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Determining a Correlation Between Individual Differences In Eye Movements and Working Memory

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Thesis Summary

Visual perception is accomplished through saccadic eye movements, a system in which the eyes continually reorient their points of greatest visual acuity through a series of ballistic movements. Eye movements can be broken down into two main parts, the fixation, where the fovea (the point of greatest visual acuity) focuses on a certain point in the visual field to acquire information, and the saccade, a rapid eye movement to another fixation point in which the acquisition of visual information is suppressed.

Individual differences have been found between both fixation durations and saccade amplitudes across varying visual tasks. These individual differences have also been found cross-culturally, specifically for both English and Chinese speakers, in several visual tasks including face memorization, searching for a target object within a scene, and counting Chinese characters. Additionally, differences in fixation duration and saccade amplitude persist across differing formats, days, and visual contents as well as across varying degrees of foveal degradation.

Working memory is the process used to maintain and manipulate a small amount of information so that the information can be used to execute tasks. Several studies have shown that working memory can be correlated with general intelligence, reading comprehension, performance on the Stroop task, category learning and even moral judgments. In addition, poor visual working memory has been linked with deficits like ADHD.

The present study investigated if a relationship can be found between individual differences in saccadic eye movements and working memory measures. The focus of the study was to find a correlation between individual differences in fixation duration and established measures of working memory. Participants completed four eye movement tasks, as well as two tests of working memory.

Fifty-three USC students participated in the study either for compensation or extra credit. Eye movements were recording using an eye tracker. Every participant was administered each task in the same order and each of the six tasks took approximately 10 minutes to complete.

Previous findings that fixation durations and saccade amplitudes correlate were replicated. The data showed a negative correlation between one of the working memory tasks and eye movements during the reading task. Taken together, the results show that higher working memory span individuals utilize shorter and less varied fixation durations while reading. This provides evidence that a relationship exists between working memory and the eye movement system in reading. The present study was not designed to determine a causal role and so the data is not indicative of whether working memory influences the eye movement system or if the converse is true. However, the authors would speculate that the correlations found reflect the top down influence of working memory on the eye movement system.

Abstract

This study determined if a relationship exists between individual differences in eye movements and working memory measures. The eye movement system can provide insight into processes that occur in the mind as well as a better understanding of the relationship between quantifiable aspects of eye movements and the more abstract inner workings of the mind. Recently, consistent and reliable individual differences have been found in individuals' eye movement behaviors. For example, individuals with longer fixation durations for one visual task have longer fixations across all other visual tasks. The eye movements of participants were collected during four different viewing tasks in addition to data from two independent working memory tests (running span and automated operation span). The data showed a negative correlation between the operation span scores and eye movements during the reading task. These results suggest that the working memory system may have some influence over individual differences in eye movement behavior.

Humans are heavily reliant on vision for their everyday lives as vision is one of the critical ways in which we perceive our environment. Visual perception is accomplished through different eye movement systems, the predominate being saccadic eye movements. In saccadic eye movements the eyes continually reorient their points of greatest visual acuity through a series of ballistic movements. Eye movements during static viewing tasks can be broken down into two main parts, the fixation, where the fovea (the position of greatest acuity) focuses on a certain point in the visual field to acquire information, and the saccade, a rapid eye movement to another fixation point in which the acquisition of visual information is suppressed (Figure 1).

A few studies over the past decade have reported results indicating that individual differences exist between certain eye movement measures, suggesting that there exists something within an individual that acts on the eye movement system (Andrews & Coppola, 1999; Rayner, Li, Williams, Cave & Well, 2007; Castelhano & Henderson, 2008; Henderson & Luke, in press). Andrews and Coppola were the first to establish this phenomenon when they found that correlations existed between both fixation durations and saccade amplitudes across varying visual tasks (Andrews & Coppola, 1999). These individual differences have also been found cross-culturally, specifically for both English and Chinese speakers, in several visual tasks including face memorization, searching for a target object within a scene, and counting Chinese characters (Rayner et. al., 2007). Additionally, differences in fixation durations and saccade amplitudes persist across differing formats, days and visual contents as well as across varying degrees of foveal degradation (Castelhano & Henderson, 2008; Henderson & Luke, in press). During a fixation, the eyes engage in smaller eye movements, classified as either micro-saccades, drifts, or tremors (Martinez-Conde, Otero-Millan & Macknik, 2013). Recently, the oculomotor individual differences literature was expanded to include these micro-eye movements. Poynter et. al. used three measures, the average distance of gaze points in a fixation cluster (fixation size), the number of micro-saccades per second (micro-saccade rate) and length of the micro-saccade (micro-saccade amplitude) to determine if individual differences could be found in micro-eye movements (Poynter, Barber, Inman & Wiggins, 2013). Poynter et. al. (2013) demonstrated that these three measures (fixation size, micro-saccade rate and micro-saccade amplitude) all correlated significantly with each other as well as with the previously established stable measures of fixation duration and saccade amplitude.

Thus it seems as though individual differences in saccadic eye movements are consistent across tasks. This indicates that measures of saccadic eye movements are a stable and reliable measure, but it is still unknown what exactly these individual differences reflect. One possibility is that these eye movement differences are influenced by other cognitive individual differences, perhaps intelligence, speed of processing, or working memory. The coupling of eye movement individual differences with higher order cognitive measures of individual variability provides an elegant conceptual connection between visual cognition and executive functioning. Saccadic eye movements are used to perceive complex, real world stimuli as a continuous and critical part of everyday life. The processing of visual stimuli involves many cognitive systems, such as working memory and speed of processing, so it would follow that the top down influence of higher-level systems could influence fixation durations and saccade amplitudes.

One such higher-level system is working memory. Working memory is the process used to maintain and manipulate a small amount of information so that the information can be used to execute tasks (Baddeley, 1992). Working memory is what is responsible for skills like the ability to perform a series of math operations or understand the meaning of a complex sentence. Several studies have shown that performance on working memory tasks can be correlated with performance on intellectual aptitude tests, general intelligence, reading comprehension, performance on the Stroop task, reasoning ability factors, category learning and even moral judgments (Daneman & Carpenter, 1980; Oberauer, Wilhelm, Schulze & Sub, 2005; Kane & Engle, 2003; Kyllonen & Christal, 1990; DeCaro, Thomas & Beilock, 2008; Moore, Clark & Kane, 2008). In addition, poor visual working memory (the small amount of visual information held in the mind to carry out cognitive tasks) has been linked with deficits like ADHD (Castellanos & Tannock, 2002; Rapport, Alderson, Kofler, Sarver, Bolden & Sims, 2008; Klingberg, Fernell, Olesen, Johnson, Gustafsson & Dahlstrom, 2005).

Working memory may also influence eye movements because the processing of visual stimuli is intertwined with the working memory system. The famous Baddeley and Hitch model of working memory included a "visuospatial sketchpad" (Baddeley & Hitch, 1974), and several studies since then have shown that visual input can be held in working memory (Downing, 2000; Awh & Jonides, 2001; Schneider, 2013; Chun, 2011).

Given the relationship between working memory and visual input, it is conceivable that working memory measures will relate with eye movement measures. In fact, a series of four experiments done by Postle, Idzikowki, Sala, Logie & Baddeley (2006) found evidence that, "the control of visual imagery and visual working memory may derive from the same cognitive resources that support eye movement control" (Postle et. al, 2006). Additionally, it has been shown that the contents of visual working memory can influence gaze correcting saccades, saccade curvature, and the inhibition of saccades to the location held in working memory (Hollingworth & Richard, 2008; Theeuwes, Olivers & Chizk, 2005; Belopolsky & Theeuwes, 2009; for a review see Theeuwes, Belopolsky & Olivers, 2009).

Present Study

The present study investigated if a relationship can be found between individual differences in saccadic eye movements and working memory measures. The focus of the study was to find a correlation between individual differences in fixation duration and established measures of working memory. This study furthered the investigation into individual differences by determining if there is an underlying working memory process responsible for these differences. Past studies have established mean fixation duration as a measure that varies from individual to individual across many different tasks and concepts. However, what causes these individual variations remains unknown. The present study addressed this question by seeking to find a relationship between eye movements and performance on cognitive tests of working memory. Participants completed four eye movement tasks, as well as two tests of working memory.

Eye movements for the present study were collected from four different viewing tasks. These tasks were paragraph reading, paragraph pseudo-reading, scene viewing for a later memory task and searching through a scene for a hidden letter. These four tasks have produced stable individual differences in the past (Henderson and Luke, in press), and were also chosen because they provide a range of viewing situations that replicate realistic eye viewing.

The two working memory task used in the present study were the automated operation span task and the running span task. The automated operation span task was chosen because it is highly reliable and has been used throughout the working memory individual differences literature (Unsworth, Heitz, Schrock & Engle, 2005; Kane, Brown, McVay, Silvia, Myin-Germeys & Kwap, 2007; Jha, Stanley, Kiyonaga, Wong & Gelfand, 2010; Moore et. al., 2008; DeCaro et. al., 2008; Heitz & Engle, 2007). When trying to relate variations between individuals' eye movements and working memory, it is important to use a well-established measure of working memory so that it is more likely that the working memory measure is reliable. The running span task was chosen as an added working memory task because it utilizes auditory stimuli and therefore will provide information about how generalizable the working memory results are in relation to eye movements.

An exponentially modified Gaussian analysis (ex-Gaussian analysis) was used to analyze the fixation durations for each participant. This analysis is used to model data consisting of both a normal distribution and an exponential distribution. The mu parameter estimates the mean value of the normal distribution, the sigma value estimates the standard deviation of the normal distribution and the tau value represents the mean of the exponential function. Thus, this more complex form of analysis will allow the skew of the data to be taken into consideration and perhaps produce a more accurate statistical model of what is occurring in the data. The ex-Gaussian analysis has traditionally been used to analyze reaction time data for many tasks, like the lexical decision task

(Steinhauser & Hübner, 2009; Dawson, 1988; Heathcote, Popiel & Mewhort, 1991; McAuley, Yap, Christ, & White, 2006; Schmiedek, Oberauer, Wilhelm, Süß, & Wittmann, 2007; Balota & Yap, 2011). However, this author could only find three uses of the analysis with eye movement data (Staub, White, Drieghe, Hollway, & Rayner, 2010; Reingold, Reichle, Glaholt, & Sheridan, 2012; Luke, Nuthmann & Henderson, 2013). Because the ex-Gaussian analysis incorporates measures of skew, it was used in the present study because it might provide a more sensitive model with which to detect individual differences in oculomotor behavior.

Method

Participants. Fifty-three University of South Carolina students participated in the study either for compensation (eight dollars per hour) or extra credit. All participants participated voluntarily, had normal or corrected to normal vision, were native English speakers and were unaware of the purpose of the study. This study was approved by the University of South Carolina Institutional Review Board and every participant signed an informed consent form.

Apparatus. The eye movement data were recorded with a SR Research Eyelink 1000 eye tracker (spatial resolution 0.01°) sampling at 1000 Hz. Participants sat approximately 90 cm away from a 20 inch monitor, such that computer images subtended approximately 20°x15° of visual angle. Chin and headrests were used to minimize head movements. Eye movements were recorded from the right eye, but viewing was binocular. A nine-point calibration routine given at the beginning of the each new eye tracking block mapped eye position to screen coordinates using SR Research Experiment Builder software. If recalibration was needed during testing, data collection was paused and a recalibration was administered. Eyetracker calibration was not accepted until the average error was less than .49° and the maximum error was less than .99°.

Working memory tests were administered on a ViewSonic Graphics Series G90fB monitor manufactured by Dell Precision T3500. The running span test was an application entitled RunningSpan 8.0.0.0 for Windows (Copyright University of Missouri All rights reserved, see Bunting, Cowan & Saults, 2006). The Automated Operation Span task was an E-Run 2.0 Script file (see Unsworth et. al., 2005, downloaded from http://psychology.gatech.edu/renglelab/tasks.html).

Stimuli. Scene Memorization. For the scene memorization task, 40 color photographs of various indoor and outdoor scenes were used (Figure 2).

Scene Search. The search task used 48 photographs similar to those used in the memorization task and in two thirds of the pictures, a letter “L” was hidden within the picture. Participants were given one practice example before data collection began in order to acquaint themselves with what the target would look like.

Reading. The reading task used 35 texts written in English, taken from online magazine and newspapers. Each text was approximately 40 words and was presented such that approximately 3.5 characters subtended 1 degree visual angle. The letter was 12 point Tahoma font and was grey.

Pseudo-reading. The pseudo-reading task used a pseudo-reading font that was developed by replacing each letter with a pseudo-letter (Henderson & Luke, 2012). This was done for 35 texts, which were then presented such that the pseudo text was the same size as the reading text (because of the pseudo-letter’s resemblance to LEGO toys, the font was named LEGO text).

AOSPAN. The AOSPAN utilized black and white letters and numbers (Figure 3).

Running Span. The auditory stimuli for the running span tasks were the digits 1-9 recorded by a male voice and compressed to 250 ms.

Procedure. Participants completed both the eye tracking and working memory tasks during a single 2 hour session. Every participant was administered each task in the same order: scene memory, reading, scene search, pseudo-reading, running span, and operation span. Each task used identical stimuli presented in identical order.

During each eye movement task, the participant was asked to look at a fixation cross presented in the center of the computer screen and to press a button on a button response pad while fixating. If the fixation was within 2 degrees of the fixation cross, the trial began. Each stimulus was presented for 12 seconds and then returned to the fixation cross, with the exception of the scene search task. In this task, if the participant located the target letter, they could press a button to end the trial early.

Scene Memorization. Participants were instructed to look through the image and memorize the scene for a memory test given at the end of the experiment.

Reading Task. Participants were asked to read through paragraphs of text in a natural manner. If the participant reached the end of the text before the 12 seconds had expired, the participant was asked to reread the text from the beginning.

Scene Search. Participants were instructed to search through the scene for a hidden letter "L". Participants were told to press a response button if they found the target letter.

Pseudo-reading task. Participants were instructed to move their eyes through a paragraph block of pseudo-text as if they were reading it. Each eye movement task took approximately 10 minutes to complete.

AOSPAN. The Automatic Operation Span task required the participant to perform a series of simple two-step math operations while remembering single letters interleaved between the math operations (Figure 3). The test began with a practice session in which participants familiarized themselves with the program and tasks. Participants practiced recalling the letters and then the math operations, followed by a practice of the two interleaved. Each letter (F, H, J, K, L, N, P, Q, R, S, T, and Y) was presented in the center of the screen for 800 ms. After presentation, the participants were shown a 4x3 matrix of the possible 12 letters and were instructed to click on the presented letters in the order in which the letters were presented. The math operations were a combination of multiplication and addition of single digit integers. Participants were instructed to click the screen to signal when they had completed the math operation and were then shown a true or false statement about the math equation. The participants were instructed to respond with either true or false. Completion time for an individual math problem was calculated during the practice trials in order to accommodate for individual differences in mathematic ability. During the actual testing, a time limit of 2.5 times the standard deviation of this time was instated to ensure that participants were working as quickly as possible. If the participant had not signaled they had completed the math problem within this time frame, the trail was counted as an error. Additionally, participants were asked to stay above 85 percent accuracy with their math responses and their accuracy percentage was displayed in the upper right hand corner of the screen when the feedback screen was displayed. During the actual testing, participants performed 3 sets of trails for 3, 4, 5, 6, and 7 set sizes (amount of letters to be recalled). After the participant reported the remembered letters, a feedback screen appeared to report how many letters were recalled in the correct serial position. Completion of this test took approximately 10 minutes total. *Running Span.* Participants completed a total of 32 trails. Participants were instructed to listen to a list of rapidly spoken digits, which ended unpredictably. After the instruction screen, the word "ready" appeared on the screen for 2 seconds followed by a list of 12-20 random digits. When the digit list ended, response boxes appeared on the screen and the participants were asked to recall as many digits as they could from the end of the list in the order in which the digits were presented. Subjects used the keyboard number pad to input responses and the entire test took approximately 10 minutes to complete.

Data Analysis. Analysis of the results was performed using the R programming software. Fixation durations greater than 1500 ms and less than 50 ms were excluded from the data, as well as blinks. Data from 8 participants were excluded due to experimenter error, and/or missing data. This exclusion also included participants who had mean fixation durations 3 standard deviations above or below the mean (13.11% of data excluded). The same exclusion criterion was applied to the working memory data, but no participants fell outside this range. For every participant, each fixation duration was entered for each of the four eye tracking tasks into the QMPE software to do the Ex-Gaussian analysis (Heathcote, Brown & Cousineau, 2004).

Results

The running span task was scored as an average of the number of correctly recalled numbers in the correct serial position (*M* = 3.28, *SD* = 0.84). The AOSPAN produced two separate scores. The first, called the O-score, was the sum of all letters in every perfectly recalled set (*M* = 39.38, S*D* = 18.51). The second, called the O-total, was the total number of letters recalled in the correct serial position (*M* = 53.65, *SD*=18.14). The correlation between the running span and AOSPAN score reached significance ($r = 0.27$, $p < 0.05$).

Table 1 presents the Ex-Gaussian values for the eye movement data. The eye movement data replicated previous findings of high co-variance of fixation durations across both tasks and individuals (Figure 4). Pearson's correlations between mean fixation durations across the four eye movement tasks were all highly significant (r = 0.60-0.77, $p = 0.000$). The mu values of fixation durations were found to correlate across all tasks (r = 0.35-0.74, $p = 0.000$). For the sigma values, the only significant correlations were between memory and search ($r = 0.61$, $p = 0.000$), pseudo-text and memory ($r = 0.40$, $p = 0.0013$), and pseudo-text and search ($r = 0.42$, $p = 0.0006$). The tau values significantly correlated for memory and reading ($r = 0.36$, $p = 0.037$), memory and search ($r = 0.42$, $p = 0.001$), and memory and pseudo-text ($r = 0.40$, $p = 0.001$).

No significant correlations were found between mean fixations durations of any of the four visual tasks and either working memory score. The running span scores did not produce significant correlations with any of eye movement measures, including the ex-Gaussian values. However, both the AOPSAN score and total correlated significantly with the mu value of fixation durations from the reading task ($r = -0.45$, $p = 0.0023$, $r = -0.42$, $p = 0.0042$ for score and total respectively). In addition, the AOSPAN score and total correlated with the sigma value from the reading task ($r = -0.34$, $p = 0.0227$, $r = -0.37$, $p = 0.0143$ for score and total respectively). The operation score value also correlated with the tau value from the reading task ($r = 0.32$, $p = .0317$).

Discussion

The present study sought to determine if a relationship exists between individual differences in working memory and saccadic eye movement measures. It was predicted that the data would show co-variation in individual differences between the two measures. To determine if a correlation could be found, two working memory and four eye tracking tasks were administered to participants. An ex-Gaussian analysis was used to estimate the mu, sigma and tau values of the eye movement data and then Pearson's coefficients were calculated to find if a significant correlation existed.

This study was aimed to tease apart the two possible explanations for oculomotor individuals differences. The first explanation is that these individual differences in eye movements are based on a lower level, independent system. Quite simply, the individual differences could be independent of other measures of variability across individuals. This would provide insight into current eye movement models, as it would suggest that the eye movement system is separate, or only weakly integrated with other cognitive systems. In this way, null results would indicate that the oculomotor variability among individuals is unrelated to higher order cognitive processing.

However, if a correlation were found between individual differences in eye movements and working memory measures, this would indicate the top down influence of the working memory process on the oculomotor system. Additionally, these results would speak to the predictive power of eye movements to identify more abstract cognitive measures.

The results produced intriguing implications. Previous findings that fixation durations correlate across visual tasks were replicated[1]. However, the only significant correlations between eye movement and working memory measures were found between the reading task and the AOPSAN task. A negative correlation was found between the mu value of fixation durations during reading and scores on the operation span, indicating that individuals with better performance on working memory tasks exhibited shorter fixation durations. Additionally, the sigma value of the fixation durations negatively correlated with performance on the operation span task, suggesting that as working memory performance increases, an individual displays less variability in his or her fixation durations. Taken together, the results show that higher working memory span individuals utilize shorter and less varied fixation durations while reading. This provides evidence that a relationship exists between working memory and the eye movement system in reading. The present study was not designed to determine a causal role and so the data is not indicative of whether working memory influences the eye movement system or if the converse is true. However, the authors would speculate that the correlations found reflect the top down influence of working memory on the eye movement system.

It is interesting to note that no significant correlations were found when using mean and standard deviation measures, but that an ex-Gaussian analysis produced significant results. This demonstrates that the ex-Gaussian analysis can be useful in

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[1] Saccade amplitudes were examined as well and were found to replicate previous findings (Figure 5 and Figure 6). Saccade amplitudes showed weaker, but still signicant correlations between eye movement tasks (r = 0.31-0.59, p = 0.000-0.0013). However, there were no significant correlations found between mean saccade amplitudes and working memory measures.

analyzing eye movement data. Since the mu and sigma values, not the mean and standard deviation values, produced correlations, this would indicate that the exponential portion of the data generated enough skew to influence the data. It was only once the exponential function has been modeled into the data that the resulting values were accurate enough to correlate with working memory measures. If there were no activity in the exponential tail of the data, then this difference would not have been found. Thus this study shows that ex-Gaussian modeling of eye movement data is a viable analysis option.

Also of interest is that only the reading task produced correlations with working memory scores. Of the four eye movement tasks, it could be argued that reading is the most automatic and natural. Given the subject pool of literate undergraduates, reading is likely a mechanical, almost instinctual process. Because of the findings, this could mean that working memory has a larger influence on tasks with more automaticity in comparison with less familiar tasks. Perhaps the novelty of an unfamiliar or less rehearsed task recruits a processing mechanism that is less reliant on working memory than an automatic task. Alternatively, the correlation between eye movements during reading and working memory measures could be a product of the level of cognitive engagement involved in reading. Because reading is a complex skill composed of a myriad of differing tasks, from lexical processing to figurative interpretations, this would make reading the most cognitively taxing of the four eye movement tasks. The difficulty of reading relative to the other tasks may have recruited other processes not utilized in the other three eye movement tasks, working memory being one of these. Indeed, there is some evidence to suggest that increasing task difficulty increases the utilization of working memory (Barch, Braver, Nystrom, Forman, Noll & Cohen, 1997; Jensen &

Tesche, 2002). A follow up study directly comparing tasks with varying degrees of automaticity and difficulty would further investigate these theories.

Given that the only significant correlations found were with the reading eye movement data, this may suggest that reading ability or reading experience is a confounding variable. It is possible that reading skills influence both working memory performance and eye movements, so the relationship found in the present study is simply a reflection of this. More experienced readers may have developed more consistent and measured eye movement behavior during reading, producing the resulting less varied fixation durations. Better readers may require less time to visually encode and process information, resulting in the shorter fixation durations. Lastly, better or more experienced readers may read more or perform better because the readers have higher working memory spans or, through their reading experiences, may have developed a better functioning working memory. Combining these situations would mean that higher working memory span individuals would have shorter and less varied fixation durations, as found in the present study. However, in the given example, the characteristics are not the direct result of the working memory system acting on eye movements or vice versa. Instead they are the indirect result of reading experience or skill level. A follow up study in which comprehension questions are utilized to test reading comprehension would help investigate this hypothesis.

The running span task did not produce any significant correlations. One explanation for this may be that the running span task presented stimuli auditorally, and did not involve visually presented stimuli. Though the operation span task does not test purely visual working memory, it does require more visual processing than the running span task, which could explain why the operation span task produced significant correlations while the running span did not. When reading, visual input (i.e. letters) are converted to phonological sounds and words, a process very similar to what the operation span task entails. While the operation span task only employs letters, meaning there is no semantic processing taking place, the letters are clearly processed in a similar manner to the processing of letters during reading. Perhaps this is why the operation span task correlated with reading eye movements and the running span task did not. However, this is merely conjecture. Further studies done using a visual working memory span task like the picture span task would help tease apart whether it is the conversion of visual input to phonological information that explains the link between reading and the operation span (Tanabe & Osaka, 2009).

The present study helped elucidate what individual differences in saccadic eye movements reflect. The results indicate that working memory scores correlate with fixation duration measures during reading. Follow up studies to investigate if this correlation can be found using varying working memory and visual tasks will provide further knowledge of the relationship between these two systems.

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Table 1. Mean mu, sigma and tau values of fixation durations for each task.

Condition	Mu	Sigma	Tau
Fixation Duration (ms)			
Pseudo reading	160.89	51.13	99.98
Reading	173.62	57.25	92.41
Memory	163.86	49.80	112.90
Search	145.56	42.40	64.32

Table 2. Correlations between the mu values of fixation durations for each task and working memory scores. * p < .05, **p < .01, *** p < .001

Measures (mu value)	1	2	3	4	5	6	7
1. Memory	__						
2. Reading	0.48***	__					
3. Search	0.75***	0.32*	__				
4. Pseudo	0.52***	0.48***	0.48***	__			
5. Running Span	-0.10	-0.11	0.07	0.03	__		
6. OSPAN score	0.05	-0.45**	0.13	0.03	0.27	__	
7. OSPAN total	0.09	-0.42**	0.11	-0.04	0.17	0.87***	__

Table 3. Correlations between the sigma values of fixation durations for each task and working memory scores. * $p < .05$, ** $p < .01$, *** $p < .001$

Measures (sigma value)	1	2	3	4	5	6	7
1. Memory	__						
2. Reading	0.19	__					
3. Search	0.61***	0.16	__				
4. Pseudo	0.40**	0.21	0.42***	__			
5. Running Span	-0.08	0.01	0.10	-0.03	__		
6. OSPAN score	-0.01	-0.34*	0.14	0.09	0.27	__	
7. OSPAN total	-0.02	-0.37*	0.03	0.00	0.17	0.87***	__

Table 4. Correlations between the tau values of fixation durations for each task and working memory scores. * p < .05, **p < .01, *** p < .001

Measures (tau value)	1	2	3	4	5	6	7
1. Memory	__						
2. Reading	0.26*	__					
3. Search	0.42***	0.03	__				
4. Pseudo	0.40**	0.20	0.16	__			
5. Running Span	0.00	0.08	-0.12	0.13	__		
6. OSPAN score	0.21	0.32*	-0.06	0.13	0.27	__	
7. OSPAN total	0.11	0.29	0.04	0.18	0.17	0.87***	__

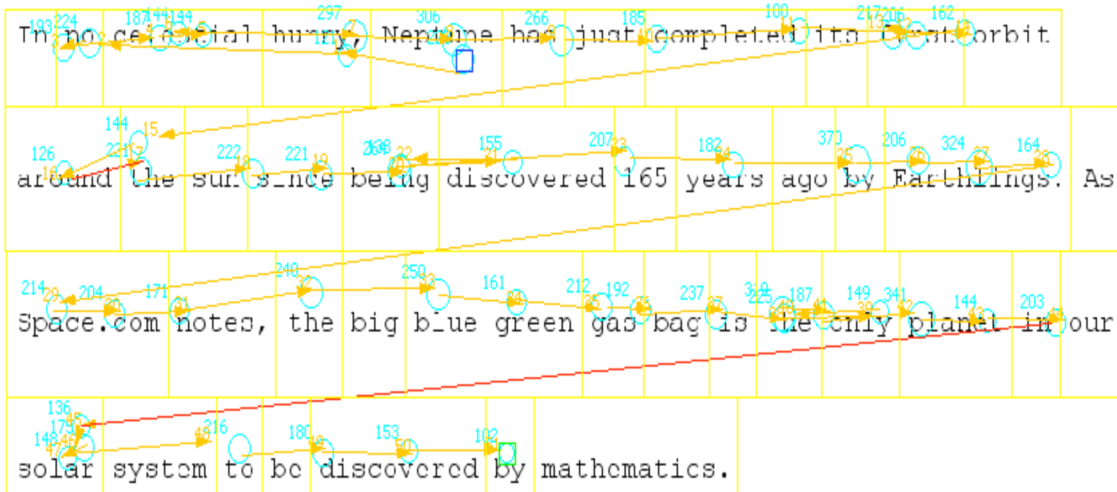

Figure 1. Example eye movement data. This data was taken from a randomly selected participant during the reading task. The data represents eye movements recorded during one 12-second trial. The eye movements are overlaid over the stimulus. Saccades are represented by orange arrows and fixations by light blue circles with the fixation durations (in milliseconds) displayed above each fixation.

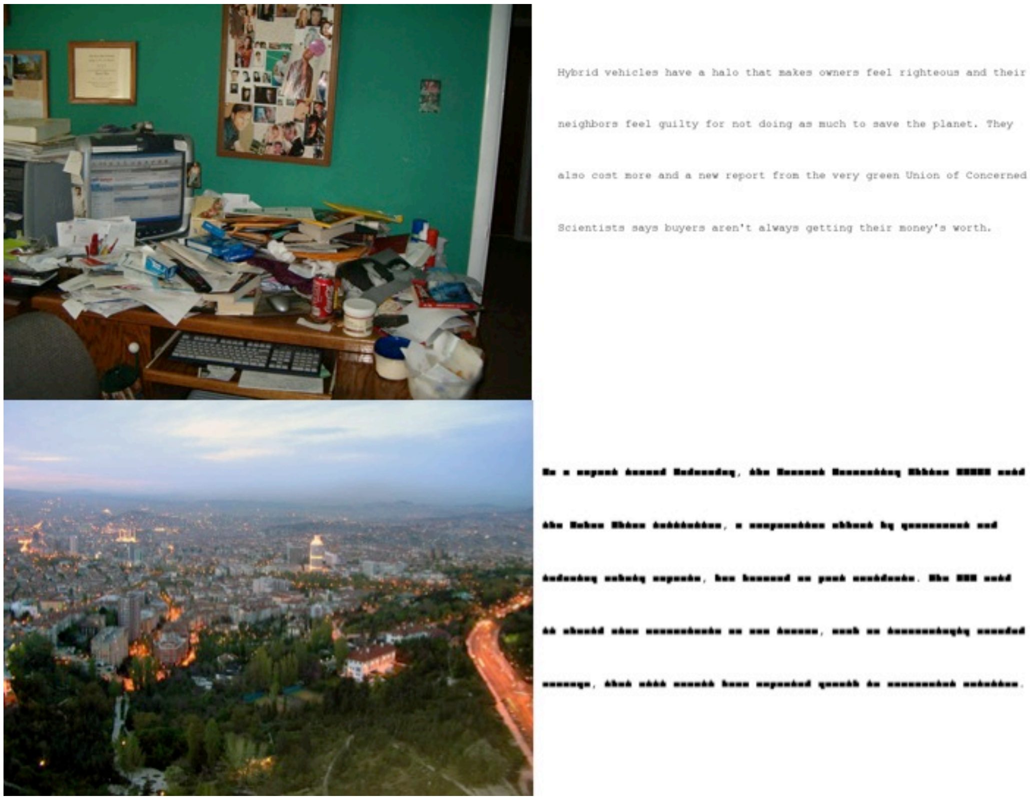

Figure 2. Examples of each eye tracking task. Upper left quadrant depicts the scene memorization stimuli, upper right the reading task, lower left the search task and lower right the LEGO text.

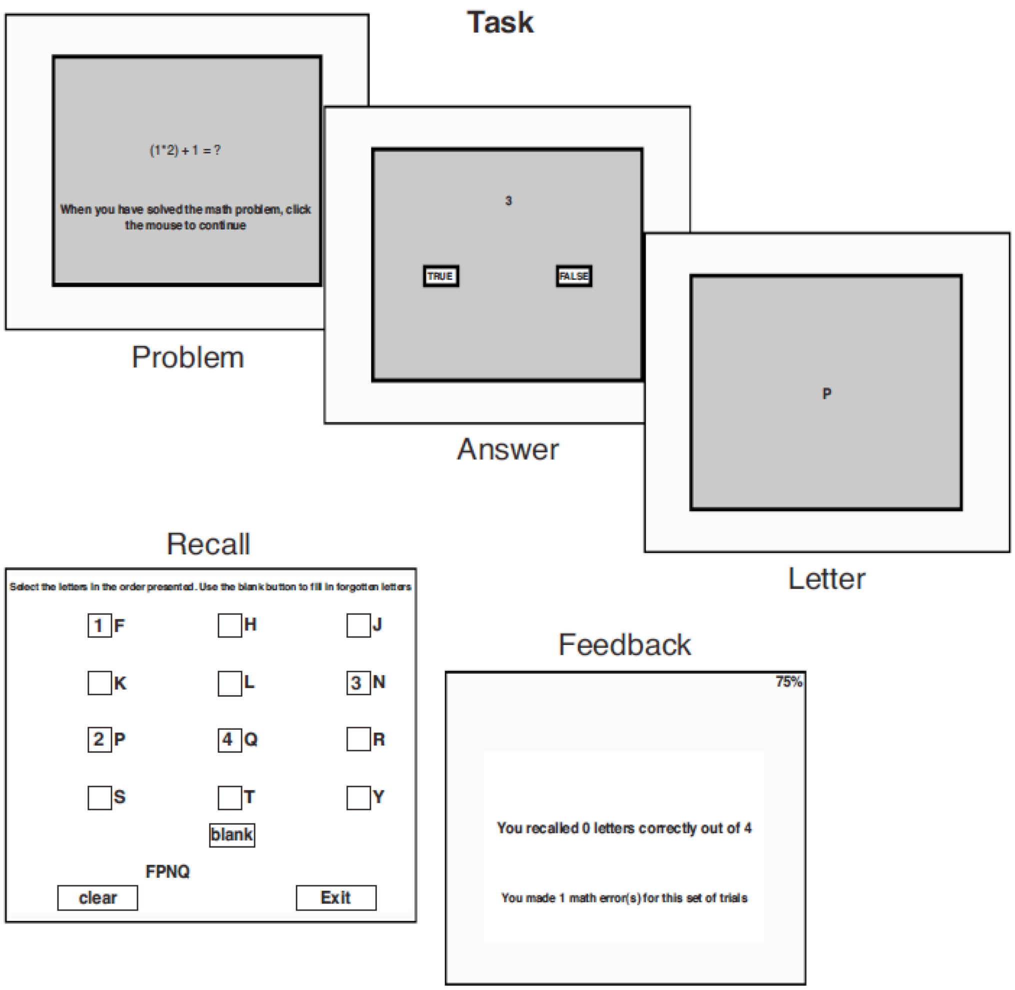

Figure 3. Example of AOSPAN stimuli and procedure. Image from Unsworth, Heitz, Schrock, and Engle, 2005.

Figure 4. Correlations between the mu value of fixation durations are shown with confidence intervals beneath. In the upper right portion of each diagram the scatterplot of each correlation is depicted. Correlations for fixation durations are very strong and all highly significant.

Figure 5. Correlations between the mean fixation duration values for each task are shown with confidence intervals beneath. In the upper right portion of each diagram the scatterplot of each correlation is depicted. Correlations for fixation durations are very strong and all highly significant.

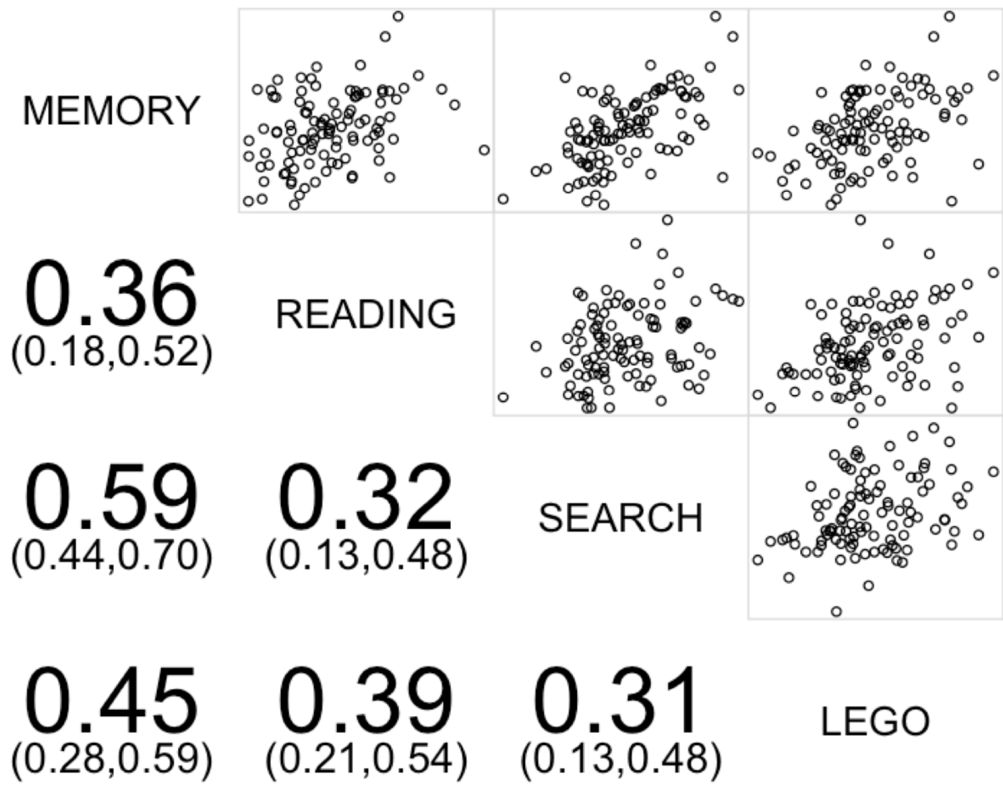

Figure 6. Correlations between the mean saccade amplitudes for each task are shown with confidence intervals beneath. In the upper right portion of each diagram the scatterplot of each correlation is depicted. Correlations for saccade amplitudes are strong, though not as strong as fixation durations, and all are significant.