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Gender-specific Contribution of a Visual Cognition Network to Reading Abilities

British Journal of Psychology, in press

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Word count: 3,411 (*Short Report*)

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Abstract

Based on the assumption that boys are more likely to tackle reading based on the visual modality, we assessed reading skills, visual short-term memory (VSTM), visual long-term memory for details (VLTM-D), and general non-verbal cognitive ability in primary school children. Reading was within the normal range both in accuracy and understanding. There was no reading performance gap in favour of girls, on the contrary, in this sample boys read better. An entire array of visual, non-verbal processes was associated directly or indirectly with reading in boys, whereas this pattern was not observed for the girls.

Keywords: Gender differences, Reading, Visual Short-Term Memory, Visual Long-Term Memory, Non-verbal Intelligence

Over the last decades there has been a vivid discussion regarding reading-related gender differences in school children. While some studies reported significant advantages of reading achievement for girls (i.e., the “reading gender gap”, see Lynn & Mikk, 2009; OECD, 2004), others questioned whether these differences should be considered large enough to represent a noteworthy effect (e.g., Hyde, 2005). In general, the most consistently and robustly reported gender difference in cognitive processing styles refers to a small but significant advantage for boys in visuospatial tasks involving memory (e.g., mental rotation), whereas girls are frequently reported to perform slightly better in verbal tasks (e.g., Andreano & Cahill, 2009; Halpern, 2000; Linn & Petersen, 1985; Moore & Johnson, 2008; Voyer, Voyer, & Bryden, 1995). As a consequence, it appears conceivable that boys might take advantage of their pronounced visuospatial skills during reading, so that reading performance in boys may be closer related to visual (word) processing skills compared to girls. Indeed, many children show a selective correlation between one word memory modality (i.e., visual or auditory) and reading (Lange-Küttner & Krappmann, 2011). Hence, the research question in the current study was whether aspects of visuospatial memory performance are relevant for the development of reading skills and contribute differently to reading performance in boys and girls.

Visual short-term memory (VSTM) is conceptualized as a cognitive component that temporarily stores incoming visual information for ongoing cognitive tasks (see Baddeley, Eysenck, & Anderson, 2009). With respect to reading, VSTM can be regarded as a gatekeeper between the short-lived flow of perceptual impressions of notation and the crystallized knowledge of language-specific orthographic patterns of letter combinations (see Dehaene et al., 2010). Although in adults visual and verbal STM are assumed to be modular systems (De Renzi & Nichelli, 1975; Shallice & Warrington, 1970), their interplay in complex cognitive tasks such as reading is less well understood. On the one hand, many studies suggested separated systems for pictures and words in visual memory (e.g., Whitehouse, Maybery, &

Durkin, 2006), and some previous reading studies found no correlation between reading ability and visual STM, but only with verbal STM (e.g., Gathercole, Alloway, Willis, & Adams, 2006; Scanlon & Vellutino, 1997). On the other hand, many studies indicated that basic visual skills might be directly related to reading skills (e.g., Bosse, Tainturier, & Valdois, 2007; Cornelissen, Hansen, Hutton, Evangelinou, & Stein, 1998; Dehaene et al., 2010; Lange-Küttner & Krappmann, 2011; Pammer, Lavis, Handen, & Cornelissen, 2004; Stein, 2003; Vidyasagar & Pammer, 2009).

One reason for this mixed evidence may be that most of these studies did not report gender analyses. Another reason may relate to the fact that most of these studies did not utilize VSTM tasks emphasizing visual attention to detail, which may be of crucial relevance for developing reading skills. For example, Scanlon and Vellutino (1997), who overall did not report a systematic correlation between VSTM and reading, mentioned that reading skills could be predicted by performance in a visual task in which "accurate performance is dependent on careful (sometimes feature-by-feature) scrutiny of the target and foil items" (Scanlon & Vellutino, 1997, p. 208). Furthermore, a study involving the Benton Visual Retention Test (BVRT), which specifically emphasizes "attention to detail" in complex visual patterns, suggested a common underlying factor for visual and verbal memory tasks (Larrabee, Kane, Schuck, & Francis, 1985). Since written words consist of complex visual patterns where highly detailed physical differences in word structure can play a major role with respect to a word's meaning (Lange-Küttner, 2005), it may well be that VSTM tasks that involve "attention to detail" would be specific enough to tap into a gender-specific underlying mechanism of word decoding.

Indeed, first evidence for a gender-specific contribution of visual skills to reading performance in children was reported recently (Mohamed, Elbert, & Landerl, 2010). In their sample of Arabic primary school children, boys outperformed girls with respect to reading skills. Mohamed et al. reported that this male advantage in literacy skills was related to visuo-spatial abilities as measured by the Raven Coloured Progressive Matrices Test (CPM), an entirely non-verbal test that assesses reasoning using increasingly detailed visual patterns.

In the present study, we tested whether there is a connection between VSTM performance in another test that emphasizes attention to visual detail, namely the BVRT, and reading skills in English school children. More specifically, we tested whether there is a gender-specific relation between VSTM and reading abilities which probably results from modality-specific reading strategies in girls and boys. Since reading generally involves the retrieval of visual patterns (i.e., words) from long-term memory, we additionally developed and administered a novel computer-based assessment of visual long-term memory for details (VLTM-D).

Method

Participants

Thirty-six children (18 boys, *M* = 10 years, *SD* = 7 months and 18 girls, *M* = 10 years, *SD* = 8 months) with a multi-cultural background (33% Caucasian, 25% African, 19% Asian, 22% mixed/other ethnicity) from a Primary School in the City of London, UK, took part in the study. Mean age and amount of prior reading instruction did not significantly differ across gender groups (Table 1), all *t*s < 1. The children were a random sample based on obtaining parent consent via the classroom teacher. All children had normal or corrected-to-normal vision.

Material and Procedure

Children were tested individually in a quiet and separate room in the school, far away from their classroom. Each assessment lasted about 70 minutes. Tests were administered in the same fixed sequence as reported in the following paragraphs, except for the VLTM-D, where presentation was given at the beginning and the corresponding recognition test at the end of the session.

Reading. The Neale Analysis of Reading Ability (NARA II; Neale, 1997) provides standardized scores for reading accuracy and comprehension. It is widely used in research and education in English-speaking countries. Children read aloud small stories of increasing difficulty, and the investigator counts any reading errors. After each story, comprehension questions are asked. The total amount of reading errors yields a reading accuracy score.

Visual short-term memory. The BVRT (Benton, 1974) was developed originally as a tool designed to assess “visual perception, visual memory, and visuoconstructive abilities” (Benton, 1974, p. 1). Further research demonstrated that in healthy participants the BVRT mainly assesses VSTM (e.g., Moses, 1986), with an emphasis on visual detail information. We administered the BVRT in its reproduction form: Participants reproduced ten complex abstract geometrical stimuli on a plain sheet of paper without time constraints immediately after presentation. The amount of reproduction errors (as defined in the manual) served as the variable of interest (see Moses, 1986).

General cognitive non-verbal abilities. Part 1 of the Culture Fair Test (CFT 20; Cattell, 1960; revised by Weiss, 1998) tests a series of abstract geometrical matrices. It assesses non-verbal reasoning.

Visual long-term memory. Previous visual LTM tests focus on recognizing distinct objects as a whole, whereas written language is special in that small details of visual patterns are of vital importance for the specific identity of orthographic representations. VLTM-D consists of two parts, an encoding part, in which 25 complex abstract figures (black and white line drawings) are presented for five seconds each, and a recognition part administered one hour later, in which 50 displays are presented in randomized order. In the encoding part, children were asked to memorize all items as accurately as possible for the subsequent recognition test. In the recognition part, each display consisted of five alternative figures that only differed in minor details (see Figure 1). Only half of the displays contained a figure that was presented in the encoding part. For each display, participants verbally indicated whether one of the five items was presented during presentation at the beginning of the session (object-related question), and if yes, which one exactly (detail-related question). Correspondingly, an object-related score (sum of item-related errors) and a detail-related score (sum of detail-related errors) were obtained (test can be requested from the first author).

Results

Correlation tests were carried out two-tailed. Gender differences in reading and visual cognition were tested using a split-sample (Lange-Küttner, 2010). There was no gender difference in general non-verbal cognitive abilities (CFT 20), $t(34) = 1.3$, *ns*, nor in VSTM abilities, $t(34) = 1.19$, *ns* (see Table 1). Mean standardized NARA test scores (defined by a mean of 100 and standard deviation of 15, with higher scores representing better performance) revealed average and thus representative reading abilities in both gender groups (girls: $M = 100$ accuracy, $M = 103$ comprehension; boys: $M = 108$ accuracy, $M = 113$ comprehension).

Boys exhibited marginally higher reading accuracy than did girls, see Table 1, $t(34) = 2.06$, $p = .051$. Boys' significantly higher comprehension scores, $t(34) = 2.44$, $p = .021$, showed that this was not due to more superficial reading. There was a strong correlation between NARA accuracy and comprehension raw scores, $r = .85$, $p < .001$ (see also Spooner, Baddeley, & Gathercole, 2004). The following analyses will focus on reading accuracy only, which exhibited more overall variance in the sample (*SD* = 19 vs. *SD* = 7.5 for comprehension) and was thus considered to be more informative about individual differences.

Similar to previous studies (e.g., Gathercole, Alloway, Willis, & Adams, 2006; McDougall, Hulme, Ellis, & Monk, 1994; Scanlon & Vellutino, 1997), there was no significant correlation between VSTM (amount of errors in the BVRT) and reading accuracy (NARA raw scores), $r = -.24$, *ns*, in the whole sample. Most importantly, however, when carrying out the split-sample correlation analysis for gender, there was no significant correlation for girls, $r = .22$, *ns*, but a high and significant negative correlation for boys, $r = -.62$, $p = .006$, indicating that fewer VSTM errors went hand in hand with higher reading accuracy, $z = 2.60$, $p = .005$, for the gender difference between correlations. The inspection of the scatterplots (see Figure 2) demonstrates that this gender difference was not due to one or two outliers in either of the two groups.

There was a correlation between the non-verbal intelligence score of the CFT20 and reading accuracy for the entire sample, $r = .37$, $p = .027$. But like for the BVRT, the split-sample analysis for gender showed that the non-verbal CFT20 intelligence score was correlated significantly with reading in boys, $r = .49$, $p = .038$, but not in girls, $r = .26$, *ns* ($z = 0.74$, *ns*, for the gender difference between *r*s). Furthermore, the CFT20 was significantly correlated with the BVRT in boys, $r = -.71$, $p = .001$, but not in girls, $r = .18$, *ns* ($z = 2.93$, $p = .002$, for the gender difference between *r*s).

The two long-term memory scores of the VLTM-D did neither significantly correlate with reading accuracy in the entire sample, *p*s > .67, nor for boys, *p*s > .14, or girls, *p*s > .28. There were no gender differences concerning the VLTM-D scores, all $t < 1$. Importantly, however, we found that although the VLTM-D did not correlate with the non-verbal intelligence score CFT20 in the complete sample, *p*s > .12, it did in the gender-split sample:

The object-related errors of the VLTM-D showed a significant negative correlation with the CFT20 in boys, $r = -.54$, $p = .022$, but not in girls, $r = .11$, *ns* ($z = 1.94$, $p = .052$, for the gender difference between *r*s). Conversely, the detail-related errors of the VLTM-D showed a positive correlation with the CFT20 in girls, $r = .53$, $p = .023$, but not in boys, $r = -.17$, *ns* ($z = 2.08$, $p = .040$, for the gender difference between *r*s).

With respect to correlations between detail-related visual LTM and STM, we found a significant correlation of the object-related VLTM-D score and BVRT errors in boys, $r = .48$, $p = .042$, whereas there was no such correlation in girls, $r = .02$, *ns* ($z = 1.37$, *ns*, for the gender difference between *r*s). To make the gender-specific correlational structure clear to the reader, a flowchart diagram illustrates the pathways between the two scores of visual long-term memory (object-score and detail-score), visual short-term memory, visual non-verbal intelligence, and reading in boys and girls (Figure 3).

Because we were now interested in how visual abilities would interact with reading accuracy and gender, and correlations could not test this directly, we divided the complete sample into two groups of low vs. high VSTM skills, based on the median of the BVRT error score. An ANOVA was conducted with NARA reading accuracy as a dependent variable and VSTM skill (low vs. high) and gender (male vs. female) as independent variables. No significant between-subject main effects of the STM and gender variables with respect to reading accuracy were found, all *p*s > .20, showing comparable performance. However, the predicted interaction of gender and VSTM skill was significant, $F(1,34) = 5.64$, $p = .024$, $\eta_p^2 = .15$. Post hoc Bonferroni-adjusted tests revealed a significant reading advantage for boys with high VSTM skills compared to low VSTM skills, $t(16) = 3.35$, $p = .008$, whereas this was not the case for girls, $t(16) = 1.10$, *ns* (see Figure 4). Partialling out non-verbal cognitive ability (CFT 20) as a covariate did not abolish the still significant difference between high and low VSTM skills in the group of boys, $F(1,17) = 4.52$, $p < .05$.

Discussion

Overall, the standardized NARA scores indicated that the present sample of school girls and boys exhibited average reading skills, ensuring the representativeness of the group comparisons. We addressed the question whether British primary school boys and girls differ with respect to the correlation between visual processing skills and reading performance. This prediction was derived from previous observations indicating a close link between visual memory and reading skills (e.g., Bosse, Tainturier, & Valdois, 2007; Dehaene et al., 2010; Stein, 2003; Vidyasagar & Pammer, 2009), and a small but significant male advantage for visual memory skills (e.g., Andreano & Cahill, 2009; Halpern, 2000). We reasoned that boys might take advantage of their pronounced visuospatial skills, and hypothesized that their reading performance would be closely related to visual cognition.

The present data clearly supported this assumption: Only in boys, visual abilities, and in particular VSTM skills, were closely related to reading performance. Importantly, this result was not obtained for boys with reading problems, but within an average population of school children, where reading performance was better for boys than for girls.

Given that the present sample was taken from a multiethnic school population in London, it appears interesting that this main finding is well in line with another recent study reporting data from Arabic primary school children (Mohamed et al., 2010). First, their data also suggested better reading skills for boys compared to girls. Second, and most importantly, they also found evidence for the claim that this male advantage in literacy skills was related to visuo-spatial abilities. This consistency significantly enhances the reliability, external validity, and credibility of the present findings which supported the hypothesis that visuo-spatial cognition in boys can support their reading excellence.

Overall, these data offer a new perspective on previous research that reported mixed evidence regarding the relationship between VSTM and reading (e.g., Gathercole, Alloway, Willis, & Adams, 2006; Scanlon & Vellutino, 1997). Our data suggest that analyses that do not take gender into account may easily conceal the importance of visual abilities for reading in boys. Furthermore, most previous studies did not utilize VSTM tasks emphasizing attention to visual detail. The BVRT shares the productive aspect of drawing visual detail with drawing in general, where with the onset of reading and writing in school, symbolic pictograms loose in importance, while resource-intensive realistic detail and geometric perfection becomes more relevant (Lange-Küttner, 1998).

For beginning readers words basically represent complex visual patterns where small details are of great importance for the formation and retrieval of orthographic representations in long-term memory. Such a long-lasting storage of orthographic patterns is sometimes referred to as “visual word form system” or “orthographic input lexicon” (see Dehaene et al., 2010; Price & Devlin, 2003 for a debate), and the present results suggest a close link between visual word form processing and object-related visual shape processing in the boys’ group. This gender-specific effect corresponds with a previous study on the neural basis of gender differences in visual word learning, which reported gender-specific activation patterns in fusiform regions (e.g., Chen et al., 2007; Dong et al., 2008).

Current models of word identification postulate at least two distinct processing pathways, namely a grapheme-phoneme conversion route and a lexical pattern decoding route (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). Lexical processing was broadly defined as the ability to form, store, and access orthographic representations (Castles & Nation, 2006) involving memory for specific visual patterns (Barker, Torgesen, & Wagner, 1992). Corresponding orthographic processing skills have been shown to predict variance in word recognition even when phonological and alphabetic skills were controlled (e.g., see

Barker, Torgesen, & Wagner, 1992; Berninger, 1994; Cunningham & Stanovich, 1990). Interestingly, there is also previous evidence for gender effects with respect to the relative weight of the two word processing routes. Coltheart, Hull, and Slater (1975) reported that adult males were more likely to use visual cognition during lexical access, while females relied more strongly on phonological processing (see also Wolf & Gow, 1986). While future research would have to investigate the latter more closely in the context of the assessments used in the present study, our results are well in line with the assumption that males especially rely on visual cognition during the online process of reading.

More specifically, it is important to consider the significant indirect contribution of the object-score of the visual VLTM-D (LTM specifically assessed with highly detailed complex line drawings) to reading, as it correlated with both BVRT performance and non-verbal visual intelligence (CFT20) in boys' only. Probably, this can be tentatively interpreted as evidence that the stronger activity of VSTM in boys may have been closely linked to a more pronounced, and perhaps even meaningful, visualization of orthographic patterns retrieved from LTM during reading. Within this context, the object-specific VLTM-D score would denote the presence of an object that covers a visual area like a word, while the detail-related score only denoted a small part of an object itself – comparable to a part of a letter.

Based on the present study alone, at least two further causes for the strong correlation between visual skills and reading in boys appear plausible. First, it appears that reading development in boys generally relies on the use of VSTM in a more pronounced way, which in turn was linked with a whole array of visual cognition processes. This would speak for a more general visual approach of boys to reading. Second, that boys who were poorer in VSTM were also poorer in reading, is in line with the magnocellular theory of reading and reading-related deficits (Stein, 2003). This theory assumes that magnocellular deficits might pose difficulties in visual attention to detail, processing of serial information (Cornelissen et al., 1998), and eye movement control (e.g., see Huestegge, Radach, Corbic, & Huestegge, 2009). These factors should also be major determinants underlying both VSTM (as measured by the BVRT) and word processing performance (Chuah & Maybery, 1999; Pickering, Gathercole, & Peaker, 1998).

Interestingly, unlike in boys we observed a positive correlation between visual intelligence and detail-related errors in the VLTM-D for girls, as if too much attention to visual details might detract them from more general goals of visual cognition. This can indeed be the case, as for instance in cube drawing, drawing too many surface details can distort the overall shape (Lange-Küttner, Ebersbach, & Lorenz, under review). However, this potential gender-specific contribution of visual LTM needs to be examined more closely in future research before any stronger statements can be made.

Finally, the overall finding that boys relied more strongly on visual strategies might at least partly explain why boys more often suffer from severe reading problems (e.g., Liederman, Kantrowitz, & Flannery, 2005), since low visual skills would impede the first parse on the visual intake of a word in boys, but not (or to a lesser degree) in girls. If one assumes that boys are predominantly visuo-spatial processors, we could presume that dyslexic boys are dependent on both an effective visual and phonological processing strategy, whereas dyslexic girls (like normally reading girls) just never relied on a visual strategy in the first place (see Heim et al., 2008, for a discussion). However, these potential implications of the current findings should be addressed explicitly in future studies.

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Table 1

Sample characteristics as a function of gender.

	Boys (n = 18)		Girls (n = 18)	
	M	*SD*	*M*	*SD*
Age	10;3	7	10;5	8
Years of school education	5;5	0;5	5;6	0;7
Culture-Fair Test (IQ)	109	17	103	11
NARA reading accuracy score	81	12	68	22
NARA reading comprehension score	35	6	29	8
BVRT (Visual STM errors)	3.83	3.2	4.83	1.5

Figure captions

Figure 1. Examples of VLTM-D items. Each line represents the five variants of one figure. Whereas only one particular figure was presented in the encoding part, all five variants were displayed during the recognition test phase.

Figure 2. Scatterplots for the correlation between visual short-term memory (amount of errors in the BVRT) and reading accuracy (NARA raw scores) for girls (upper panel) and boys (lower panel).

Figure 3. Pathway diagram of visual STM, visual LTM and non-verbal visual intelligence in relation to reading accuracy (gender-specific correlations)

Figure 4. Mean reading accuracy (NARA scores + *SE*) as a function of gender and VSTM skills.

Figure 1

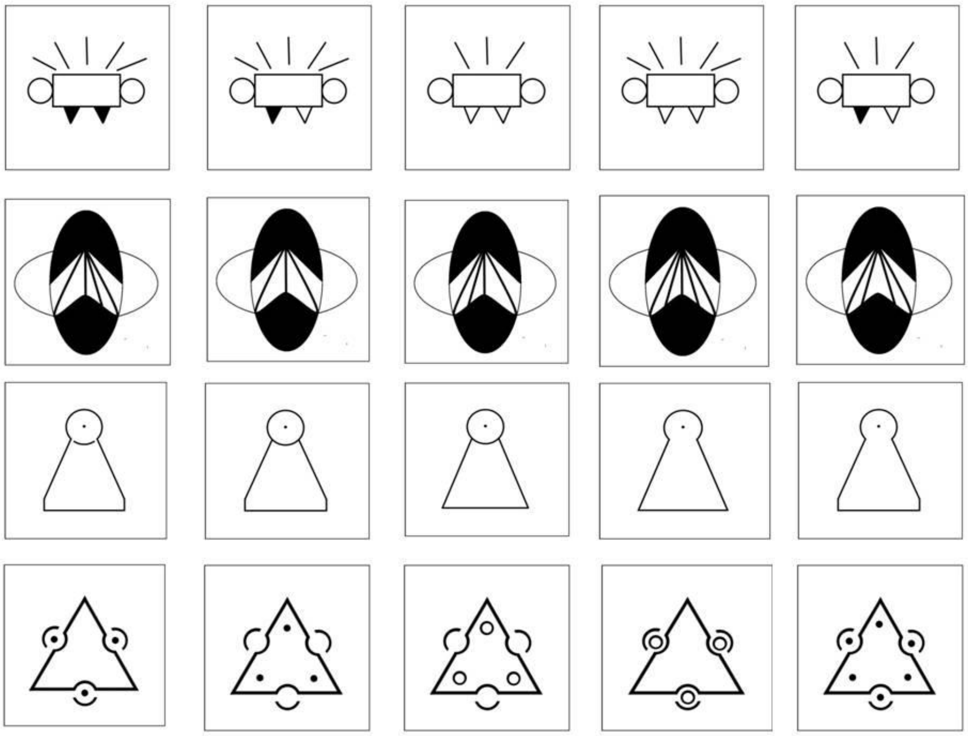


Figure 2

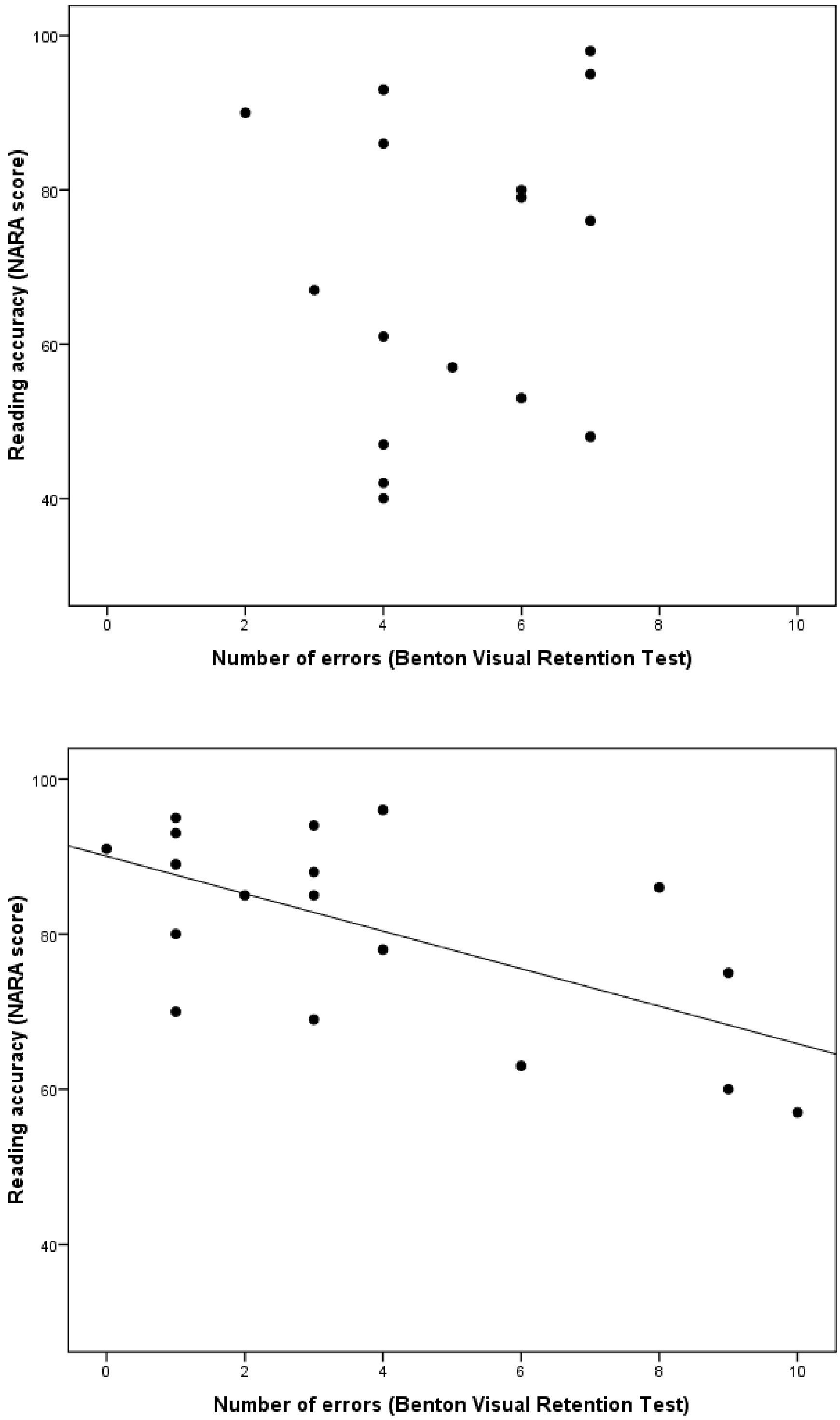

100
80
60
40
Reading accuracy (NARA score)
0
2
4
6
8
10
Number of errors (Benton Visual Retention Test)
100
80
60
40
Reading accuracy (NARA score)
0
2
4
6
8
10
Number of errors (Benton Visual Retention Test)

Figure 3

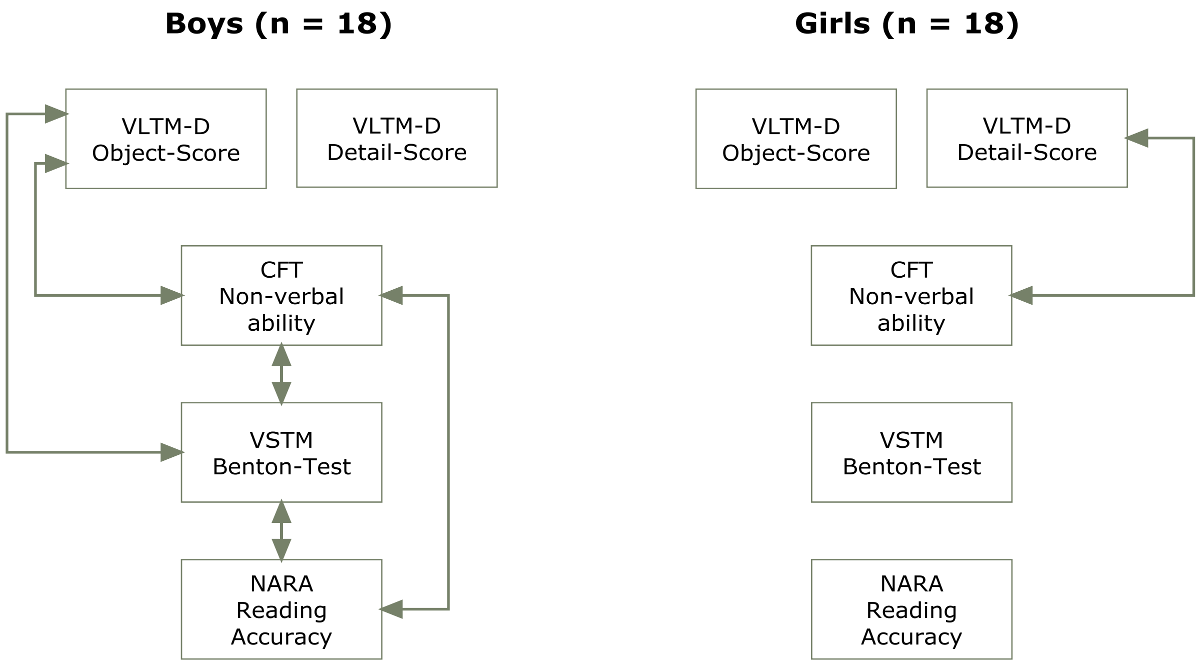
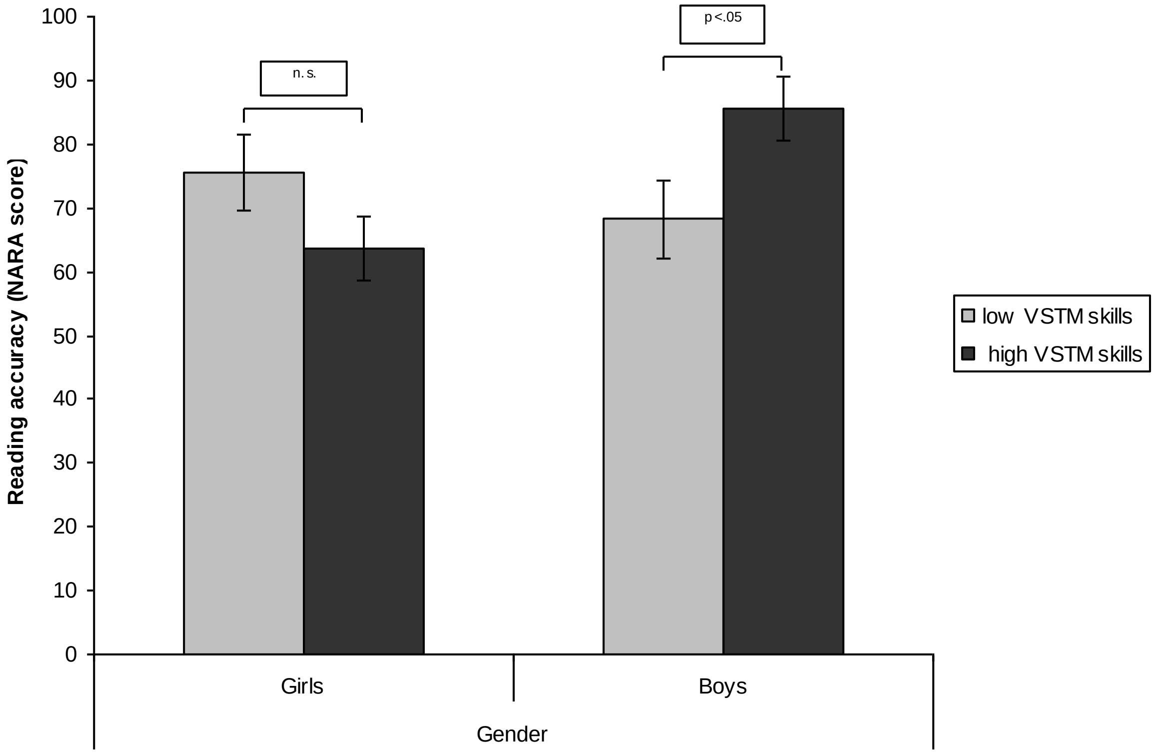

Boys (n = 18)
VLTM-D
Object-Score
VLTM-D
Detail-Score
CFT
Non-verbal
ability
VSTM
Benton-Test
NARA
Reading
Accuracy
Girls (n = 18)
VLTM-D
Object-Score
VLTM-D
Detail-Score
CFT
Non-verbal
ability
VSTM
Benton-Test
NARA
Reading
Accuracy

Figure 4



100
90
80
70
60
50
40
30
20
10
0
Reading accuracy (NARA score)
n. s.
p <.05
Girls
Boys
Gender
low VSTM skills
high VSTM skills