucid Rapid and the scores obtained in standardised conventional tests administered during the study. Table 6 shows the correlations between the test scores. The correlation values were rather varied and low, where

Table 5: Contingency table for results obtained on the Lucid Rapid and conventional formal assessments.

	Diagnosis in formal assessments	
Lucid Rapid Results	Dyslexic	Not Dyslexic
At risk of Dyslexia	77	18
Low risk of Dyslexia	17	15

most of the correlations were below 0.30. The phonological processing, auditory sequential memory and phonic decoding scores correlated with a number of conventional test scores. However, for the purpose of this exploratory study in ascertaining how measures on the Lucid Rapid compared with equivalent measures in formal assessments, only tests which measure similar broad cognitive domains on the Lucid Rapid and formal assessments were reported. It is important to understand if the measures on the Lucid Rapid reliably measure what they purport to measure. Although various significant correlations were found for the various measures on the Lucid Rapid and other measures within the cognitive and literacy domains in formal assessments, the depth of the analysis is beyond the scope of this exploratory study. Instead, they are reported in the Appendix for further analysis at a later point in time.

The phonological processing test scores on the Lucid Rapid correlated significantly with the Phonological Processing subtest on the DAS-II ($r=0.22$, $p=.037$), and the Rhyme subtest on the PhAB ($r=0.21$, $p=.0094$), but not with the Alliteration subtest on the PhAB ($r=0.11$, $p=.17$). The auditory sequential memory test scores on the Lucid Rapid correlated significantly with the Recall of Digits Forward subtest on the DAS-II/BAS-II ($r=0.28$, $p=.0001$). The Phonic Decoding test scores on the Lucid Rapid also correlated significantly with the Non-word/Pseudoword subtests on the PhAB/WIAT-II ($r=0.24$, $p=.003$).

The visual-verbal integration memory scores did not correlate with comparable test scores on the Recall of Objects/Recall of Objects-Immediate Verbal subtests on the DAS-II/BAS-II. As the visual-verbal integration memory was only administered to children below 8-years-old, and given that there were far fewer 8-year-olds in this sample, the lower number of children in this group has contributed to a lack of statistical power to the analysis. Overall, the phonological processing, auditory sequential memory and phonic decoding tests on the Lucid Rapid correlated with comparable tests in formal assessments. However, the visual-verbal integration memory scores did not correlate with comparable tests in formal assessments.

The Kendall Rank Correlations were also computed on the probability categories of the Lucid Rapid and scores obtained in standardised conventional tests administered during the study. For the purpose of the analysis, the probability categories were recorded as 0 for ‘low probability’, 1 for ‘moderate probability’, 2 for ‘high probability’ and 3 for ‘very high probability’. Table 7 shows the correlations between the test scores and the probability categories. As can be seen from Table 7, the Lucid Rapid Probability Categories correlated negatively with the test scores of a number of tests in conventional assessments. Negative correlations were found for cognitive measures, such as General Conceptual Ability/Full Scale Intelligence Quotient (DAS-II/BAS-II/WISC-IV) ($r=-0.25$, $p=.0003$), Non-verbal Reasoning Cluster (DAS-II/BAS-II) ($r=-0.21$, $p=.0024$), Verbal Cluster/Verbal Comprehension subtest (DAS-II/BAS-II/WISC-IV) ($r=-0.21$, $p=.002$), Vocabulary/Word Definition subtest (DAS-II/BAS-II/WISC-IV) ($r=-0.21$, $p=.026$), Recall of Digits Forward subtest (DAS-II/BAS-II) ($r=-0.34$, $p=.0001$) and Working Memory Cluster/Index (DAS-II/WISC-IV) ($r=-0.27$, $p=.026$). Negative correlations were also found for literacy measures, such as spelling ($r=-0.25$, $p=.0003$), word reading ($r=-0.28$, $p=.0001$), reading comprehension ($r=-0.31$, $p=.00$) and listening comprehension ($r=-0.20$, $p=.021$). Negative correlations were found for phonological measures as well. The probability categories were negatively correlated to the Phonological Processing subtest (DAS-II) ($r=-0.30$, $p=.007$), Alliteration subtest (PhAB) ($r=-0.22$, $p=.014$), Rhyme Fluency subtest (PhAB) ($r=-0.24$, $p=.011$), Naming Speed – Digits subtest (PhAB) ($r=-0.28$, $p=.002$) and Rhyme subtest (PhAB) ($r=-0.24$, $p=.0069$).

Table 6: Correlations between Lucid Rapid Scores and Conventional Tests Scores (*N* shown for each pair in parenthesis).

		Phonological Processing	Auditory Sequential Memory	Phonic Decoding	Visual–Verbal Integration Memory
Cognitive Abilities Tests	General Conceptual Ability/Full Scale Intelligence Quotient	0.21*** (127)	0.16** (127)	0.13 (79)	0.15 (48)
	Non-verbal Reasoning Cluster	0.18** (121)	0.15* (121)	0.08 (73)	0.08 (48)
	Special Non-verbal Composite	0.08 (97)	0.03 (97)	0.08 (60)	0.12 (37)
	Verbal Cluster/ Verbal Comprehension Subtest	0.17** (126)	0.14* (126)	0.13 (78)	0.03 (48)
	Spatial Cluster	0.14* (119)	0.10 (119)	0.05 (72)	0.30** (47)
	Vocabulary Subtest/ Word Definitions Subtest	0.16** (124)	0.16* (124)	0.10 (76)	0.09 (48)
	Verbal Similarities Subtest	0.17** (120)	0.14* (120)	0.03 (73)	0.01 (47)
	Speed of Information Processing Subtest/ Processing Speed Index	0.08 (122)	0.01 (122)	0.00 (75)	0.02 (47)
	Recall of Digits Forward Subtest	0.28*** (119)	0.27*** (119)	0.21* (72)	0.17 (47)
	Recall of Digits Backward Subtest	0.05 (119)	0.00 (119)	0.02 (72)	0.13 (47)
	Recall of Sequential Order Subtest	0.03 (48)	0.05 (48)	0.05 (31)	–0.05 (17)
	Working Memory Cluster/Index	0.18 (41)	0.16 (41)	0.20 (29)	–0.06 (12)
	Recall of Objects Subtest/Recall of Objects Verbal – Immediate	–0.08 (112)	–0.04 (112)	–0.04 (67)	0.07 (45)
	Recall of Objects Spatial – Immediate Subtest	0.07 (61)	0.03 (61)	0.18 (36)	–0.19 (25)

*$p<0.05$ **$p<0.01$ ***$p<0.001$

Continued

		Phonological Processing	Auditory Sequential Memory	Phonic Decoding	Visual-Verbal Integration Memory
Literacy Abilities Tests	Spelling Test	0.19** (125)	0.17** (125)	0.23** (77)	0.12 (48)
	Word Reading Test	0.21*** (125)	0.15* (125)	0.33*** (77)	0.04 (48)
	Non-word Subtest/ Pseudoword Subtest	0.22*** (121)	0.13* (121)	0.21** (74)	0.18 (47)
	Listening Comprehension Subtest	0.12 (81)	0.20* (81)	0.09 (40)	0.06 (41)
	Reading Comprehension Subtest	0.24*** (121)	0.16* (121)	0.23** (74)	–0.08 (47)
Phonological Abilities Tests	Phonological Processing Subtest	0.26* (49)	0.14 (49)	0.16 (32)	–0.21 (17)
	Alliteration Subtest	0.11 (75)	0.16 (75)	0.28* (45)	0.30* (30)
	Alliteration Fluency Subtest	0.14 (73)	0.01 (73)	0.17 (45)	–0.20 (28)
	Rhyme Fluency Subtest	0.14 (71)	0.03 (71)	0.30** (44)	–0.06 (27)
	Naming Speed (Digit) Subtest	0.15 (70)	0.25** (70)	0.27* (42)	0.07 (28)
	Naming Speed (Pictures) Subtest/ Rapid Naming Subtest	0.05 (118)	0.09 (118)	–0.06 (73)	–0.09 (45)
	Rhyme Subtest	0.21** (76)	0.10 (76)	0.43*** (46)	0.14 (30)

*$p<0.05$ **$p<0.01$ ***$p<0.001$

Table 7: Correlations between Lucid Rapid Probability Categories and Conventional Tests Scores (sample size shown for each pair in parenthesis).

		Lucid Rapid Probability Category
Cognitive Abilities Tests	General Conceptual Ability/ Full Scale Intelligence Quotient	–0.25*** (127)
	Non-verbal Reasoning Cluster	–0.21** (121)
	Special Non-verbal Composite	–0.10 (97)
	Verbal Cluster/ Verbal Comprehension Subtest	–0.21** (127)
	Spatial Cluster	–0.13 (119)
	Vocabulary Subtest/ Word Definitions Subtest	–0.20** (124)
	Verbal Similarities Subtest	–0.13 (120)
	Speed of Information Processing Subtest/ Processing Speed Index	–0.05 (122)

*$p<0.05$ **$p<0.01$ ***$p<0.001$

Continued

		Lucid Rapid Probability Category
Literacy Abilities Tests	Spelling Test Word Reading Test	–0.25*** (125) –0.28*** (125)
	Non-word Subtest/ Pseudoword Subtest	–0.24*** (121)
	Listening Comprehension Subtest	–0.20* (81)
	Reading Comprehension Subtest	–0.31*** (121)
Phonological Abilities Tests	Phonological Processing Subtest	–0.24* (48)
	Alliteration Subtest	–0.22* (75)
	Alliteration Fluency Subtest	–0.09 (73)
	Rhyme Fluency Subtest	–0.24* (71)
	Naming Speed (Digit) Subtest	–0.28** (70)
	Naming Speed (Pictures) Subtest/ Rapid Naming Subtest	–0.06 (103)
	Rhyme Subtest	–0.24** (76)

*$p<0.05$ **$p<0.01$ ***$p<0.001$

		Lucid Rapid Probability Category
Cognitive Abilities Tests	Recall of Digits Forward Subtest	−0.34*** (119)
	Recall of Digits Backward Subtest	0.01 (119)
	Recall of Sequential Order Subtest	0.01 (48)
	Working Memory Cluster/Index	−0.27* (41)
	Recall of Objects Subtest/Recall of Objects Verbal-Immediate	0.08 (112)
	Recall of Objects Spatial-Immediate Subtest	0.03 (61)

*$p<0.05$ **$p<0.01$ ***$p<0.001$

Home language use

To investigate the relationship between home language usage and the results obtained on the Lucid Rapid, the risk levels of the screening results were categorised according to the home language usage of the children (see Table 8). The data for three children were removed because of missing data (i.e. their home language usage was not available). A chi square test was performed to examine the relationship between the results obtained on the Lucid Rapid and home language usage. Results showed that home language usage did not affect the Lucid Rapid screening results, χ^2 (3, N=124)=5.03, p=.16.

Although the above analysis indicated that home language usage did not affect the Lucid Rapid screening results, children who spoke Mandarin at home tended to be classified as 'Moderate Risk'. Another chi square test was performed on home language usage and a binary categorisation of the Lucid Rapid screening results (see Table 9), similar to the analysis of diagnostic accuracy on the Lucid Rapid. The further analysis was performed to examine whether home language usage affected the Lucid Rapid if the screening results were subjected to a binary categorisation. Results showed that children who spoke Mandarin at home tended to be classified as at risk of dyslexia, χ^2 (1, N=124)=3.89, p=0.048.

An examination of the children's home language usage was made on the true positive and negative, as well as false positive and negative groups (see Table 10). A chi square test was performed to ascertain whether home language usage affected the distribution of the different diagnostic classifications. Results showed that home language usage affected the distribution, χ^2 (3, N=124)=11.53, p=0.009. An examination of

Table 8: Lucid Rapid Screening Results categorised by home language usage.

	Home Language	
LUCID Rapid Risk Level	English	Mandarin
Low	29	3
Moderate	36	15
High	18	4
Very High	14	5

Table 9: Lucid Rapid Screening Results (Binary) categorised by home language usage.

	Home Language	
LUCID Rapid Risk Level	English	Mandarin
Low Risk	29	3
At Risk	68	24

Table 10: Diagnostic classification categorised by home language usage.

	Home Language	
Classification	English	Mandarin
True Positives	59	15
True Negatives	14	1
False Positives	9	9
False Negatives	15	2

Table 10 showed that this was likely to be due to the higher proportion of Mandarin speakers in both the true positive and the false positive categories. The above analysis suggests that home language usage might affect the Lucid Rapid screening results to some extent. However, the above analysis was based on a forced binary categorisation of the Lucid Rapid screening results and not the original categorisation as intended by the developers of the screening tool. Hence, we have to treat these findings as preliminary and further research is required to examine the effects of using the Lucid Rapid screening tool within a multilingual environment.

Discussion

The screening of children at risk of dyslexia using CBA is a relatively new initiative implemented by the DAS. Having screened more than 400 children using the Lucid Rapid, it is important to evaluate the Lucid Rapid as a tool for the screening of children at risk of dyslexia in the Singaporean context. The gender ratio in this sample was 2.2 boys to 1 girl and seemed to suggest that more boys suspected of a learning difficulty were referred for the screening on the Lucid Rapid than girls. This could be attributed to a referral bias where boys with a learning difficulty tend to act out their difficulties more than girls (Shaywitz et al., 1990).

Overall, the findings based on this exploratory study seem to suggest that the Lucid Rapid can generally be a useful tool in the identification of children at risk of dyslexia, and who may require further psychological assessments and intervention. Generally, children who were found to be at risk of dyslexia on the Lucid Rapid were likely to be diagnosed as dyslexic during formal psychological assessments. However, some misclassifications by the Lucid Rapid were noted and analysed to understand some of the reasons which could account for the misclassifications.

The Lucid Rapid in this study showed a sensitivity rate (proportion of students who were dyslexic and were correctly identified by the Lucid Rapid to be at risk of dyslexia) of 81.9 per cent suggesting that the Lucid Rapid can identify children who are dyslexic rather accurately. The results also showed a specificity rate (proportion of students who were not dyslexic but were identified by the Lucid Rapid to be at risk of dyslexia) of 45.5 per cent suggesting that the Lucid Rapid is less specific in identifying children who are not dyslexic. While the Lucid Rapid showed an acceptable sensitivity rate of at least 80 per cent, its specificity rate of 45.5 per cent seemed rather low. It has been argued that sensitivity rate should be at least 80 per cent and specificity rate at least 90 per cent in order for a screening test to be considered as satisfactory (Glascoe & Byrne, 1993).

When examining the profile of the 18 children in the false positive group (children found to be at risk on the Lucid Rapid and not found to be dyslexic in formal assessments), nine showed language difficulties which could be due to a specific language impairment or a lack of exposure to the English language; three were globally delayed and their difficulties were each compounded by a non-English speaking background; two were suspected to have Attention Deficit Hyperactivity Disorder; one was suspected to have Pervasive Developmental Disorder and another was suspected to have Dyscalculia. The remaining two did not show sufficient evidence to warrant a diagnosis of dyslexia; a 6-year-old who begun home schooling only for a year and another did not seem to show apparent difficulties. The profile of the false positive group suggests that although the Lucid Rapid may not be very specific in identifying children with no dyslexia, it has identified children who may have other learning difficulties and who may require additional learning support and further assessments.

As noted in the profile of children in the false positive group, about 50 per cent of children in this group showed difficulties with language which could be due to specific language impairment or a lack of exposure to the English language. Given the varying degree of English proficiency of children in Singapore, it would be important to understand if the children's home language could impact their results on the Lucid Rapid. Although the children's home language in this study did not seem to affect their at risk levels on the Lucid Rapid, children who spoke Mandarin at home tended to be classified as at risk of dyslexia when the results were subjected to a binary categorisation. The results in this sample also showed that the children's home language usage affected their categorisation in the true positive and negative groups as well as false positive and negative groups, with a higher proportion of children with Mandarin-speaking background in both the true positive and false positive groups. Thus home language might affect the Lucid Rapid results to some extent. There is a chance that a child's lack of proficiency in English might contribute to the child's categorisation in the at risk group on the Lucid Rapid. However, as the binary classification was used, these results are only preliminary and subject to further research. We acknowledge the limitations of self reports. As the information on home language usage was self-reported, there were concerns relating to socially desirable responses provided by parents. The quality of English in Singapore varies, and it is not uncommon for Singaporean families to adopt more than one language in the home environment. Some parents may tend to report English as the dominant language used, despite the lack of quality and frequency of usage of the language. The effect of quality and frequency of usage of spoken English at home on the child's proficiency in the language was not determined. It is acknowleged that this could have impacted on the results reported above on the relationship between home language usage and the results obtained on the Lucid Rapid.

The study showed that the Lucid Rapid has a positive predictive value (also known as precision rate) of 81.1 per cent (proportion of children found to be at risk of dyslexia on the Lucid Rapid and eventually correctly diagnosed to be dyslexic) and a negative predictive value of 46.9 per cent (proportion of children with low risk of dyslexia and correctly diagnosed not to be dyslexic). Although the Lucid Rapid demonstrated a relatively high positive predictive value at 81.1 per cent, it was of concern that for every five children with dyslexia, one was misclassified to be at low risk of dyslexia on the Lucid Rapid. It was important to identify the profile of children who fell within this group. Children in the false negative group (children with low risk of dyslexia on the Lucid Rapid and eventually found to be dyslexic) have been found to show lower phonic decoding scores as compared to their non-dyslexic counterparts in the true negative group (children with low risk of dyslexia on the Lucid Rapid and correctly found to be not dyslexic). The mean score of phonic decoding in the false negative group was found to be within the lower end of the average range. An examination of the profile of the 17 children in the false negative group showed that most displayed weaknesses in phonological measures on the Lucid Rapid.

Thus, it might be reasonable to infer that children who obtained a low risk probability and scores in the lower end of the average range on phonic decoding on the Lucid Rapid might warrant further investigation by way of formal psychological assessments. These highlight the importance of interpreting the child's individual Lucid Rapid scores together with consideration of the child's overall risk factor before recommendations to teachers and parents can be made. This is consistent with the proposed guidelines set out in the administration manual of the Lucid Rapid in the interpretation of scores (Singleton et al., 2004). Apart from phonic decoding, it was found that children in the false negative group showed lower auditory sequential memory scores as compared to their non-dyslexic counterparts in the true negative group. Nonetheless, despite the lower sequential auditory memory scores in the false negative group, the mean scores were within the above average range. The higher scores were likely to contribute to the low risk classification of children in this group. The false negative group in this sample also tended to score lower on the spelling and word reading tests in formal assessments when compared to the true negative group although these scores were within the average range.

Generally, the phonological processing, auditory sequential memory and phonic decoding scores on the Lucid Rapid correlated with the most comparable scores in formal assessments. However, the correlations were not high. Although the measures on the Lucid Rapid and conventional formal assessment were deemed comparable, there were salient differences in the test delivery on the Lucid Rapid compared with tests in formal assessments. This is consistent with a study conducted by Singleton (2001). Singleton found significance but not exceptionally high correlations between two CBAs measuring verbal and non-verbal abilities with established cognitive tests on the BAS-II. He postulated that it was likely that the tests were not measuring exactly the same cognitive skills, and the absence of verbal responses on the CBAs might preclude important components in cognitive assessments. The measure of visual-verbal integration memory on the Lucid Rapid did not correlate with comparable tests in formal assessments. In view of the lower number of children below 8-years-old in this sample, the number of data available for this analysis was limited. A bigger sample size of children below 8-years-old would increase the statistical power of the analysis. Thus, the lack of statistical correlation on the visual-verbal integration memory on the Lucid Rapid with comparable conventional tests should be interpreted with caution.

Risk levels on the Lucid Rapid have been found to be negatively correlated with cognitive measures in formal assessments such as general cognitive ability, non-verbal inductive reasoning ability, verbal ability, vocabulary knowledge, short-term auditory memory and working memory. These suggest that children who were found to be at risk of dyslexia on the Lucid Rapid in this sample tended to show weaker scores on a number of cognitive measures, and children who obtained low risks of dyslexia on the Lucid Rapid in this sample tended to show better scores on a number of cognitive measures. Further research would be required to ascertain if these cognitive measures mediate the children's at risk levels on the Lucid Rapid.

Risk levels on the Lucid Rapid have been found to correlate negatively to a number of phonological measures in formal assessments as well. Children who were found to be at risk of dyslexia on the Lucid Rapid in this sample tended to obtain lower scores on phonological measures while children found to be at low risk of dyslexia on the Lucid Rapid in this sample tended to obtain better scores on measures of phonological processing. Risk levels on the Lucid Rapid have also been found to negatively correlate with literacy measures, such as reading, spelling, reading comprehension and listening comprehension abilities.

These correlations are encouraging and imply the inherent usefulness of the Lucid Rapid in identifying children with dyslexia and literacy difficulties. Notwithstanding the limitations of the study, the Lucid Rapid has been found to have practical application in the screening of children with dyslexia/ literacy difficulties. It is speedy to administer and can be administered to relatively larger groups of children in a relatively short time, as compared to formal assessments. It has also proven to be an effective tool in raising awareness of dyslexia in Singapore, as well as providing opportunities for informed discussions with parents about their children's learning difficulties.

However, as gleaned from the findings of this study, it is important that administrators of the Lucid Rapid are well-versed in the interpretation of the results. As the Lucid Rapid and other CBA cannot easily accommodate information, such as the child's educational or familial background, as well as the child's use of compensatory strategies during testing (Singleton et al., 2009), it is imperative that the screening results are interpreted in conjunction with background information gathered from teachers and parents so that informed recommendations may be made, preventing children who need learning support to slip through the net and denied attention. It is also important to ensure that children who do not have a learning difficulty are correctly identified as such.

This is only an exploratory study in the evaluation of the effectiveness of Lucid Rapid in Singapore and its limitations are acknowledged. The sample of children used in this study was based on an unselected sample of children, referred for the screening by parents and teachers who suspected that their children might have learning difficulties. In this sample, 74 per cent were found to be dyslexic as compared to the estimated prevalence of dyslexia of five per cent to 10 per cent in a general population (Rodgers, 1983; Shaywitz et al., 1992; Siegel, 2006). It might be inappropriate to generalise some of these findings to the general school population.

Despite working with the set basic criteria for the diagnosis of dyslexia in conventional assessments, a varied battery of normalised tests can be used in the formal assessments of children with dyslexia. As formal assessments were administered by a total of 19 psychologists in this study, both from the DAS and external agencies, there were likely to be differences in the criteria and personal preferences amongst the professionals in the conventional tests used. The varied normalised tests administered have resulted in the varied sample numbers used for data analysis. This is likely to limit the robustness of the study. Thus, designated specific tests in conventional assessments would provide some standardisation to the sample numbers.

The DAS experience in using the Lucid Rapid for the mass screening of children at risk of dyslexia in Singapore can no doubt be useful information for practitioners who are using CBA for the identification of children who might be at risk of dyslexia. Although the Lucid Rapid has been shown to be rather accurate in identifying children with dyslexia, it is important to be vigilant in identifying the false positives and false negatives. It is also important to understand that the children's proficiency in the English language may affect results on the Lucid Rapid. This research should be relevant to practitioners who have a keen interest in using the Lucid Rapid or other CBA for the identification of children at risk of dyslexia.

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Appendix

The phonological processing measure on the Lucid Rapid was found to correlate significantly with cognitive measures such as, General Conceptual Ability/Full Scale Intelligence Quotient (r=0.21, p=.001), Non-verbal Reasoning Cluster (r=0.18, p=.006), Verbal Cluster/Verbal Comprehension subtest (r=0.19, p=.003), Spatial Cluster (r=0.14, p=.03), Vocabulary/ Word Definitions subtests (r=0.15, p=.02), Verbal Similarities subtest (r=0.17, p=.009) and Recall of Digits Forward subtest (r=0.28, p=.009). Significant correlations were also observed for literacy measures such as, Spelling (r=0.19, p=.002), Word Reading (r=0.21 p=.0007), Non-word/Pseudoword (r=0.20, p=.0016) and Reading Comprehension (r=0.24, p=.0002).

The auditory sequential memory measure on the Lucid Rapid was found to correlate significantly with General Conceptual Ability/Full Scale Intelligence Quotient (r=0.16, p=.009), Non-verbal Reasoning Cluster (r=0.15, p=.02), Verbal Cluster/Verbal Comprehension subtest (r=0.15, p=.02), Vocabulary/Word Definitions subtest (r=0.19, p=.002), Verbal Similarities subtest (r=0.14, p=.03) and Recall of Digits Forward subtest (r=0.27, p=.0001). Significant correlations were also observed for literacy measures such as Spelling (r=0.17, p=.007), Word Reading (r=0.15, p=.02), Listening Comprehension (r=0.20, p=.01) and Reading Comprehension (r=0.16, p=.004).

Phonic decoding on the Lucid Rapid was found to correlate significantly with the Recall of Digits Forward subtest (r=0.21, p=.009) as well as literacy measures such as, Spelling (r=0.24, p=.003), Word Reading (r=0.33, p=.0001), and Reading Comprehension (r=0.23, p=.004). Phonic decoding on the Lucid Rapid also correlates with the Alliteration test (r=0.28, p=.01), Rhyme test (r=0.43, p=.0001), Rhyme Fluency test (r=0.30, p=.009) and Naming Speed (Digit) test (r=0.27, p=.01).

Visual-verbal integration memory on the Lucid Rapid was also found to correlate significantly with the Spatial Cluster (r=0.30, p=.005) and the Alliteration test (r=0.30, p=.03).