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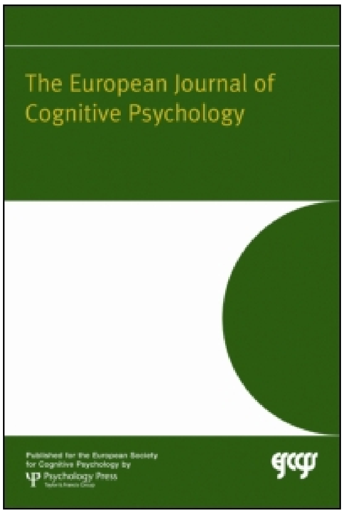

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Backwards digit recall: A measure of short-term memory or working memory?

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Backwards digit recall: A measure of short-term memory or working memory?

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Backwards digit recall is often employed as a measure of working memory (e.g., Gathercole, Pickering, Ambridge, & Wearing, 2004). However, some researchers suggest that it may be better described as a task assessing short-term memory (e.g., Engle, Tuholski, Laughlin, & Conway, 1999). The present study explored the relationships between backwards digit recall and commonly used measures of short-term and working memory in children and in adults. The results suggested that backwards digit recall can best be described as a measure of working memory in children, but short-term memory in adults. The results are discussed in terms of both theoretical and practical implications for memory research.

Keywords: Short-term memory; Working memory.

Short-term memory and working memory are both central constructs in theories of memory and cognition. The term “short-term memory” is typically used to refer to systems specialised for the temporary storage of information within particular informational domains. The term “working memory” is used to describe a more complex system responsible for both the processing and storage of information during cognitive tasks (e.g., Baddeley, 2000). Measures of short-term memory are thus distinguishable from, but related to, measures of working memory. Both short-term and working memory can be assessed using a range of tasks (e.g., for a review see Oberauer, 2005), but short-term memory is commonly assessed using tasks in which participants are given a list of items and asked to recall the list in the same order. Working memory is often assessed using tasks in which participants recall a set of items in the same order, but also engage in a processing activity which is interleaved between the memory items. For example, in counting recall (Case, Kurland, & Goldberg, 1982) participants

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are asked to count the number of items in a series of arrays and then recall the successive tallies of each array.

The cognitive resources proposed to underlie performance on short-term memory and working memory tasks differ widely across alternative models. According to one of the most popular models (Baddeley, 2000), working memory consists of four components. There are two domain-specific short-term memory systems: the phonological loop, which is responsible for the storage of verbal information, and the visuospatial sketchpad, which is responsible for the maintenance of visuospatial information. These are governed by the central executive, which is likened to a mechanism of attentional control. The fourth component, the episodic buffer, is responsible for integrating information from the subcomponents of working memory and long-term memory. In a similar approach to working memory, Kane, Conway, Hambrick, and Engle (2007) view working memory as a synergy between short-term memory and attention. Short-term memory is assumed to be a result of storage and rehearsal processes, with attentional processes being employed to reactivate memory traces and inhibit irrelevant information. Within both of these models short-term memory tasks are thought to employ domain-specific storage systems, with working memory tasks drawing upon both storage and attentional resources (e.g., Baddeley & Logie, 1999; Duff & Logie, 2001).

A further theoretical account proposed by Unsworth and Engle (2007) is that short-term memory and working memory measures employ the same basic processes but they differ in the extent to which these processes operate. This framework combines an active maintenance component (primary memory) with a controlled search and retrieval processes (secondary memory). Items are thought to be initially maintained in primary memory but then displaced to secondary memory by other incoming items or distracting information. Thus, short-term memory tasks will employ primary memory, only drawing upon secondary memory when long lists of items are presented and the early items in the list have been displaced. Working memory tasks, however, will employ both primary and secondary memory because processing activities displace items from primary memory.

Within each of these approaches the extent to which short-term memory and working memory tasks employ storage and attentional resources (or primary and secondary memory) can vary as a function of individual ability or task content. For example, when completing a short-term memory task like digit recall adults should find the coding and rehearsal processes to be routine and not attentionally demanding. In comparison, 4-year-old children may need to employ attentional resources in order to keep memory items active prior to recall (see also Kane et al., 2007). When completing a working memory task like counting recall adults may not find counting attentionally demanding unless they are asked to count using an unfamiliar sequence. In contrast, children may need to employ executive-attentional resources even for basic counting (see also St Clair-Thompson, 2007).

There may also be individual differences in the extent to which short-term and working memory tasks allow for strategy use. When executive-attentional resources are employed during a task, they prevent continual rehearsal and grouping of information to be remembered (e.g., Cowan et al., 2005). Thus, participants of higher ability, who do not need to employ attentional resources, are better able to employ strategies that can maintain memory items. In such cases working memory tasks can become equated with short-term memory tasks, in which there is no active processing of information (Cowan et al., 2005; Unsworth & Engle, 2007).

One task which has been used within research into both short-term memory and working memory is backwards digit recall, in which participants are asked to recall series of digits in reverse order. This task differs from short-term memory tasks because of the requirement to reverse the sequence. However, it also differs from working memory tasks because all of the items to be remembered are presented in succession, and there is no processing activity interleaved between the items. It is possible that some participants reverse the digit sequence immediately during presentation, resulting in intervening processing, however, the task could also be completed successfully by delaying the reversal until all the digits are available. There is therefore some debate surrounding whether this task is a measure of short-term memory or working memory. Some researchers consider forwards and backwards recall to require a similar level of complexity (e.g., Rosen & Engle, 1997), and have found that they load onto the same factor during factor analysis (e.g., Colom, Abad, Rebello, & Shih, 2005; Engle et al., 1999). However, other researchers assume that a transposition of order requires the involvement of executive-attentional resources (e.g., Elliot, Smith, & McCulloch, 1997) and have found that performance on backwards digit recall is closely related to performance on other working memory measures (e.g., Gathercole et al., 2004; Oberauer, SὒB, Schulze, Wilhelm, & Wittmann, 2000).

The source of the discrepancy between these findings is not obvious. However, it is possible that it results from differences in individual ability or task content. Studies that have suggested that backwards digit recall measures short-term memory (e.g., Colom et al., 2005; Engle et al., 1999) have employed adult participants. Those that have proposed it assesses working memory (e.g., Gathercole et al., 2004) have used children. The exception to this is the study by Oberauer et al. (2000). However, in this case the methods of administration and scoring differed from a standard span procedure. Commonly participation on a short-term or working memory task is ceased when a participant incorrectly recalls the sequence of items in a number of trials at any list length. However, in the study by Oberauer et al. (2000) each participant continued with trials at longer list lengths, being scored on the number of individual digits recalled accurately in the correct place in the sequence. According to Unsworth and Engle (2007), using this method would have employed secondary memory (or attentional resources) because the list lengths would have exceeded the capacity of short-term memory.

The differences observed in backwards digit recall between children and adults could be explained by the relative contributions of storage and attentional resources or the differential employment of memory strategies. Children could find the task of reversing a digit sequence attentionally demanding, thus employing executive-attentional resources and minimising the opportunity for rehearsal and grouping strategies. In contrast, adults could find reversing a sequence to be a routine task, not needing attentional resources, and allowing more opportunities to employ strategies. This would result in backwards digit recall assessing working memory processes in children, but short-term memory processes in adults. The present study investigated this issue by exploring the relationships between backwards digit recall and measures of short-term and working memory in children and adults. The methods of administration and scoring were held constant across the two age groups. It was hypothesised that performance on the backwards digit recall task would be more closely related to measures of working memory than short-term memory in children, but more closely related to measures of short-term memory than working memory in adults.

METHOD

Participants

The participants were 77 children with a mean age of 7 years and 9 months (*SD* = 7 months), and 75 adults with a mean age of 20 years and 6 months (*SD* = 2 years). The children were recruited from two primary schools in the North of England and the adults were psychology students who participated to partially fulfil a course requirement.

Materials and procedure

Each participant completed five commonly used measures of short-term and working memory. In the digit recall test participants were asked to recall, in the same order, sequences of digits spoken aloud by the experimenter. Sequences were constructed randomly and without replacement from the digits 1 to 9 and were presented at the rate of one per second. Following two practice trials, testing began with a maximum of six trials with one digit. If four trials were recalled correctly the participant was credited with correct recall in all six trials at that list length, and the number of digits was then increased by one. When three or more lists of a particular length were recalled incorrectly testing ended. The score was calculated as the number of trials on which the digits were recalled correctly.

The span procedure outlined for the digit recall task was shared by all of the other tests. In the word recall test participants were asked to recall sequences of monosyllabic words. In the backwards digit recall test participants were asked to recall sequences of digits in reverse order. In the listening recall task participants heard a series of sentences and were asked to judge the veracity of each. At the end of each trial they were asked to recall the final word from each sentence in sequence. The sentences were taken from Towse, Hamilton, Hitch, and Hutton (2000), with children being presented with the short version of the sentences and adults being presented with the long version. In the counting recall test participants were asked to count the number of items in a series of arrays and then at the end of each trial they were asked to recall the successive tallies of each array. Here the target items that had to be counted shared a feature (either shape of colour) with distractor items.

RESULTS

The descriptive statistics for the measures of short-term memory and working memory are presented in Table 1.

The correlations between scores on each task are presented in Table 2. The upper triangle shows the correlations for children and the lower triangle shows the correlations for adults. In children backwards digit recall was significantly correlated with digit recall, $r(76) = .33$, $p < .01$, listening recall, $r(76) = .47$, $p < .01$, and counting recall, $r(76) = .39$, $p < .01$. In adults

TABLE 1
Descriptive statistics for measures of short-term and working memory in children and in adults

	Children		*Adults*	
Measure	*Mean*	*SD*	*Mean*	*SD*
Digit recall	27.5	5.2	34.9	2.0
Word recall	19.7	1.9	27.8	1.3
Backwards digit recall	10.1	3.5	16.2	2.0
Listening recall	12.1	3.5	21.6	2.1
Counting recall	17.1	2.9	27.3	1.5

TABLE 2
Correlation coefficients for the memory measures: upper triangle represents coefficients for children and lower triangle represents coefficients for adults

	1	*2*	*3*	*4*	*5*
1. Digit recall	—	.55**	.33**	.44**	.35**
2. Word recall	.54**	—	.18	.32**	.25*
3. Backwards digit recall	.61**	.59**	—	.47**	.39**
4. Listening recall	.27*	.34**	.40**	—	.71**
5. Counting recall	.31**	.14	.34**	.44**	—

*$p < .05$, **$p < .01$.

backwards digit recall was significantly correlated with performance on each of the other four tasks, with coefficients ranging from .34 to .61.

In order to explore relations between scores on the backwards digit recall task and scores on each of the other memory tasks, a series of confirmatory factor analyses (CFAs) were conducted using AMOS 7.0 (Arbuckle, 2006). Two models of the factor structure of the short-term and working memory tasks were tested in each group. Each consisted of a short-term memory factor incorporating digit recall and word recall, and a working memory factor incorporating listening recall and counting recall. In Model 1 backwards digit recall also loaded on to the working memory factor, and in Model 2 it loaded on to the short-term memory factor. Model fit was assessed using chi-squared, the goodness-of-fit index (GFI), the comparative fit index (CFI), and the root-mean-square error of approximation (RMSEA). Nonsignificant chi-squared values, GFI and CFI in excess of .95, and a RMSEA less than .10 are indicative of an excellent fit (e.g., Arbuckle, 2006). The fit indices for the two models in each age group are presented in Table 3. Alternative models in which the short-term and working memory measures loaded on to the same factor were also tested but failed to satisfy statistical criteria for a good fit.

In children, Model 1, in which backwards digit recall loaded on to the working memory factor, provided an excellent fit to the data. In contrast, for adults, Model 2 provided an excellent fit. In order to assess whether the factor structure was significantly different for children and adults a multisample analysis was then computed in which factor loadings and factor covariance were constrained to be equal in both groups. The fit indices for this model are shown in Table 3. The model did not provide a good account of the data, with a significant chi-squared value and a RMSEA in excess of .10. Taken together these results show that the factor structure differed significantly between children and adults. The best fitting model for each age group is shown in Figure 1.

TABLE 3
Factor loading scores from principal component analysis of memory measures

Model	χ^2	*df*	*p*	*GFI*	*CFI*	*RMSEA*
Children						
Model 1	1.21	4	.88	0.99	1.00	0.00
Model 2	9.43	4	.05	0.95	0.95	0.14
Adults						
Model 1	12.48	4	.01	0.94	0.92	0.17
Model 2	5.54	4	.24	0.99	0.97	0.07
Multisample						
Model 1	35.41	11	.00	0.88	0.91	0.12

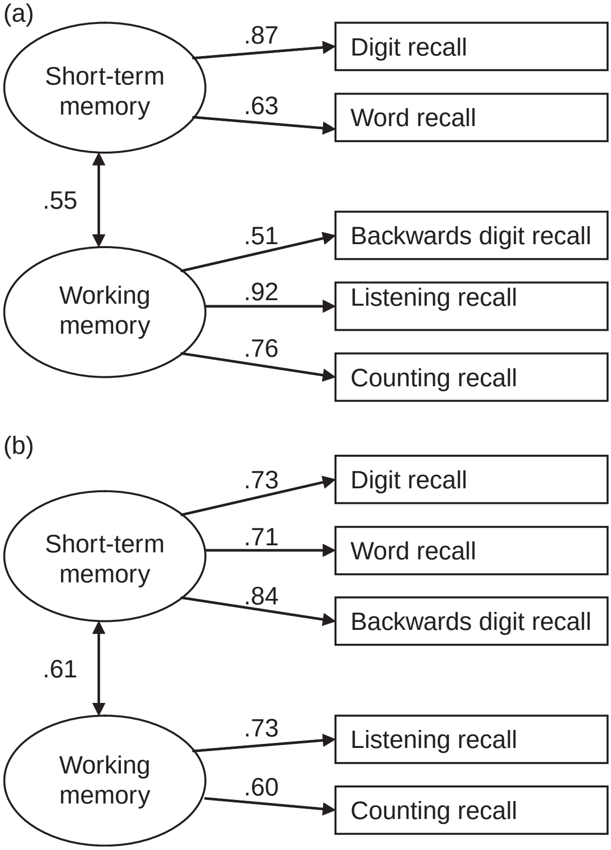

Figure 1. Best fitting models for (a) children; (b) adults.

DISCUSSION

The aim of the present study was to explore whether backwards digit recall can best be described as a measure of short-term memory or working memory in children and adults. In children backwards digit recall loaded onto a working memory factor and in adults it loaded onto a short-term memory factor. The results are therefore consistent with previous suggestions that backwards digit recall measures working memory in children (e.g., Gathercole et al., 2004), but also findings that it measures short-term memory in adults (e.g., Colom et al., 2005; Engle et al., 1999).

These findings provide evidence for the view that the extent to which memory tasks employ storage and attentional resources (or primary and secondary memory) can vary as a function of individual ability. In children a transposition of order appears to require the involvement of executive-attentional resources (e.g., see also Elliot et al., 1997), resulting in backwards digit recall performing as a working memory task. However, in adults it seems less attentionally demanding, drawing primarily upon short-term memory resources (e.g., see also Rosen & Engle, 1997).

It is, however, worthy of note that there are a number of possibilities for why backwards digit recall does not appear to demand attention in higher ability participants. First, reversing a digit sequence could genuinely be a routine task, meaning that performance is only determined by storage capacity and not processing efficiency (see also Bayliss, Jarrold, Gunn, & Baddeley, 2003). Second, rather than resulting from the degree of executive-attentional resources per se, the findings could result from the lack of a processing activity that is sufficiently demanding to disrupt rehearsal and grouping strategies that are commonly used during short-term memory tasks (Cowan et al., 2005). Thus, the factor structure could represent the use of maintenance strategies. Alternatively, because backwards digit recall differs from other working memory tasks in that there is no processing activity interleaved between the memory items, the contrasting pattern of results between children and adults could have resulted from other strategic differences. For example, children may be more likely to reverse the digit sequence during presentation, preventing the use of maintenance strategies. In contrast, adults may adopt a strategy of delaying the reversal, allowing for rehearsal and grouping of the information to be remembered. However, it is important to note that differences in the relative contributions of storage and attentional resources have also been observed in other working memory tasks. For example St Clair-Thompson (2007) reported differences in counting recall, suggesting that children found counting more demanding upon working memory than adults. Thus, tasks of short-term memory and working memory should not be dichotomised to simply reflect distinct resources, but rather individual ability needs to be considered when making judgements about the cognitive underpinnings of tasks.

The results of the present study highlight a problem with assessing working memory using dual tasks, involving both processing and storage. Performance on such tasks is difficult to interpret due to being influenced by storage, processing, strategy use, and domain-specific abilities (e.g., see also Cowan et al., 2005). The current study further suggests that performance in influenced by individual ability, with higher ability participants not needing to employ executive-attentional resources or still being able to employ maintenance strategies. Such findings have lead researchers to suggest that working memory might be better measures by single tasks like running memory span (see also Cowan et al., 2005).

The current findings also have other practical implications for research domains that rely on the use of short-term and working memory assessments, particularly backwards digit recall. For example, backwards digit recall is included in all Wechsler Intelligence Scales (together with the Wechsler Memory Scales), and the Mini Mental Status Examination (MMSE). These are among the most commonly used measures in neuropsychological research and clinical evaluation. A better consideration of the cognitive processes underlying performance on backwards digit recall may increase the power of assessments to discriminate between groups, or may eliminate discrepancies in research areas that rely on this task. Memory tasks also play an important role in research examining relationships between memory and educational attainment. On occasions, depending upon the ability of participants, the tasks might not accurately measure the ability of interest. For example, research within science education has commonly employed backwards digit recall as a measure of working memory in adults. The present study suggests this task assesses short-term memory, leaving relationships between working memory and attainment in science largely unexamined (see also St Clair-Thompson & Botton, in press).

The results of the present study also have implications for the use of forwards and backwards digit recall in the Wechsler Intelligence Scales. The scales include a single subtest which involves both forwards and backwards digit recall. The results from both forwards and backwards recall are combined into a single score that contributes to the Verbal IQ and Full Scale IQ. The strategy of combining scores on forwards and backwards digit recall is really only tenable if they are tapping the same cognitive processes (see also, Richardson, 2007). The present study suggests that this strategy may need to be reexamined in certain populations, particularly those of lower ability.

Given the wide use of backwards digit recall, understanding the mechanisms underlying task performance has important implications. The present study suggests that backwards digit recall assesses short-term memory in adults. However, dissociations between forwards and backwards recall have been found in adults with lower memory scores. For example, impairments in backwards but not forwards digit recall are observed in adult dyslexics and in old age (e.g., Vasic, Lohr, Steinbrink, Martin, & Wolf, 2008). Further research would therefore benefit from a fuller examination of the relationship between backwards digit recall and measures of short-term and working memory in a range of populations. Further research is also needed to examine the cognitive processes underlying the present findings and to explore the impact of strategy use on backwards digit recall.

In conclusion, the present study suggests that backwards digit recall can best be described as a measure of working memory in children, but a task of short-term memory in typically developing adults. It is suggested that further research is needed to examine the processes involved in backwards digit recall in a range of populations. More generally it is suggested that it is important to consider individual ability when making judgements about the cognitive underpinnings of memory tasks.

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