8-2022

Relationship Between Attention and Order Errors in Serial Order Memory

Katherine A. Hernandez

The Relationship Between Attention and Order Errors in Serial Order Memory

A Thesis

Submitted to the Graduate Faculty of the
University of South Alabama

in partial fulfillment of the
requirements for the degree of

Master of Science

in

Psychology

by
Katherine A. Hernandez
B. A., Southeastern Louisiana University
August, 2022

Acknowledgments

I would like to sincerely thank my research mentor, Dr. Dakota Lindsey, for aiding in the production of this project as well as his support in all of my research endeavors. With your guidance, I have grown immensely as a student and researcher. I cannot thank you enough for all your help throughout my educational experience here at the University of South Alabama. Additionally, I would like to thank Dr. Ben Hill for allowing me to utilize data collected by his lab for this project and for his assistance in the development of this project. The current state of the project as well as its future directions would not have been possible without your help. I would also like to give special thanks to Dr. James Van Haneghan and Dr. Joshua Foster for advising the statistical analyses of the project; your expertise have immensely improved its outcome. Lastly, I would like to thank my friends and family for their constant support in my pursuit of higher education. Without your endless encouragement, none of this would have been possible.

Table of Contents

List of Tables

List of Figures

Figure Page

List of Abbreviations

AC	=	Attention Control
IM	=	Item Memory
OM	=	Order Memory
PEBL	=	Psychology Experiment Building Language
BST	=	Bivalent Shape Task
CFA	=	Confirmatory Factor Analysis
RMSEA	=	Root Mean Square Error of Approximation
SRMR	=	Standardized Root Mean Square Residual
CFI	=	Comparative Fit Index
N	=	Number of Subjects
M	=	Mean
SD	=	Standard Deviation
Fl	=	Flanker Task
GL	=	Global Local Task
DSI	=	Digit Span Item Errors
RSI	=	Reading Span Item Errors
SSI	=	Symmetry Span Item Errors
DSO	=	Digit Span Order Errors
RSO	=	Reading Span Order Errors
SSO	=	Symmetry Span Order Errors
RT	=	Reaction Time

Abstract

Hernandez, Katherine A., M. S., University of South Alabama, August 2022. The Relationship Between Attention and Order Errors in Serial Order Memory. Chair of Committee: Dakota, Lindsey, Ph.D.

To investigate if attentional control (AC) predicts the amount of order errors made within serial memory tasks. We also investigated the relationship between AC and item memory (IM), and the relationship between IM and order memory (OM). Data were collected from undergraduate students at the University of South Alabama. Participants completed three attentional conflict tasks (Bivalent shape task, Global local task, and Flanker task) and three serial memory tasks (symmetry span, digit span, and reading span). The final sample of 112 participants completed all memory tasks and at least two conflict tasks. Confirmatory factor analysis was used to form an AC latent variable from response time difference scores (congruent versus incongruent trials), and IM and OM variables were formed from item and order errors in the memory tasks. Structural equation modeling was used to test correlations among latent variables. The latent AC factor failed to converge. We ran three structural equation models using each conflict task as a predictor variable for both IM and OM. The relationship between IM and OM was significant in all three models. The only other significant pathway across all three models was the relationship between the Flanker task and IM ($\beta = .278$, SE = .105, $p = .001$). Overall, performance on the three conflict tasks did not directly predict order errors. Flanker task performance did directly predict item errors, thus indirectly predicting the amount of order errors in those same tasks.

Keywords: attentional control, item memory, order memory.

The Relationship Between Attention and Order Errors in Serial Order Memory

The two cognitive constructs of attention and working memory are often discussed and referred to as being separate and distinct from one another. Attention can be defined as “selective focus on limited amounts of information present in the immediate environment,” (Broadbent, 1958). Working memory is often spoken about as a separate system and can be defined as “a system dedicated to the maintenance and manipulation of internal information,” (Baddeley & Hitch, 1974). Although these two constructs are typically referred to as independent of one another, William James spoke of the relationship between attention and memory as being “linked through consciousness; short-term memory holds the contents of consciousness, while attention dictates what content becomes conscious,” (James, 1981). The nature of the relationship between attention and memory has captivated the field. A longstanding theory to help explain this relationship suggests that working memory is attention turned inward toward internal representations of stimuli (Kiyonaga & Egner, 2013; Oberauer & Hein, 2012). If attention and memory operate along the same mechanisms, then understanding and applying models of attention can help us to gain more insight into how the memory system works.

The spotlight theory of attention suggests that our attention serves as a spotlight shining onto our external environment (Eriksen & Hoffman, 1973); As the attentional spotlight shines onto the external world, it extracts certain stimuli from the environment to then be encoded into working memory for later use. The size of the attentional spotlight determines how well a person can control what their attention extracts from the environment and helps to explain individual differences in attentional control (Eriksen &

St. James, 1986). If an individual has poor attentional control, they cast a very wide spotlight into their external environment. A wide spotlight highlights more stimuli in the environment, some of which are relevant to the task at hand (targets) while many others are irrelevant and should be ignored (distractors). When more items compete for selection, an individual is less likely to encode the targeted item from their environment. On the other hand, if an individual has better attentional control, they cast a narrower spotlight into their environment. Because fewer items fall into their narrow spotlight, it is more likely that the individual will select the target item within the environment.

Following the theory that working memory is attention turned inward, the attentional spotlight theory can also inform how memory retrieval works. The attentional spotlight can be turned inward toward internal representations of stimuli within long-term memory. As the spotlight shines within memory, certain stimuli (relevant memories or experiences) are extracted and can then be recalled and utilized. Like the perceptual spotlight, those with poor attentional control will cast a wider spotlight within their memory. Within that spotlight, distracting, irrelevant memories are activated along with the targeted memory a person is trying to retrieve. When more items compete for selection in memory, an individual is less likely to retrieve the targeted item from their memory. If an individual has better attentional control, they will cast a narrower spotlight. Due to less distracting information falling in the range of the narrow spotlight, it is more likely a person will retrieve the targeted item from their memory. Logan et al. (2021) demonstrated that a computational model of Eriksen’s attentional spotlight could capture performance in a memory version of the flanker task, further supporting the claim that attention and memory retrieval employ similar cognitive processes.

To help explain individual differences amongst both attentional control and memory retrieval, Unsworth and Engle (2007) suggested that individuals with lower attentional control have a more noisy search process when attempting to retrieve something from memory. They describe the noisy search process as the use of less effective retrieval cues when attempting to extract an item from long-term memory; in using less effective retrieval cues, a person must search a larger space for a target item, thus producing more inaccurate retrieval attempts. Unsworth and Engle's (2007) description of a noisy search is similar to the internal attentional spotlight. The larger search space is similar to having a wider spotlight; those who have poorer attentional control cast a larger spotlight and thus have a larger search space.

Previous investigation of the relationship between attention and memory retrieval has primarily focused on the retrieval of the identity of the targeted items. Alice Healy (1982) referred to the memory for items presented within a list as "item memory." A person's item memory is often measured by analyzing the number of item errors they commit. An item error occurs if an individual recalls an item within a list that did not appear within the presented list. Unsworth and Engle (2007) posed the explanation for why individuals retrieve incorrect items or make item errors: the lower attentional control a person has, the more ineffective their retrieval cues, thus the more item errors they will make. While their theory explains why an individual can remember the items presented within a list, it does not adequately explain how an individual can remember items in a specific order or at a specific time they are needed. This concept is a term Healy (1982) distinguished as "order memory". Order memory refers to the memory for the sequential order of items within a list and can be assessed through order errors. An order error occurs when an individual recalls an item that was present in the to-be-remembered list, but not in the correct order, or position, in which it was presented.

Research examining the relationship between attention and order memory is sparse across the field. The few studies that have investigated this relationship also point to a close association between attention and order memory. For example, Van Dijck et al. (2013) investigated the influence of spatial attention on order memory. Participants within this study were shown a horizontally presented string of letters and asked to serially recall, from left to right, the letters most recently presented to them. The researchers observed that after a participant reported one letter of the sequence, their gaze would shift rightward to the next letter position before reporting their response for that position. They explained that the rightward shift focused their attention on a new spatial location and allowed them to use it as a retrieval cue to remember the item that was presented in that spatial position. However, because this study contained no control condition where a participant was unable to shift their gaze rightward, it is unclear whether the gaze shifts directly caused improvements in order memory. Further investigation into the relationship between attentional control and order memory is warranted, and that is the purpose of the present study.

Unsworth and Engle (2007) posit that effective retrieval cues aid in accurate recall of items, and those with better attentional control use these more effective retrieval cues. Further, Van Dijck et al. (2013) posit that individuals shift their focus to new cues to help them remember items in order. Because a shift of attention is responsible for the change in retrieval cue, those with better attentional control are likely better at changing retrieval cues and, consequently, likely better at remembering items in the proper order. To have an effective retrieval cue for each to-be-remembered item in a sequence, the internal spotlight must shift within memory to focus on each of the target items in the order they are meant to be recalled; the more efficient the shifting of the spotlight within memory, the better order memory an individual may have. Shifting attention poorly, too early, or too late should lessen the likelihood that the spotlight highlights the correct memory in the correct order. Those with worse attention control have a larger spotlight of attention, leading to worse item memory, and they may also be worse at shifting their spotlight, leading to worse order memory.

The current study intends to take a differential approach in investigating how attentional control is related to the amount of order errors an individual makes. While the primary focus of this investigation is to determine how attentional control contributes to order memory, the study will also investigate the previously established relationship between attentional control and item memory. Our study will utilize a variety of attentional conflict tasks and serial order memory tasks to assess how the factors governing performance in attention control tasks influence the number of item or order errors a person makes. We plan to examine three different relationships by creating three latent variables: attentional control, item memory, and order memory. The latent variable of attentional control should reflect a person's general ability to utilize attention to resolve conflicting information within a task. The latent variable of item memory should reflect someone's general ability to remember the items within a presented list. The latent variable of order memory should reflect a person's general ability to remember the sequential order of items within a list. We intend to examine the relationships among all three of the latent variables.

As evidenced by Unsworth and Engle (2007), we expect attentional control to influence a person's ability to remember the identities of items within a list. Although item memory and order memory are often distinguished, Ward, Tan, and Grenfell-Essam (2010) demonstrated that memory retrieval proceeds similarly whether the person is required to recall items in order (in a serial recall task) or not (in a free recall task). Likewise, we expect item memory and order memory to be related in the current study. The nature of the relationship between attentional control and order memory is the primary focus of the current study. We expect attention control to influence a person's ability to remember items in order because attention control may determine how effectively someone can shift attention to aid the sequential recall of new items.

Method

Participants and Data Acquisition

Data were acquired from an archival data set collected by graduate students belonging to the research lab of Dr. Benjamin Hill. The study that produced this data was reviewed and approved by the Institutional Review Board and the University of South Alabama. Participants recruited for the original study were undergraduate students enrolled at the University of South Alabama. Data were initially acquired from 206 participants between the fall academic semester of 2015 and the spring semester of 2017. Data were collected through the Psychology Experiment Building Language (PEBL; Mueller & Piper, 2014). Participants were included in the study based on their participation in six of the tasks within the PEBL battery, three attention tasks and three serial order memory tasks. The details of these tasks will be discussed later in the paper. Participants were included in the study if they had valid, complete data for all three of the serial order memory tasks, and at least two out of three of the attention tasks. There were a total of 107 participants with available data for all six tasks. If a participant only has available data for two out of the three attention tasks, imputation will be used for whichever single attention task a given participant is missing. Imputation was favored over deletion in order to preserve as much data as possible for analyses. We examined accuracy in the tasks and excluded participants who do not appear to be committing enough effort. Additionally, we excluded participants who timed out on any task. After all inclusion criteria were met including imputed data, the total sample size consisted of 112 participants.

Attention Measures

All three attention measures were attentional conflict tasks. In an attentional conflict task, participants are shown a stimulus in which different features of that stimulus may support different responses. The objective of these tasks is to respond as quickly and accurately as possible to one specific feature of the stimulus while ignoring other features. In some trials (congruent trials), all features of the stimulus support the same response. Conflict arises in trials (incongruent trials) when different features of the stimulus point to different responses. These tasks measure attention control because an individual must attend to the correct feature of the stimulus to give the correct response. People with worse attention control find it more difficult to ignore the irrelevant stimulus features, and they give the correct response less frequently and less quickly as a result. This study looked at the response time difference scores between incongruent and congruent trials as the dependent variable; the worse an individual is at filtering out trial irrelevant information, the larger their response time difference score will be. As evidenced by Draheim at al., (2019), difference scores are an unreliable measure that result in low correlations among tasks that use them as dependent measures; because of this, they can be problematic measures for latent variable analysis. Participants must have exhibited 80% overall accuracy on each attention measure to be included in the study.

The Bivalent Shape Task

The Bivalent Shape Task (BST) (Esposito et al., 2013; Mueller & Esposito, 2014), serves as a non-verbal analog to a number of traditional attentional conflict tests such as the color-word Stroop test (Stroop, 1935) and Eriksen flanker test (Eriksen & Schultz, 1979). The presentation of each trial consisted of one target stimulus and two response stimuli. The target stimulus was a large shape, either a circle or square, presented in either blue or red at the center of the screen. While the target stimulus was still present, two response shapes were presented at the bottom of the screen: a red circle in the lower left portion of the screen, and a blue square in the lower right. The response shapes were presented consistently throughout the task. The objective of the task was to match the shape of the target stimulus to the shape of either of the response choices, ignoring the color. By making a left indication, the participant was reporting that the shape of the target stimulus was a circle. By making a right indication, the participant was reporting that the target stimulus was a square. Conflict arose when the shape and color of the target stimulus were supporting different response choices. A congruent trial was one in which both the shape and color of the target stimulus matched just one of the response stimuli at the bottom of the screen. An incongruent trial was one in which the shape of the target stimulus matched the shape of one of the response stimuli, but the color of the target stimulus matched the color of the other response stimulus. A neutral condition was presented in the task, however, this type of trial was not scored or analyzed.

The task consisted of one practice block and four consecutive test trial blocks with 20 trials each. Each block consisted of one trial type. Block one consisted of six practice trials with one example of each type of stimulus. Block two consisted of neutral trials in which the target stimulus was only presented in the black outline form with no color fill. Block three depicted only congruent trials in which the target stimulus matched both response choices for both features (color and shape). Block four consisted of the incongruent trials where the presented target stimulus matched the response choices in shape but not in color. The final block depicted a mixed block in which all six target types were presented with five trials per type for a total of 30 trials. The administration of the task took approximately five minutes.

The dependent variable of interest was the response time difference score between congruent and incongruent trials. An individual score was computed by taking an average of all congruent trial scores and all incongruent trial scores only within the mixed block and subtracting them. This yielded an individual response time difference score for each participant.

Eriksen Flanker Task

An adaptation of Eriksen's flanker task (Eriksen & Schultz, 1979), roughly modeled after Stins et al., (2008), was implemented as part of the PEBL battery. At the start of this task, a fixation cross was presented and was immediately followed by a horizontal array of five equally sized and spaced white arrows. The center arrow is the target stimulus, which was to be attended to, while the other four arrows are denoted as flankers, which were to be ignored. On each trial, participants were instructed to indicate which way the center arrow was facing using the left or right arrow key on their keyboard. Congruency conditions were defined by the flanker stimuli. In congruent trials, the target and flanker arrows pointed in the same direction. In incongruent trials, the target arrow pointed in the opposite direction of the flanker arrows. A neutral condition was included in the task administration where the flanker items were denoted as horizontal lines with no arrowhead. Conditions of this nature were not included in data analysis. Participants were administered eight practice trials and 16 test trials (for a total of 24 trials). Response times were averaged across all congruent and all incongruent trials and subtracted from one another to yield a response time difference score for each participant.

Navon Global-Local Task

A more basic version of the Navon Global-Local task (Navon, 1977) was adapted for administration within the PEBL battery. Participants were shown large letters, the global stimuli, that are made up of many small letters, the local stimuli. PEBL's adapted version of the task only utilized the letters S and H as representations of either the global or local stimuli. The identities of both the global and local stimuli were clearly identifiable and visible to the participant. The objective of the task was for participants to identify the local stimuli or the global stimuli quickly and accurately. In the congruent conditions both the local and the global stimuli are the same letter; both stimuli are either S or H. In the incongruent conditions, the letter of the local stimulus was not the same as the letter portrayed as the global stimulus. Participants indicated their response by clicking the left or right shift key. By clicking the left shift key the participant indicated H as their response, while clicking the right shift key indicated S as their response. Participants completed a total of 300 trials split into seven blocks. The first three blocks consisted of practice trials and were not included in data analysis. Blocks four through seven required the participant to report either the local or global stimulus. Additionally, the latter four blocks included neutral trials throughout, but such trials were also not included in data analysis. Response times were averaged for all congruent trials and all incongruent trials and then subtracted from one another to produce the response time difference score for each participant.

Serial Order Memory Tasks

Data from three serial order memory tasks were included in data analyses. In a serial order memory task, participants are shown a string of stimuli and are instructed to recall those stimuli in the order in which they were presented to them. Often, the length of the string is manipulated, and the number of recalled digits is recorded to get an index of memory span. In the current study, the dependent variables of interest for these tasks were the number of item errors and the number of order errors a person commits. An item error is characterized by an individual recalling an item that was not present in the most recent list the person was shown. An order error is characterized by the correct recall of an item that was presented in the most recent list, however, the item was not reported in the correct location in which it was originally presented. Item errors and order errors were measured through processes outlined by Lindsey and Logan (2021). To score the number of item errors, we summed the number of omissions and intrusions. An omission occurs when a response was not given for a particular position. This includes blank responses within the string of reported letters, and/or the difference in length between the response string and the target string if not all required letters were reported. An intrusion occurs when an item was reported that was not present in the most recent list shown. To calculate item errors, the proportion of both omissions and intrusions within each trial was calculated. The proportions calculated within each trial were then summed across trials for each participant to create their item error score. To quantify order errors, we counted the number of times a correctly reported item from the most recent list was not reported in the correct position in which it was presented. The proportion of misorders was calculated within each trial. The proportions of misorders within each trial were summed across trials for each participant to create their order error score.

Symmetry Span

The PEBL symmetry span task is based on the original test created by Kane et al., (2004), with automated modifications based on procedures outlined by Unsworth et al., (2009). This task consisted of a storage task, the primary focus of the task, and an intermittently presented processing task. The storage task involved the repeated, individual presentation of a 4 x 4 matrix with one square filled in red. The objective of the task was to recall the sequence of red-square presentations most recently presented to them. The processing task, a symmetry-judgement task, was presented intermittently between red square presentations. The symmetry task consisted of an 8 x 8 matrix presentation with some squares filled in black. Participants were instructed to decide whether this design was symmetrical across its vertical axis. Once participants made their decision for the current presentation, the next presentation of the to-be remembered-stimulus was shown. Set sizes ranged between two and five symmetry-memory matrices per trial with two practice trials and two trials dedicated to each span length (for ten trials total). Item errors and order errors were scored for each individual trial. An item error within this task is committed when a participant clicks a location in the grid that was not highlighted red in the current trial. An order error for this task is committed when a participant clicks a grid location that was highlighted red, but it was not clicked in the correct order. Errors for all list lengths, regardless of span, were scored for data analyses. Participants must have exhibited 80% accuracy on the intervening processing task to be included in the study.

Reading Span

The PEBL reading span test was established based on the original test created by Daneman and Carpenter (1980), with automated modifications based on procedures outlined by Unsworth et al., (2009). Like the symmetry span task, participants were presented a storage task in which they were shown lists of individually presented letters. Following the presentation of the letters, participants were required to report the letters they were most recently shown in the order in which they were presented. The letter list lengths varied between three and seven to-be remembered letters throughout the task with three trials being devoted to each list length. Additionally, participants were intermittently shown a processing task in which they had to make a judgement about a sentence between letter presentations. In the sentence judgement task, participants were required to indicate if a sentence was true or false. Following their decision of the sentence, the next letter would be presented. Participants were given three practice sessions prior to the start of the real trials: letter practice, sentence practice, combined letter span and sentence practice. The last practice session mimicked the test trials. Responses from the last 27 trials were included in data analyses. Item errors and order errors for each trial were scored as the dependent variables. For this task, an item error was scored as a participant reporting a letter that was not presented in the most recent list they were shown; an order error was scored as a participant reporting a letter that was presented in the most recent list but was not reported in the order in which it was presented. Errors for all list lengths were scored for data analyses. Participants must have exhibited 80% accuracy on the intervening processing task to be included in the study.

Digit Span

The PEBL Battery utilized an adapted version of a standard digit span task (Croschere et al., 2012; Mueller, 2011). This storage task consisted of digits being serially presented on the computer screen. This particular task did not include an intervening processing task. The objective of the task was for participants to report back the digits in the order they were presented. The smallest list length a participant had to recall consisted of two digits. The largest list length varied by participant depending on how many digits the person could remember. Two sets of each list length were presented. Item errors for this task were characterized by a participant reporting a digit that was not presented to them in the most recent list they were asked to recall. An order error was characterized by a participant reporting a correct digit from the list most recently shown, but not reporting that digit in the correct location within the list. Errors for all list lengths were scored.

Statistical Analyses

We were interested in three latent variables, attention control, item memory, and order memory, and planned to form a corresponding factor through confirmatory factor analysis (CFA) for each. Through structural equation modeling, we investigated the relationship between the three latent factors as depicted in Figure 1. The latent variable of attentional control is created from the attentional conflict tasks. This latent variable should reflect someone's general ability to resolve conflict. The observed variable for each attentional conflict task was made up of the averages of all response time difference scores across participants from the respective task. The lower a person's response time difference score within an attentional conflict task, the better their attentional control. The latent variable item memory was composed of the item error scores from each of the serial recall tasks. This latent construct should reflect someone's general ability to remember items within a list. The observed variables for each serial recall task were made up of the averages of all item errors made within their respective task. The smaller the amount of item errors, the better a person's item memory is. The latent variable order memory was made up of the order error scores from each of the serial recall tasks. This latent construct should reflect someone's general ability to remember items in order within a list. The observed variables for each span task were created through the same process as the item error observed variables but utilize order errors instead. Like item memory, the more order errors a person has, the worse their order memory is.

Prior to assessing model fit, CFA will be utilized due to our pre-experimental assumptions about the nature of their relationships. Our CFA was performed to assess the loadings of each task on to their corresponding latent variable and to assess the multiple correlations (r^2) to determine the shared variance in the variables explained by their corresponding latent factor. A 9 x 9 bivariate correlation matrix is presented to represent the intercorrelations between all tasks. Within the correlation matrix, we expect to see higher correlations amongst tasks that load on to the same latent variable. Data analysis was performed in Mplus, a statistical modeling program (Muthén & Muthén, 1998-2017).

Fit Statistics

Several fit statistics are reported for the model. Chi square (χ^2), an absolute fit index, is reported as a "goodness-of-fit" statistic. For this fit index, a non-significant chi-square value is desired to be indicative of acceptable model fit. The root mean square error of approximation (RMSEA) is reported to estimate how well the model fits to the population. The standardized root mean square residual (SRMR) is reported to assess the average deviation of the reproduced covariance matrix from the observed. For both of these fit indices, values of .05 or below are indicative of a good fit, and values up to .08 are acceptable (Browne & Cudeck, 1993; Kline, 2015). The Comparative Fit Index (CFI), a relative fit index, is also reported to test the proposed model against a null model for comparison. Values for this index range between 0 and 1.0 with 0.95 or above being indicative of a good fit (Hu & Bentler, 1999).

Proposed Structural Equation Model

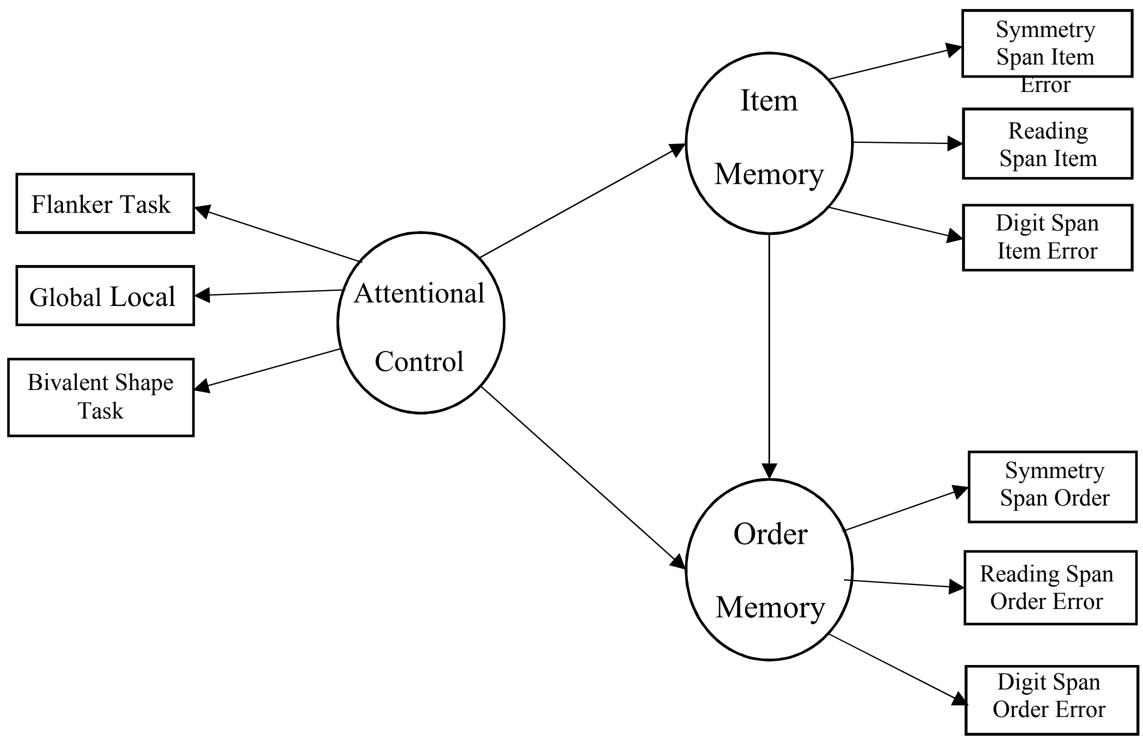

Figure 1. Proposed Structural Equation Model

Results

Descriptive statistics and bivariate correlations amongst all tasks are represented in Tables 1 and 2, respectively. For the Bivalent Shape task, the descriptive statistics show a low mean response time difference score (M=59.2) compared to the standard deviation for this task (SD=121). This result could potentially be due to outliers of scores within the task. It is also worth noting that more item errors were committed within the Symmetry Span task (M=0.257) compared to item errors within the Digit Span task (M=0.0642) and the Reading Span task (M=0.161). This difference may be due to decreased difficulty in rehearsing verbal information compared to spatial locations. Additionally, missing data points within two attention tasks, the Bivalent Shape task and the Flanker task, were acknowledged and intended to be imputed. However, due to the results of the structural equation model, those tasks were used as predictor variables instead of outcome variables. Because of this, Mplus was unable to impute values for those data points and were not included in the analysis.

Table 1

Descriptive Statistics of Task Performance

	BST	Fl	GL	DSI	RSI	SSI	DSO	RSO	SSO
N	110	109	112	112	112	112	112	112	112
Missing	2	3	0	0	0	0	0	0	0
Mean	59.2	50.9	45.3	0.0642	0.161	0.257	0.162	0.144	0.100
Std Dev	121	60.6	36.5	0.0418	0.134	0.141	0.0748	0.0804	0.0826

Note. BST = Bivalent Shape Task RT, Fl = Flanker RT, GL = Global Local RT, DSI = Digit Span Item Error, RSI = Reading Span Item Error, SSI = Symmetry Span Item Error, DSO = Digit Span Order Error, RSO = Reading Span Order Error, SSO = Symmetry Span Order Error; all RT scores represent reaction time difference scores.

Table 2

Bivariate Correlation Matrix

	1	2	3	4	5	6	7	8	9
BST	-								
Fl	-0.105	-							
GL	0.062	0.056	-						
DSI	-0.129	0.100	0.093	-					
RSI	-0.049	0.252**	0.084	0.319***	-				
SSI	-0.041	0.107	0.082	0.092	0.330***	-			
DSO	-0.055	0.119	0.139	0.310***	0.089	0.016	-		
RSO	0.066	0.083	0.060	0.207	0.318***	0.111	0.252**	-	
SSO	-0.025	0.148	0.094	0.013	0.263***	0.376***	-0.038	0.294**	-

Note. Table 2. * p < .05, ** p < .01, *** p < .001; all values are reported as Pearson's r; all RT scores represent reaction time difference scores; BST = Bivalent Shape Task RT, Fl = Flanker RT, GL = Global Local RT, DSI = Digit Span Item Error, RSI = Reading Span Item Error, SSI = Symmetry Span Item Error, DSO = Digit Span Order Error, RSO = Reading Span Order Error, SSO = Symmetry Span Order Error.

Confirmatory Factor Analysis

We first ran the confirmatory factor analysis (CFA) to assess the loadings of the average item and order error scores for each serial order memory task onto their corresponding memory latent construct. Because the two latent constructs of item memory and order memory are measured using the same tasks, we wanted to ensure that they were able to be assessed as separable constructs. The first CFA model we tested included item memory and order memory as two separate latent constructs ($\chi^2 = 6.384$, $p = .382$, RMSEA = .024 [.00, .127], CFI = .994, SRMR = .040). The second CFA model consisted of only one latent factor, memory, with all item memory and order memory observed variables loading onto the common memory factor ($\chi^2 = 14.656$, $p = 0.041$, RMSEA = .099 [.019, .170], CFI = .889, SRMR = .058). Because the two-factor memory model is nested within the one factor memory model, we utilized a $\Delta\chi^2$ test to assess which model was a better fit to the data. The $\Delta\chi^2$ yielded a difference score of 8.272, p <.005. This led us to conclude that the two-factor model was a significantly better fit for the data and able to be measured as separable constructs within the serial order memory tasks.

Based on these results, the model included two latent factors for memory distinguishing item memory and order memory. We allowed the residuals of digit span item errors and digit span order errors, as well as symmetry span item errors and symmetry span order errors to cross-correlate with one another. Modification indices found within the output of the analyses indicated that allowing the errors of these two tasks to cross correlate with their corresponding observed variable would improve model fit. Intuitively, it is expected that the residual errors of these tasks should correlate with each other because they are different dependent variables from within the same task. By allowing the residuals for digit span order errors and digit span item errors as well as symmetry span order errors and symmetry span item errors to cross-correlate, we hoped to account for the task commonalities.

To assess the loadings of the attention tasks on to the attention control latent construct, we performed a third CFA allowing all three attention tasks to load onto the attentional control latent construct. The latent attentional control factor could not converge. The results of this CFA could be due to the bivariate correlations, presented in Table 1, being fairly low among the attention tasks. Potential reasons (e.g., difference scores; Draheim et al., 2019) for the low correlations between the attention tasks are described and discussed later in the paper. Based on the results of the CFA, we created three separate structural equation models that utilized each attentional control task as an observed predictor for the two memory factors. All prior proposed pathways remained the same.

Structural Equation Model

The three models are depicted in Figures 2, 3, and 4. The first model included the Bivalent Shape Task as the observed predictor for item memory and order memory. The model fit the data well, $\chi^2 = 8.697$, $p = 0.5611$, RMSEA = .00 [.00, .093], CFI = 1.00, SRMR = 0.044. The Bivalent Shape Task did not significantly predict item memory (β = -.079, SE = .118, p = .500) or order memory (β = .104, SE = .110, p = 0.343) and accounted for .6% of the variance in item memory and 1% of the variance in order memory. However, item memory significantly predicted order memory (β = .522, SE = .172, p = .002) and accounted for 27% of the variation. The second model included the

Global Local task as the observed predictor for item memory and order memory. The model fit the data well, $\chi^2 = 8.905$, $p = 0.5411$, RMSEA = .00 [.00, .094], CFI = 1.00, SRMR = 0.044. The Global Local task did not significantly predict item memory ($\beta = .108$, $SE = 0.112$, $p = 0.333$) or order memory ($\beta = .061$, $SE = .124$, $p = .624$) and accounted for 1% of the variance in item memory and .3% of the variance in order memory. Again, item memory significantly predicted order memory ($\beta = .530$, $SE = .161$, $p = .001$) and accounted for 28% of the variation. The third model utilized the Flanker task as the observed predictor for item and order memory. The model fit the data well, $\chi^2 = 8.464$, $p = 0.584$, RMSEA = .00 [.00, .092], CFI = 1.00, SRMR = .042. The Flanker task significantly predicted item memory ($\beta = .278$, $SE = .105$, $p = .001$), but did not significantly predict order memory ($\beta = .048$, $SE = .148$, $p = .748$). The Flanker task accounted for 7% of the variance in item memory and .2% of the variance in order memory. Once again, item memory significantly predicted order memory ($\beta = .553$, $SE = .169$, $p = .001$) and accounted for 30% of the variation.

Bivalent Shape Task Model

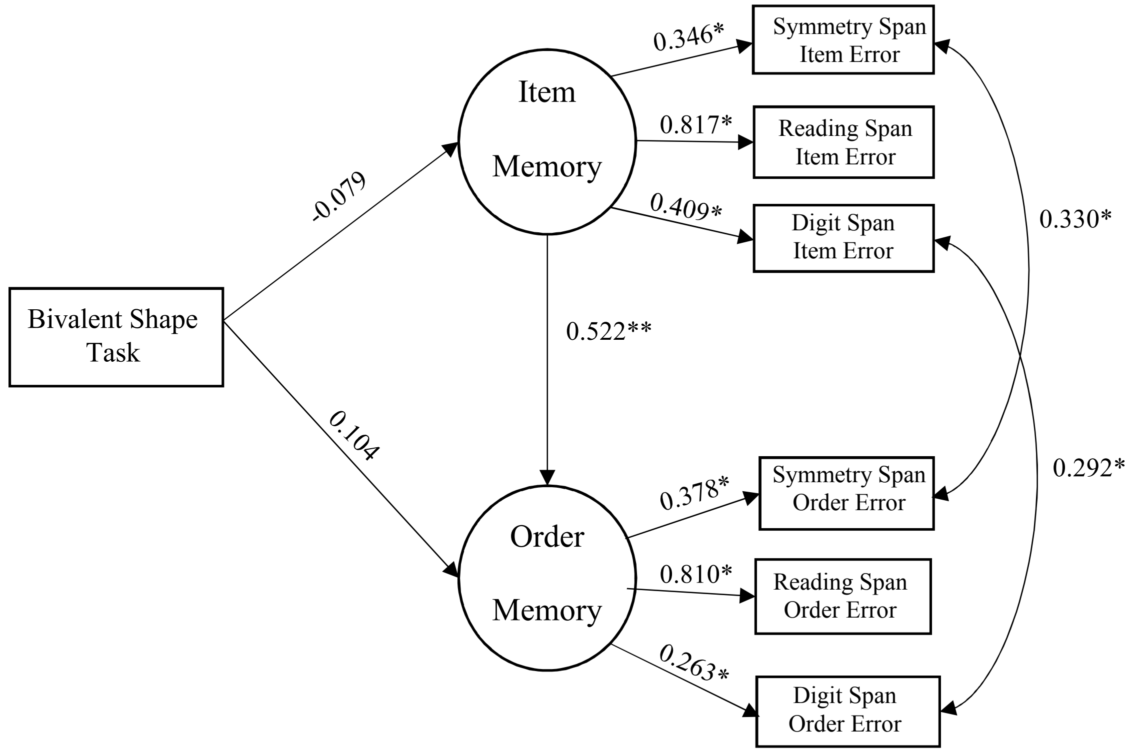

Figure 2. * p < .05, ** p < .01, *** p < .001; all values are reported as standardized on X and Y.

Global Local Task Model

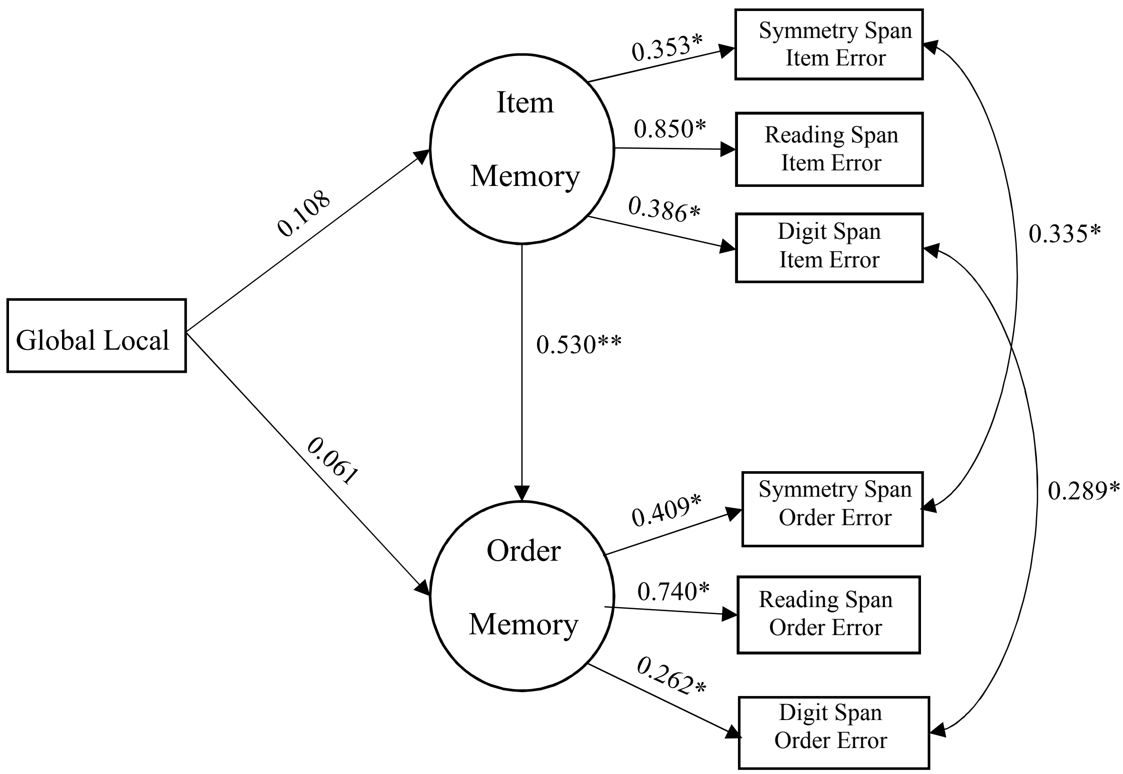

Figure 3. * p < .05, ** p < .01, *** p < .001; all values are reported as standardized on X and Y.

Flanker Task Model

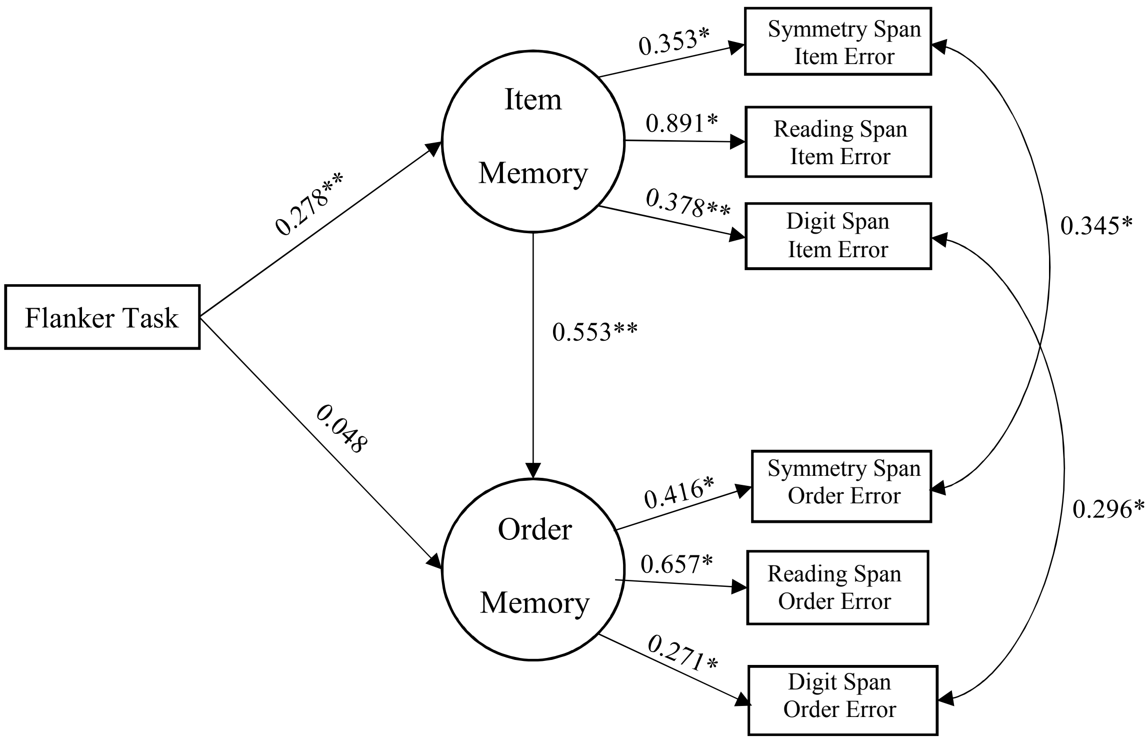

Figure 4. * p < .05, ** p < .01, *** p < .001; all values are reported as standardized on X and Y.

Discussion

Overall, this study aimed to examine the relationship between attention and working memory through the investigation of three different relationships. We hypothesized that item and order memory are separable but related constructs. We hypothesized that attentional control is related to both item memory – through the size of the attentional spotlight - and order memory – through the shifting of the attentional spotlight. To differentially test these relationships, we created three latent constructs, attention control, item memory, and order memory. We preformed CFA to test the loadings of each task on to their corresponding latent construct. Following the CFA, we chose to use each of the three attention tasks as predictor variables for both item memory and order memory within our structural equation models due to the failure of convergence of the attentional control latent construct.

Based on the results from the two-factor CFA, we found that allowing item memory and order memory to function as separable constructs was a superior fit to the data. People who made more item errors within one serial order memory task also made more item errors in other serial order memory tasks. People who made more order errors in one task made more order errors in the others. The current study supports Healy's (1982) separation of item memory and order memory and demonstrates that they are distinct stimulus-general memory constructs that are worth studying at the latent level. Additionally, the most consistent finding amongst the structural equation models is the relationship between item memory and order memory. Across all three models, item memory significantly, and positively, predicted order memory. Individuals who made more item errors also made more order errors. Although item memory and order memory were shown to operate better as separate constructs, the two were related.

The modeling of the attentional conflict tasks revealed a tenuous relationship between attentional control tasks and item memory, and no relationship between attentional control and order memory. The worse a person performed on the Flanker task the worse they were at reporting the correct items. However, people who performed worse on the flanker task were not any worse at reporting correct items in their correct order.

Based on the differential relationship of attention control with item memory and order memory, it may be the case that attention control is only related to certain aspects of memory retrieval. The present results would indicate that attention control is related to a person's ability to narrow their search within memory but not their ability to shift to new retrieval cues. Based on the positive relationship between attentional control and item memory in the flanker model, we conclude that attention does play a role in correctly retrieving an item from memory. The worse attentional control and individual has, the larger their external spotlight making the selection of a target item in the environment more difficult. Further, it seems to be the case that this larger spotlight is then cast inward making it more difficult for a person to adequately retrieve the target item from their memory. Based on the nonsignificant relationship between attentional control and order memory, we can conclude that attentional control may not determine the effectiveness of shifting to retrieval cues within memory to influence order of report. Attentional control may not play a role in the shifting of the attentional spotlight for effective, ordered retrieval.

Limitations

The lack of relationship between item memory and attention control may simply reflect issues with the tasks used to measure attention control. We used each individual attentional conflict task as a predictor variable, and tasks themselves are not a pure measure of the underlying construct within them. The relationship between order memory and the attention tasks may have been attenuated by task-specific variability in the attention tasks. Additionally, we measured difference scores in the attention tasks, and utilizing difference scores for differential analyses can be problematic (Draheim et al., 2019). Difference scores tend to be unreliable measures that produce low correlations among tasks. The correlations among the attention tasks themselves may have been attenuated due to low reliability. Additionally, difference scores have increased sensitivity to differing interactions of speed and accuracy (Draheim et al., 2019). In lieu of using reaction time difference scores, Draheim and colleagues (2019) suggest using component scores (e.g. incongruent trials only), controlling for the speed-accuracy tradeoff, or combining reaction time and accuracy into a single metric, to name a few. In the future, we plan to utilize one of Draheim's (2019) alternatives as we believe that utilizing response time difference scores significantly contributed to the failure of convergence for the attentional control factor.

The attentional conflict tasks used also may not capture the aspects of attention (for example, the shifting of the spotlight) that are important to order memory. By nature, the attentional conflict tasks rely on the focus of attention (that is, the size of the attentional spotlight) as opposed to the shifting of attention. In the flanker task, for example, having a large attentional spotlight would be detrimental because more distractors would fall within the scope of the wide spotlight. However, having poor attentional shifting would not because the target stimuli are always presented at the center of the display. In the future, we hope to include a shifting attention task within future analyses; this may allow us to better understand attention's role in the shifting of retrieval cues and the theoretical shifting of the attentional spotlight. Difference scores will not be used alongside the shifting attention tasks.

Within the proposed structural equation model, we allowed everything but two variables to correlate with one another. Each pathway between the latent constructs were included in the model due to theoretical foundations from the literature. Digit span item and order errors and symmetry span item and order errors were allowed to correlate with one another due to recommendations made by Mplus. Correlating these measures was justified because they are extracted from the same task. Each of the three models fit the data almost perfectly, but that may reflect overfitting of the data.

References

Baddeley, A. D., & Hitch, G. (1974). Working Memory. In G. H. Bower (Ed.), *Psychology of Learning and Motivation* (Vol. 8, pp. 47–89). Academic Press. https://doi.org/10.1016/S0079-7421(08)60452-1

Broadbent, D. E. (1958). The selective nature of learning Perception and communication (pp. 244-267).

Browne, M. W., & Cudeck, R. (1993). Alternative ways of assessing model fit. *Testing structural equation models*, *154*, 136-162.

Croschere, J., Dupey, L., Hilliard, M., Koehn, H., & Mayra, K. (2012). The effects of time of day and practice on cognitive abilities: Forward and backward Corsi block test and digit span. PEBL Technical Report Series.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. Journal of Verbal Learning and Verbal Behavior, 19(4), 450–466. https://doi.org/10.1016/S0022-5371(80)90312-6

Draheim, C., Mashburn, C. A., Martin, J. D., & Engle, R. W. (2019). Reaction time in differential and developmental research: A review and commentary on the problems and alternatives. *Psychological Bulletin*, *145*(5), 508–535. https://doi.org/10.1037/bul0000192

Eriksen, C. W., & Hoffman, J. E. (1973). The extent of processing of noise elements during selective encoding from visual displays. Perception & Psychophysics, 14(1), 155-160.

Eriksen, C. W., & Schultz, D. W. (1979). Information processing in visual search: A continuous flow conception and experimental results. Perception & Psychophysics, 25(4), 249–263. https://doi.org/10.3758/BF03198804

Eriksen, C. W., & St. James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception & Psychophysics*, *40*(4), 225–240. https://doi.org/10.3758/BF03211502

Esposito, A. G., Baker-Ward, L., & Mueller, S. T. (2013). Interference suppression vs. response inhibition: An explanation for the absence of a bilingual advantage in preschoolers' Stroop task performance. Cognitive Development, 28(4), 354–363. https://doi.org/10.1016/j.cogdev.2013.09.002

Healy, A. F. (1982). Short-term memory for order information. In *Psychology of Learning and Motivation* (Vol. 16, pp. 191-238). Academic Press.

Hu, L., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal*, *6*(1), 1–55. https://doi.org/10.1080/10705519909540118

James, W. (1981). *The principles of psychology* (Vol. 1). Cambridge, MA: Harvard University Press. (Original work published 1890).

Kane, M., Hambrick, Z., Tuholski, S., Wilhelm, O., Payne, T., & Engle, R. (2004). The Generality of Working Memory Capacity: A Latent-Variable Approach to Verbal and Visuospatial Memory Span and Reasoning. Journal of Experimental Psychology. General, 133, 189–217. https://doi.org/10.1037/0096-3445.133.2.189

Kiyonaga, A., & Egner, T. (2013). Working memory as internal attention: Toward an integrative account of internal and external selection processes. *Psychonomic Bulletin & Review*, *20*(2), 228–242. https://doi.org/10.3758/s13423-012-0359-y

Kline, R. B. (2015). *Principles and practice of structural equation modeling*. Guilford publications.

Lindsey, D. R. B., & Logan, G. D. (2021). Previously retrieved items contribute to memory for serial order. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *47*(9), 1403–1438. https://doi.org/10.1037/xlm0001052

Logan, G. D., Cox, G. E., Annis, J., & Lindsey, D. R. (2021). The episodic flanker effect: Memory retrieval as attention turned inward. *Psychological Review*, *128*(3), 397.

Mueller, S. T. (2011). PEBL: The psychology experiment building language. Recuperado de: www. pebl. sf. net/battery. html.

Mueller, S. T., & Esposito, A. G. (2014). Computerized Testing Software for Assessing Interference Suppression in Children and Adults: The Bivalent Shape Task (BST). Journal of Open Research Software, 2(1), e3. https://doi.org/10.5334/jors.ak

Mueller, S. T., & Piper, B. J. (2014). The Psychology Experiment Building Language (PEBL) and PEBL Test Battery. *Journal of Neuroscience Methods*, *222*, 250–259. https://doi.org/10.1016/j.jneumeth.2013.10.024

Muthén, L.K. and Muthén, B.O. (1998-2017). Mplus User's Guide. Eighth Edition. Los Angeles, CA: Muthén & Muthén.

Navon, D. (1977). Forest before trees: The precedence of global features in visual perception. Cognitive Psychology, 9(3), 353–383. https://doi.org/10.1016/0010-0285(77)90012-3

Oberauer, K., & Hein, L. (2012). Attention to Information in Working Memory. *Current Directions in Psychological Science*, *21*(3), 164–169. https://doi.org/10.1177/0963721412444727

Stins, J. F., Polderman, J. C. T., Boomsma, D. I., & de Geus, E. J. C. (2008). Conditional accuracy in response interference tasks: Evidence from the Eriksen flanker task and the spatial conflict task. Advances in Cognitive Psychology, 3(3), 409–417. https://doi.org/10.2478/v10053-008-0005-4

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*(6), 643–662. https://doi.org/10.1037/h0054651

Unsworth, N., & Engle, R. W. (2007). The nature of individual differences in working memory capacity: active maintenance in primary memory and controlled search from secondary memory. Psychological review, 114(1), 104.

Unsworth, N., Redick, T. S., Heitz, R. P., Broadway, J. M., & Engle, R. W. (2009). Complex working memory span tasks and higher-order cognition: A latent-variable analysis of the relationship between processing and storage. Memory, 17(6), 635–654. https://doi.org/10.1080/09658210902998047

Ward, G., Tan, L., & Grenfell-Essam, R. (2010). Examining the relationship between free recall and immediate serial recall: The effects of list length and output order. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *36*(5), 1207–1241. https://doi.org/10.1037/a0020122

van Dijck, J.-P., Abrahamse, E. L., Majerus, S., & Fias, W. (2013). Spatial Attention Interacts With Serial-Order Retrieval From Verbal Working Memory.

Psychological Science, *24*(9), 1854–1859.
https://doi.org/10.1177/095679761347961

Biographical Sketch

Name of Author: Katherine Anne Hernandez

Place of Birth: Mandeville, Louisiana

Graduate and Undergraduate Schools Attended:

University of South Alabama, Mobile, Alabama
Southeastern Louisiana University, Hammond, Louisiana
Louisiana State University, Baton Rouge, Louisiana

Degrees Awarded:

Master of Science in Experimental Psychology, 2022, Mobile, Alabama
Bachelor of Arts in Psychology, 2020, *magna cum laude*, Hammond, Louisiana

Awards and Honors:

Outstanding Brain and Behavior Science Masters Student Award, Department of Psychology, 2021
Graduate Research Assistant, Department of Psychology, 2022
Graduate Research Assistant, Department of Psychology, 2021
Graduate Research Assistant, Department of Psychology, 2020