THE ROLE OF WORKING MEMORY BURDEN AND FLUID INTELLIGENCE IN THE ORGANIZATION OF MEMORY

A Thesis
Present to
The Academic Faculty

By

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In partial Fulfillment
Of the Requirements for the Degree
Master of Science in the
School of Psychology

Georgia Institute of Technology

December, 2014

The Role of Working Memory Capacity and Fluid Intelligence in the Organization of Memory

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ACKNOWLEDGEMENTS

I would like to thank my research assistants, Tamara Ware and Daniel Blanchard for helping me with this project. I would also like to thank my committee.

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SUMMARY

One of the best ways to increase memory performance on a task is to organize the to-be-remembered material (Postman, 1972). Throughout a number of experiments, the amount a subject organizes a list of words has been shown to be related to their overall recall performance (e.g., Mandler & Pearlstone, 1966). However, few studies have investigated whether other cognitive abilities are related to the organization of memory and whether these other abilities contribute to the relationship between organization and memory performance. In the present study subjects completed four sets of multitial free recall and the consistency in which subjects recalled words (a measure of organization) was compared to performance on multiple measures of working memory capacity and fluid intelligence. I show that working memory capacity is related to the organization of memory particularly when subjects were told to use an organizational strategy and that fluid intelligence is related to organization regardless of strategy. Additionally, both working memory capacity and organization predict unique variance in immediate free recall performance.

CHAPTER 1
INTRODUCTION

A student taking a class in European History decides to make a concept map and link all the major events in the French Revolution to help him study for an upcoming test. An older adult having trouble with her memory, uses a peg word system to help her remember which groceries to buy. A subject in a psychology experiment remembers a list of letters by chunking the letters into words. In these examples, people are organizing information to help improve their memory. Psychologists have repeatedly shown the benefits of organizing to-be-remembered items (e.g., Mandler & Pearlstone, 1966). However, researchers have conducted few differential studies investigating individual differences in the organization of memory (Mandler, 2011). It is still unknown whether the extent to which a subject organizes to-be-remembered items is related to working memory capacity and fluid intelligence. Also, considering working memory capacity, fluid intelligence, and organization are all related to free recall performance, it is unclear whether organization predicts unique variance in free recall performance or if the relationship organization and free recall performance can be explained completely by working memory capacity and fluid intelligence.

CHAPTER 2
BACKGROUND

2.1 Organization and Memory

One of the first cognitive studies to address the organization of memory did so serendipitously. Bousfield and Sedgewick (1944) were trying to model performance on a verbal fluency task (e.g., generating as many animals as possible in a given amount of time) and noted that subjects tended to generate words in semantic clusters. For instance, when subjects were instructed to name as many four-legged animals as possible, they generated instances of the farm animals in a cluster. In a follow-up study, subjects were presented with a list of words from four semantic categories in a randomized order (Bousfield, 1953). The number of times the subjects recalled two words sequentially from the same category was greater than that expected by chance. This finding suggested that subjects were using semantic organization to recall the words.

For these studies the experimenters have predetermined which words should be recalled together if subjects are organizing the words in memory (e.g., words in a particular semantic category). However, these studies fail to take into account that a subject could be grouping words together in a way that makes sense to that particular subject (i.e., subjective organization). As an example, a subject may recall the words *corn*, *pig*, and *barn* together. Even though the 3 words may come from different semantic categories (i.e., vegetables, animals, and buildings) the subject may be using a different organization structure (farm-related words).

Miller (1956) argued that recoding to-be-remembered items could overcome the limitations of short-term memory. For example, a subject could attempt to remember the letters *F, B, I, C, I, A* in serial order. This would presumably fill the subject's short-term memory. However, the subject could chunk the 6 letters into two acronyms making: *FBI* and *CIA*.

Miller's notion of chunking led many psychologists to propose a strong theory of organization. This is the idea that organization is the causal mechanism behind why subjects are able to remember more items than would be predicted by their limited short-term memory capacity (Mandler, 1967; Postman, 1972).

Organization is not just relevant to words that are easily categorizable. Tulving (1962) had subjects perform a multitrial free recall task in which one list of unrelated words was presented multiple times, in different order each time. Subjects tended to recall the words in a similar sequence after each list presentation. This is noteworthy because the order in which the words were presented changed for each trial. This finding suggests that subjects were using an organizational strategy to help recall the words. The amount of organization increased with each presentation of the list and was positively correlated with recall performance. Critically, this study examined subjective organization, organizational patterns which were unique for each subject. This approach accounts for the fact that subjects have different life experiences and may group words in different ways.

To explicitly measure how subjects organized a list of words, Mandler and Pearlstone (1966) presented subjects with cards containing words. Half of the subjects sorted these cards into categories of their own choosing and the others sorted the words into the same categories as a previous subject in the experimental condition. At the end of the experiment, subjects were given an incidental free recall task for the sorted words. Subjects recalled virtually the same number of words in both conditions indicating that categorizing words is not more beneficial for memory than adopting someone else's categorization. Critically, the number of categories subjects sorted the words into was positively correlated with the number of words recalled. This result suggests that a greater amount of organization is associated with better recall of information (Mandler, 1967).

More recent researchers studying the organization of memory have adopted a weaker theory of organization believing that organization increases recall but is not the sole causal mechanism increasing memory performance. For instance, Craik and Lockhart (1972) argued that organizational processing is a "deep" form of processing that requires more effort than physical or phonological processing, thus leading to improved recall. Additionally, researchers have found that a mixture of both organizational and item-specific processing (e.g., pleasantness rating) lead to better recall than either task alone (Einstein & Hunt, 1980; Hunt & Einstein, 1981). Regardless of whether researchers adopt the strong or weak theory of organization, all agree that organizing material leads to improved recall (Postman, 1972).

Although many studies stress the importance of the link between free recall performance and organization, few studies have examined what other cognitive abilities are related to organization. In one program of research, subjects were determined to be high organizers or low organizers based on median split of an organization measure from multitrial free recall task (Ozier, 1980). Ozier argued that subjective organization was independent of cognitive ability by showing that high and low organizers did not differ on two different measures of intelligence and a digit span task. In one study, high organizers and low organizers performed either a serial recall task or a free recall task (Earhard, 1967). High organizers were predicted to outperform low organizers on a free recall task but that both groups would perform equally well on a serial order recall task because the order at recall was structured. Unexpectedly, high organizers outperformed low organizers on both memory tasks. This finding is troubling; measures of subjective organization should only correlate with tasks that allow subjects to determine their order of recall. If high organizers outperform low organizers on memory tasks that should not have anything to do with organization then it may be the case that some third variable like working memory capacity or fluid intelligence causes both subjective organization and memory performance.

2.2 Individual Differences in Working Memory Capacity

Working memory capacity is an individual's ability to maintain and manipulate information in memory in the presence of interference and has traditionally been measured by complex span tasks. In these tasks subjects are presented with to-be-remembered items and perform a processing task in between item presentations. At the end of a trial a recall screen appears and subjects have to indicate the items that were presented in correct serial order. For example, in the operation span task subjects must solve math equations while trying to remember letters (see Figure 1 for an example). Working memory capacity has been shown to be related to a variety of higher order cognitive abilities such as intelligence (Engle, Tuholski, Laughlin, & Conway, 1999; Kyllonen & Christal, 1990), reading comprehension (Daneman & Carpenter, 1980; Turner & Engle, 1989), multitasking (Hambrick et al., 2010), following directions (Engle, Carullo, & Collins, 1991), and computer programming (Shute, 1991). Importantly, working memory capacity is related to performance on a free recall task (Unsworth & Engle, 2007).

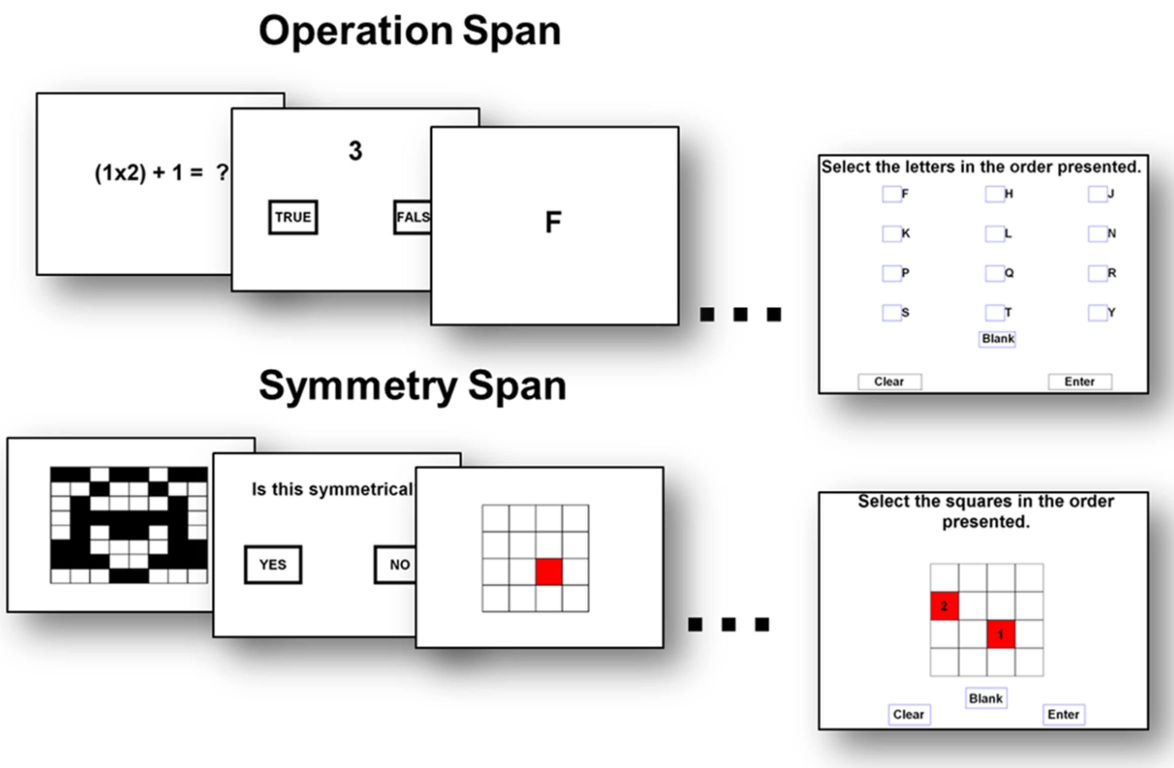

Figure 1. *Examples of the operation and symmetry span tasks.*

There is some evidence to support the theory that organization and working memory capacity are related (Rosen & Engle, 1997; Unsworth, Spillers, & Brewer, 2011). In one experiment, subjects with high working memory capacity (high spans) and subjects with low working memory capacity (low spans) performed a verbal fluency task (Rosen & Engle, 1997). Independent raters judged how many clusters of semantically similar items occurred together for each subject. High spans recalled more category instances than low spans and the cluster size for high spans was larger than the cluster size for low spans. These results suggest that high spans may be better at using the semantic structure of memory to guide their recall. However, one problem with this study is that the conditions in which high and low spans learned the items could be different. Perhaps high spans recall more instances of a category because they have had better education than lows. Ideally, the best way to examine the role of working memory capacity in the organization of memory would be to control the circumstances that items are presented to subjects.

2.3 Present Study

The present study was designed to answer three major questions. First, I wanted to determine whether subjective organization was a stable individual difference. If subjective organization measures are unrelated to one another, then the measures are not measuring a stable individual difference. Previous studies have classified subjects as high and low organizers based on one list of multitrial free recall (Earhard, 1967). The present study improves upon this method by treating subjective organization as a continuous variable and including four multitrial free recall lists to obtain multiple measures of subjective organization.

Second, I examined the relationships between working memory capacity, fluid intelligence, and subjective organization. Previous research has claimed that subjective organization is not related to other cognitive abilities (Ozier, 1980). However, fluid intelligence has been shown to be related to using effective memory strategies (Hertzog, Dunlosky, & Robinson, 2013; Hertzog & Robinson, 2005), and subjects who report using an organizational strategy have better performance on complex span tasks (Dunlosky & Kane, 2007). Additionally, I examined whether working memory capacity and fluid intelligence were more strongly related to subjective organization when subjects were explicitly told to use organization to aid recall or when subjects were not given any specific instructions. Previous research has shown that the correlation between operation span performance and reading comprehension increases when subjects are told to use a rehearsal strategy on the operation but not when given a semantic or imagery recall strategy (Turley-Ames & Whitfield, 2003). Thus, the operation span task becomes more predictive of reading comprehension when subjects are forced to use a strategy that maximizes reliance on working memory capacity (i.e., rote-rehearsal). Working memory capacity is, therefore, not related to the implementation of any strategy but the implementation of specific strategies. Because chunking words together requires multiple words to be activated in memory, I predicted that giving subjects an organizational strategy will increase the correlation between working memory capacity and the subjective organization measures.

Finally I wanted to address how working memory capacity, fluid intelligence, and subjective organization are related to the immediate free recall of words. Both working memory capacity (Unsworth & Engle, 2007) and subjective organization (Sakoda, 1956; Tulving, 1962) have been repeatedly shown to correlate with recall performance. However it is unclear if subjective organization predicts free recall performance above and beyond working memory capacity and fluid intelligence. I predicted that, although subjective organization would be related to cognitive ability, it would still predict unique variance in the immediate free recall task.

CHAPTER 3
METHOD

3.1 Subjects

One-hundred and thirty-five subjects were recruited from the Georgia Institute of Technology and from the Atlanta community. Subjects completed the study either for partial credit for a course (2 credit hour) or for monetary compensation (a 30 dollar check). Subjects were between 18 and 30 years of age and had completed a general screening study with our lab.

3.2 Procedure

Screening Tasks. Subjects completed a battery of different tasks during a general screening session(s). The tasks that are relevant to the present study include:

Operation Span (OSpan; Unsworth, Heitz, Schrock, & Engle, 2005). Subjects were presented with a math equation and then a solution (see Figure 1). They indicated whether the solution was correct and were then presented with a letter. After 3 - 7 math operation/letter pairings, a recall screen appeared for subjects to indicate the letters in the order in which they were presented. The proportions of letters recalled in correct serial order was the dependent variable.

Symmetry Span (SymSpan; Unsworth, Heitz, Schrock, & Engle, 2005). Subjects were presented with a 16 x 16 black and white grid (see Figure 1). Subjects indicated whether the grid was symmetric about the vertical axis. A 4 x 4 matrix was then displayed with one of the cells of the matrix highlighted. After 2 - 5 symmetry judgment/matrix locations, a recall screen appeared and subjects were to select the matrix locations in correct serial order. The proportion of matrix locations recalled in the correct order was the dependent variable.

Running Letter Span (RunSpan; Broadway & Engle, 2010). Subjects were visually presented with a brief series of letters. After the letter presentations, subjects attempted to recall a certain number of the most recent letters in correct serial order. For example, if a subject was asked to recall the last 3 letters and presented with the letters *Q, T, J, K, D,* the correct response would be *J, K, D.* The number of letters to be recalled ranged from 3 to 7 and subjects were presented with the number of letters to-be-recalled at the beginning of each block of two trials. The proportion of letters recalled in correct serial order was the dependent variable.

Raven's Advanced Progressive Matrices (Ravens; Raven, Raven, & Court, 1998). Subjects were presented with a 3 x 3 matrix of figures. The bottom-right figure was missing and subjects had to select the correct figure out of 8 answer choices that completed the matrix in a way that was consistent with the underlying logical pattern of the other figures. Subjects had 10 minutes to complete 18 problems.

Letter Sets (Ekstrom, French, Harman, Dermen, 1976). Subjects were presented with 5 sets of 4 letters. Every set except for one followed a certain pattern. Subjects had to select the set of letters that did not follow the pattern. Subjects had 7 minutes to complete 30 problems.

Number Series (NumberSer; Thurstone, 1938). Subjects were presented with a series of numbers that were arranged in a particular way and asked to select the next number to be consistent with the logical order of the rest of the series. Subjects had 5 minutes to complete 15 problems.

Immediate Free Recall (IFR). Subjects were visually presented with 7 lists of 12 words. Words were presented at a rate of one word per second. After the words were presented, subjects had 30 seconds to write down as many of the words as they could remember. The total number of words correctly recalled was taken as an individual's IFR score. Primary memory and secondary memory measures were also derived from this task using Tulving and Colata's (1970) procedure.

Subjective Organization Session. Subjects were be invited back to complete an additional session if they had completed all of the previous screening tasks.

Multitrial Free Recall. Subjects completed four sets of multitrial free recall. Each set was comprised of 9 presentations of a list of 35 words. The order of the words was randomized for each presentation and the words were presented on a computer screen for 1.5 s each. After each list presentation, subjects were instructed to recall as many words as they could remember into a microphone. Each list contained 35 randomly selected words from the English Lexicon Project norms (Balota et al., 2007) with the following parameters: every word was a noun, between 5-7 letters in length, and contained only 2-3 syllables.

The first two lists of multitrial free recall were presented without informing subjects about any strategies that may improve their performance. Subjects were simply instructed to recall the words in any order. For the third and fourth sets of multitrial free recall, subjects were encouraged to use organization to aid their performance on the task.

Specifically subjects were instructed, "In the next two sets of trials, we would like you to use a strategy to help you remember the words. We would like you to try to connect the words together in memory. For instance, if you were presented with the words, dog, wealth, and tall. You could think about a wealthy dog that is also tall. You could then try to recall these words together during the recall periods."

There were two critical measurements from the multitrial free recall. The total number of words correctly recalled was calculated for each trial. The average of words recalled per list was used as the individual difference measure. To measure subjective organization, paired frequency

(PF) was calculated for every successive pair of trials (Sternberg & Tulving, 1977). Paired frequency is a bidirectional measure of subjective organization that was adapted from Bousfield and Bousfield's (1966) intertrial repetition measure. It is highly correlated with other measures of subjective organization and is also the most psychometrically reliable measure (Sternberg & Tulving, 1977). Because paired frequency scores were between two pairs of trials, I averaged all the paired frequency values for each list to obtain 4 average paired frequency scores for the correlational analyses.

CHAPTER 4
RESULTS

The data from six subjects were excluded because subjects failed to report any words for three or more trials in the multitrial free recall or the computer software crashed for a subject. This left the data from 129 subjects. The descriptive statistics for each task is presented in Table 1 and the correlation matrix for the tasks is presented in Table 2. For all repeated measures analyses, if the assumption of sphericity was violated (i.e., Mauchly's test was significant), I used the Greenhouse-Geisser degrees of freedom correction. The use of this correction is indicated by the non-integer degrees of freedom in the ANOVA tables.

Table 1. *Descriptive statistics for each task*

Task	Mean	Variance	Skewness	Kurtosis	Internal Consistency
Operation Span	**57.21**	**129.511**	**-0.69**	**0.20**	**.84**[2]
Symmetry Span	**26.35**	**72.354**	**-0.20**	**-0.60**	**.84**[2]
Running Span	**39.91**	**131.55**	**-0.19**	**0.42**	**.81**[2]
RAPM	**9.48**	**12.56**	**-0.16**	**-0.372**	**.80**[2]
Letter Sets	**15.24**	**19.70**	**-0.25**	**-0.67**	**.82**[2]
Number Series	**9.02**	**7.67**	**-0.26**	**-0.26**	**.76**[2]
PF List 1	**1.68**	**2.30**	**1.47**	**2.60**	**.88**[3]
PF List 2	**1.77**	**2.77**	**1.61**	**2.96**	**.90**[3]
PF List 3	**2.49**	**6.95**	**1.77**	**3.42**	**.94**[3]
PF List 4	**3.26**	**10.63**	**1.09**	**0.30**	**.94**[3]
MTFR List 1	**15.13**	**18.57**	**0.30**	**-0.10**	**.95**[3]
MTFR List 2	**13.76**	**21.69**	**0.27**	**-0.08**	**.95**[3]
MTFR List 3	**14.56**	**33.18**	**0.14**	**-0.44**	**.97**[3]
MTFR List 4	**15.72**	**41.32**	**0.03**	**-0.92**	**.97**[3]
PM Recall[1]	**2.62**	**0.46**	**-0.73**	**2.01**	**.80**[2]
SM Recall[1]	**2.01**	**0.76**	**0.84**	**1.55**	**.78**[2]
IFR Total[1]	**4.63**	**1.43**	**0.21**	**1.75**	**.79**[2]

[1]**Based off of 126 subjects**
[2]**Cronbach's Alpha from Shipstead, Lindsey, Marshall, & Engle (2013)**
[3]**Cronbach's Alpha from the present study**

Table 2. *Correlation Matrix*

	OSpan	Sym Span	Run Span	RAPM	Letter Sets	Num Series	PF List1	PF List2	PF List3	PF List4	MTFR List1	MTFR List2	MTFR List3	MTFR List4	PM Recall[1]	SM Recall[1]
OSpan	1															
SymSpan	0.37	1														
RunSpan	0.42	0.31	1													
RAPM	0.31	0.44	0.49	1												
LetterSets	0.13	0.33	0.44	0.56	1											
NumSeries	0.19	0.38	0.35	0.61	0.58	1										
PFList1	-0.01	0.23	0.25	0.49	0.28	0.31	1									
PFList2	0.05	0.28	0.23	0.45	0.26	0.30	0.74	1								
PFList3	0.15	0.37	0.29	0.49	0.30	0.36	0.69	0.70	1							
PFList4	0.12	0.33	0.26	0.46	0.27	0.37	0.60	0.64	0.82	1						
MTFRList1	0.09	0.26	0.23	0.44	0.25	0.31	0.80	0.64	0.64	0.64	1					
MTFRList2	0.11	0.31	0.37	0.45	0.28	0.35	0.61	0.83	0.64	0.64	0.79	1				
MTFRList3	0.10	0.31	0.30	0.50	0.36	0.36	0.62	0.64	0.82	0.77	0.74	0.74	1			
MTFRList4	0.12	0.31	0.28	0.50	0.31	0.35	0.58	0.61	0.71	0.85	0.75	0.76	0.88	1		
PMRecall[1]	0.19	0.25	0.46	0.44	0.38	0.27	0.34	0.39	0.45	0.44	0.34	0.40	0.46	0.43	1	
SMRecall[1]	0.27	0.27	0.40	0.43	0.27	0.26	0.36	0.37	0.42	0.49	0.36	0.38	0.46	0.44	0.18	1
IFRTotal[1]	0.31	0.34	0.55	0.56	0.42	0.34	0.46	0.50	0.56	0.53	0.45	0.50	0.59	0.57	0.70	0.83

[1]Correlations for the immediate free recall task are from 126 subjects

4.1 Multitrial Free Recall

First, I examined whether the instruction manipulation had any effect on the mean number of words recalled for the multitrial free recall task. For the first two lists, the numbers of words correctly recalled were averaged for each trial to obtain a score for recall performance when subjects were not instructed to use a strategy (Discovery). The same procedure was used for the lists 3 and 4 to create a recall score for the number of words recalled when subjects were given an organization strategy (Implementation). A 2 x 9 within-subjects ANOVA with the effects of strategy (Discovery, Implementation) and trial was conducted (see Table 3 for the ANOVA statistics). As can be seen in Figure 2, subjects recalled more words with each successive trial and, critically, subjects recalled more words when they were instructed to use an organizational strategy (M = 15.55 words) compared to when they were not given a strategy (M = 14.80 words).

Table 3. *ANOVA Table for Multitrial Free Recall Measures*

Measure/Effect	F	df	p	η^2_p
Words Recalled				
Strategy	5.73	(1, 128)	0.02	0.04
Trial	384.00	(2.19, 285.39)	< 0.01	0.75
Trial (Linear Contrast)	543.11	(1,128)	< 0.01	0.81
Trial (Quadratic Contrast)	307.50	(1,128)	<0.01	0.71
Strategy X Trial	1.19	(5.84, 787.12)	0.31	0.01
Paired Frequency				
Strategy	42.33	(1, 128)	< 0.01	0.25
Pair	384.00	(1.87, 239.82)	< 0.01	0.43
Pair (Linear Contrast)	136.31	(1,128)	< 0.01	0.52
Pair (Quadratic Contrast)	13.13	(1,128)	< 0.01	0.09
Strategy X Pair	8.88	(3.82, 488.47)	< 0.01	0.07
Strategy X Pair (Linear Contrast)	16.96	(1,128)	< 0.01	0.12
Strategy X Pair (Quadratic Contrast)	6.37	(1,128)	0.01	0.05

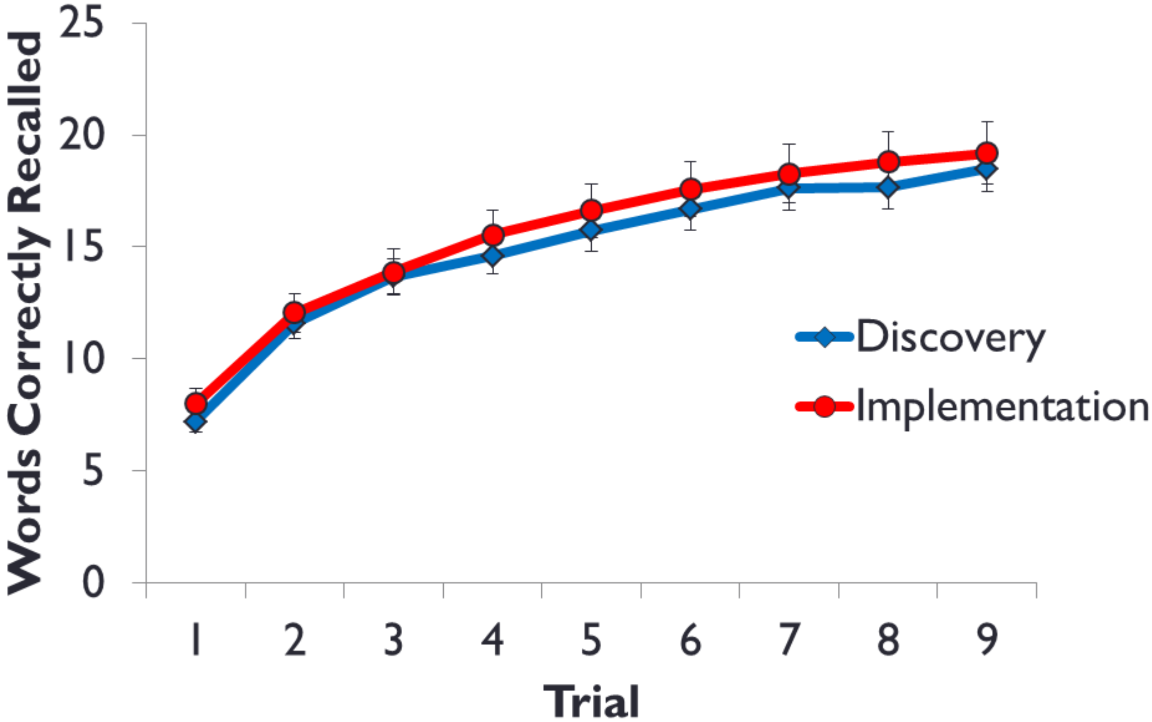

Figure 2. *Words Recalled. The amount of words correctly recalled in the multitrial free recall lists by strategy and trial. Error bars represent 95% confidence intervals.*

Additionally, I examined whether the instructional manipulation affected the extent to which subjects organized the words they recalled. To do this, paired frequency scores for each successive pair of trials were averaged for the first two lists and the last two lists. A 2 x 8 within subjects ANOVA with the effects of strategy (Discover, Implementation) and pair of trials was conducted. Subjects' recalled appeared more organized when they were given an organizational strategy (*M* = 2.88) compared to when they were not given a strategy (*M* =1.73; see Figure 3). Over the course of each list, paired frequency scores increased. However, paired frequency scores increased at a greater rate when subjects were given the organizational strategy.

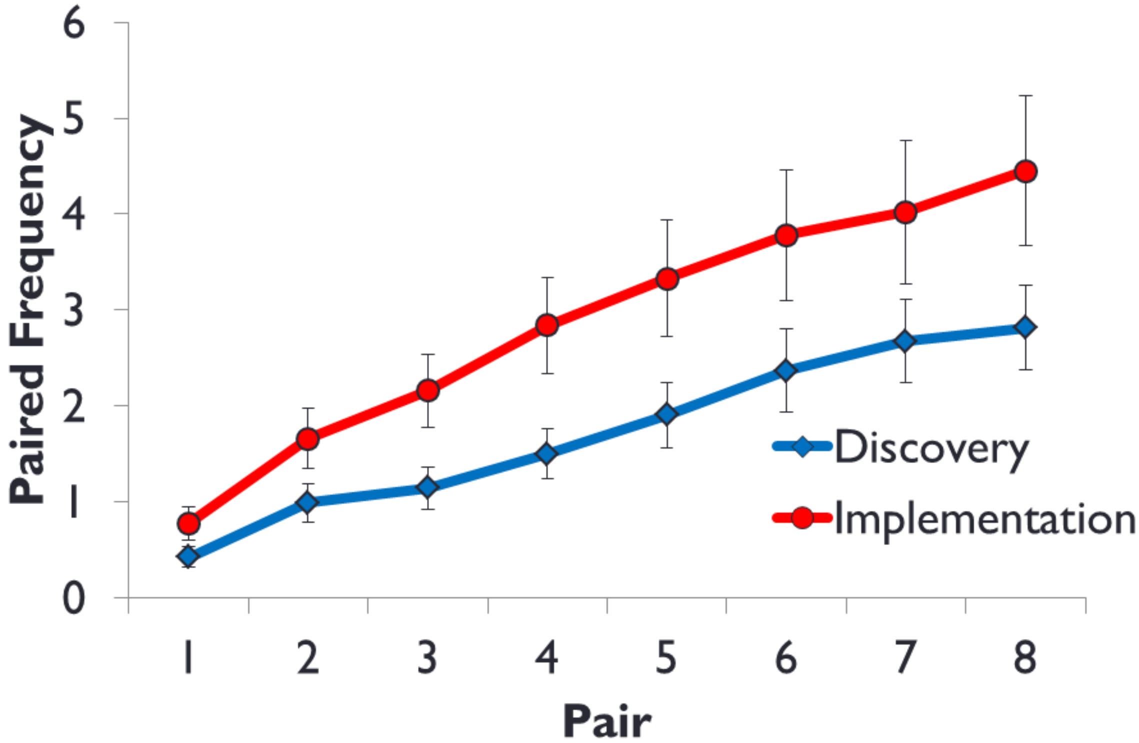

Figure 3. *Paired Frequency. The paired frequency scores from the multitrial free recall lists by strategy and pair (the first pair represents the PF score for list presentations 1 and 2, the second pair represents the PF for lists 2 and 3, etc.). Error bars represent 95% confidence intervals.*

Although both the number of words recalled and PF scores increased with organizational instructions, the sizes of the effects were different. The effect size for words recalled was medium-sized (Cohen, 1988; $\eta^2_p = .04$) while the effect for paired frequency was quite large ($\eta^2_p = .25$). This discrepancy is problematic for the strong theory of organization. The theory would predict that a manipulation that produced a sizable increase in organization would produce an increase in words correctly recalled of a similar magnitude. Additionally, it is difficult to argue that that increasing organization causes increased free recall performance when the increase in recall is not large. For these reasons I examined the effect of the strategy manipulation for individuals with high and low working memory capacity. One potential reason for not finding a large effect of strategy may be that some subjects do not have the working memory capacity needed to successfully implement the organizational strategy.

I computed z-scores for the three working memory tasks (Operation Span, Symmetry Span, and Running Span) and averaged them together to form a working memory capacity composite. The 25% of subjects that had the highest composite scores were classified as high spans and the 25% with the lowest scores were classified as low spans (32 subjects in each group). To analyze the words correctly recalled for both spans, a 2 x 2 x 9 mixed factorial ANOVA was conducted with the between groups variable of span (high, low) and the within subjects variables of strategy (Discovery, Implementation) and trial (see Tables 4 and 5 for the ANOVA statistics). On average, subjects recalled more words when given the organizational strategy (15.52 words) than when given no strategy (14.91 words; see Figure 4). Critically, the magnitude of this effect depended on span. Low spans recalled roughly the same amount of words regardless of strategy instructions while high spans recalled significantly more words when they were given organizational instructions, $t(31) = -2.67$, $p = .01$., $d = .56$. This result could explain the medium-sized effect of the strategy manipulation in the analysis with all the subjects. One reason that the size of the strategy effect is attenuated for the overall analysis could be because low spans do not show an effect of the strategy manipulation. This interaction between span and strategy could exist for a number of reasons. Low spans may not have the ability to successfully utilize an organizational strategy or they may not be attempting to use the strategy in the first place.

Table 4. *ANOVA Table for Individual Difference Analyses with Multitrial Free Recall Accuracy*

Measure/Effect	F	df	*p*	η^2_p
Words Recalled				
Span	12.22	(1, 62)	< 0.01	0.17
Strategy	6.51	(1, 62)	0.01	0.10
Trial	234.18	(2.10, 129.98)	< 0.01	0.79
Trial (Linear Contrast)	335.42	(1, 62)	< 0.01	0.84
Trial (Quadratic Contrast)	146.28	(1, 62)	< 0.01	0.70
Span X Strategy	6.51	(1, 62)	< 0.01	0.10
Span X Trial	3.85	(2.10, 129.98)	0.02	0.06
Span X Trial (Linear Contrast)	4.75	(1, 62)	0.03	.07
Span X Trial (Quadratic Contrast)	5.00	(1, 62)	0.03	.08
Strategy X Trial	0.79	(4.63, 287.15)	0.56	0.01
Span X Strategy X Trial	0.70	(4.63, 287.15)	0.63	0.01

Table 5. *ANOVA Table for Individual Difference Analyses with the Paired Frequency Scores*

Measure/Effect	F	df	*p*	η^2_p
Paired Frequency				
Span	12.29	(1, 62)	< 0.01	0.64
Strategy	24.63	(1, 62)	< 0.01	0.28
Pair	59.18	(1.88, 116.59)	< 0.01	0.48
Pair (Linear Contrast)	82.46	(1, 62)	< 0.01	0.57
Pair (Quadratic Contrast)	9.38	(1, 62)	< 0.01	0.13
Span X Strategy	9.03	(1, 62)	< 0.01	0.13
Span X Pair	6.75	(1.88, 116.59)	< 0.01	0.10
Span X Pair (Linear Contrast)	9.16	(1, 62)	< 0.01	0.13
Span X Pair (Quadratic Contrast)	< 1.00	(1, 62)	0.52	0.01
Strategy X Pair	5.02	(3.20, 198.12)	< 0.01	0.08
Strategy X Pair (Linear Contrast)	8.01	(1, 62)	< 0.01	0.11
Strategy X Pair (Quadratic Contrast)	5.10	(1, 62)	0.03	0.08
Span X Strategy X Pair	2.68	(3.20, 198.12)	0.04	0.04
Span X Strategy X Pair (Linear Contrast)	5.22	(1, 62)	0.03	0.08
Span X Strategy X Pair (Quadratic Contrast)	< 1.00	(1, 62)	0.66	< 0.01

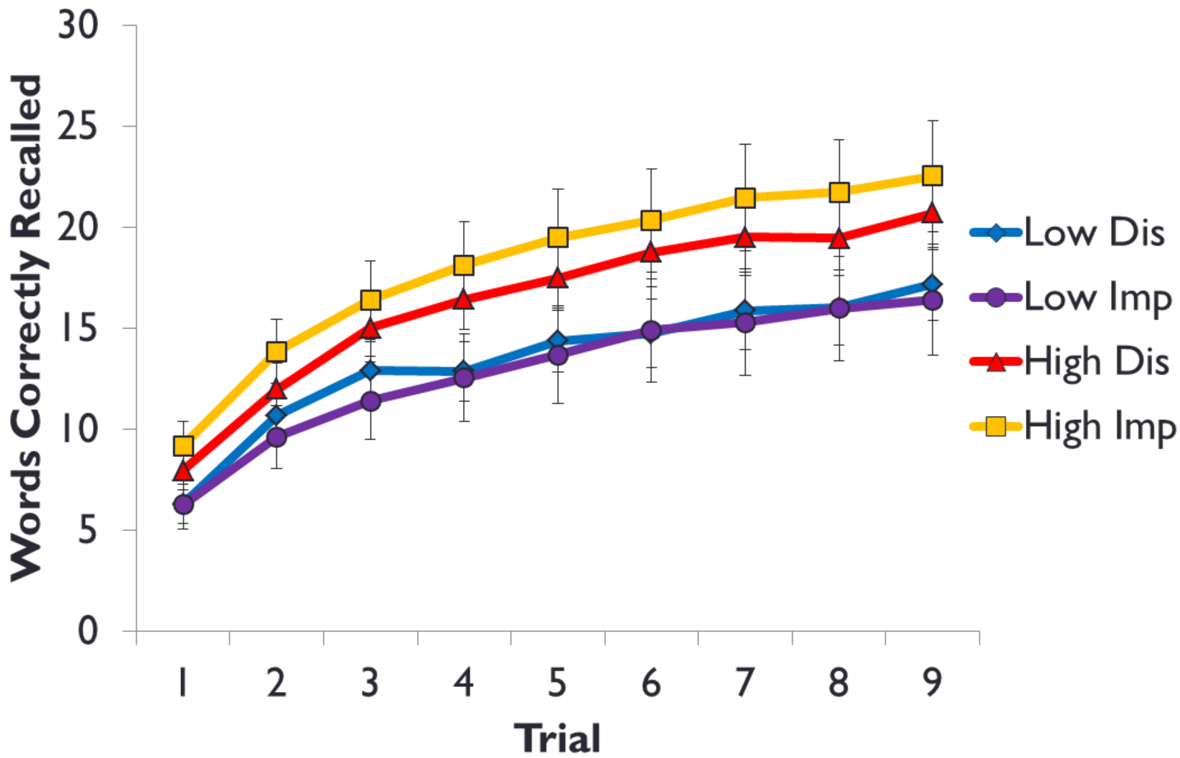

Figure 4. *Individual Differences in Words Correctly Recalled. The amount of words correctly in the multitrial free recall lists by strategy (Discovery, Implementation), span (high span, low span) and trial. Error bars represent 95% confidence intervals.*

To examine the extent to which high and low spans organized their recall, the paired frequency data were subjected to a 2 x 2 x 8 mixed factorial ANOVA with the between groups variable of span and the within subjects variables of strategy and pair (see Figure 5). Similar to the overall analysis, subjects showed more evidence of organizing their recall after receiving the organizational instructions. This effect was qualified by span; high spans show greater organization after the instructional manipulation than low spans. However, there was still an effect of strategy for low spans, $t(31) = -2.28$, $p = .03$, $d = .45$. Thus, low spans followed instructions and attempted to organize their recall. They were not as successful at this strategy as were the high spans and even though low spans were utilizing an organizational strategy this did not increase the number of words recalled.

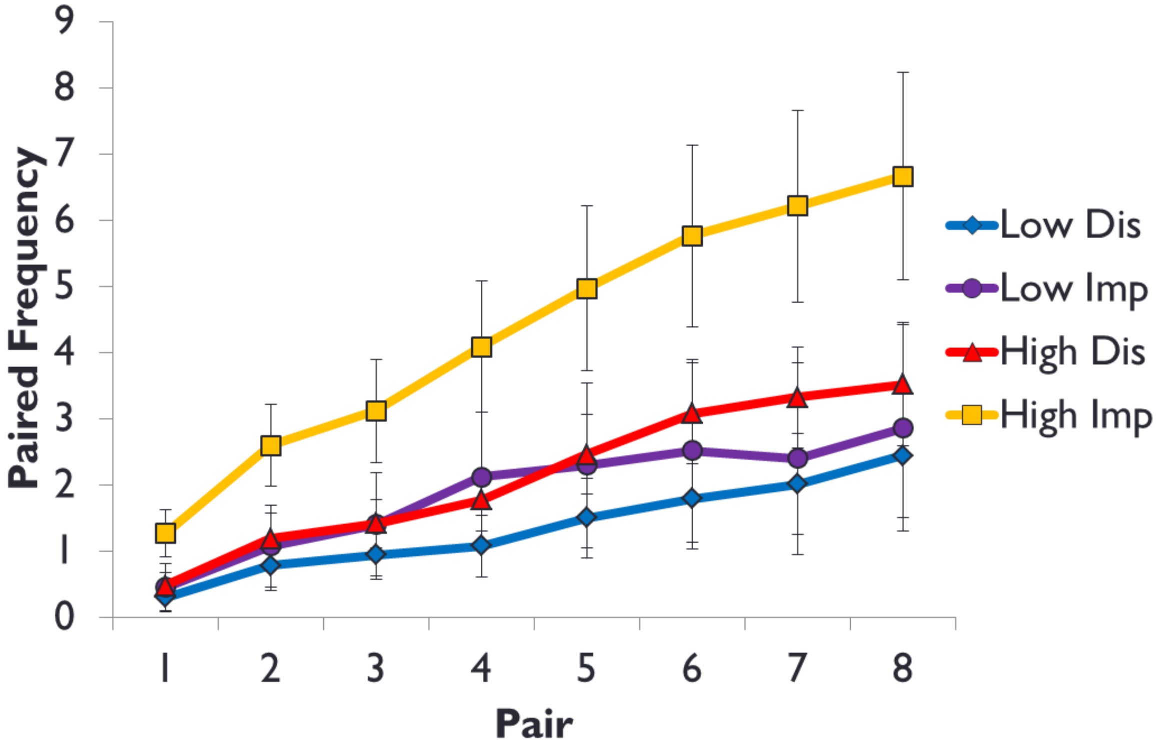

Figure 5. *Individual Differences in Paired Frequency. The paired frequency scores from the multitrial free recall lists by strategy (Discovery, Implementation), span (high span, low span) and pair. Error bars represent 95% confidence intervals.*

4.2 Subjective Organization As A Stable Individual Difference

A principal components analysis was conducted with the mean paired frequency scores from the 4 lists to examine whether subjective organization is a stable and reliable individual difference. If subjective organization is a reliable individual difference, this analysis should show that one component accounts for the majority of the variance and that all 4 mean paired frequency scores load highly onto that component. This is exactly what was found. Only the first component had an eigenvalue greater than one (indicating that only one component accounted for a practically significant amount of variance in task performance) and all the mean paired frequency scores had loadings greater than .85 for this component (see Tables 6 and 7).

Table 6. *Principal Components Analysis with Paired Frequency Data.*

Component	Eigenvalue	Percent of Variance Accounted For
1	**3.09**	**77.23**
2	**.48**	**12.07**
3	**.26**	**6.54**
4	**.17**	**4.16**

Table 7. *Principal Components Analysis with Paired Frequency Data.*

Measure	Component 1	Component 2	Component 3	Component 4
PFList1	**.86**	**.37**	**.35**	**.06**
PFList2	**.87**	**.32**	**-.38**	**.03**
PFList3	**.92**	**-.25**	**.03**	**-.32**
PFList4	**.87**	**-.43**	**.00**	**.25**

4.3 Relationship Between Subjective Organization And Cognitive Abilities

A confirmatory factor analysis was conducted (Three Factor CFA) to examine whether an individual's subjective organization ability is related to working memory capacity and fluid intelligence. The mean PF scores for all four lists loaded onto a subjective organization factor (SO; see Figure 6). Although SO was correlated with both working memory capacity and fluid intelligence, substantive claims regarding the subjective organization factor could not be made because of the poor fit of the model (see Table 8; CFI < .95 and χ^2/df > 2.00).

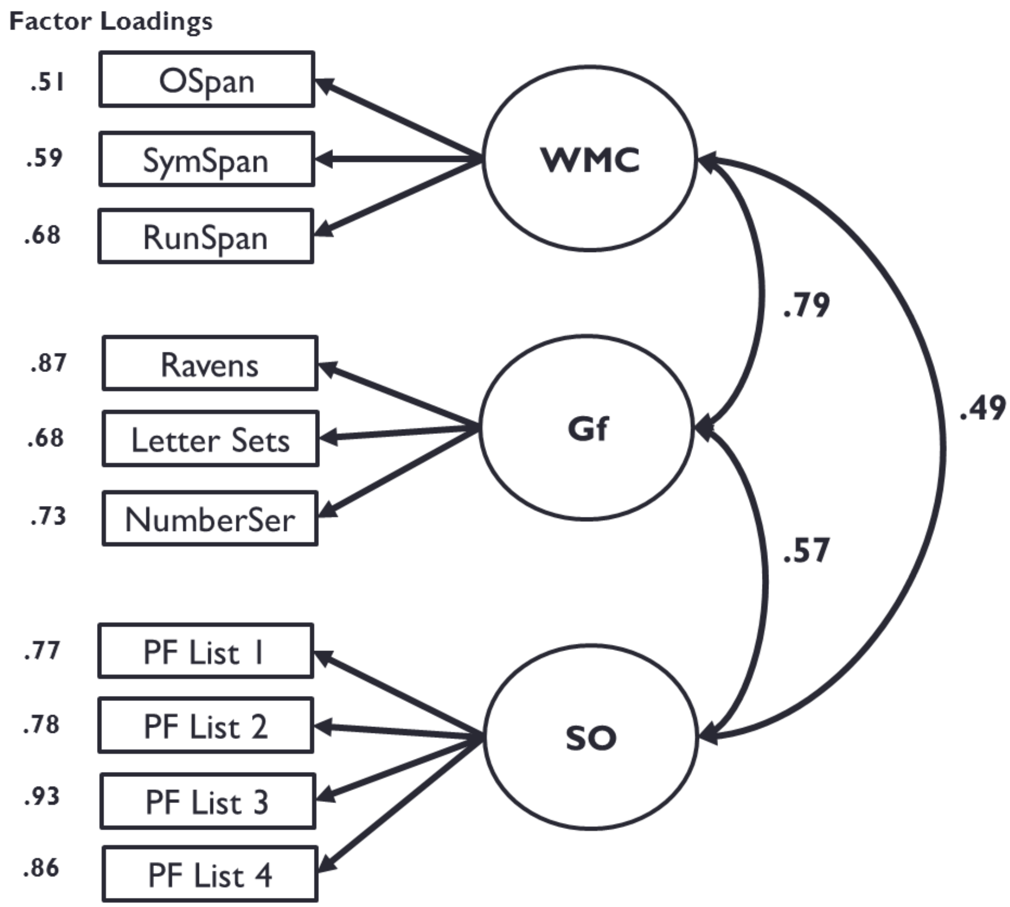

Figure 6. *Confirmatory factor analysis: Three Factor CFA. SO = Subjective Organization, OSpan = Operation Span, SymSpan = Symmetry Span, RunSpan = Running Letter Span, Ravens = Raven's Advanced Progressive Matrices, NumberSer = Number Series, PF Lists 1-4 = The average PF measure for each set of multitrial free recall trials.*

Considering subjects were told about organizing their recall for half of the multitrial free recall lists, I conducted another confirmatory factor analysis (Four Factor CFA) to model the variance specifically related to implementing an organizational strategy. To accomplish this I crossloaded the mean paired frequency scores for lists 3 and 4 crossload onto an Implementation (Impl.) factor (see Figure 7). The fit of this model was good (CFI > .95 and χ^2/df < 2.00). Contrary to Ozier's (1980) finding that subjective organization was unrelated to cognitive ability, subjective organization was related to both working memory capacity and fluid intelligence. However, there was a dissociation between working memory capacity and fluid intelligence in their relationship to subjective organization. Both constructs were related to the SO factor but only working memory capacity was related to the implementation factor. To test whether the working memory capacity/implementation and fluid intelligence/implementation correlations were significantly different, the correlations were constrained to be the same in a separate model. This resulted in significantly worse model fit ($\Delta\chi^2(1) = 4.29$, $p < .05$) indicating that working memory capacity was statistically be related to the implementation factor than fluid intelligence.

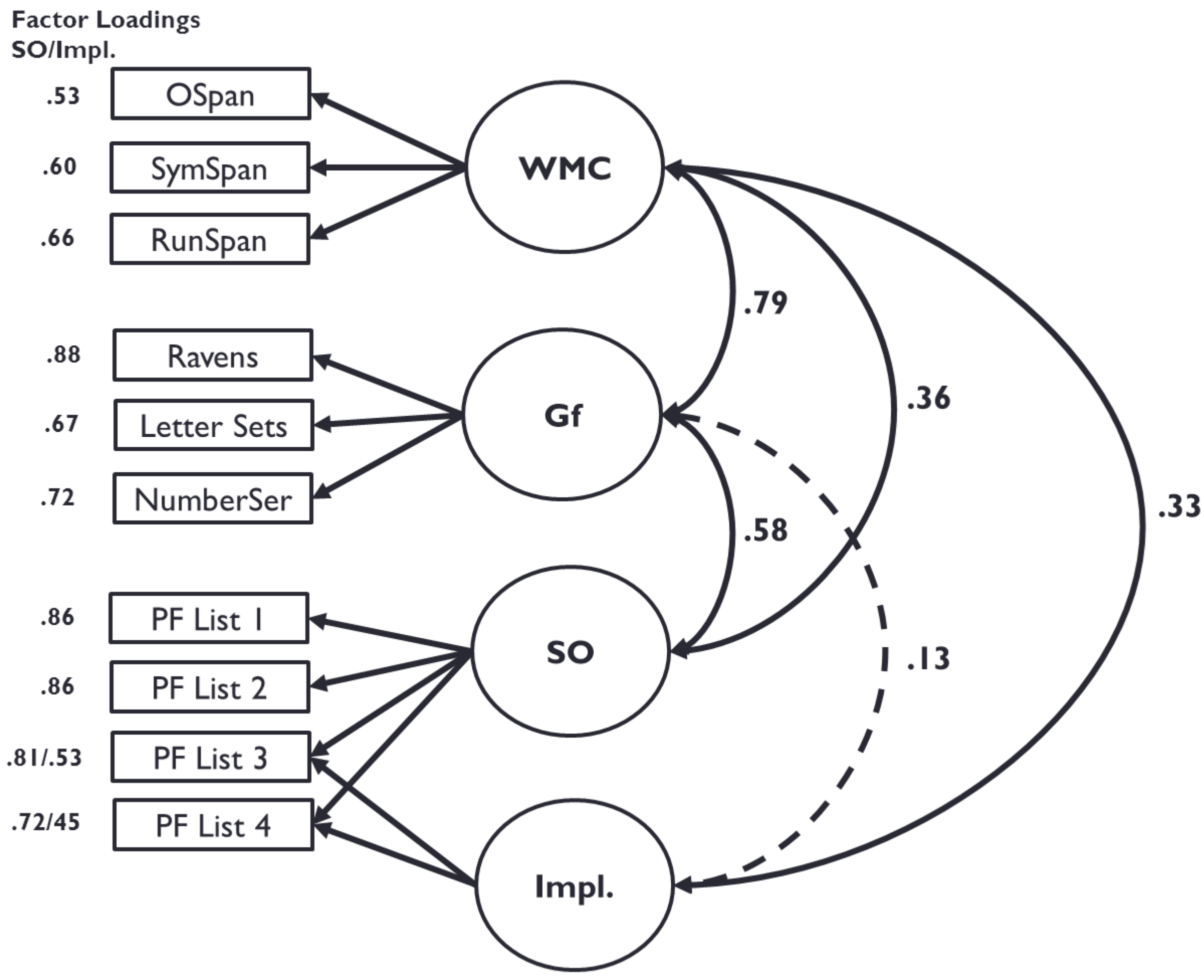

Figure 7. *Confirmatory factor analysis: Four Factor CFA. SO = Subjective Organization, Impl. = Implementationb OSpan = Operation Span, SymSpan = Symmetry Span, RunSpan = Running Letter Span, Ravens = Raven's Advanced Progressive Matrices, NumberSer = Number Series, PF Lists 1-4 = The average PF measure for each set of multitrial free recall trials.*

A potential disadvantage with the previous models is that paired frequency scores were averaged for each list. Considering the degree of organization increased across trials (Figure 3), working memory capacity and fluid intelligence might be related to subjective organization differentially across a number of trials for the multitrial free recall task. For instance, working memory capacity might not be strongly related to subjective organization after the first two trials but may be highly related subjective organization for the later trials. In other words, working memory capacity would be related to the rate of increase in subjective organization across trials but not to subjective organization scores for the first pair of trials. The best way to answer these kinds of questions is with latent growth curve models in which the contribution of the intercept of paired frequency scores and the slope of growth in the paired frequency scores can be separated.

I created two latent growth curve models to examine the influence of working memory capacity and fluid intelligence for paired frequency scores for the multitrial free recall blocks in which subjects were given an organizational strategy and when they were not given this strategy. The paired frequency scores for the first two blocks and the last two blocks were averaged for each pair of trials for these analyses. Considering the increase in paired frequency scores was not linear (see Figure 3), I decided to estimate the slope of improvement in paired frequency scores by setting the path between the first paired frequency score to the slope factor to be zero and the path between the last paired frequency score and the slope factor to be one. The other slope paths were free to vary (McArdle, 1988). Additionally, the error terms for the adjacent paired frequency scores were allowed to correlate. The models are presented in Figures 8 and 9. The fit statistics for these models are presented in Table 8 and the factor loadings for the working memory capacity and fluid intelligence factors are included in Table 9.

Table 8. *Model Fit Indices*

Model	χ^2	df	*p*	χ^2/df	CFI	RMSEA
Three Factor CFA	**69.35**	**32**	**<.01**	**2.17**	**.94**	**.10**
Four Factor CFA	**40.87**	**28**	**.06**	**1.45**	**.98**	**.06**
LGC- Discover	**98.41**	**70**	**.01**	**1.41**	**.97**	**.06**
LGC - Implement	**74.77**	**70**	**.33**	**1.07**	**.99**	**.03**
SEM-All Paths	**49.51**	**33**	**.03**	**1.50**	**.98**	**.06**
SEM-Two Paths	**50.43**	**35**	**.05**	**1.44**	**.98**	**.06**

Table 9. *Factor Loadings for the Latent Growth Curve Analyses*

Model	OSpan	SymSpan	RunSpan	Ravens	Letter Sets	NumberSer
LGC-Discover	**.53**	**.57**	**.69**	**.88**	**.67**	**.71**
LGC- Implement	**.52**	**.58**	**.68**	**.85**	**.69**	**.74**

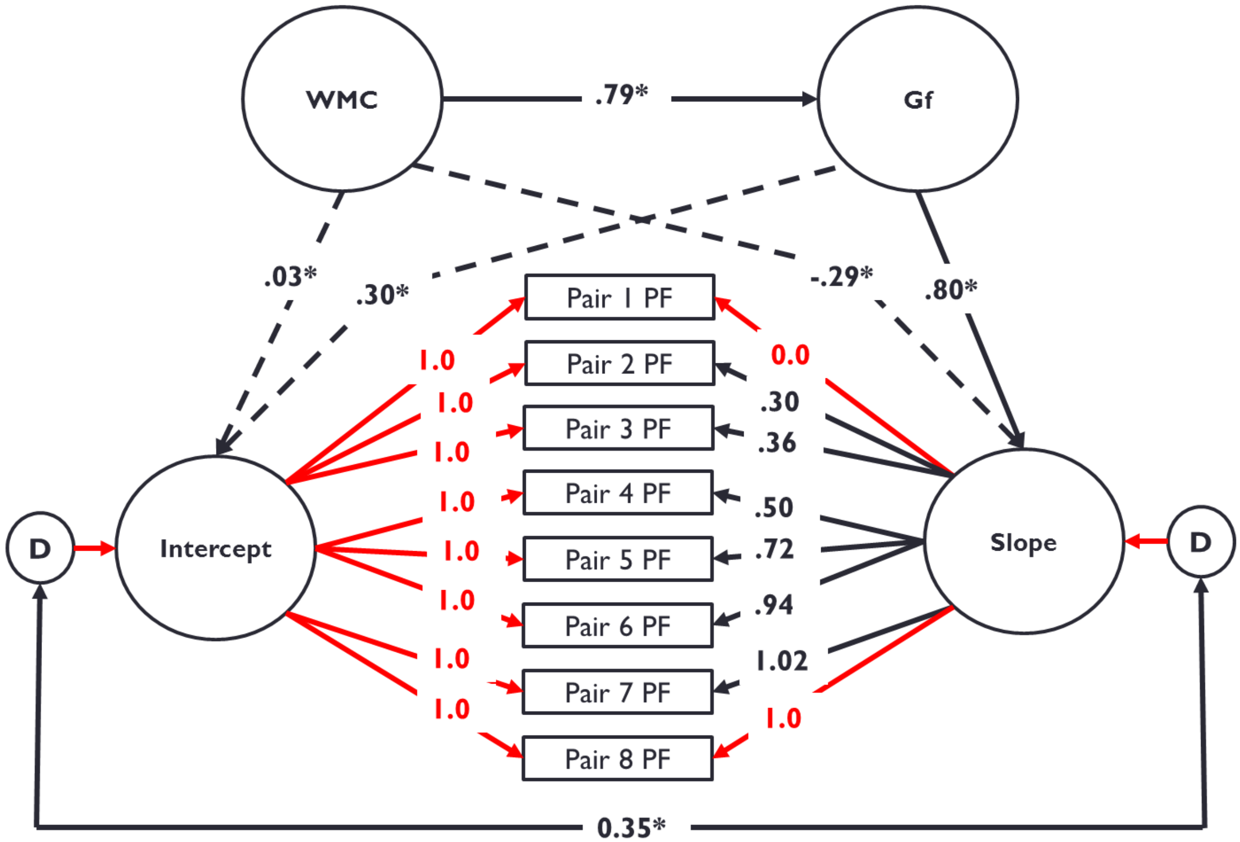

Figure 8. *LGC – Discover. Latent growth curve model explaining the relationship between WMC, Gf, and the slope and intercept for the paired frequency (PF) scores for the first two blocks of multitrial free task. Red lines indicate set paths and black lines indicate estimated paths/correlations. All number are unstandardized weights except for the numbers followed by an asterisk (*) which indicates a standardized path/correlation. Errors in adjacent PF scores were allowed to correlate.*

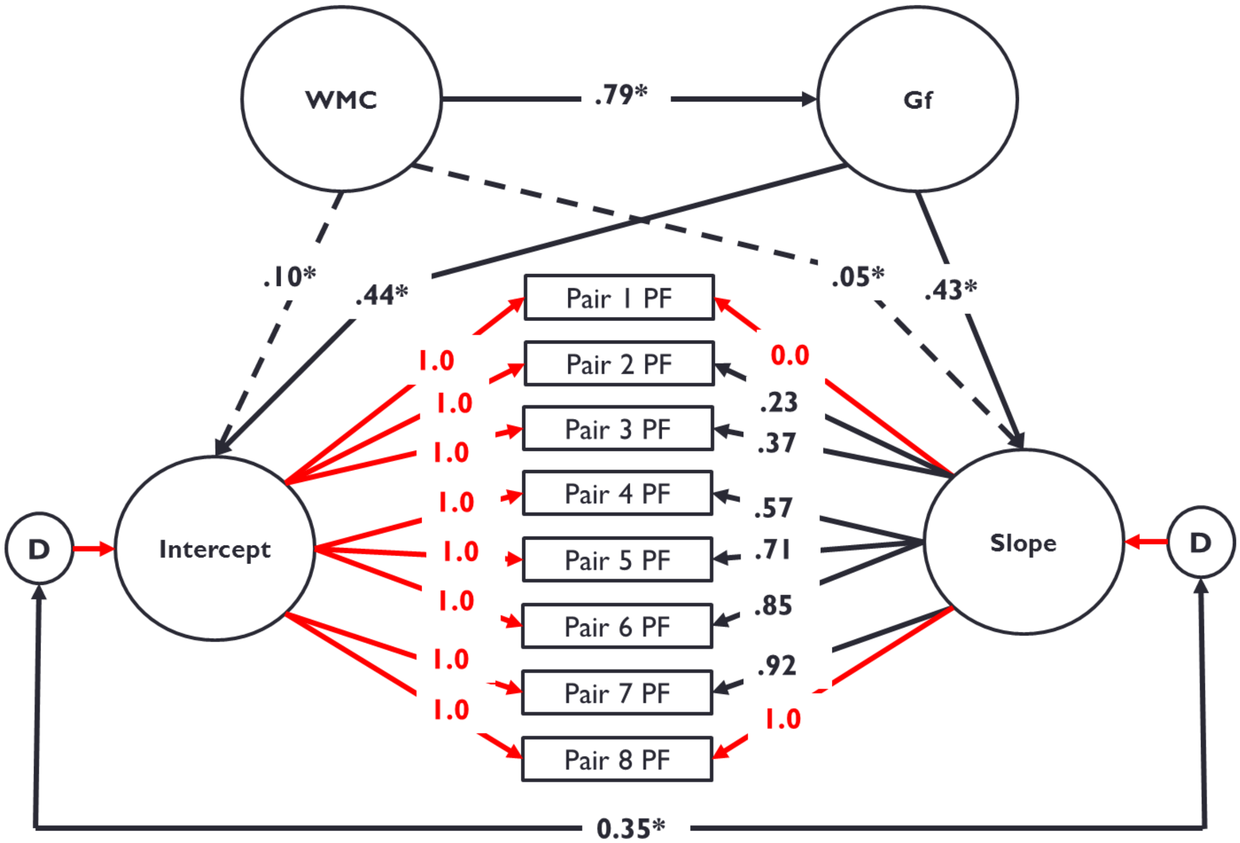

Figure 9. *LGC – Implement. Latent growth curve model explaining the relationship between WMC, Gf, and the slope and intercept for the paired frequency (PF) scores for the last two blocks of multitrial free task. Red lines indicate set paths and black lines indicate estimated paths/correlations. All number are unstandardized weights except for the numbers followed by an asterisk (*) which indicates a standardized path/correlation. Errors in adjacent PF scores were allowed to correlate.*

The red paths were set and the black paths were free to vary. Unlike the other models presented in this paper, the weights for the paths and correlations are unstandardized. Standardized weights are presented with an asterisk (*). The fit of these models was good (CFIs > .95 and RMSEA < .06; Byrne, 2013). The most pervasive finding from these two models is that fluid intelligence is related to the slope of improvement for the paired frequency scores regardless of whether subjects received organizational instructions. Described in terms of simple correlations, this means that the correlations between cognitive ability measures and paired frequency scores increase across each presentation of the word lists.

Giving subjects an organizational strategy increases fluid intelligence's relationship to the intercept of the paired frequency scores. This makes sense because subjects are beginning to organize their recall on trial one when they receive. Additionally, fluid intelligence accounts for working memory capacity's relationship to both the intercept and slope of the increase in the paired frequency scores. This is not surprising considering the strong relationship between working memory capacity and fluid intelligence.

4.4 Does Subjective Organization Predict Unique Variance?

To determine whether subjective organization predicted the same variance in immediate free recall performance as working memory capacity and fluid intelligence, I created a structural equation model (SEM-All Paths). The same factor structure from the four factor solution was used because of its superior fit to the three factor solution. The fit of this model was good (see Table 8) and only the paths for working memory capacity and subjective organization were significant. To create a more parsimonious model, I dropped the paths for the fluid intelligence and implementation factor (SEM-Two Paths, See Figure 10). This did not result in a significant decrease in model fit ($\Delta\chi^2(2) = .92$, $p > .05$). Thus, subjective organization measures collected from a different memory task predicted immediate free recall performance above and beyond working memory capacity and fluid intelligence. Another interesting finding from this model is that fluid intelligence's relationship to immediate free recall performance is completely accounted for by working memory capacity and subjective organization.

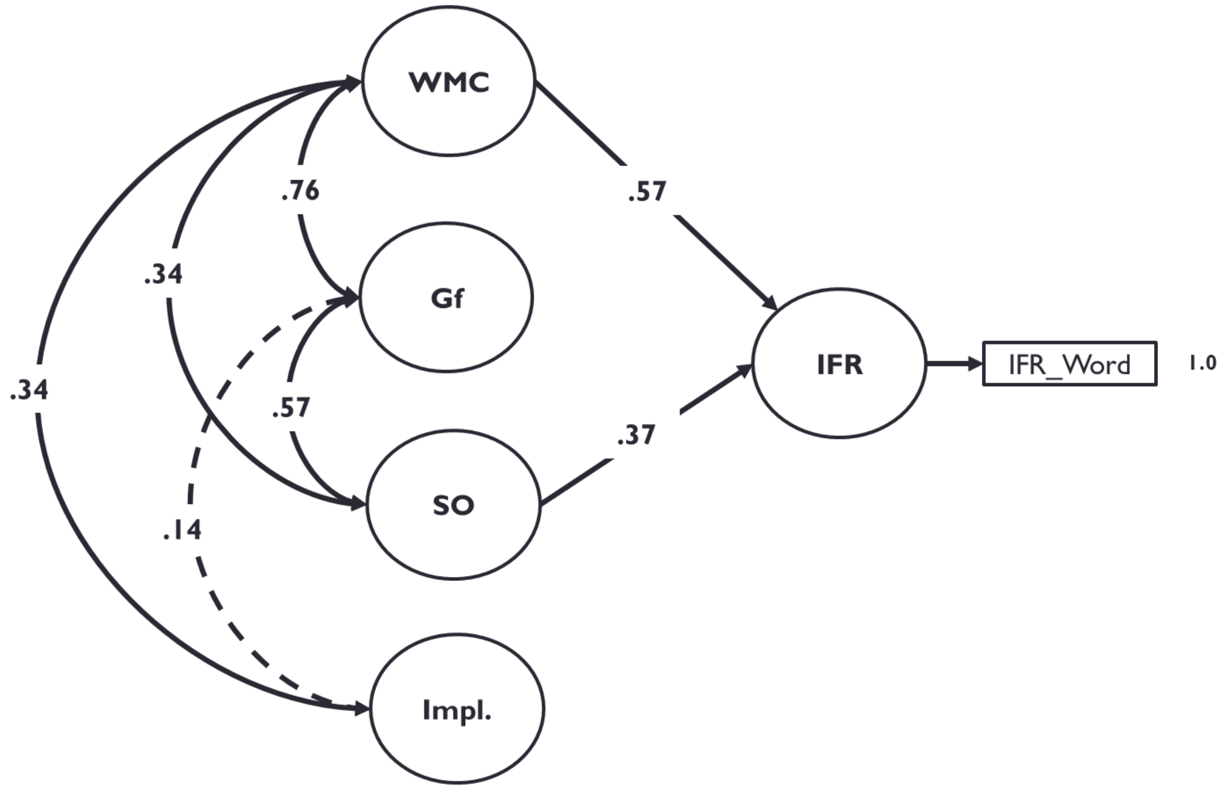

Figure 10. *Structural model for SEM – Two Paths. SO = Subjective Organization, Impl. = Implementation, IFR = Immediate Free Recall.*

CHAPTER 5
DISCUSSION

In the first large-scale study of individual differences in subjective organization, I showed that subjective organization is a stable individual difference, it is correlated with both working memory capacity and fluid intelligence, and it uniquely predicts immediate free recall performance above and beyond the other cognitive abilities.

5.1 Subjective Organization, Working Memory Capacity, and Fluid Intelligence.

Both working memory capacity and fluid intelligence were correlated with paired frequency scores, however, the two abilities were correlated with the paired frequency scores for different reasons. Working memory capacity was related to both the subjective organization and the implementation factor. Thus, although working memory capacity was related to the paired frequency scores when subjects were not given a strategy, it was more strongly related to the paired frequency scores when subjects were told to use an organizational strategy.

One potential reason for this result is that working memory capacity is necessary to chunk words together in memory. To successfully chunk words together, subjects must have words currently activated in memory. Subjects with high working memory capacity are able to keep more of the items activated in memory than subjects with low working memory capacity (see Figure 11 for a theoretical example). Thus, those with high working memory capacity are able to chunk larger groups of items and have a better selection of items to chunk. This idea is similar Oberauer's work on the relationship between relational integration and working memory capacity (Oberauer, Süβ, Wilhelm, & Sander, 2007; Oberauer, Süβ, Wilhelm, & Wittmann, 2003). He makes the argument that working memory capacity is important for forming temporary relationships among items. If this is the case, the correlation between paired frequency scores and working memory capacity should increase when subjects were told to implement an organizational strategy. This is exactly what we found with working memory capacity's correlation with the implementation factor. The results from our ANOVAs were consistent with this interpretation as well. High spans' PF scores greatly improved after the instructional manipulation in comparison to the low spans.

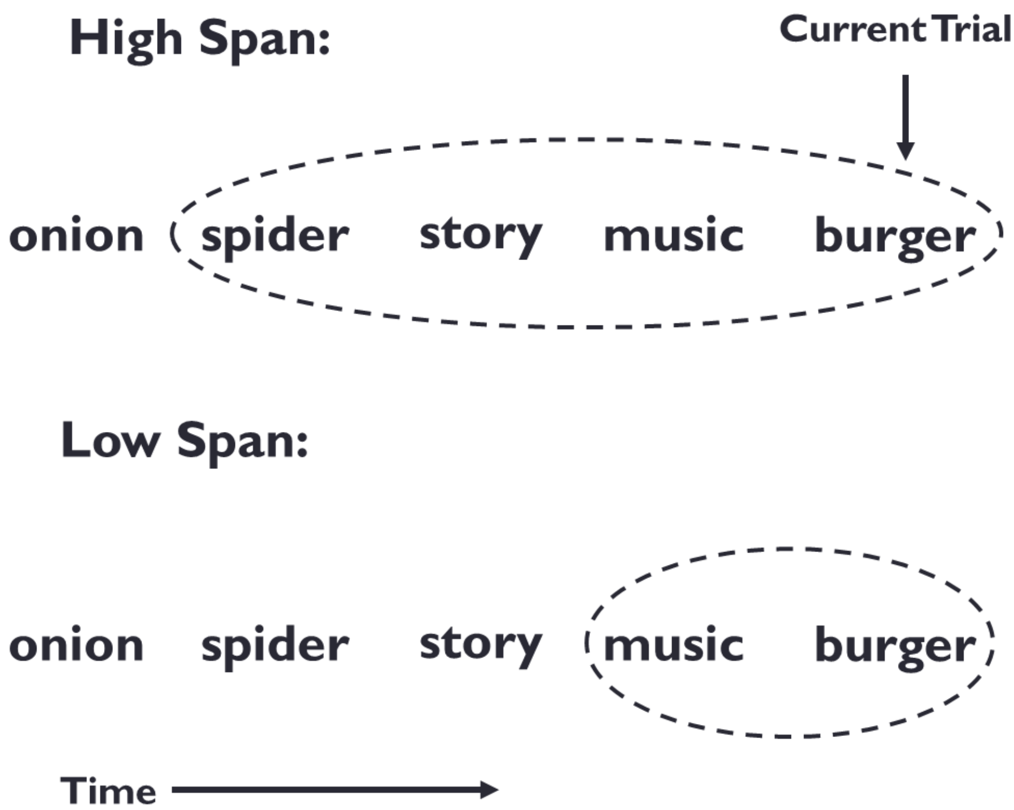

Figure 11. *Theoretical model explaining the relationship between WMC and SO. The dotted line represents the number of words that are held in an accessible state in short-term memory for high and low span subjects.*

On the other hand, fluid intelligence was more strongly related to the subjective organization factor than working memory capacity and not related to the implementation factor. This means that fluid intelligence was substantially related with the paired frequency scores from all the lists regardless of strategy instructions. One reason for why fluid intelligence was related to subjective organization is that those with greater fluid intelligence were better able at finding relationships between seemingly unrelated words. All the fluid intelligence tasks that were used in this study required subjects to uncover a pattern among a variety of items (e.g., finding relationships among figures in RAPM). Thus, these tasks all measure subjects' ability to find relationships among items, an ability that is also needed to chunk words together in a free recall task. Another potential explanation for the correlation between fluid intelligence and subjective organization comes from the memory strategies literature. Subjects with high fluid intelligence come to the lab knowing effective ways to remember words, including chunking words together (Hertzog, Dunlosky, & Robinson, 2013; Hertzog & Robinson, 2005). Fluid intelligence may show a relationship with subjective organization because those with higher fluid intelligence know that chunking the words will benefit their memory performance.

One of the key findings of the present research is the dissociation between working memory capacity and fluid intelligence. Probably the most prominent finding in the study of working memory capacity is its relationship with fluid intelligence. Some researchers have even questioned whether the two constructs reflect the same ability (Ackerman, Beier, & Boyle, 2005; Heitz et al., 2006; Kane, Hambrick, & Conway, 2005; Kyllonen & Christal, 1990). The present study provides a clear dissociation between the two constructs. Even though working memory capacity and fluid intelligence are strongly related (a correlation of .79 at the latent level), the two constructs predict different variance in the paired frequency scores. Working memory capacity seems to be strongly related to the implementation of an organizational strategy while fluid intelligence appears to be important regardless of instruction.

5.2 Predicting Immediate Free Recall.

The great interest in memory organization stemmed from the relationship between organization and free recall performance (e.g., Tulving, 1962). It was unclear from early studies whether subjective organization predicted free recall independent of cognitive ability or whether cognitive ability completely mediated the relationship between organization and free recall performance. The present research shows that paired frequency scores calculated from multitrial free recall lists were not only related to performance on an immediate free recall task but predicted a sizable amount of unique variance. The paired frequency scores measure whether subjects are likely to use an effective strategy to remember words (i.e., chunking). Working memory capacity and fluid intelligence tasks do not directly measure subjects' ability to chunk words and this is why paired frequency scores predict unique variance in free recall performance.

Additionally, fluid intelligence does not seem to predict a substantial amount of unique variance in immediate free recall performance. Interestingly, fluid intelligence's relationship with free recall performance is accounted for completely by its correlations with both working memory capacity and subjective organization. Thus, it seems that fluid intelligence is related to immediate free recall performance for two reasons. Those with high fluid intelligence are more likely to adopt and implement chunking strategies and more likely to have great working memory capacity which allows them to keep more words activated in memory.

5.3 Future Directions.

Although the present research indicates that subjective organization is an important individual difference to consider when predicting any free recall performance it is unclear the extent to which the ability transfers to other memory tasks. Words are easier to organize than numbers but it is unknown whether the ability to organize words is related to the ability to organize numbers. Additionally, the finding that working memory capacity is related to the implementation of effective strategies leads to many novel predictions. If this finding is true, putting high spans under cognitive load should lead them to have lower paired frequency scores on a multitrial free recall task and the effect would be greater for when subjects were explicitly told to use an organizational strategy. One limitation of the present study is that an individual's ability to organize information was defined solely by their paired frequency scores on a multitrial free recall task. This is a very narrow definition and future research should examine whether organization of stimuli other than words shows the same relationship to both working memory capacity and fluid intelligence.

References

Ackerman, P. L., Beier, M. E., & Boyle, M. O. (2005). Working Memory and Intelligence: The Same or Different Constructs?. *Psychological Bulletin*, *131*, 30-60. doi:10.1037/0033-2909.131.1.30

Bailey, H., Dunlosky, J., & Kane, M. J. (2008). Why does working memory span predict complex cognition? Testing the strategy affordance hypothesis. *Memory & Cognition*, *36*, 1383-1390. doi:10.3758/MC.36.8.1383

Balota, D. A., Yap, M. J., Cortese, M. J., Hutchison, K. A., Kessler, B., Loftis, B., & ... Treiman, R. (2007). The English Lexicon project. *Behavior Research Methods*, 39, 445-459.

Bousfield, W. A. (1953). The occurrence of clustering in the recall of randomly arranged associates. *Journal of General Psychology*, 49, 229-240.

Bousfield, A. K., & Bousfield, W. A. (1966). Measurement of clustering and of sequential constancies in repeated free recall. *Psychological Reports*, *19*, 935-942. doi:10.2466/pr0.1966.19.3.935

Bousfield, W. A., & Sedgewick, C. W. (1944). An analysis of sequences of restricted associative responses. *Journal of General Psychology*, 30, 149-165.

Broadway, J. M., & Engle, R. W. (2010). Validating running memory span: Measurement of working memory capacity and links with fluid intelligence. *Behavior Research Methods*, 42, 563-570. doi:10.3758/BRM.42.2.563

Byrne, B. M. (2013). *Structural equation modeling with EQS: Basic concepts, applications, and programming*. Routledge.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Routledge.

Craik, F. I., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning & Verbal Behavior*, 11, 671-684. doi:10.1016/S0022-5371(72)80001-X

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

Dunlosky, J., & Kane, M. J. (2007). The contributions of strategy use to working memory span: A comparison of strategy assessment methods. *The Quarterly Journal Of Experimental Psychology*, *60*, 1227-1245. doi:10.1080/17470210600926075

Earhard, M. (1967). Subjective organization and list organization as determinants of free-recall and serial-recall memorization. *Journal of Verbal Learning & Verbal Behavior*, 6, 501-507. doi:10.1016/S0022-5371(67)80007-0

Einstein, G. O., & Hunt, R. (1980). Levels of processing and organization: Additive effects of individual-item and relational processing. *Journal of Experimental Psychology: Human Learning and Memory*, 6, 588-598. doi:10.1037/0278-7393.6.5.588

Ekstrom, R. B., French, J. W., Harman, M. H., & Dermen, D. (1976). *Manual for kit of factor-referenced cognitive tests*. Princeton, NJ: Educational Testing Service.

Engle, R. W., Carullo, J. J., & Collins, K. W. (1991). Individual differences in working memory for comprehension and following directions. *Journal of Educational Research*, 84, 253-262.

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. A. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General*, 128, 309-331. doi:10.1037/0096-3445.128.3.309

Hambrick, D. Z., Oswald, F. L., Darowski, E. S., Rench, T. A., & Brou, R. (2010). Predictors of multitasking performance in a synthetic work paradigm. *Applied Cognitive Psychology,* 24, 1149-1167. doi:10.1002/acp.1624

Heitz, R. P, Redick, T. S., Hambrick, D. Z., Kane, M. J., Conway, A. R. A., & Engle, R. W. (2006). WM, EF, and gF are not the same. *Behavioral and Brain Sciences,* 29, 135-136.

Hertzog, C., Dunlosky, J., & Robinson, A. E. (2013). *Intellectual abilities and metacognitive beliefs influence spontaneous use of effective encoding strategies.* Manuscript submitted for publication.

Hertzog, C., & Robinson, A. (2005). Metacognition and Intelligence. In O. Wilhelm, R. W. Engle (Eds.), *Handbook of understanding and measuring intelligence* (pp. 101-123). Thousand Oaks, CA US: Sage Publications, Inc. doi:10.4135/9781452233529.n7

Hunt, R., & Einstein, G. O. (1981). Relational and item-specific information in memory. *Journal of Verbal Learning & Verbal Behavior*, 20, 497-514. doi:10.1016/S0022-5371(81)90138-9

Kane, M. J., Hambrick, D. Z., & Conway, A. A. (2005). Working Memory Capacity and Fluid Intelligence Are Strongly Related Constructs: Comment on Ackerman, Beier, and Boyle (2005). *Psychological Bulletin*, *131*, 66-71. doi:10.1037/0033-2909.131.1.66

Kyllonen, P. C., & Christal, R. E. (1990). Reasoning ability is (little more than) working-memory capacity?. *Intelligence*, 14, 389-433. doi:10.1016/S0160-2896(05)80012-1

Mandler, G. (1967). Organization and memory. In K.W. Spence & J.T. Spence (Eds.), *The psychology of learning and motivation: Advances in research and theory* (pp. 328–372). New York, NY: Academic Press.

Mandler, G. (2011). From association to organization. *Current Directions In Psychological Science*, *20*, 232-235. doi:10.1177/0963721411414656

Mandler, G., & Pearlstone, Z. (1966). Free and constrained concept learning and subsequent recall. *Journal of Verbal Learning & Verbal Behavior*, 5, 126-131. doi:10.1016/S0022-5371(66)80005-1

McArdle, J. J. (1988). Dynamic but structural equation modeling of repeated measures data. In J. R. Nesselroade, R. B. Cattell (Eds.), *Handbook of multivariate experimental psychology (2nd ed.)* (pp. 561-614). New York, NY US: Plenum Press. doi:10.1007/978-1-4613-0893-5_17

Miller, G. A. (1956). The magical number seven, plus or minus two: some limits on our capacity for processing information. *Psychological Review*, 63, 81-97. doi:10.1037/h0043158

Oberauer, K., Süß, H., Wilhelm, O., & Sander, N. (2007). Individual differences in working memory capacity and reasoning ability. In A. A. Conway, C. Jarrold, M. J. Kane, J. N. Towse (Eds.) , *Variation in working memory* (pp. 49-75). New York, NY US: Oxford University Press.

Oberauer, K., Süß, H., Wilhelm, O., & Wittman, W. W. (2003). The multiple faces of working memory: Storage, processing, supervision, and coordination. *Intelligence, 31*, 167-193. doi:10.1016/S0160-2896(02)00115-0

Ozier, M. (1980). Individual differences in free recall: When some people remember better than others. In G H. Bower (Eds.), *The psychology of learning and motivation: Advances in research and theory: Advances in research and theory* (pp. 309-364). New York, NY: Academic Press.

Postman, L. (1972). A pragmatic view of organization theory. In E. Tulving & W. Donaldson (Eds.), *Organization and memory* (pp. 3-48). New York, NY: Academic Press.

Raven, J., Raven, J. C., & Court, J. H. (1998). *Manual for Raven's Progressive Matrices and Vocabulary Scales.* New York, NY: Psychological Corporation.

Rosen, V. M., & Engle, R. W. (1997). The role of working memory capacity in retrieval. *Journal of Experimental Psychology: General*, 126(3), 211-227. doi:10.1037/0096-3445.126.3.211

Sakoda, J. M. (1956). Individual differences in correlation between clustering and recall of meaningful words. *Journal of General Psychology*, 54, 183-190.

Shute, V. J. (1991). Who is likely to acquire programming skills?. *Journal of Educational Computing Research*, 7, 1-24. doi:10.2190/VQJD-T1YD-5WVB-RYPJ

Sternberg, R. J., & Tulving, E. (1977). The measurement of subjective organization in free recall. *Psychological Bulletin*, 84, 539-556. doi:10.1037/0033-2909.84.3.539

Tulving, E. (1962). Subjective organization in free recall of 'unrelated' words. *Psychological Review*, 69, 344-354. doi:10.1037/h0043150

Tulving, E., & Colotla, V. A. (1970). Free recall of trilingual lists. *Cognitive Psychology*, 1, 86-98. doi:10.1016/0010-0285(70)90006-X

Turley-Ames, K., & Whitfield, M. M. (2003). Strategy training and working memory task performance. *Journal Of Memory And Language, 49*, 446-468. Doi:10.1016/S0749-596X(03)00095-0

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent?. *Journal of Memory and Language*, 28, 127-154. doi:10.1016/0749-596X(89)90040-5

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, 104-132. doi:10.1037/0033-295X.114.1.104

Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior Research Methods*, 37, 498-505.

Unsworth, N., Spillers, G. J., & Brewer, G. A. (2011). Variation in verbal fluency: A latent variable analysis of clustering, switching, and overall performance. *The Quarterly Journal of Experimental Psychology*, *64*, 447-466. doi:10.1080/17470218.2010.505292