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A Study of Cognitive Processes Underlying Different Working Memory Tasks

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Supervisor

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Date..August...15,.1989....

DEDICATED TO THE MEMORY OF MY GRANDFATHER, LIPMAN GELBART

ABSTRACT

The major goal of the present study was to investigate working memory tasks and to determine the underlying processes tapped by these tasks in terms of the two aspects (storage and manipulation) of working memory. The goal of Experiment 1 was to investigate the effects of different items and rates of presentation on performance of a working memory task developed by Dobbs and Rule (in press), presumed to reflect the role of the active manipulation component of working memory. Results indicated that the procedures of this task preclude the use of memory strategies such as rehearsal, which affect performance on memory span tasks, and it is concluded that this task is a viable measure of the active component of working memory, the central executive. The goal of Experiment 2 was to determine in finer detail the underlying processes in the Dobbs/Rule task, as well as in other tasks presumed to measure working memory. Results indicated that different underlying processes are tapped by these different indices of working memory. Results are discussed in terms of three processes (storage, manipulation and selection) differentiating performance on the various tasks investigated.

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INTRODUCTION

The concept of working memory has assumed a central role in theory and in research (Baddeley, 1986; Baddeley & Hitch, 1974; Daneman & Carpenter, 1980; Dobbs & Rule, in press; Gick, Craik & Morris, 1988; Light & Anderson, 1985; Morris, Gick & Craik, 1988; Turner & Engle, 1989). The term 'working memory' has been used to describe memory requirements that involve the combination of storage with ongoing processing of material to be recalled (Baddeley, 1986; Baddeley & Hitch, 1974). The major characteristic distinguishing the concept of working memory from earlier notions of short-term memory is primarily in the emphasis placed on the manipulation of information, rather than on simple storage capacity.

According to Baddeley (Baddeley, 1986; Baddeley & Hitch, 1974), working memory is made up of three components: an articulatory loop, a visuospatial sketchpad, and the central executive. The first two components are considered to be the passive slave systems for temporary storage of auditory and visual information, respectively. The central executive is considered to be the supervisor/scheduler and the active part of the system. It is responsible for the selection, organization, activation and inhibition of cognitive processes, which have been conceptualized as the critical components of working memory. As such, the central executive is used for decision making, and controlling the amount of resources to be allocated among the requirements of the ongoing information processing (Baddeley, 1986). Working memory is thought to be involved in a wide range of tasks such as reading, mental arithmetic, comprehension and reasoning.

Baddeley (1986) reviewed the literature on working memory and concluded that the research has focused, almost exclusively, on delineating the attributes of the passive slave systems. This is unfortunate because studies of the active manipulation aspect of working memory are more likely to be relevant to furthering our understanding of more complex tasks involving mental manipulation, and for understanding individual differences that occur on these tasks in developmental studies and in pathology. Baddeley concludes that the central executive remains the most important, but least understood component of working memory.

Dobbs and Rule (in press) have developed a working memory task that they presume reflects the role of the active component of working memory, while minimizing the role of the two passive storage systems. The task is flexible enough to incorporate information that is presented visually, spatially or auditorily, with a variety of stimulus materials (e.g., digits, letters, words and pictures).

Although the Dobbs/Rule working memory task appears to be effective in demonstrating age-related changes and in detecting some aspects of pathology, little is known about the task or how performance on it might change with manipulations of basic parameters. In particular, the presumption of a minimal role of the passive systems has not been tested. The goal of the first experiment was to investigate the effects of different items and rates of presentation on performance of this task and to determine whether the passive systems of working memory play a minimal role in performance.

A number of tasks have been developed that presumably measure working memory, that is, simultaneous storage and manipulation. These tasks appear to vary in the type and amount of processing and storage that is required, yet all presumably assess working memory performance. These various tasks all have been independently assessed and tested. However, the commonality of what is being measured in these tasks has yet to be determined. Whether on not these tasks are tapping the same underlying ability needs to be investigated.

At present there is little knowledge concerning the relationship between the various working memory measures. If the various measures are not highly correlated, then conclusions about the role of working memory involvement in any task based on any single measure of working memory is questionable. In view of this, Salthouse (unpublished manuscript) has suggested that multiple measures of working memory would provide a more reliable and less task specific assessment of the working memory construct.

Another approach is to examine directly the relationship between the various measures of working memory. In order for these measures to be convincing as indices of working memory, some of them should be at least moderately correlated with one another. An investigation of working memory tasks, that is, tasks which have both a passive storage and an active manipulation component to them, will be undertaken in the second experiment. The goal of the second experiment is to examine the interrelations among measures hypothesized to reflect working memory and most importantly, to analyze more specifically what underlying processes are involved in the various tasks presumably measuring working memory, in terms of the storage and manipulation components of working memory. The role of the active component of working memory (the central executive) in these tasks is of particular interest.

EXPERIMENT 1

Dobbs and Rule (in press) have developed a working memory task that they presume reflects the role of the active component of working memory, while minimizing the role of the passive storage systems. In the Dobbs/Rule task, a series of items is presented. For the first (0-Lag) series, the person is instructed to repeat each item before the next item is presented. For the second (1-Lag) series, the person is to repeat the item that was given one back from the current item. The 2-Lag series requires responding with the item two back from the current item. The 0-Lag series is a simple tracking conditon; no items must be kept in memory. With increasing lags, more items must be kept in memory and increasingly complex mental manipulations are required in terms of encoding, storage, updating and retrieval of information. With increasing lags, more items must be stored prior to retrieval, and the subject begins to output the items later than at the lower lags. Dobbs and Rule emphasize these increasing demands for manipulation with increasing lags as being the major determinent of performance. However, it is clear that there is a concurrent increase in storage demands and perhaps, these requirements of the passive systems have a substantial effect. Little is known about the task or how performance on it might change with manipulations of basic parameters. In particular, the presumption of a minimal role of the passive storage systems has not been tested.

The goal of the first experiment was to investigate the effects of different types of stimulus materials and rates of presentation on the Dobbs/Rule working memory task. Dobbs and Rule (in press) have attempted to assess the role of storage for performance on the task. For that goal, subjects completed both the digit span task (forward and backward) and the Peterson-Peterson short-term memory task as measures of storage capacity, and their working memory task. Pearson correlations showed that performance on the Lag 1 version was reliably although weakly correlated with performance on the memory span tasks and not correlated with performance on the short-term memory task, which is consistent with the presumed minimal storage requirements of the Lag 1 condition. With increases in the storage demands of the working memory task in the Lag 2 condition, the relationship with all the storage measures increased and was reliable. The authors concluded that the Lag 1 version of the working memory task is a good index of the active manipulation aspects of working memory because span memory does not seem to be an integral aspect of the task.

The first experiment of the present research extended the analysis of the contribution of the passive systems to performance with the Dobbs/Rule task. The main issue was whether memory strategies, such as rehearsal, which are used in tasks assessing storage of information, play a role in this working memory task. Turner and Engle (1989) suggest that any method that inhibits the use of memory strategies, such as rehearsal, should lead to a more accurate and "purer" measure of working memory capacity. If the procedures of the Dobbs/Rule task inhibit or preclude the use of memory strategies such as rehearsal, this would add further evidence for its viability as a measure of the central executive, without confounds from other aspects of memory.

With auditory presentation, the auditory loop and rehearsal mechanisms might be expected to play a major role in the Dobbs/Rule task. In span studies, word length is, perhaps, the primary variable determining span size (Baddeley, Thomson & Buchanan, 1975; Klapp, Marshburn & Lester, 1983; Schweickert & Boruff, 1986). There is a limited time that items can be kept in memory without being "refreshed" by rehearsal. Because long words each take longer to say than do short words, fewer long words can be rehearsed in the limited time interval. The number of items recalled is smaller if the pronunciation time per item is longer (Klapp, Marshburn & Lester, 1983; Schweickert & Boruff, 1986). If rehearsal, which is a memory strategy used to maintain storage, is important for performance in the Dobbs/Rule working memory task, then using long words with three syllables would be expected to result in poorer performance than if short (single syllable) words are used because of the relatively short intervals available for rehearsal. Moreover, the decremental effect should become increasingly apparent with higher lags as the amount of material to rehearse increases at the rate of three to one (in terms of syllables) with the long as compared to the short words. Slower presentation rates, allowing for more rehearsal, should increase performance for both word conditions.

In the first experiment, to test the role that the auditory loop might play in the Dobbs/Rule task, one and three-syllable words were presented at a slow (2.6 sec.) and a fast (1.8 sec.) rate. If storage is important for performance on this task, and if storage is differentially increased for the two types (lengths) of words, then it is expected that we would find an interaction between word length and lag. Two other types of materials (digits and letters) were included in this investigation in order to expand the comparison, and because these materials are frequently used in experiments measuring span. Thus far, the Dobbs/Rule working memory task has been assessed using three levels of complexity. However, with 30-year old subjects relatively little change in performance was found, although large effects were found for older subjects. Nevertheless, if this task is to be useful in studies using young adults, it must be able to reveal differences in performance with the younger age groups. In the first experiment, the number of lags that were tested was extended to Lag 5.

METHOD

Subjects

Eighteen males and twenty-two females (mean age=21.73), who reported that they were not presently on medication (tranquilizers or psychotropic drugs) and had no history of head injury, were tested. They participated as an option for partial fulfillment of their introduction to psychology class course requirements. All were native speakers of English.

Design

Participants were randomly assigned to one of two conditions. In one condition, the presentation rate was 1.8 seconds, whereas in the other, the presentation rate was 2.6 seconds. There were nine male and eleven female participants in each condition. Participants were tested individually in one session and were debriefed fully about the goals of the research at the end of the session.

The experiment was designed with Rate as a between-subject factor and two within-subject factors: Item Type and Lag. Four types of items were used: digits, letters, short one-syllable words and long three-syllable words. Both digits and letters were chosen from a set of nine items. All digits from 1 through 9 were used and the letters were: A, C, F, I, J, K, L, M, and N. The word items (Appendix A) were chosen from words occurring at least 15 times per million words of text (Kucera & Francis, 1967). Each participant was tested on each of the four items at each of the six lags. A latin square design was used to determine the order of presentation of Item Types for each subject.

Procedure

Participants were administered the working memory task described by Dobbs and Rule (in press) in the auditory modality. Participants wore headphones and stimuli were presented using a pre-recorded casette tape. For the first series (0-Lag), the person was required to repeat the item immediately after hearing it. For the 1-Lag series, the person repeated the item that was said one previous to the current item. For the 2-Lag condition, the person was required to repeat the item two previous to the one being presented. The number of items back to the one to be reported increased by one for each subsequent series, with the maximum conditon being the 5-Lag series. Enough items were presented such that 10 correct responses were possible in all conditions. This required the presentation of 10 items for the 0-Lag condition, 11 for the 1-Lag condition, 12 for the 2-Lag conditon, 13 for the 3-Lag condition, and 14 for the 4-Lag condition and 15 for the 5-Lag conditon. If a participant was unsuccessful on the first trial of each series, a second trial was administered. Participants were required to complete all six series, regardless of whether or not they were successful at a particular lag.

RESULTS

The working memory score was calculated as the number correct to first error for each series presented. In cases where participants were given two trials at a particular lag, the better of the two scores was used in the analysis. The data were analyzed in a 2 X 4 X 6 analysis of variance, with Rate (1.8 sec. vs. 2.6 sec.) as a between-subject variable, and Item Type (digits, letters, short words and long words), and Lag (0, 1, 2, 3, 4, and 5) as the within-subject variables. Tests involving within-subject factors were conservatively corrected, employing the Greenhouse-Geiser adjustment. The F's reported have been adjusted by the Greenhouse-Geiser correction factor.

The results showed a main effect for Item Type, $F(3,106)=46.13$, $P< .001$. The mean scores for this analysis were: digits ($M= 8.21$), letters ($M= 7.71$), short words ($M= 7.00$) and long words ($M= 6.33$). The Lag variable also produced a reliable effect, $F(3,119)=258.96$, $p< .01$. The mean scores for this analysis were: Lag 0= 10.00, Lag 1= 9.98, Lag 2= 8.62, Lag 3= 6.59, Lag 4= 4.74, and Lag 5= 3.97. These main effects were qualified by a significant interaction between Item Type and Lag, $F(8,319)=9.29$, $p< .001$. Figure 1 shows the form of this interaction. People began to show differences at the 2-Lag series. It is clear from Figure 1 that there are ceiling effects due to perfect performance at lags 0 and 1, and this may account for the significant interaction found. Another analysis, in which performance at lags 0 and 1 were not included, still indicated a significant Item X Lag interaction, $F(7,264)=3.12$, $p < .001$.

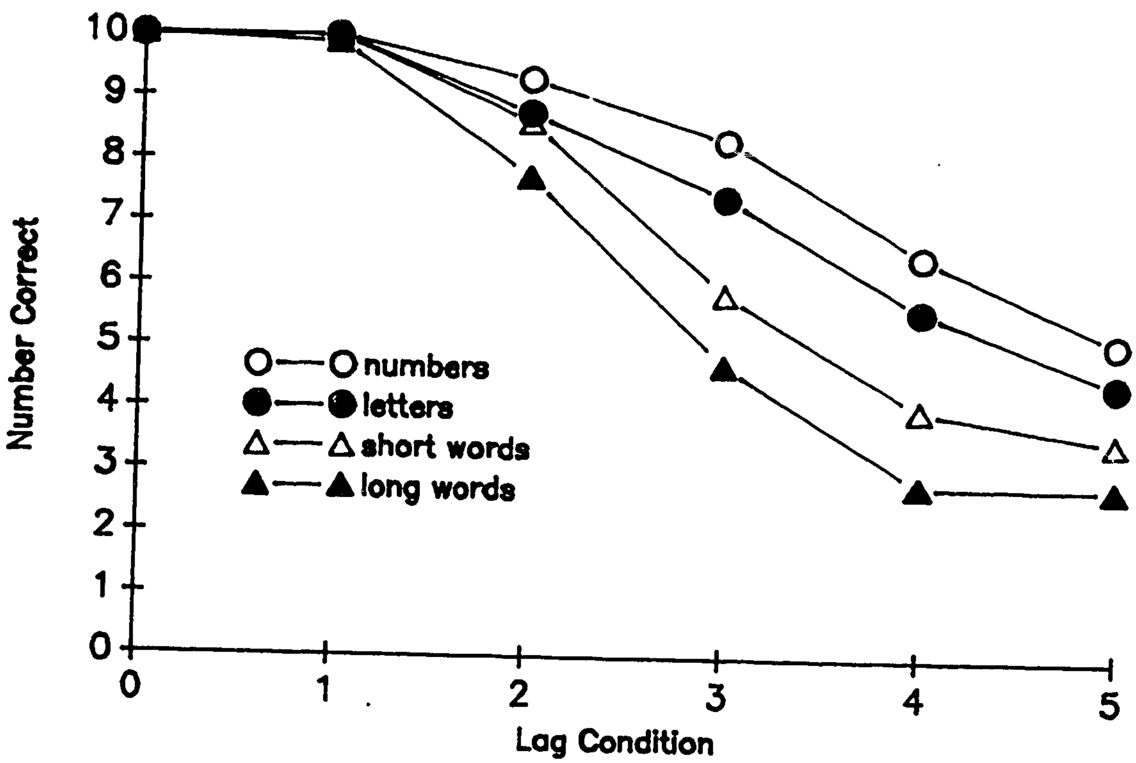

Figure 1: Mean number correct to first error, for each lag condition by each item type.

There was a trend for Rate of Presentation to alter performance, $F(1,38)=3.69$, $p< .06$, in that the slower the presentation rate, the better the performance (2.8 sec., M= 7.44; 1.8 sec., M=7.08). The Rate manipulation did not interact with Item Type or Lag (both Fs <1.00,n.s). An analysis, without data at Lags 0 and 1, showed the same result.

The possible interaction between Word Length and Rate was of special interest because of its relevance to the word length effect and implications about possible rehearsal effects. More time for rehearsal was available with the slower rate and more rehearsal could occur with short words. Thus, to the extent that rehearsal occurred, it should be revealed in the Rate X Lag interaction with the word items. If rehearsal does play a role in maintaining storage of information in performance of this task, it is expected that with more time, rehearsal could and would occur with the result being enhanced performance. At higher lags, there are more word items to keep in mind, and if rehearsal occurs, performance should be better with a slower rate of presentation, even at the higher lags. The three-way interaction of Rate X Item X Lag was not reliable ($F<1.00$, n.s). Of primary importance was the Rate X Lag interaction with words only. This interaction indicated no significant effects of Rate of Presentation, ($F<1.00$, n.s.). Thus, there the maximum condition being the 4-Lag series.

Paced visual serial addition task (PVSAT)

Subjects were presented with a list of single digits one after the other on the computer monitor. They were required to add the digits in pairs and give their answer aloud. That is, the second digit was to be added to the first, the third to the second, and so on.

A demonstration with written digits was given until the subject understood what he/she had to do, then a practice trial of 10 digits was administered. Digits were presented one at a time every 1.8 seconds to make the presentation rate consistent with that of the Dobbs/Rule task. The score was total answers correct, the maximum being 60.

Stroop task

The Stroop task used in this experiment consisted of two types of material, printed on sheets of 8.5 X 11 paper, which the subject was instructed to read aloud as quickly as possible. The first sheet consisted of 100 rectangular patches of colour (red, blue, green), which were arranged in random order. The task here was to correctly name the colours as fast as possible. The second sheet consisted of 100 colour words (RED, BLUE, GREEN) printed in an ink whose actual colour was different from the colour designated by the word (e.g., the word BLUE might be printed in red ink, the word GREEN in blue ink). Here the task was to name the colour of the ink in which the word was printed as quickly as possible. The 100 items in both cases comprised 5 columns of 20 items per column. The two sheets were administered in the order described. The total time taken for responding to the 100 items on each sheet was scored. The measure used was the difference (in seconds) between response to the first sheet and response to the second sheet (taken from Golden, 1978).

RESULTS

Table 1 gives the mean performance and standard deviation for each task. All subjects performed all tasks.

Table 2 shows the Pearson correlation coefficients calculated between the tasks administered. It can be seen that the number of simple correlations among the variables which are statistically significant is quite large. Task which appear to have a large storage component correlated with each other (e.g., forward and backward spans, forward and alphabetize spans) as did tasks which seem to have a large manipulation component (e.g., PVSAT and word version of Dobbs/Rule task, Stroop task and digit/letter version of Dobbs/Rule task). Principal components factor analysis was performed to determine the underlying constructs that might account for the main sources of variation in the set of correlations. In this approach, linear combinations of the original variables (principal components) are derived, and a small number of these account for most of the variation or the pattern of correlations. This method indicated how the variables cluster or group together, and the principal components that are derived can be meaningfully interpreted.

TABLE 1

Means and standard deviations for each task used in Experiment 2.

	Means	Standard Deviations
Digit-Lag 1	10.00	(0)
Digit-Lag 2	9.62	(1.04)
Digit-Lag 3	8.42	(2.51)
Digit-Lag 4	7.06	(2.79)
Digit/Letter-Lag 1	10.00	(0)
Digit/Letter-Lag 2	9.25	(1.62)
Digit/Letter-Lag 3	8.54	(2.11)
Digit/Letter-Lag 4	6.42	(3.27)
Word-Lag 1	10.00	(0)
Word-Lag 2	9.04	(1.91)
Word-Lag 3	6.02	(2.88)
Forward Span	4.35	(.70)
Backward Span	3.85	(.77)
Alphabet Span	4.33	(.72)
PVSAT	43.50	(10.73)
Daneman & Carpenter	25.00	(5.26)
Stroop Task	42.92	(18.66)

Table 2: Pearson correlation coefficients among tasks in Experiment 2.

	DIG3	DIG4	DL2	DL3	DL4	WORD2	WORD3	FWD	BKWD	ALPH	PVSAT	DC	STROOP
DIG2	.47**	.32*	.45**	.17	-.01	.48**	.29*	.01	-.08	.21	.03	.03	.18
DIG3		.57**	.27*	.20	.24*	.23	.54**	.31*	.19	.18	.35**	.15	.30*
DIG4			.22	.25*	.37**	.34**	.50**	.26*	.27*	.18	.32*	.23	.02
DL2				.42**	.15	.45**	.36**	-.23	-.23	-.15	.22	-.05	.36**
DL3					.33**	.17	.05	.07	-.04	.14	.12	.29*	.49**
DL4						.03	.34**	.03	.04	-.11	.19	.23	-.16
WORD2							.46**	.15	.12	-.01	.19	.03	-.12
WORD3								.30*	.33*	-.01	.38**	.13	.08
FWD									.49**	.35**	.13	.28*	.11
BKWD										-.02	.24	.44**	-.02
ALPH											.22	.15	.01
PVSAT												.06	.25*
DC													-.01

*$p < .05$; **$p < .01$

Note: DIG2,3,4 = Dobbs/Rule task with digits at Lags 2,3 and 4 respectively.

DL2,3,4 = Dobbs/Rule task with digits and letters at Lags 2,3, and 4.

WORD2,3 = Dobbs/Rule task with words at Lags 2 and 3.

FWD, BKWD, ALPH = forward, backward and alphabet word span tasks.

PVSAT = paced visual serial addition task.

DC = Daneman and Carpenter task.

STROOP = Stroop task.

The group of tasks was categorized into two sets, one made up of the Dobbs/Rule tasks, and one made up of the other tasks. A separate principal components factor analysis was done on each set of tasks. It was presumed that there are similar processes underlying the performance on the set of Dobbs/Rule tasks. It was further presumed that different processes underly some aspects of performance on the different versions on the task. For example, the higher lags undoubtedly require storage of more items and the digit/letter version requires a selection component.

A principal components factor analysis was conducted on the set of Dobbs/Rule tasks so as to determine what processes are involved in the different versions of the task. Three factors accounting for 70.4% of the variability in the set of measures were chosen for further analysis based on their eigenvalues being greater than 1 (Kaiser, 1960) and based on their Scree plots (Catell, 1966). These factors were rotated to the Varimax criterion (additional rotations Oblimin, Quartimax and Equamax did not result in different patterns of loadings). The loadings of the Dobbs/Rule mesures on each of the Varimax-rotated factors are shown in Table 3. The tests with high loadings (>.45) on the first factor include the Dobbs/Rule tasks with the highest level of storage: digits for Lags 3 and 4, digit/letter at Lag 4 and the word task at Lag 3. These tasks appear to have the largest storage component within the set of Dobb/Rule tasks. The second factor consists of tests that seem to require little storage relative to the manipulation component. All the tasks at lag 2 load on this factor. The third factor is determined by tasks that have a selection component. The digit/letter task at lags 2, 3 and 4 load on this factor.

A principal components analysis was conducted on the other set of tasks. Three factors accounting for 70.8% of the variability in the set of measures were chosen for further analysis, based on their having eigenvalues greater than 1, and based on their Scree plots. As with the analysis on the Dobbs/Rule set of tasks, these factors were rotated to the Varimax criterion.

The loadings of these measures on each of the factors are shown in Table 4. The first factor includes tasks that seem to be predominantly storage relative to manipulation. The second factor consists of tasks that appear to require minimal storage and have a selection component. The third factor is determined by the forward and alphabet span tasks. Interpretation of this factor will be dealt with in the discussion section.

TABLE 3

Varimax rotated loadings for the Dobbs/Rule Tasks

	FACTOR 1	FACTOR 2	FACTOR 3
DIG-LAG 2	.26	.77	-.01
DIG-LAG 3	.75	.28	.04
DIG-LAG 4	.79	.17	.17
DIG/LETT-LAG 2	.09	.70	.48
DIG/LETT-LAG 3	.02	.21	.89
DIG/LETT-LAG 4	.55	-.30	.60
WORD-LAG 2	.26	.75	.02
WORD-LAG 3	.78	.29	-.01

TABLE 4

Varimax rotated loadings for the Other Tasks

	FACTOR 1	FACTOR 2	FACTOR 3
FORWARD SPAN	.63	.14	.46
BACKWARD SPAN	.89	.12	-.10
ALPHABET SPAN	.02	.06	.96
PVSAT	.15	.73	.21
DAN. & CARP.	.74	.08	-.08
STROOP TASK	-.06	.83	-.08

Factor scores were then calculated for each person. These standardized scores can be thought of as scores that would have been recorded had the underlying factors been measured directly. Correlational analysis was performed on the factor scores derived from factors from the two sets of tasks so as to determine the relationships between the processes underlying the two sets of tasks. Table 5 shows the Pearson correlation coefficients calculated between the two sets of factor scores. It can be seen that the factor scores derived from the first factor of the Dobbs/Rule tasks correlate moderately highly (.38) with the factor scores derived from the first factor of the other set of tasks. These factors are made up of tasks with a heavy storage component. The factor scores based on the third factor of the Dobbs/Rule tasks correlate moderately (.33) with the factor scores derived from the second factor of the other tasks. The tasks making up these factors are tasks with a selection component. The second factor derived from the Dobbs/Rule tasks is made up of tasks that seem to have a heavy manipulation component with minimal storage, and factor scores derived from this factor are not significantly correlated with any of the other factor scores.

TABLE 5

Correlations among factor scores used in Experiment 2

	OTHER 1	OTHER 2	OTHER 3
DOBBS/RULE 1	.38**	.23	.13
DOBBS/RULE 2	-.09	.19	-.05
DOBBS/RULE 3	-.06	.33*	-.07

* = $p < .05$, ** = $p < .005$

DISCUSSION

The results indicated a large number of significant simple correlations among the tasks. Further analysis, using a principal components analysis, was performed on the tasks in order to determine the underlying constructs accounting for the main source of variation in the set of correlations. This analysis was done separately for the set of Dobbs/Rule tasks and for the other tasks.

For the Dobbs/Rule tasks, three factors emerged. The first factor was comprised of the tasks which appear to have the most extensive storage component, those at the highest lags for each of the versions of the task: the digit version at Lags 3 and 4, the digit/letter version at Lag 4 and the word version at Lag 3. Retrieval processes begin later than with the lower lags and more information must be stored in memory. As the lag increased, the corrlations with storage measures (forward and backward word spans) increased as well. These results suggest that there is a similar cognitive process underlying perfomance on these tasks.

The second factor consisted of tasks which seem to have prdominantly a manipulation component, with little storage. All versions of the Dobbs/Rule task at Lag 2 loaded on this factor. It appears that these tasks are assessing the more active part of working memory since storage requirements are minimal for the tasks at Lag 2. Furthermore, none of the tasks at Lag 2 correlated with the storage measures (forward and backward word spans), although the tasks at the higher lags did correlate with these storage measures. The weak correlation found between the Lag 2 conditions of the task and the storage measures indicate that it may be a good measure of the ability to manipulate information in working memory that is minimally influenced by differences in storage capacity. Dobbs and Rule (in press), found that the Lag 1 version of their task, within an older population, was weakly related to forward and backward spans, and concluded that this version of the task may provide an advance over other measures of working memory for which span memory is an integral aspect of the task, especially if the intent is to assess the active manipulation aspects of working memory. In the present experiment, the same can be said for the Lag 2 version of the task, within a younger population. Finally, the third factor was determined by tasks that appear to have a large selection component. In the digit/letter task, the requirement is to report back the digits, although both digits and letters are presented. The participant must ignore the letter and select the digit for recall. He/she must inhibit reporting the letter seen.

It appears then that the Lag 2 version of the Dobbs/Rule tasks may provide the best measure of working memory wihin this set of tasks and subject population, if the intent is to assess the active manipulation component of working memory. The other versions do have a manipulation component in addition to a larger storage component, but it is difficult to isolate the manipulation component of the task at the higher lags. It is the storage component that appears to differentiate versions of this task at the higher lags from those at the lower lags. Further evidence for this comes from the finding that as the lag increases, the relationship with storage measures increases as well.

For the other set of tasks, the first factor was comprised of the forward and backward word span tasks and the Daneman and Carpenter task. Both the forward and backward word span tasks require storage of a relatively large amount of information. In addition to storage, the backward span requires reordering of information. The Daneman and Carpenter task does have a manipulation component (reading sentences or reading and verifying sentences). However, the only measurement made is the number of words recalled correctly with the presumption that the processing requirements interfere with span. It appears that these three tasks all have a large storage component relative to the manipulation component, and it is the storage component which differentiates them from the other tasks in this set.

The second factor was determined by the paced visual serial addition task and the Stroop task. Both these tasks require the selection of items and the inhibition of particular responses. There is a lesser emphasis on storage. The Stroop task requires inhibiting responding with the names of the colours of words. The PVSAT requires adding digits to the digit just seen and inhibitng the addition of digits to the answer just reported. Finally, the third factor was made up of the forward span task and the alphabet span task. Both of these tasks have a large storage component, although the alphabet span task has more of a manipulation requirement. Subjects are required to organize words mentally in alphabetical order and output them as such. However, the processes underlying this third factor are less clear than with the other factors. We are uncertain what psychological processing component underlies performance on the tasks in this factor.

Correlations between the factor scores derived from the factors from the two principal components factor analyses indicated that the factor scores derived from the first factor of the Dobbs/Rule tasks correlated moderately highly (.38) with the factor scores derived from the first factor of the other tasks. The tasks with the high loadings for these factors were the Dobbs/Rule digit task at Lags 3 and 4, the Dobbs/Rule digit/letter task at Lag 4, the Dobbs/Rule word task at Lag 3, the forward and backward word span tasks and the Daneman and Carpenter task. Heavy demands on the storage component of working memory as a prerequisite for successful manipulation seem to be the important aspect of these tasks. It is the storage component which differentiates these tasks from the other ones. Daneman and Carpenter (1980) reported a moderately high correlation (.55) between their task and the forward word span task, indicating the importance of information storage for successful performance of their task. The present study obtained a lower correlation (.28) between the forward word span task and the Daneman and Carpenter task, and a moderately high correlation (.44) between the Daneman and Carpenter task and the backward word span task. All of these tasks load together and are correlated with each other, and it can be concluded that they are predominantly storage-based.

A moderate correlation was found between factor scores derived from the third factor of the Dobbs/Rule task and the factor scores derived from the second factor of the other tasks. The tasks involved were comprised of the digit/letter versions of the Dobbs/Rule task, the PVSAT and the Stroop task. As previously mentioned, subjects must inhibit some respnse and select another response. It appears as though all these tasks have a selection component to them, and it is this selection component that differentiates them from the other tasks.

GENERAL DISCUSSION

The major goal of the present study was to investigate working memory tasks and to determine the underlying processes tapped by these tasks in terms of the two aspects (storage and manipulation) of working memory. Of particular interest was how the active component of working memory (the central executive) might play a role in various tasks.

The goal of Experiment 1 was to investigate the effects of different items and rates of presentation on performance of a working memory task developed by Dobbs and Rule (in press). They presumed that their task reflects the role of the active manipulation component of working memory, while minimizing the role of the passive storage systems. Results indicated that the procedures of the Dobbs/Rule task preclude the use of memory strategies such as rehearsal, which affect perfomance on memory span tasks. These results provide evidence for the viability of the Dobbs/Rule task as a measure of the more active component of working memory, the central executive, without confounds from other aspects of memory.

The goal of Experiment 2 was to investigate different working memory tasks and to determine the cognitive processes underlying performance on these tasks. Results indicated that tasks with similar underlying constructs are tapping the same underlying cognitive processes. It can be concluded that tasks that loaded together and correlated with each other are tapping the same underlying processes. Three components of memory emerged as the most important processes underlying performance in the tasks investigated in this research: storage, manipulation and selection. The commonality of what is being measured in all these tasks was determined by the factors derived from the principal components factor analysis and the Pearson corrlations. The results indicate that all these tasks are indices of working memory; however, they differ in terms of the underlying processes required for successful performance, in particular in terms of the active manipulation component of working memory.

Virtually all previous studies of working memory have relied on single and different measures of working memory. There was little knowledge concerning the relationship between the various measures, and consequently, conclusions about the role of working memory involvement in any task based on any single measure of working memory was questionable. The present study shed light on the relationship between various tasks which have been presumed to measure working memory. The commonality of what is being measured by, or the underlying cognitive processes tapped by, different working memory tasks was determined. It was concluded that three processes, storage, maniupulation and selection, differentiated performance on the various tasks investigated. Baddeley (1986) suggested that tasks assessing the central executive component of working memory would help us in understanding more complex tasks involving manipulation as well as understanding individual differences on these tasks. Further research will provide us with a more specific analysis of subprocesses of manipulation that are required by the tasks used in the present study, as well as by other working memory tasks.

Results from this experiment have implications for working memory and changes in performance on tasks involving working memory which occur with aging and pathology. Lezak (1983) stated that the executive functions can be conceptualized as having four components: (1) goal formulation; (2) planning; (3) carrying out goal-directed plans; and (4) effective performance. She further states that in much of the literature concerning the executive functions, frontal lobe damage is implicated. Baddeley (1986), in his review of working memory, pointed out that age differences do not appear (or are minimal) in tasks that have a relatively passive storage requirement. He suggested that the memory tasks that show the clearest impairment are those which would be most likely to make demands on the central executive. This has been restated more recently (Craik, Morris & Gick, in press; Morris & Baddeley, 1988). It appears as though older people have particular difficulty with the active processing aspects of working memory tasks (Craik, 1986; Craik, Morris & Gick, in press; Dobbs & Rule, in press; Morris, Gick & Craik, 1988). Morris and Baddeley (1988) provide evidence from their labs that people with probable Alzheimer's disease (AD patients) are unable to coordinate two tasks, and suggest that, based on their results, AD patients have an impaired central executive system.

Results from a study investigating minor head injury and whiplash patients (Schwartzberg, Dobbs, Rule & Vanast, 1988) indicated that these people were impaired on the Dobbs/Rule working memory task. Another working memory task that has been used in research investigating the effects of minor head injury is the paced auditory serial addition task, the PASAT (Gronwall & Sampson 1974; Gronwall & Wrightson, 1974;). These studies have found that the PASAT correlated with persistent posttraumatic symptoms after minor head injury. However, it has been observed that both head-injured and control subjects have a strong dislike for this test, hence diminishing its value in a battery of tasks requiring frequent administration (Hugenholtz, Stuss, Stethem & Richard, 1988). The Dobbs/Rule working memory task appears to be fairly easy to administer, and seems to be sensitive enough to detect neuropsychological deficits following minor head injury and whiplash, even at two years post-injury

(Schwartzberg et al., 1988).

The functioning of the central executive component of working memory seems to be impaired as revealed by tasks assessing the manipulation component of working memory, in older people, in AD patients, in patients with frontal lobe damage and in people who have sustained minor head trauma. It is thus potentially important for diagnostic evaluation to have tasks that explicitly assess the central executive component of working memory. It appears, based on the results from the present study, that the Dobbs/Rule tasks at the lower lags are predominantly manipulation-based tasks. The Dobbs/Rule tasks at the lower lags may thus prove useful in detecting dysfunctions in the early stages of pathology, and appear to be the best tasks within the group of tasks examined in the present study for explicitly assessing the active component of working memory.

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APPENDIX A

Short word lists used in Experiment 1

LAG 0

TRIAL 1	TRIAL 2
FIG	FAT
BAY	ICE
RUN	MAN
KID	HAT
LIE	CUP
CUP	LIE
HAT	KID
MAN	RUN
ICE	BAY
FAT	FIG

LAG 1

TRIAL 1	TRIAL 2
CAP	LEG
BED	LID
SUM	TAX
BAG	FAT
WAR	DOG
SKY	SKY
DOG	WAR
FAT	BAG
TAX	SUM
LID	BED
LEG	CAP

LAG 2

TRIAL 1	TRIAL 2
RAY	LAW
COW	POT
FOG	FUR
ROW	GIN
PIT	CAT
GUN	LID
LID	GUN
CAT	PIT
GIN	ROW
FUR	FOG
POT	COW
LAW	RAY

LAG 3

TRIAL 1	TRIAL 2
JET	HEN
CAR	TEA
GUN	BUS
PIT	EYE
BAR	BID
LOT	LIP
PAY	PAY
LIP	LOT
BID	BAR
EYE	PIT
BUS	GUN
TEA	CAR
HEN	JET

LAG 4

TRIAL 1	TRIAL 2
HEN	PEN
NET	ACT
AIR	TIE
DOC	GAS
SEA	JAW
PIN	CAR
BET	TAP
TAP	BET
CAR	PIN
JAW	SEA
GAS	DOC
TIE	AIR
ACT	NET
PEN	HEN

LAG 5

TRIAL 1	TRIAL 2
FLY	FEE
JOB	WIT
KEY	AIR
ARM	LAP
JAR	MUD
ACT	GAP
ROD	BOY
HAY	HAY
BOY	ROD
GAP	ACT
MUD	JAR
LAP	ARM
AIR	KEY
WIT	JOB
FEE	FLY

is no indication that increased time for rehearsal with the word items resulted in better performance. The data for this analysis are shown in Figure 2. It should be noted from Figure 2 that no differences exist at the 0 and 1-lag conditions due to a ceiling effect. Examination of the other lags reveals strikingly parallel curves. An analysis, without lag 0 and lag 1 data, also revealed no significant differences, ($F<1.00$, n.s.). This confirms that differences in presentation rates, reflecting differences in rehearsal time, do not account for differences in performance on the word items and do not especially provide an advantage for the longer words.

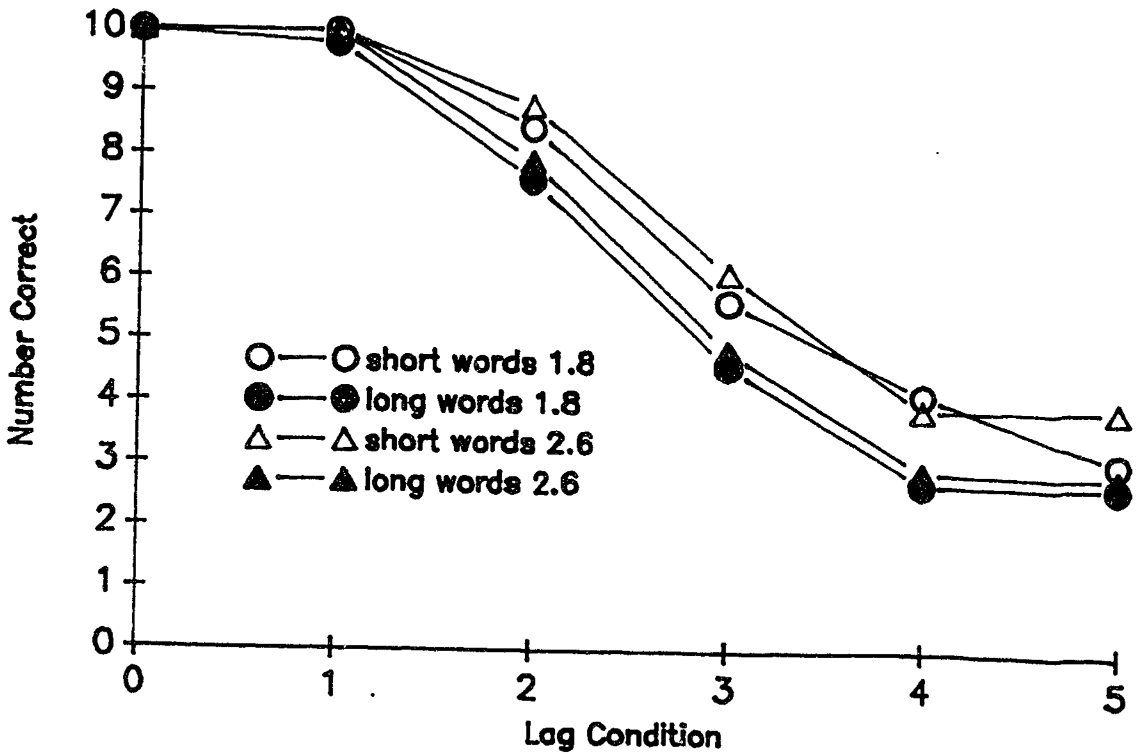

Figure 2: Mean number of words correct to first errror, by word length and presentation rate, for each lag condition.

DISCUSSION

The results of the experiment indicated that performance on the Dobbs/Rule working memory task is reliably affected by the types of items used in the memory set. Performance was best for digits and worst for the long three-syllable words. Performance for all the items declined with each successive lag after the 1-Lag condition.

In explaining the differences between digits and letters, two interpretations were considered. Conrad (1964) observed that in a listening task, when a given letter was misrecalled, the error tended to be phonologically similar to the correct letter, (for eg., 'B' would be more likely to be recalled as 'D' than as 'R'). Conrad demonstrated a high correlation between the probability that one letter would substitute for another in memory and the probability that those two letters would be confused in a listening task. Based on this phonological similarity effect, a more lenient criterion was defined that counted as correct any response that was phonologically related to the presented item, and the score for letters was re-evaluated with this criterion. Before re-evaluation, the difference between digits and letters was reliable $F(1,38)=10.11$, $p < .003$. The mean scores for digits were as follows: 10.00, 10.00, 9.32, 8.35, 6.50 and 5.12 for Lags 0 to 5 respectively, and no correction was applied through lenient scoring because of the lack of phonological overlap between the digits. Before re-evaluation, the mean scores for letters were: 10.00, 10.00, 8.78, 7.42, 5.62 and 4.45 for Lags 0 to 5 respectively. After re-evaluation, allowing for phonological overlap, the mean scores for letters were as follows: 10.00, 10.00, 8.45, 7.91, 5.62 and 4.43 for lags 0 to 5 respectively. Even after using a more lenient criterion for scoring that allowed for phonological errors, a significant difference still existed between the digits and letters, $F(1,38)=4.40$, $p < .05$. Thus, it seems unlikely that the greater phonological similarity of the letters can account for all of the difference in performance found for digits and letters.

Dempster (1981), in his review of memory span, concluded that digits yield higher spans than words. It has also been demonstrated that people have higher digit spans than letter spans (Brener, 1940), and this may account for some of the variance observed between stimulus items. A number of explanations have been put forth to interpret the differences with the different stimulus materials in memory span studies. It has been suggested that estimates of memory span appear to vary with the type and the familiarity of stimulus material, its principal auditory features, the mode of vowel articulation, the presence of repeated items in the stimulus string (Drewnowski, 1980) and the duration of the verbal trace (Schweickert & Boruff, 1986). Although it is uncertain which of these can explain the differences observed between the different stimulus items in the present experiment, it is likely that the differences can be attributed to a number of these. Digits are more familiar items than letters or words in the sense that they are utilized more often, as in remembering phone numbers, addresses, time etc. This may explain why performance was best with digits, and why performance was better with digits than with letters.

A difference in performance was observed between the short and long words. The usual explanation for this in span studies is that word length has an effect (Baddeley, Thomson & Buchanan, 1975; Klapp, Marshburn & Lester, 1983; Schweickert & Boruff, 1986). There is a limited time that items can be kept in memory without being "refreshed" by rehearsal. Because long words each take longer to say than do short words, fewer long words can be rehearsed in the limited time interval. This interpretation does not explain the difference in performance with short and long words in this experiment. There were no significant differences between the two groups with different presentation rates (1.8 sec. vs. 2.6 sec.) on the word items. If there was rehearsal, it seems reasonable that we would have found the group with a slower presentation rate, and hence more rehearsal time, would have performed better than the group with the faster presentation rate. This did not occur. Thus, it seems unlikely that memory strategies such as rehearsal can account for the observed differences in performance for the items in the present study.

Another interpretation of the data also based on presentation rates is that the response interval for the items may have differed enough to account for the difference in performance for the two types of word items. Longer words may have required more time for presentation than shorter words, hence reducing the amount of available time for responding (the inter-item interval). This was investigated by measuring the response intervals (in seconds). The analogue audio signal was displayed on a computer monitor and the inter-stimulus interval (response interval) was measured from the end of one spoken word to the beginning of the next spoken word. The means for response intervals obtained for the 1.8 second presentation rate were 1.45 for short words and 1.28 for long words. The means for the 2.6 second presentation rate were 2.42 for short words and 2.24 for long words. There is a slight difference between the response interval for the two types of words (.17 or .18 seconds). However, two-tenths of a second does not seem to be long enough to provide a significant advantage in terms of amount of response time between items, and thus does not appear large enough to account for the difference observed in the data between the two types of words.

In conclusion, the task appears to be a good one for investigating the effects of manipulation. This task emphasizes the manipulation component of working memory while precluding the use of memory strategies, in that it does not appear to be affected by memory strategies such as rehearsal, which affect performance on memory span tasks. Thus, the task does not appear to depend on span memory and passive storage processes. It appears to reflect the role of the more active component of working memory, the central executive. Dobbs and Rule (in press) demonstrated substantial differences in performance beginning at age 40. Results from this study demonstrate significant differences in performance, within a younger population, in working memory, with higher lags and with different stimulus materials. The data from this study indicate that the task may provide a useful index of working memory that can be used in future investigations for comparative purposes assessing working memory.

EXPERIMENT 2

Early theories (eg., Waugh and Norman, 1965) viewed short-term memory as a fixed number of slots. Baddeley and Hitch (1974) argued that this focused too much on the storage functions of short-term memory and not enough on the processing functions. They argued for working memory and for the importance of both storage and processing in a functional analysis of the working memory system. As indicated by the following review of the literature, both storage and processing are important in working memory. Working memory has been shown to be important in complex tasks such as reading comprehension and arithmetic. However, it is apparent that the research to date has not provided a clear analysis of the underlying processes, in particular the executive or control processes, tapped by the various tasks used.

Baddeley and Hitch (1974) investigated the extent to which the mutual interference between tasks (verbal reasoning, comprehension and immediate serial recall) would reflect the competing demands made on the control aspects of working memory. A consistent pattern of effects was found across the 3 types of tasks studied, suggesting the operation of a common system. They suggested that the system appears to have something in common with the mechanism responsible for digit span, because it is susceptible to disruption by a concurrent digit span task, and like the digit span seems to be based at least in part on phonemic coding. However, the degree of disruption observed (by a concurrent digit span task), even with a near-span concurrent memory load, was far from complete. This suggested that although the digit span and working memory overlap, there appears to be a considerable (non-storage) component of working memory which is not taken up by the digit span task. Relatively small effects of phonemic coding and articulatory suppression provided further evidence for this view and suggested that the articulatory component may comprise only one feature of working memory.

Baddeley and Hitch (1974) suggested that the core of the working memory system consists of a limited capacity "work space" which can be divided between storage and control processing demands. They hypothesized that the storage component is relatively passive and makes few demands on the central executive, provided its capacity is not exceeded. They demonstrated that when capcity is exceeded (when more than two items must be stored), then demand on the central executive increases. It then becomes more heavily involved in initiating and controlling cognitive processes that will enable the additional information to be retained in memory. The rate at which other (executive control) processes are carried out would then be impaired, and the more difficult the problem, the greater the effect of an additional short-term storage load. Wright (1981) also showed that with young adults, the combination of a highly demanding task with any additional demand for capacity reduces performance on one or both tasks.

Hitch (1978) assessed individual calculation strategies in mental arithmetic, and found that people perform mental addition in stages. He proposed that these stages can be analyzed in terms of the processing and storage into a working memory system and the mobilization of long term knowledge. He proposed a long term storage which includes a library of strategies and facts, and an executive processor which selects information from working storage and transforms it, as well as putting transformed information back into long term storage. Hitch concluded that in mental arithmetic, the executive processor and working store correspond to components of the working memory system suggested by Baddeley and Hitch (1974).

Daneman and Carpenter (1980) devised a working memory measure taxing both processing and storage. They suggested that a task that has heavy processing requirements should decrease the amount of additional information that can be maintained. It had been suggested that processes attributable to working memory play a critical role in reading comprehension (Kintsch & Van Dijk, 1978). Daneman and

Carpenter suggested that good readers may have more efficient processes so they effectively would have more capacity for storing and maintaining information. Because traditional short term memory tasks, such as digit and word spans, do not correlate, or correlate weakly, with reading ability, Daneman and Carpenter suggested that these tasks tap primarily storage functions and require only relatively simple processes. They do not sufficiently tax the processing component of working memory. They developed a measure of working memory that presumably required both processing and storage aspects of working memory. They argued that any measure reflecting the capacity of working memory that is important in reading comprehension must require the use of reading strategies, suggesting that the working memory span measure depends on the type of background task used while measuring the span. The background task must include reading if the span measure predicts individual differences in reading comprehension. The central issue for these authors was whether their working memory task correlated well with reading comprehension performance (presumed to require the processing aspects of working memory). The authors found high correlations between their task and three measures of reading comprehension and no significant correlations between a simple word span and the comprehension measures. They did however find a moderately large correlation (.55) between their reading span and word span. They concluded that working memory capacity is the source of the correlation between reading comprehension and their reading span, and hence, an important source of individual differences in reading.

Contrary to Daneman and Carpenter's suggestion that their sentence span task taps different processes than simple span tasks, Light and Anderson (1985) found that the reading span task (Daneman and Carpenter's task) was not a better predictor of paragraph memory than simple span measures (digit and word). They concluded that the various span measures used all tap the same underlying ability. They suggested that even simple spans require both storage and manipulation of information: Keeping track of order presented and which words have been produced already during recall is not a purely passive process, but rather a process that requires active manipulation of information in working memory. The only measurement made in the Daneman and Carpenter reading span task is the number of words recalled correctly, with the presumption that the processing (reading sentences) interferes with span. To what extent it is storage-based or manipulation based is uncertain.

The results of Stine and Wingfield (1987) contrast with those of Light and Anderson (1985). Stine and Wingfield used a task based on Daneman and Carpenter's (1980) task, where subjects were required to listen to text (not read the text materials, as in Light and Anderson's study), and perform comprehension operations (i.e., respond 'True' or 'False' to the statements they heard). They found that their listening span, which they presumed was a measure of the ability to manipulate information in working memory, was related to recall performance, although digit span which they regarded as a measure of the ability to simply hold things in working memory (i.e., capacity), was not. They suggested that active processing in working memory was used more in their listening task than was simple rote retrieval of information held in memory.

Baddeley, Logie, Nimmo-Smith and Brereton (1985) attempted to replicate and extend the work of Daneman and Carpenter. Their working memory span was based on Daneman and Carpenter's (1980) reading span task. However, instead of just reading sentences, subjects were required to categorize each sentence on the basis of whether or not it made sense. This presumably increased the processing requirements of the task. Their findings indicated that comprehension appeared to be significantly correlated with working memory span. However the magnitude of the correlation was not as great as that observed by Daneman and Carpenter with their specially devised measure of reading, but was close to their observed correlations with a more general measure of comprehension.

They conclude that the working memory span score has the weakness of being rather general. Their working memory span task is itself a highly complex task involving not only the storage and retrieval of verbal material, but also comprehension. It involves a lot of subcomponents (e.g., comprehension, selection and operation of strategies of learning and recall), and thus has a very good chance of capturing the aspects of working memory which are important, yet is too general to know which of the several factors might be of crucial importance. Thus, from these studies, it is difficult to know what processes are involved in the Daneman and Carpenter task.

Baddeley et al. (1985) conducted a second experiment designed to throw some light on the Daneman and Carpenter measure. They compared it to an alternative measure of working memory span, the counting span task (Case, Kurland & Goldberg, 1982). The counting span task involves the presentation of a series of slides, each containing a number of dots which the subject is required to count. As each new slide appears, the subject must remember the number of dots that appeared on previous slides while counting the dots on the new slide. This counting task does not rely on the processing of prose, but seems to have the two working memory components, namely the simultaneous storage and manipulation of information. The subject must simultaneously select the critical dots, count them, and retain the totals counted on previous slides.

Baddeley et al. (1985) hypothesized that if comprehension is limited by the capacity of a very general working memory system, and counting span is a good measure of this, then the correlation between performance on this concurrent memory and counting span task should be similar to that obtained using the Daneman and Carpenter measure. Findings indicated that the two working memory measures intercorrelated but are clearly far from equivalent measures. Counting span contributed much more weakly to prediction of reading comprehension than did the sentence span. Furthermore, the variance accounted for by counting span was equally well accounted for by the sentence span measure. They concluded that the decision as to whether the correlation between working memory span and reading reflects a general and limited capacity general processor, or whether it is the reflection of a more specific language-based processing system, must await the development of a wider range of measures of working memory capacity.

Turner and Engle (1989) suggest an alternative explanation of Daneman and Carpenter's (1980) findings. They suggest that people may be good readers because they have a large working memory capacity available for processing and storage, independent of the background task being performed.

A good reader may have more working memory capacity available for processing and storage rather than a poor reader whether performing a reading or a non-reading task; there is no domain specificity. This explanation would predict that the working memory span (complex span) index could be embedded in any task that requires processing beyond the span task and still reflect individual differences in working memory capacity that are important in higher level cognitive functioning.

In their first experiment, the authors varied the processing requirements (arithmetic, verification of sentences) and the type of item to be stored (digit, word). They also used simple span (word, digit) tasks. They found no relationship between comprehension and simple span measures. They found similar correlations between the complex spans and the comprehension measure, implying that working memory capacity transcends task. Turner and Engle suggest that individuals may be good or poor reading comprehenders because of a large or small working memory capacity, not because of more or less efficient reading skills (as Daneman and Carpenter had suggested).

The purpose of the second experiment by Turner and Engle (1989) was to study the relationship between the complex working memory span and comprehension measures while manipulating the difficulty of the processing component of the complex span tasks. No relationship had been found between the comprehension and simple span measures in the first experiment, and the authors suggest that one reason for this may be that individual differences in simple spans may be a result of differences in the use of memory strategies, such as chunking and rote rehearsal. It is unlikely that the same strategies would be very important to reading comprehension.

Turner and Engle proposed that the complex span measures may more closely reflect the number of "items" that can be represented in the working memory without rehearsal. The complex span measures may correlate with reading comprehension because the processing component of the task (ie., reading unrelated sentences or solving operation strings) inhibits the use of these memory strategies. The authors suggest that any method of eliminating the use of memory strategies while measuring working memory should lead to a more accurate and "purer" measure of working memory capacity. If the use of memory strategies are inhibited by using a verification task while measuring span, the authors predict that, as the difficulty of the sentence or arithmetic-related (operation) verification tasks is increased, the correlations between working memory span and comprehension ought to increase up to that point where difficulty level is very demanding. This prediction was borne out in that working memory-comprehension correlations were a function of the different levels of difficulty.

In relating the data to Baddeley's (Baddeley, 1986; Baddeley and Hitch, 1974) working memory model, the authors concluded that it is uncertain which part of the working memory system is primarily responsible for the background task, and which component the complex span measures. It may be that complex spans reflect individual differences in the central executive or that they reflect differences in the articulatory loop, or some interaction of the two. At present this remains uncertain.

It appears then that, although the various tasks discussed do seem to be assessing working memory in that both a storage and manipulation component exist, it is difficult to determine what they are actually measuring in terms of the two aspects (storage and manipulation) of working memory. Furthermore, it is not clear whether or to what extent the tasks are explicitly assessing the more active component of working memory. Tasks assessing this central executive component of working memory would help in understanding more complex tasks involving mental manipulation, as well as understanding individual differences on these tasks (Baddeley, 1986). The goal of the second experiment was to investigate tasks which presumably have both a storage and manipulation component to them, and to determine what these tasks are in fact measuring in terms of the two aspects of working memory. This was accomplished by examining the measures hypothesized to reflect working memory and then attempting to determine what underlying processes are involved in these various tasks.

The tasks that were used for the second experiment were chosen based on their presumed storage and manipulation requirements. The tasks chosen should not be considered a complete compilation of all such tasks. The Dobbs/Rule task was chosen because it is presumed to have both storage and manipulation components, with an emphasis on manipulation. It was presented using digits and words. In addition, a third set of stimuli were included in the study. Participants were presented pairs of digits and letters, and were required to ignore the letters and respond with the digits only. It was expected that this would increase the complexity of the task in that, in addition to doing the task as in the word only or digit only conditions, a selection component is added to the requirements.

Daneman and Carpenter (1980) presume that their task is one that measures both the processing and storage functions of working memory. However, on the surface it appears that it is a measure of memory span in which the processing involved in the manipulation component of the task (the sentence reading) serves as the interference task. This task was included as well because it has been extensively used to assess working memory.

A third working memory task that was used was a visual version of Gronwall and Sampson's (1974) paced auditory serial-addition task, in which digits are presented and subjects are required to add them in pairs. (It will be referred to as the paced visual serial addition task, or PVSAT). It was presumed that this task has a minimal storage component (only one digit has to be remembered at a time). Subjects are required to add numbers that are presented to them, and add them to each other, not to the answers they give. They must encode information, hold each item after processing and retrieve the held item for addition to the next digit. Hence, in this task as in one of the Dobbs/Rule tasks, there is a selection component in that subjects must ignore stimuli (ie., the answers they give).

The Stroop task was used in order to have a task with minimal storage components and predominantly a selection component. Here, the subjects must inhibit what they want to say (ie., the names of the colours). Performance on the Stroop task reflects the ability of subjects to maintain one course of action (colour naming) while there is interference from other stimuli (word reading). Subjects must shift attention from the reading of the words to the perceptual property of the words (that is, the colour of the ink in which they are printed). As with the paced visual serial addition task and the Dobbs/Rule digit/letter task, there is a selection component.

A task that appears to be essentially a storage task is the forward span task. In this task, the subject is presented with a list of items and must store them and then output them at the end of the series. This task was chosen in order to compare it with other tasks and to determine which other tasks have large storage requirements. The backwards span was chosen because it was presumed that it had a large storage requirement, with more manipulation than the forward span. Subjects are required to reorder the information they encode. Increasing manipulation is presumed to be required with the alphabet span, where subjects must encode words, mentally reorganize and output them in alphabetical order. The alphabet span task was used for comparative purposes with all the other tasks.

The primary goal of the second experiment was to compare a variety of tasks presumed to measure working memory by determining the interrelations among measures hypothesized to reflect the active manipulation component of working memory. These also were compared to tasks presumed to be largely storage-tasks in nature, so as to determine how much of a storage component the tasks have. It is only with correlational evidence of this type that we will be able to determine the degree to which different measures of working memory actually measure the same processes, in particular the more active manipulation components of working memory.

It was expected that tasks requiring a great deal of storage would intercorrelate, and that tasks with a large manipulation component would intercorrelate. It could then be concluded that the tasks that seem to have similar underlying constructs are tapping the same underlying cognitive processes.

METHOD

Subjects

Twenty four males and twenty-four females (mean age=21.4[illegible]th no reported history of head injury were tested. [illegible]e participants was taking amy medication (tranq[illegible]sychotropic drugs) at the time of testing. All par[illegible]s an option for partial fulfillment of their intr[illegible]on to psychology class course requirements. Subjects were native speakers of English.

Design

Subjects were tested on all tasks. There was an equal number of male and female participants. Participants were tested individually for two sessions (approximately one half-hour per session, with the sessions 7-10 days apart), and at the end of the second session they were told the purpose of the experiment.

The following nine tasks were used: the Dobbs/Rule working memory task with digits, a version of that task using digit and letters that required selection, the Dobbs/Rule task with words, the Daneman and Carpenter working memory span task, the word span forward task, the word span backward task, the alphabetize word span task, the Stroop task and a visual version of Gronwall and Sampson's paced auditory serial addition task (PVSAT). All the tasks were presented in the visual modality so as to keep the modality consistent across tasks. All of the tasks except for the Stroop and the Daneman and Carpenter task were presented on a computer monitor. The words used in the span tasks and the Dobbs/Rule task were concrete, one-syllable words, chosen from Kucera and Francis (1967). The items were chosen from words occurring at least 14 times per million words of text (Appendix B).

A full latin square design balancing the order of presentation would have required 18 different orders. It was therefore decided to divide the tasks into two sets. One set of tasks was comprised of the forward and backward word spans, the PVSAT, the Dobbs/Rule task with words, and the Daneman and Carpenter task. Each of these tasks appeared first, second, third and fourth the same amount of times within the set (the backward and forward word span tasks were counted as one task; The forward word span task was always presented right before or right after the backward word span task. It appeared before the backward span the same amount of times that it appeared after the backward span). The second set of tasks was comprised of the Dobbs/Rule task with digits, the Dobbs/Rule task with digits and letters, the alphabetize span task and the Stroop task. As with the first set of tasks, each was presented first, second, third or fourth the same number of times within the set. The first and second set of tasks were counterbalanced for presentation, in that each set of tasks was presented during the first session the same number of times as each set was presented at the second session. None of the words used was repeated within a session or set of tasks. Care was taken to avoid alphabetical arrangement of words and obvious associations between adjacent words in lists.

Experiment 1 indicated significant differences between Lags 2 and 3 on the Dobbs/Rule task, and very poor performance on Lags 4 and 5. Based on this finding, a decision was made to use only Lags 1 through 3 in the present experiment. However, pilot work indicated that performance was perfect or close to perfect with the digits, and the digits and letters, even at the higher lags. It was therefore decided that, in the present experiment, participants would be required to complete Lags 1 through 4 for these items, and Lags 1 through 3 for the word items.

Procedure

Span tasks

For the word span forward and backward tasks, the participant was shown a sequence of words (Appendix B) at the rate of one word/second, beginning with a series of four words and continuing (with each successive series having one more item than its predecessor) until two successive trials of a particular series were failed. For the forward span task, participants were shown a series of words and at the end of the series, the word 'RECALL' appeared on the screen. When the word 'RECALL' appeared, the participant was required to repeat back the words just seen in the order in which they had appeared. For the backward span task, participants were shown a series of words. At the end of the series, the words 'RECALL BACKWARDS' appeared on the screen, and at this time, the person was required to repeat back the word just seen in the order backward to the way they were presented.

For the alphabet span task, the participants were presented with series of word items (Appendix B), also at a rate of one word per second, beginning with a series of two words. At the end of each series, the word 'RECALL' appeared on the screen and the participant was required to repeat back the words just seen in alphabetical order. As with the two other span tasks, this continued until two successive trials of a particular series were failed.

For all the span tasks, span was defined as the largest series that could be reproduced. If a participant was unable to complete even the trial with four items on the forward and backward span tasks, he/she was given a span of 3.

Daneman and Carpenter working memory span task

This task was based on the technique used by Daneman and Carpenter (1980). In Daneman and Carpenter's (1980) task, subjects had to read a series of sentences aloud at their own pace and recall the last word of each sentence. In the present experiment, in order to ensure that the subject comprehended the sentences, they were required to verify whether each sentence made sense or whether it was nonsense, and then recall the final word of each sentence. An example of a sentence that made sense was 'The sad clown sang a depressing song' and one that did not make sense was 'The past craze carpeted the happy envelope'. Each sentence was typed on a single line across the center of an 8 X 5-inch index card. The cards were arranged in three sets of two, three, four and five sentences (Appendix B).

The experimenter showed one card at a time to the subject. After the subject read each sentence aloud, the card was turned over face down. The subject was to decide whether or not the sentence made sense and to indicate the decision by circling either 'S' for sense or 'N' for nonsense. Then the next card was presented. The word 'RECALL' appeared on the back of the last card of a series to signal that it was time to write down the final words of each of the sentences. Instructions indicated tht the series was to be recalled in the order in which they had been presented. Subjects were given two practice items at the two sentence level before the test began. They were warned to expect the number of sentences per set to increase during the course of the test. Subjects completed all sentence levels even if they were unsuccessful at a particular level. Performance was scored in terms of the total number of words recalled from all trials in the correct serial position, the maximum being 42. This measure has been used by other researchers (e.g., Baddeley, Logie, Nimmo-Smith & Brereton, 1985; Turner & Engle, 1989).

Dobbs/Rule working memory tasks

The procedure for this task was as described for Experiment 1. For the digit and digit/letter versions of the task, particpants completed Lags 1 through 4, and for the word version, participants completed Lags 1 through 3. For the digit/letter version, participants were presented with pairs of digits and letters, that is, they saw one letter and one digit simultaneously. The position of the digit, as well as the position of the letter, occurred with equal frequency on the left and right side. For the 1-Lag series, they were required to repeat the digit that was seen one back from the current pair of items. For the 2-Lag series, the person was required to repeat the digit seen two back from the current pair of items. The number of digits back to the one to be reported increased by one for each subsequent series, with

Long word lists used in Experiment 1

LAG 0

TRIAL 1

EQUIPEMENT
INSTITUTE
ASSIGNMENT
INDUSTRY
MANAGER
COMPANY
ASSEMBLY
ELECTION
AVENUE
CREATION

TRIAL 2

CREATION
AVENUE
ELECTION
ASSEMBLY
COMPANY
MANAGER
INDUSTRY
ASSIGNMENT
INSTITUTE
EQUIPMENT

LAG 1

TRIAL 1

AGENCIES
FAMILY
COMMERCIAL
CREATION
ATMOSPHERE
MAINTENANCE
HOSPITAL
ACCEPTANCE
CONVICTION
ATLANTIC
UNION

TRIAL 2

UNION
ATLANTIC
CONVICTION
ACCEPTANCE
HOSPITAL
MAINTENANCE
ATMOSPHERE
CREATION
COMMERCIAL
FAMILY
AGENCIES

LAG 2

TRIAL 1

NEWSPAPER
REMEMBER
LIEUTENANT
COMMISSION
BUSINESS
RELIGION
ATLANTIC
EMPLOYMENT
PROPERY
LIBRARY
ENGINEER
AUDIENCE

TRIAL 2

AUDIENCE
ENGINEER
LIBRARY
PROPERY
EMPLOYMENT
ATLANTIC
RELIGION
BUSINESS
COMMISSION
LIEUTENANT
REMEMBER
NEWSPAPER

LAG 3

TRIAL 1

RESISTANCE
ENERGY
RELIGION
BUSINESS
TRAGEDY
INSTRUMENT
GOVERNOR
ORCHESTRA
COLLECTION
DEPARTMENT
CONFUSION
INSURANCE
PRSIDENT

TRIAL 2

PRESIDENT
INSURANCE
CONFUSION
DEPARTMENT
COLLECTI
ORCHEST
GOVERNO
INSTRUMEN
TRAGEDY
BUSINESS
RELIGION
ENERGY
RESISTANCE

LAG 4

TRIAL 1

PRESIDENT
MANAGEMENT
FEDERAL
VEHICLE
INCIDENT
GOVERNMENT
ORIGIN
ARTICLE
ENERGY
PERCENTAGE
ASSISTANCE
RESOURCES
MEMBERSHIP
EXPANSION

TRIAL 3

EXPANSION
MEMBERSHIP
RESOURCES
ASSISTANCE
PERCENTAGE
ENERGY
ARTICLE
ORIGIN
GOVERNMENT
INCIDENT
VEHICLE
FEDERAL
MANAGEMENT
PRESIDENT

LAG 5

TRIAL 1

PROFESSOR
ARTERY
PRODUCTION
SOLUTION
POETRY
MEMBERSHIP
PROVISION
OFFICIAL
TELEPHONE
APARTMENT
REPUBLIC
VACATION
FEDERAL
UNIFORM
DIRECTOR

TRIAL 2

DIRECTOR
UNIFORM
FEDERAL
VACATION
REPUBLIC
APARTMENT
TELEPHONE
OFFICIAL
PROVISION
MEMBERSHIP
POETRY
SOLUTION
PRODUCTION
ARTERY
PROFESSOR

APPENDIX B

Word lists used in Dobbs/Rule working memory task in Experiment 2

LAG 1

TRIAL 1	TRIAL 2
FAN	GAS
SKY	EYE
PLUG	SEAT
TREE	JAR
GUN	POND
BAY	MOUTH
YARD	BAG
MEAT	TRUCK
OAK	CHAIR
PIT	WINE
COAT	PIN

LAG 2

TRIAL 1	TRIAL 2
BAR	PAN
WAVE	WALL
ROPE	NUT
TEXT	CLAY
MILK	MAN
GAME	RAIL
EAR	BAT
FORK	HEN
CAT	SHIP
SALT	GLASS
PILL	LID
HAM	THROAT

LAG 3

TRIAL 1

CARD
HORN
OIL
PEN
FISH
BANK
MALE
LIP
TRAIN
STONE
JAIL
ARM
ROD

TRIAL 2

JET
WIRE
SNOW
HAY
TOOL
GIRL
BOAT
MUD
CLOCK
FIG
KEY
PIPE
LAMP

Sentences used in the Daneman & Carpenter task

(N or S denotes nonsense or sense respectively)

S The last refuge of the parrots was the tall tree
S The sad clown sang a depressing song

S The tiny anelope ran swiftly across the prarie
N The shards of broken ice cream littered the empty stone

N The hungry carpet swam the rushing river
N The empty house warbled gracefully to the parcel

S The particle of soot landed on my lunch
N The silent morning pounded in the bedroom
S The waves of vicious bees swept across the land

N The deep green thoughts hurried furiously to the party
N The drunken sailor sand the cold water
S The empty pasture was quiet in the moonlight

S The last word was eaten by the voracious snowball
S The purring kitten lapped up the last dregs of milk
S The baseball game continued till after dark

N The herds of tiny buffalo galloped across the crackers
N The typewriter walked quickly through the deserted room
S The passionate seamstress sewed busily on the gown
N The pesky napkings lolled at the side of the pool

S The truth of the matter was that the dealer had cheated
S The large signs warned of the danger around the bend
S The quiet mouse crept through the cat's domain
N The crazy quilt laughed acorns at the sunset

N The innocent victims parcelled mittens for the bed
S The yards of beautiful cloth were draped across the table
N The angry turtle beat the bad idea
S The cooperative children played quietly in the back yard

S The sporting dolphins pushed the ball with their noses
N The past craze carpeted the happy envelope
S The movie did not make a profit in spite of the big crowd
N The thousands of screaming chincillas waxed the cars
N The occasional headlight lit in the bedroom window

S The sand of the rain on the roof was very annoying
N The last straw caressed the overloaded candy
N The energy of the small digit carried across the pencil
S The tall trees swayed gently in the soft breeze
N The blue pages of the autograph book tinkled with peanuts

N The difficult story panted in the evening light
N The few patient spiders angled for hearty livers
S The careful pilot safely landed the burning plane
N The golden harvest was toasted on the pillow
S The captain of the team was the first one in the shower

Words used in forward word span task

4-words

TRIAL 1

BELT TENT COW EYE

TRIAL 2

WINE SLIDE GLASS CLOCK

5-words

TRIAL 1

TRAY BIRD PAGE CHILD STOVE

TRIAL 2

HAM JAR PIPE MAN BAY

6-words

TRIAL 1

SOUP CAR PLATE HAIR BARN TOOTH

TRIAL 2

BAG SHIP EAR FIG PIT LID

7-words

TRIAL 1

CUP PLANT SKIN RICE NET BEARD VAN

TRIAL 2

KEY TRAIN GUN LIP HAY MEAT PIN

8-words

TRIAL 1

DRESS FACE WAX BOY SNAKE KNIFE HEART VEIN

TRIAL 2

FAN CHAIR ROPE SAT STONE MUD PLUG TRUCK

Words used in backward word span task

4-words

TRIAL 1

CHURCH SUIT PALM BEEF

TRIAL 2

ROCK BED SEAL PAINT

5-words

TRIAL 1

TAIL MOLD BRUSH ROOM GUM

TRIAL 2

BOX CELL LEG POOL HAT

6-words

TRIAL 1

PATH ARC COLT ROSE GOLD SOAP

TRIAL 2

DOG CHIN RING FILM PARK GIN

7-words

TRIAL 1

HORN FOOT BEER GATE SUN WHEEL MAID

TRIAL 2

LAWN NECK TEA ROAD CHAIN DESK SHELL

8-words

TRIAL 1

SHIRT MUD ICE KID HAND DIRT TOOL BUS

TRIAL 2

TIE SAND POT LAKE JAW FIRE GRASS CAP

Words used in the alphabet word span task

2-words

TRIAL 1	TRIAL 2
GUM LAWN	BAY JAR

3-words

TRIAL 1	TRIAL 2
LAKE PATH SUIT	CAR NET PIN

4-words

TRIAL 1	TRIAL 2
BOX CELL GRASS ROCK	BAG COW TREE VAN

5-words

TRIAL 1	TRIAL 2
GATE MAID PAINT RING TOOL	BIRD LID MAN ROPE SNOW

6-words

TRIAL 1	TRIAL 2
CAP FOOT GIN MUD POT SAND	FACE GIRL KEY MILK PEN SALT

7-words

TRIAL 1

BEEF HORN LEG PALM ROSE SOAP TEA

TRIAL 2

CHILD EAR HAIR NUT PAN SNAKE WINE

8-words

TRIAL 1

BEER CHIN DIRT GOLD HAT ICE SHIRT TIRE

TRIAL 2

ARM BAT CUP JET PLATE RAIL TRAY VEIN

9-words

TRIAL 1

ARC BED CHAIN DESK FILM POOL ROAD SUN TIE

TRIAL 2

BOY CLOCK EAR HAM LIP MEAT STONE TOOL YARD

10-words

TRIAL 1

BUS CHURCH DOG HAND JAW KID PARK ROOM SEAL TAIL

TRIAL 2

BARN CHAIR DRESS GUN HEN JAR LAMP PIPE SOUP TRUCK