Using eye movements to index reading comprehension ability

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Reading comprehension is an essential skill in modern society, yet little is known about the processes that support successful reading comprehension. The debate about which cognitive skills are involved in reading comprehension, and which are necessary for successful comprehension is therefore still ongoing. This complexity, which makes reading comprehension so difficult to define, also makes it difficult to measure. Previous studies suggest that reading comprehension tests do not all measure the same cognitive skills to the same extent (e.g. Keenan, Betjemann, & Olson, 2008), and that they are not all equally sensitive to reading difficulties (e.g. Keenan & Meenan, 2014). We investigated this issue by examining the degree to which three widely-used reading comprehension tests assess the same cognitive processes. Additionally, we investigated the potential of eye movements as an ecologically valid, online measure of reading comprehension.

We administered three reading comprehension tests to 79 adults: the *Gray Oral Reading Test* (GORT-5; Wiederholt & Bryant, 2012), the sentence comprehension subtest of the *Wide Range Achievement Test* (WRAT-4; Wilkinson & Robertson, 2006), and the *York Assessment for Reading Comprehension* (YARC; Snowling et al., 2009). In the GORT, participants read 11 passages aloud, and answered comprehension questions. In the WRAT, participants were given 31 sentences which had a word missing in them, and had to provide the missing word (cloze procedure). In the YARC, participants read 2 long passages silently, followed by comprehension questions and a summarization question. The tests were administered in random order, and participants' eye movements were monitored while they completed the tests.

The correlations between reading comprehension tests scores were significant but moderate (0.59-0.63). For each test, the correlations between test scores and eye-movement measures yielded different patterns of results. Test scores were more strongly correlated with early eye-movement measures (gaze duration, first fixation duration) for the GORT and the YARC, and with late eye-movement measures (go-past time, total reading time) for the WRAT (Table 1). To further examine the relationship between comprehension and eye movements, we carried out two additional analyses. To extract a common comprehension component from the three scores, we calculated the mean and the standard deviation of the three scores. We then correlated these with eye-movement measures. The former tells us about how someone's overall performance relates to their overall eye-movement behaviour, and the latter tells us about whether variability in the scores relates to variability in the eye movements. The results showed that the mean scores correlated with both early and late measures (Table 2). On the other hand, the standard deviation correlated with the late measures (regression rate, reading speed), which are associated with higher-level processes of reading, but not with the early measures (gaze duration, frequency effect on gaze duration), which are associated with earlier processes of reading such as lexical processing (Clifton, Rayner, & Staub, 2007)

Our results show that reading comprehension test scores are more strongly related to lexical processing in the GORT and YARC, and more strongly related to post-lexical processing in the WRAT. In line with previous research, these results indicate that reading comprehension tests do not all measure the same cognitive skills to the same degree. This has implications for the interpretation of reading comprehension test scores in both research and clinical settings. The results from the additional analyses shed light on the cognitive skills involved in reading comprehension, as well as the feasibility of using eye-movement behaviour to measure reading comprehension.

Table 1: Correlations between comprehension scores and eye movements

Measure type	Measure	GORT	WRAT	YARC
Global	Reading Speed	0.15 *	0.35 *	0.20 *
Global	Fixation Duration	-0.09 *	-0.13 *	-0.17 *
Global	Saccade Length	0.16 *	-0.02	0.05
Global	Number of Fixations	-0.06 *	-0.33 *	-0.08 *
Early	First-Fixation Duration	-0.08 *	-0.06 *	-0.16
Early	Gaze Duration	-0.16 *	-0.06 *	-0.24 *
Early	First-Pass Number of Fixations	-0.14 *	-0.02	-0.30 *
Late	Go-Past Time	-0.06	-0.34 *	-0.13
Late	Total Reading Time	-0.1 *	-0.34 *	-0.08

Note: This table shows the coefficients of correlations between comprehension scores and eye-movement measures for each test. Global measures were aggregated at the test level, while early and late measures were aggregated at the item level. Reading speed was calculated in words per minute, saccade length was calculated in characters, all other measures are in milliseconds. The WRAT scores were more strongly correlated with late and global measures, while the scores of the GORT and YARC were more strongly correlated with early measures. * = $p < 0.05$

Table 2: Correlations between mean and variance of scores and eye movements

Measure type	Measure	Mean	SD
Global	Reading Speed	0.50 *	0.27 *
Early	Gaze Duration	-0.33 *	-0.07
Early	Frequency effect on gaze duration	0.45 *	-0.18
Late	Regression rate	-0.04	$0.22^{p=0.051}$

Note: This table shows the coefficients of correlations between mean and standard deviation of test scores and eye-movement measures. Participants who performed better overall also read faster, had shorter gaze durations, and larger word frequency effects. Participants who performed differently in the three tests also show larger differences in reading speed and regression rate between the tests. This effect is not found for the early measures. * = $p < 0.05$

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