Forward And Backward Serial Recall

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The present study examined whether forward and backward serial recall performance reflects different codes, or different levels of processing complexity. One hundred twenty-two participants saw sequences of 2 to 9 letters (phonologically similar or dissimilar) for 1 second each in the center of a computer screen, and recalled the letters in forward or backward order. Participants correctly recalled more when letters were phonologically dissimilar, and when recall direction was forward. No interaction was found between direction of recall and phonological similarity, which suggests that a phonological code was used for both forward and backward recall. Also, forward and backward recall did not differentially predict SAT performance, which suggests that forward and backward recall required a similar level of processing complexity.

Standardized tests of intelligence routinely include serial order recall tasks in their battery of subtests. These span tasks are used as measures of attention and have been found to share systematic variance with more general measures of intelligence. The nature of the relationship between attention, or memory span, and intelligence has been explored by intelligence and memory researchers alike in the past two decades (Bachelder & Denny, 1977a, 1977b; Cantor, Engle & Hamilton, 1991; Cohen & Sandburg, 1977; Crawford, 1991; Dempster, 1981; Engle, Nations & Cantor, 1990; Jensen, 1964; Jensen & Figueroa, 1976; Stankov, 1983).

In the simple span task, an individual recalls a sequence of items in the exact order of presentation. In forward recall the items are recalled in the same order of presentation. In backward recall the items are recalled in the reverse order of presentation. The typical finding is that more items are recalled in forward recall than in backward recall (Dempster, 1981). Further, some theorists have argued that the performance differences between the two span tasks reflect important differences in cognitive and intellectual processes.

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Two theoretical approaches have been taken to explain performance differences in forward and backward serial recall. The first approach, which we will call the Complexity view, is to explain the differences in terms of processing complexity, or attentional demands (Ashman & Das, 1980; Case, 1972, 1985; Case & Globerson, 1974; Jensen, 1964; Jensen & Figueroa, 1976; Schofield & Ashman, 1986). This view argues that individuals recall more items with forward recall because forward recall does not require a mental transformation of the stimuli in order to reverse the recall order of the items. In forward recall, the items are thought to be retained in a simple passive store (i.e., short-term memory) and are recalled in the same order in which they entered the store. Omission errors, should they occur, result from a limitation in the capacity of the passive store. Order errors, should they occur, result from an error-prone rehearsal process and/or the decay of information from the passive store. Backward recall relies on the same representation as forward recall, and also requires an attention-demanding mental transformation of the representation in order to construct an output string that is the reverse of the input string. The additional transformation step, with its attentional demands, creates more opportunity for transposition errors during recall, allows more time for decay from the passive store, and makes rehearsal more difficult. Thus, the Complexity view sees backward recall as involving the same processes and representations as forward recall but requires in addition, an attention demanding transformation before building the representation of the output string.

The second approach, which we will call the Representational view, argues that performance differences in forward and backward recall result from two different types of representations (Conrad, 1972; Conrad & Hull, 1964; O'Connor & Hermelin, 1976; Li & Lewandowsky, 1995). The argument is that forward recall is more suited to the use of a phonological code, whereas backward recall is more suited to the use of a visual-spatial code. Presumably, it is easier to transform (or reverse) recall direction if the items are represented as a spatial array. Consequently backward recall might only require that the items be "read" from the array in the reverse direction of entry into the array (e.g., from right to left instead of left to right). Whereas with forward recall, it is assumed that a phonological code is more suited to the retention of order information (Healy, 1975).

Jensen (1964), an adherent of the Complexity view, has made performance differences in forward and backward recall an important part of his theories of intelligence. He argues that the two span tasks represent two levels of processing complexity. Level I processing, the type of processing used in forward recall, involves the passive storage of information. This type of processing makes fewer demands on the attentional resources of an individual and is therefore less relevant to the type of processing used in more complex and challenging cognitive tasks. In contrast, Level II processing, the type of processing used in backward recall, involves active, controlled and effortful attending to perform the transformation, in addition to the Level I processing used for the storage of the initial string. Jensen & Figueroa (1976) predicted that if performance on forward and backward digit span tasks reflected Level I and Level II processing, respectively, then the magnitude of the relationship between span performance and IQ should be greater for the backward digit span task. Jensen and Figueroa found a trend in the correct direction for a stronger relationship between backward digit span and IQ when compared to forward digit span and IQ, but the relationship was not statistically significant.

A similar approach to the role of processing complexity in serial recall was taken by Case (1972, 1984; Case & Globerson, 1974). Case (1972) argued that performance on forward serial recall is superior to backward serial recall because forward serial recall uses little in the way of attentional resources. He referred to the attentional requirements of a task, in terms of executive processing space, similar to the central executive in Baddeley and Hitch's (1974) model of working memory. Case's executive processing space reflects the total amount of information an individual can keep activated, and coordinated, in any one moment. Case divided his executive processing space into two components: an operating space and a short-term storage space. Tasks that make attentional demands use more operating space, while tasks that make few demands use predominantly short-term storage space. In addition, there is a trade-off between operating and storage space based on the attentional demands of the task. Forward serial recall would be superior to backward serial recall because it only requires passive storage. Therefore, little operating space is used, leaving more storage space for the to-be-remembered items. In contrast, backward serial recall involves an attention demanding transformation, in addition to the passive storage of the items. This means that more operating space will be used and less storage space will be left over to store the to-be-remembered items.

Case and Globerson (1974) found support for the existence of an operating space. They tested a number of children on analytic (field independence) and various span tasks, which included a backward serial recall task. They found that the analytic and span tasks loaded on two separate, but correlated factors. Case and Globerson argued that the general factor that subsumed the two correlated factors reflected the use of a common operating space by all of the tasks. Presumably, the span and analytic tasks required different amounts of operating space, hence two separate factors emerged.

The Representational view evolved from studies that examined the effects of phonological similarity on serial recall. Conrad and Hull (1964), for example, found that forward serial recall was a function of the phonological similarity among letters in a memory set. Recall was better for letters that did not sound alike or rhyme than for letters that did rhyme. Conrad (1972) later compared forward recall performance of deaf children to hearing children when recalling phonologically similar or visually similar sets of letters. He found that deaf children recalled more letters from the phonologically similar set, whereas the hearing children recalled more letters from the visually similar set. He concluded that the deaf children used a visual code for representing order, whereas the hearing children used a phonological or articulatory code.

Following Conrad's (1972) work, O'Connor and Hermelin (1976) argued that if deaf individuals represent a string of letters in a spatial format, then they should perform better on backward recall because they would be able to reverse the sequence of letters by reading them from a visual image, or store. O'Connor and Hermelin found that deaf individuals did indeed show fewer order errors on backward recall when compared to the backward recall performance of hearing subjects. This finding has been taken as support for the use of two different types of representations in forward and backward recall.

More recently, Li and Lewandowsky (1995) examined how forward and backward serial recall in normal hearing adults was affected by visual-spatial interference, on the view that forward recall should depend on a phonological code (and so be unimpaired), while backward recall should depend on a visual-spatial code (and so be significantly impaired). Presenting letters in random spatial locations on a computer screen interfered with backward serial recall. In contrast, this manipulation had no effect on forward serial recall. Individuals thus appear to use a visual-spatial representation for backward serial recall when the presentation mode is visual and the letters are not vocalized during presentation.

The controversy over the nature of the representation in forward and backward recall still exists. One way to address the issue of one versus two types of representations in forward and backward recall, is to examine how phonological similarity affects recall performance. The purpose of the present study was to investigate whether performance differences in forward and backward recall reflect completely different representations, or different levels of cognitive processing (e.g., simple versus complex processing). If individuals use a phonological representation for forward and backward recall, then recall performance on both recall tasks should show a phonological similarity effect. That is, we should find fewer letters recalled from the phonologically similar strings of letters, independent of direction of recall. However, if the two tasks lead to different modes of representation, then the similarity effect should not be found with backward recall since it would not rely on a phonological code. If different levels of cognitive processing are used, then forward and backward recall should differentially predict some measure of cognitive ability. We did not have access to IQ scores for our participants but we did have access to their Verbal and Quantitative SAT scores (VSAT and QSAT). Thus, we used SAT scores as our index of cognitive ability when examining whether forward and backward recall differentially predicted a measure of cognitive ability.

Method

Subjects

122 University of South Carolina undergraduates participated in exchange for course credit. APA ethical guidelines for the treatment of human participants were followed in this study. Each participant signed a permission form allowing us access to their SAT scores from university records.

Materials

A computer program presented randomly ordered strings of letters on a computer monitor at the rate of one letter per second. The letter strings varied in length from 2 to 9 letters. There were 3 presentations of each string length for a total of 24 strings of letters, in each of the forward and backward letter tasks. The letter strings in the phonologically similar condition were chosen from C, T, D, V, B, E, Z, G, P, and the letter strings in the phonologically dissimilar condition were chosen from Y, M, K, L, W, Q, S, R, T.

Procedure

Participants were randomly divided into two groups: one group recalled phonologically similar sequences of letters and one group recalled dissimilar sequences. Each participant recalled letter strings in a forward order task and a backward order task. Task order was counterbalanced across participants. Participants completed a practice session consisting of four trials before beginning each of the forward and backward letter tasks. Each task involved the random presentation of 24 letter strings that contained 2 to 9 letters. The letters were presented one at a time in the center of the monitor at the rate of one letter per second. Participants did not vocalize the letters during presentation. After the presentation of each letter string, participants typed the string of letters into a horizontal display of dashed lines that appeared on the computer monitor. The number of dashed lines corresponded to the number of letters in the string. Participants were required to type in the letters in the exact forward or backward order. As soon as a letter was typed, the cursor moved to the next spot in the display. For forward recall, the cursor moved from left to right and for backward recall it moved from right to left. Recall was subject-paced and participants heard an error tone at the end of a sequence that was incorrect.

RESULTS

The results will be reported in two sections according to the type of analysis conducted, namely ANOVA and Correlational analyses. The section on Correlational Analyses will be further divided into three subsections: Reliability analyses, Correlation matrices, and Regression analyses. The data for all of the analyses consisted of the total number of letters recalled from perfectly recalled strings. Each participant had two scores, a forward span score and a backward span score. The maximum span score that could be achieved in each task was 132 correctly recalled letters.

ANOVA

The total number of correctly recalled letters for each participant in each recall task was submitted to an ANOVA. Table 1 shows the means and the results of the ANOVA. A phonological similarity (similar/dissimilar) X recall task (forward/backward) ANOVA revealed a main effect of phonological similarity $F(1,120) = 41.65$, $p < .0001$, MSe = 421.18, and recall task $F(1,120) = 25.67$, $p < .0001$, MSe = 113.98. The similarity main

Table 1. Means, Standard Deviations, and Analysis of Variance for Total Letters Recalled from Perfectly Recalled Strings

	Forward recall	*Backward recall*	*Mean*
Similar Letters	38.93(13.35)	33.90(15.14)	36.42(14.44)
Dissimilar Letters	57.79(18.40)	48.97(18.01)	53.38(18.66)
Mean	48.36(18.60)	41.43(18.21)	

Analysis of Variance

Source	*df*	*F*
Between Subjects		
Phonological Similarity (A)	1	41.65****
Error	120	(421.18)
Within Subjects		
Recall Task (B)	1	25.67****
A X B	1	1.92
Error	120	(113.98)

Notes: The values in parentheses in the top table reflect the standard deviation. The values in parentheses in the bottom table reflect the mean square error.
****$p < .0001$

effect reflected the fact that span was larger for dissimilar lists (53.38 letters) than for similar lists (36.42 letters). The effect of recall task reflected the fact that span was slightly larger for forward recall (48.36 letters) than for backward recall (41.43 letters). However, there was no interaction between phonological similarity and recall task, $F(1,120) = 1.92$, $p > .05$, MSe = 113.98, meaning that the similarity variable had a statistically indistinguishable effect on both forward and backward tasks. The finding that similarity did not interact with recall task suggests that a phonological representation was used for both forward and backward recall. In fact, if we consider the recall of dissimilar letters as the baseline condition, the similar letters led to a reduction of 67% of the dissimilar condition for forward recall and 69% for backward recall. Clearly, the phonological similarity effect was not different for the two recall conditions suggesting that the two recall formats did not lead to different forms of representation. The counterbalancing variable, order of task, was not significant, and did not interact with phonological similarity.

Correlational Analyses

Reliability Analysis. The reliability estimates were derived from Cronbach's alpha formula as measures of internal consistency. Estimates were calculated from the total number of correctly recalled letters from each of three presentations, of eight group sizes. For example, the total number of correctly recalled letters from one presentation of group sizes 2 through 9 became the first span score of a measure. The total number of correctly recalled letters from a second presentation of the same group sizes became the second span score, and the total number of correctly recalled letters from a third presentation became the third span score. Each of the three span scores ranged between 0 and 44 correctly recalled letters. Reliability estimates of the four span measures, using Cronbach's alpha formula, were as follows: forward similar, .64; backward similar, .73; forward dissimilar, .78; and backward dissimilar, .75. The Reliability estimates for Verbal and Quantitative SAT obtained from Educational Testing Services (ETS) was .91 for Verbal and .93 for Quantitative SAT.

Table 2. Intercorrelations Between Verbal and Quantitative SAT, and Forward and Backward Recall of Phonologically Similar and Dissimilar Strings of Letters

	Forward Recall	*Backward Recall*	*VSAT*
	Similar Letters		
Backward Recall	(.70).48***		
Verbal SAT	(.53).40**	(.46).37**	
Quantitative SAT	(.44).34**	(.63).51****	(.69).59****
	Dissimilar Letters		
Backward Recall	(.83).63***		
Verbal SAT	(.32).27*	(.32).26	
Quantitative SAT	(.50).42**	(.34).28*	(.73).62****

Notes: The values in parentheses reflect the correlation coefficients when corrected for attenuation due to measurement error.
*$p < .05$
**$p < .01$
***$p < .001$
****$p < .0001$

Correlations. The correlational analyses were clearly secondary to the results of the experiment but nevertheless speak to issues raised in the Introduction. Table 2 contains the Pearson Product Moment correlation coefficients calculated among Verbal and Quantitative SAT, and forward and backward recall. The correlations are presented in two correlation matrices that differ with respect to the phonological similarity of the items. The reliability estimates for each measure were used to correct the correlation coefficients for attenuation due to measurement error and the corrected coefficients are shown in the parentheses in Table 2. Looking primarily at the 2x2 matrix (VSAT and QSAT by forward and backward recall) for similar and dissimilar letters, we see that 7 of the 8 correlations were significant and the 8th was quite close to significance. Significant relationships were found between recall performance and SAT for all but backward dissimilar recall and VSAT. Differences between corresponding correlations for similar and dissimilar letters were tested using a Fisher z transformation of the coefficients after first correcting for attenuation. Only one significant difference was found, that between backward recall of phonologically similar letters with QSAT (.51), and the correlation of backward recall of phonologically dissimilar letters with QSAT (.28), $z(54) = 1.96$, $p < .05$. Thus, what we would note about the pattern of correlations is that those involving backward and forward recall are quite similar, failing to support the position of Jensen and Figueroa (1976) that backward recall is more predictive of higher-order cognitive tasks. Another observation is that, while those correlations involving similar letters appear to be slightly higher, the pair-wise comparisons did not support such a conclusion.

Regression Analyses

We used Verbal and Quantitative SAT as the criterion measures in the regression analyses. The mean VSAT score was 442 with the lowest score being 250 and the highest score

Table 3. Regression analyses with VSAT and QSAT as the criterion measures and forward or backward recall as the predictor variable

Step	*Predictor Variable*	*VSAT % Var*	*F*	*QSAT % Var*	*F*
Similar:					
1	Forward	.1589	9.63**	.1178	6.81**
2	Backward	.0311	1.92	.1515	10.36**
1	Backward	.1353	7.98**	.2644	18.33****
2	Forward	.0547	3.37	.0048	.33
Dissimilar:					
1	Forward	.0713	4.07*	.1732	11.10**
2	Backward	.0169	.96	.0031	.19
1	Backward	.0676	3.84*	.0814	4.70*
2	Forward	.0205	1.17	.0948	5.99**

Notes: *p < .05
**p < .01
****p < .0001

620. The distribution had a standard deviation of 79. The mean QSAT score was 507 with the lowest score being 310 and the highest score 780. The distribution had a standard deviation of 86.

Verbal SAT. We conducted four regression analyses to determine how phonological similarity and direction of recall mediated the relationship between recall performance and VSAT. Table 3 contains the four models that were used to examine the linear relationship between VSAT and forward and backward recall of similar and dissimilar strings of letters. The table is divided into two sets of regression models based on phonological similarity. Each set of regression models shows the proportion of variance explained, depending on whether forward or backward recall was entered first in the model.

The amount of variance explained in the relationship between recall performance and VSAT did not vary as a function of phonological similarity or recall direction. Table 3 shows that a similar pattern of analyses emerged for phonologically similar and dissimilar sets of letters. Forward and backward recall explained a comparable amount of variance in the relationship between recall and VSAT, when each predictor was entered first in the model. Also, forward and backward recall contributed a comparable amount of unique variance to the relationship when each was entered second in the model. For phonologically similar sets of letters, entering forward recall first accounted for 15.89% of the variance, while backward recall only accounted for an additional 3.11% of the variance. Entering backward recall first accounted for 13.53% of the variance, while forward recall only accounted for an additional 5.47% of the variance. For phonologically dissimilar sets of letters, entering forward recall first accounted for 7.13% of the variance, while backward recall only accounted for an additional 1.69% of the variance. Entering backward recall first accounted for 6.76% of the variance, while forward recall only accounted for an additional 2.05% of the variance.

Quantitative SAT. We examined how phonological similarity and direction of recall mediated the relationship between recall performance and QSAT. Table 3 contains the four models that were used to examine the linear relationship between QSAT and forward and backward recall of similar and dissimilar strings of letters.

The amount and type of variance explained in the relationship between recall performance and QSAT differed as a function of phonological similarity. Table 3 shows that backward recall explained most of the variance in the relationship between recall of phonologically similar sets of letters and QSAT when it was entered first in the model. Also, backward recall explained a significant amount of variance in the relationship between recall of phonologically similar sets of letters and QSAT when it was entered second in the model. In contrast, forward recall explained most of the variance in the relationship between recall of phonologically dissimilar sets of letters and QSAT when it was entered first in the model. Also, forward recall explained a significant amount of the variance in the relationship between recall of phonologically dissimilar sets of letters and QSAT when it was entered second in the model. For phonologically similar sets of letters, entering forward recall first accounted for 11.78% of the variance, while backward recall accounted for an additional 15.15% of the variance. Entering backward recall first accounted for 26.44% of the variance, while forward recall only accounted for an additional .48% of the variance. For phonologically dissimilar sets of letters, entering forward recall first accounted for 17.32% of the variance, while backward recall only accounted for an additional .31% of the variance. Entering backward recall first accounted for 8.14% of the variance, while forward recall accounted for an additional 9.48% of the variance.

DISCUSSION

The focus of this paper was to determine whether forward and backward serial recall reflects two different types of representations, or two different levels of processing complexity and whether the different representations or levels of complexity lead inexorably to differential ability to predict higher-order cognitive tasks. We argued that if two different types of representations were used in forward and backward recall, then we should find no phonological similarity effect for backward recall. Finding a phonological similarity effect for both forward and backward recall would suggest that the letters in both recall tasks were represented phonologically. The results of the ANOVA showed that participants recalled more letters in both tasks when the letter strings were phonologically dissimilar, with the effect of the similarity manipulation being almost identical. The equivalent phonological similarity effect for forward and backward recall suggests that participants used a phonological code to represent the letter sequences in both tasks. Jensen and Figueroa (1976) argued that the backward span task was a more valid test of general abilities than forward span because the level of complexity in the task requires a mode of thinking more appropriate to higher order tasks. We argued that if this were true, then we should find that forward and backward recall would differentially predict the measures of general ability we had available, Verbal and Quantitative SAT. The zero order correlations and the regression analyses both generally suggested that forward and backward recall do not substantially differ in their ability to predict either of the two standardized test scores.

In the introduction to this paper we discussed two theoretical approaches to explaining the performance differences that are typically found in forward and backward serial recall. The first approach was the Complexity view and the second approach was the Representational view. The Complexity view explained the differences in forward and backward recall in terms of two different levels of processing complexity. Forward recall is typically found to be greater than backward recall because it only requires the passive storage of items. In contrast, backward recall requires the passive storage of items in addition to a transformation of the items in the store, in order to recall the items in the reversed order of entry. This view predicts that forward and backward recall should differentially predict performance on some measure of cognitive ability. Our measures of cognitive ability were Verbal and Quantitative SAT. We found that the majority of our correlations did not differ in magnitude as a function of phonological similarity. Also, the regression analyses showed that, overall, forward and backward recall did not differentially predict SAT performance. As such, our recall findings do not support Jensen and Figueroa's (1976) processing complexity view of serial order recall, or Case's (1972) M space view of serial order recall.

The second theoretical approach discussed in this paper, the Representational view, explained performance differences in forward and backward serial recall in terms of two different types of representations. Forward recall relies on a phonological representation, while backward recall relies on a visual-spatial representation. Forward recall is typically greater than backward recall because the representation of order information is better suited to a phonological code. This view predicts that phonological similarity should adversely affect forward serial recall, but not backward serial recall. We found that phonological similarity had an adverse effect on both forward and backward recall. As such, our findings conflict with Li and Lewandowsky's (1995) conclusions that individuals use a visual-spatial code to represent items in backward recall. They partly based their conclusions on their presentation method. They used a visual presentation where the letters were presented one at a time in the center of the screen. Also, they did not have their participants vocalize the items. Their conclusions, about the effect of their presentation method on their findings, implied that individuals construct a modality-specific representation based on the mode of presentation. Therefore, individuals should form a visual-spatial representation of visually presented items unless encouraged to construct a phonological representation by vocalizing the items. However, we also used a visual presentation where the letters were presented one at a time in the center of the screen, and did not have our participants vocalize the items. Although Li and Lewandowsky's conclusions would suggest that this type of presentation method should not produce a phonological similarity effect, we found a phonological similarity effect. More importantly, we found a phonological similarity effect for backward recall, suggesting that individuals used a phonological, and not a visual-spatial code for backward serial recall.

This study was aimed at determining whether forward and backward recall reflects different levels of processing complexity or different types of representations. We found no evidence that suggested that backward recall required more complex processing than did forward recall. Also, we found that participants used a phonological code for both forward and backward serial recall. More importantly, we found evidence for the use of a phonological code even when the experimental procedure did not encourage the use of this type of code. We should point out that the conclusions we draw here are quite clearly supported by data from our sample which consisted of college students. We would expect to obtain a different pattern of results from a sample of children or from individuals lower in intellectual level than the current sample of college students. As we have pointed out elsewhere (Engle, Tuholski, Laughlin & Conway, submitted), tasks such as the backward span task quite likely reflect one latent construct among young children or individuals of a given intellectual level and a different construct among older individuals or individuals of higher intellectual level. Our point, reinforced by the data presented here, is that one cannot make a generalization about a given task for all ages or intellectual levels. The backward span task, in our sample of adults of college-age and college-level of intellectual development, is not demonstrably different than a forward span task either in how it is represented or in what it tells you about the intellectual abilities of the individual.

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