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Effect of Age on Forward and Backward Digit Spans*

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ABSTRACT

A number of studies has suggested that aging is characterized by a decline in the central executive while the automatic processes (in particular operations by the phonological loop) remain intact. According to interpretation, age differences should be minimal in verbal forward digit span while they should be more important in backward verbal digit span. A sample of 1,000 subjects with ages ranging from 16 years to 79 years was used to test this hypothesis. The results show no significant effect of age on the difference between digit span forward and backward. The theoretical implications of these results are discussed.

Age-related differences in working memory have been reported a number of times (see, e.g., Salthouse, 1991; Van der Linden, 1994, for a review). Working memory refers to a limited capacity system which is responsible for the processing and temporary storage of information. Baddeley's model represents a current and influential attempt to define the structure and the functioning of working memory (Baddeley, 1986). This model comprises a modality-free controlling central executive which is helped by a number of peripheral slave systems ensuring temporary maintenance of information. Two such systems have been fairly thoroughly explored: the phonological loop and the visuo- spatial sketchpad. The visuospatial sketchpad system is assumed to be involved in setting up and maintaining visuospatial material. The phonological loop system provides temporary storage for speech-based material and is composed of two subsystems: a passive phonological input store and an active articulatory rehearsal process. The central executive is assumed to be an attentional control system responsible for strategy selection and for control and coordination of the various processes involved in short-term storage and more general processing tasks. An important characteristic of this system is that its resources are limited and divided into different processing and storage functions.

A number of studies have suggested that some aspects of working memory might be particularly sensitive to the effect of age. More specifically, it has been claimed that older subjects are relatively unimpaired in short-term memory tasks that call for passive storage without requiring reorganization of material (see Craik, 1977; Welford, 1980). On the other hand, age differences are more important in working memory tasks that require subjects to carry out processing while simultaneously storing information (see Van der Linden, 1994, for a review). These findings suggest that aging is characterized by a decline in the efficiency of the central executive (Baddeley, 1986) while the automatic processes (in particular operations by the phonological loop) remain intact.

According to this “central executive” interpretation, age differences should be minimal in verbal forward digit span whereas they should be more important in backward verbal digit span. In fact, in terms of the working memory model, the phonological loop is arranged to maintain a string of verbal items in a given temporal order. Consequently, the verbal forward span can be almost completely managed by the operations of the phonological loop with a minimal implication of the central executive. On the other hand, when the items are to be repeated in the reversed order (as is the case in the verbal backward digit span), a more extensive involvement of the central executive is expected to occur.

In line with this account, some studies reported that the verbal forward digit spans of the aged were in the normal range of young adults (Parkinson, 1982; Wiergersma & Meerste, 1990). Wingfield, Stine, Lahar, and Aberdeen (1988) also observed normal digit spans in elderly subjects but found significant age differences in word span. In addition, they showed positive correlations between both span tasks and a working memory task modeled on the listening span task described by Daneman and Carpenter (1980), which suggests that these tasks are not testing orthogonal domains.

However, contrary to the above, many other studies have documented significant age-related differences in forward digit span tasks. For example, combined effect size across 13 published experiments using the forward digit span procedure showed a significant age difference (Verhaegen, Marcoen, & Goossens, 1993; see also Babcock & Salthouse, 1990). In a study conducted on 1,354 subjects from 20 to 99 years of age, Orsini et al. (1986) observed that the forward digit span held up well to age 60, and significant differences began to appear only after this age. In addition, they found a significant effect of education but no significant difference between the sexes.

Concerning the backward digit span task, some studies showed that age differences are larger in this task than in the forward digit span task (e.g., Hayslip & Kennelly, 1982). However, other studies observed that age differences are larger with forward digit span (Chamess, 1987) or similar for forward and backward digit spans (Botwinick & Storandt, 1974; Hartley, 1989). In small-scale meta-analysis of 14 studies, Babcock and Salthouse (1990) found that age differences were slightly larger with the backward digit span than with the forward digit span: On average, the advantage of the young subjects over the elderly was 8% and 14%, for forward and backward digit span, respectively. On the other hand, Verhaegen et al.'s (1993) meta-analysis showed that the backward digit span task does not yield a larger effect size than the forward digit span task. Finally, Wiegersma and Meertse (1990) found a group difference in the digit span backward but it was no longer significant when educational level was partialled out.

Given these controversial data, the main purpose of the present study was to reexamine the effects of age (and also those of education and sex) on verbal forward and backward digit span tasks on a large group of subjects.

METHOD

SAMPLE

Data from the standardization sample of the French adaptation of the Wechsler Adult Intelligence Scale-Revised (WAIS-R) were used for the analysis. The sample size was 1,000 subjects with an age range from 16 years to 79 years and 11 months. This sample can be considered as representative of the French population. It was constructed referring to the results of the general census of the population of 1982. Four stratification criteria were used: age, gender, socioeconomic status, and district category. The collection of data was done with great care by a team of psychologists trained in the administration of the WAIS-R.

The sample was composed of ten age groups, each one including 50 male and 50 female subjects. The different age groups were: 16-17 years; 18-19 years; 20-24 years; 25-34 years; 35-44 years; 45-54 years; 55-64 years; 65-69 years; 70-74 years; and 75-79 years. The educational level of each member of the sample was put into one of the five following categories: (1) lower or equal to the primary leaving certificate; (2) higher than the primary leaving certificate but lower than the high school diploma; (3) equal to the high school diploma; (4) the high school diploma and one or two years of higher education; and (5) the high school diploma and three or more years of higher education. Table 1 shows that, according to the age category, the percentage of subjects by educational level varied greatly. For example, it can be seen that almost all the subjects under 25 years had an educational level higher than the primary leaving certificate. Sixty percent of the subjects in the category 75-79 years, however, did not exceed this educational level.

***Table 1**. Percentage of Subjects in Each Age Group According to Educational Level.*

	Educational Level						
Age	1	2	3	4	5	Unknown	Total
16-17 years	1	99	0	0	0	0	100
18-19 years	0	71	15	13	0	1	100
20-24 years	1	40	17	24	18	0	100
25-34 years	8	36	14	21	21	0	100
35-44 years	21	28	12	12	25	2	100
45-54 years	40	34	10	5	10	1	100
55-64 years	38	31	12	6	10	3	100
65-69 years	37	31	9	9	12	2	100
70-74 years	46	27	9	3	14	1	100
75-79 years	60	21	8	5	6	0	100

Note. Educational levels were: (1) lower or equal to the primary leaving certificate; (2) higher than the primary leaving certificate but lower than the high school diploma; (3) equal to the high school diploma; (4) the high school diploma + 1 or 2 *years; and (5) the high school diploma + 3 years or more.*

PROCEDURE

For each subject, the results of the Digit Span subtest were recorded. This subtest had two parts. In the first part, the subject had to listen to a digit span (one digit per second) and then had to repeat it forward. The first span included three digits. The following one included one more digit ... and so on, until the last span included nine digits. The subject had two trials for each span. The subject's score was equal to the maximum of digits repeated without any error in one of the two trials.

The second part of the Digit Span subtest began in the same way. This time, however, the subject had to repeat the span backward, that is, beginning with the last digit of the span. The first span included two digits and the last one eight digits. Here too, the subject's score was equal to the maximum of digits repeated without any error in one of the two trials. Consequently, each subject had two scores; his memory of digit span forward and his memory of digit span backward. These results are analyzed below.

RESULTS

Table 2 shows the mean and the standard deviation of the forward and the backward digit span in each age group. The mean and the standard deviation of the difference is also reported for each age group.

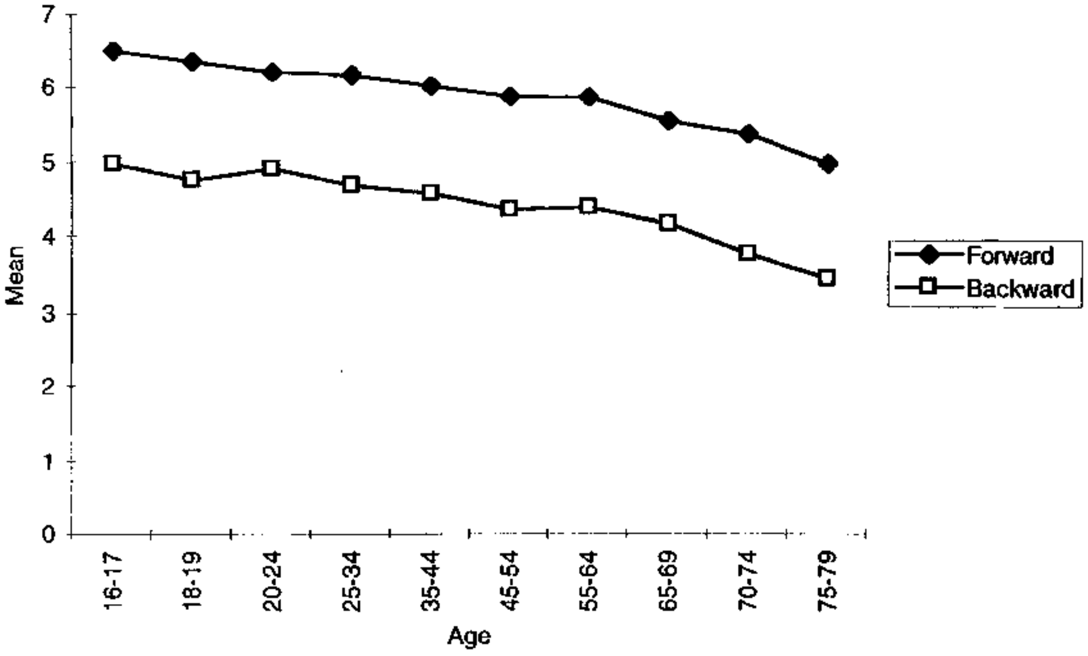
Figure 1 presents the graph of the evolution of the forward digit span and the backward digit span according to age. As we can see, the digit span decreases slightly until 65 years. After this year, performance decreases more sharply. The shape of the curve is quite similar for memory forward and backward. However, a slight break in the curve can be observed for the 18-19 years group, for the digit span backward only. This phenomenon is likely related to a sampling problem and has no psychological meaning.

The Digit Span subtest had, as lower bound, three digits forward and two digits backward, and had, as upper bound, nine digits forward and two digits backward. Consequently, it was necessary to check whether the score distribution was affected by a ceiling effect and/or a floor effect. Clearly, there was no ceiling or floor effect, neither for digit span forward nor for digit span backward. Indeed, all the subjects could repeat to a minimum three digits forward and two digits backward. Thirteen subjects in 1,000 could only repeat a three digit span forward. These subjects were spread across different age groups, with a maximum of 5 subjects in the 65-69 years group, equal to 5% of this group. Thirty-nine subjects in 1,000 could only repeat a two digit span backward. Again, these subjects were spread across different age groups, with a maximum of 17 subjects in the group 75-79 years group, equal to 17% of this group.

Table 2. Digit Span Forward and Backward at Different Ages.

Age	N	Forward		Backward		Difference	
		M	*SD*	*M*	*SD*	*M*	*SD*
16-17 years	100	6.52	1.19	5.00	1.28	1.52	1.23
18-19 years	100	6.37	1.20	4.76	1.22	1.61	1.22
20-24 years	100	6.24	1.07	4.93	1.31	1.31	1.21
25-34 years	100	6.20	1.14	4.71	1.29	1.50	1.38
35-44 years	100	6.04	1.28	4.58	1.41	1.46	1.20
45-54 years	100	5.92	1.18	4.38	1.10	1.54	1.22
55-64 years	100	5.91	1.22	4.41	1.10	1.45	1.23
65-69 years	100	5.56	1.27	4.18	1.21	1.38	1.24
70-74 years	100	5.39	1.07	3.80	1.08	1.59	1.19
75-79 years	100	4.98	0.97	3.46	0.99	1.51	1.00

Figure 1. *Digit span forward and backward according to age.*



We did not observe a ceiling effect. Only 26 subjects in 1000 could repeat a nine digit span forward. These subjects were spread across the different age groups, with a maximum of 6 subjects in the 16-17 years group (6% of this group). Only 25 subjects in 1,000 could repeat an eight digit span backward. These subjects were spread across the different age groups, with a maximum of 6 subjects in the 20-24 years group.

We assessed the statistical significance of the differences of span memory between the age groups. The analysis of variance shows a significant effect of the age variable on the memory of digit span forward, $F(9,990) = 16.861$, $p < .001$. The same observation was done for the memory of digit span backward, $F(9, 990) = 16.713$,p < .001. In order to reveal the age groups whose scores stand out significantly from those of the other age groups, a post hoc Tukey HSD test was performed. The first five groups did not differ significantly. The most noticeable differences appear after the age of 65 years. Indeed, the scores of the subjects older than 64 years are significantly lower than those of the subjects under 35 years. This phenomenon is very clear for digit span forward. It is less remarkable for digit span backward. For the 70-74 years and 75-79 years groups, the scores continue to fall significantly compared with those of younger subjects' groups.

We wanted also to appraise the influence of variables other than age on digit span memory. We first tested the difference of scores according to gender. We observed no significant difference in digit span forward related to sex, $t(998) = 0.534$, $p = 0.593$. But a significant difference, though slight, was noticed for the digit span backward, $t(998) = 0.0184$, $p < .05$. The performance of males was slightly better than that of females.

We also tested the difference of scores according to the subjects' educational level. The analysis of variance showed a significant difference of digit span forward related to the educational level, $F(5, 994) = 31.600$, $p < .001$. The same phenomenon was observed for the digit span backward, $F(5, 994) = 31.345$, $p < .001$. In both cases, the significant difference was related to the lower scores of the subjects whose educational level was lower or equal to the primary leaving certificate, in comparison with those of the other subjects. Table 3 (digit span forward) and Table 4 (digit span backward) show clearly the influence of education across the age groups. In observing these tables, we have to remember (Table 1) that the level of education was not equal in all the age groups. Younger people are much more educated than the older ones. This phenomenon arises in most of the cross-sectional studies and confuses the influence of age and education on cognitive performance across the life span (Grégoire, 1993; Kaufman, Reynolds, & McLean, 1989).

Table 3. *Digit Span Forward at Different Ages according to Educational Level.*

Educational Level

	1		2		3		4		5	
Age	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
16-17	—	—	6.55	1.17	—	—	—	—	—	—
18-19	—	—	6.24	1.15	6.53	1.30	6.77	1.30	—	-
20-24	—	—	5.98	1.03	6.41	0.94	6.25	0.99	6.78	1.11
25-34	5.50	1.51	5.80	1.08	6.50	1.02	6.67	1.20	6.48	0.81
35-44	5.43	1.12	5.76	1.21	6.33	0.89	6.25	1.14	6.68	1.38
45-54	5.65	1.10	5.79	1.12	7.00	1.33	6.40	0.89	6.30	0.95
55-64	5.55	1.22	6.03	1.16	5.92	1.00	6.00	1.26	6.50	1.27
65-69	5.00	1.22	5.48	1.15	6.56	1.24	6.44	0.88	6.27	1.19
70-74	5.07	1.04	5.67	1.11	5.56	0.88	6.33	1.15	5.64	1.01
75-79	4.65	0.84	5.43	1.08	5.50	0.53	5.00	0.71	6.00	1.10

Note. Educational levels were: (1) lower or equal to the primary leaving certificate; (2) higher than the primary leaving certificate but lower than the high school diploma; (3) equal to the high school diploma; (4) the high school diploma + 1 or 2 years; and (5) the high school diploma + 3 years or more.

Table 4. *Digit Span Backward at Different Ages According to Educational Level.*

Age	Educational Level									
	1		2		3		4		5	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
16-17	—	—	5.02	1.27	—	—	—	—	—	—
18-19	—	—	4.61	1.15	5.07	1.22	5.00	1.29	—	—
20-24	—	—	4.78	1.21	4.88	1.32	4.92	1.35	5.50	1.29
25-34	4.38	0.52	4.31	1.35	5.21	0.97	4.81	1.25	5.05	1.50
35-44	4.14	1.24	4.34	1.11	5.17	1.34	4.42	1.44	5.20	1.58
45-54	4.13	0.88	4.26	1.05	5.50	1.65	4.80	0.84	4.60	0.84
55-64	4.05	0.87	4.47	1.04	4.50	0.67	5.00	0.89	4.90	1.97
65-69	3.51	0.96	4.48	1.00	5.22	1.39	5.00	1.41	4.18	1.17
70-74	3.41	0.96	4.07	1.11	4.22	1.48	4.00	1.00	4.14	0.86
75-79	3.03	0.85	3.90	0.83	4.13	1.13	4.40	0.55	4.33	0.82

Note. Educational levels were: (1) lower or equal to the primary leaving certificate; (2) higher than the primary leaving certificate but lower than the high school diploma; (3) equal to the high school diploma; (4) the high school diploma + 1 or 2 years; and (5) the high school diploma + 3 years or more.

In order to better appraise the weight of the different variables on digit span memory, a multiple regression analysis was performed taking Age Group, Sex, and Educational Level as independent variables and memory of digit span forward and digit span backward as dependent variables. A stepwise regression was conducted. To control the influence of education, Educational Level was always introduced as the first predictor, followed by Age group and Sex. Table 5 shows the percentage of variance of digit span predictable from the variable Education and the increase of this percentage related to the introduction of the variables Age and Sex.

When the influence of education was removed, Age was a very moderate predictor of the evolution of the digit span. As for Sex, its role was unimportant, even though it was significant in the case of digit span backward. Using Age and Educational Level, we could predict less than 18% of the digit span memory forward and less than 17% of the digit span memory backward.

Table 2 shows the difference between digit span forward and backward, according to age groups. For the whole sample, the mean difference was equal to 1.493 digits, with a standard deviation of 1.213. We checked whether this difference was significantly related to Age. In other words, we tested the hypothesis of a different speed of decline of the digit span forward and the digit span backward. The analysis of variance shows no significant effect of Age on the difference between digit span forward and backward (Table 6). In this table, we can also see the result of the analysis of variance for the variable Educational Level, which is far from being significant. Only the variable

Sex appears to have a slight influence ($p < .05$) on the difference between digit span forward and digit span backward. Except for the 18-19 years age group, the difference is always greater for females than for males. We tested the interaction between Sex and Age, and between Sex and Educational Level, but both were nonsignificant (Table 6). The same result was observed for the interaction between Age and Educational Level. Consequently, the only influence observed on the difference between digit span forward and digit span backward was a slight effect of the variable Sex.

***Table 5**. Percentage of the Variance of the Digit Span Forward and Backward Predictable from the Variables Age, Educational Level, and Sex.*

	Educational Level as the only predictor	Increase in the predictable variance	
		Educational Level + Age	Educational Level + Age + Sex
Forward	7.5	+ 10.0**	*ns*
Backward	6.7	+ 9 j**	+ 0.4*

Note. N= 1,000.

* $p < .05$. ** $p < .001$.

***Table 6**. Variance Analysis of the Difference Between Digit Span Forward and Digit Span Backward According to Age, Sex, and Education.*

	df	*F*	*P*
Age	10	0.882	0.550
Education	4	0.613	0.654
Sex	1	5.75	0.049
Sex x Age	9	0.550	0.838
Sex x Education	4	1.692	0.150
Age x Education	31	0.578	0.969

Note. N = 1,000.

DISCUSSION

The study confirms the existence of age-related declines in forward and backward digit span tasks. Indeed, significant age differences were observed in both tasks and these differences began to appear essentially after age 65. Furthermore, there was no significant interaction between age and type of span. In other words, the backward digit span task did not yield larger age differences than the forward digit span task. Finally, it appears that adjusting for education differences strongly reduces but does not eliminate the influence of age.

The nature of these age-related differences in the forward and backward span tasks has not been clearly identified. Though forward digit span does not imply a great amount of processing, the task does not reduce to passive storage. According to Baddeley (1986; also Vallar & Papagno, 1986), the verbal memory span depends on both the phonological loop system and the central executive. The phonological loop system is able to store only a limited number of items in the correct order but the central executive may increase this number either by improving the working of the phonological loop (for example, by grouping items in higher level units) or by using its own storage capacity. In this context, age-related declines in verbal span tasks could be due to a problem affecting the slave system (the phonological loop) and/or the central executive.

Morris (1984) and Caplan et al. (1992) found that elderly subjects showed effects of both word length and phonological similarity, suggesting that they engaged the phonological loop with its two components: the phonological store and the articulatory rehearsal. However, these studies did not compare memory spans in young and older subjects and thus one may wonder whether these effects interact with age. In this respect, Kynette et al. (1989) suggested that the decrement of word span with age could be due to the slowing of the articulatory loop. Indeed, they observed significant age-related differences in word recall span and they found that across all age groups combined, recall span was a linear function of word repetition rate. From a more general point of view, a reduced speed in elementary operation is now considered to be an important mediating factor in age-related differences in cognitive performance (see Salthouse, 1992, 1994).

Finally, Hulme et al. (1991) also presented evidence demonstrating a long-term memory contribution to verbal memory span. More specifically, they suggest that the long-term memory for the phonological form of words is important in supporting the retrieval of partially decayed words held in a rehearsal loop. From this perspective, it could be advanced that the longterm memory contribution to span performance is also affected in normal aging.

Within such a framework, it appears that different factors can contribute to the decline of forward digit span. The general decrement of performance in the backward digit span task can be explained by suggesting that this task involves more processing and thus calls for a larger involvement of the central executive resources. However, the absence of interaction between age and type of span seems inconsistent with the view that elderly subjects have reduced power in the central executive. Alternatively, it could be that the central executive does decline, but that forward and backward spans use the central executive equally. Finally, it should be mentioned that even if this study does not show statistically significant greater age difference for backward span, there is a proportional age-related decline that is greater for backward than for forward span. For example, the backward/ forward ratio declines from around .77 for the youngest groups to .69 in the oldest. Correspondingly, forward span declines 24% from 16-17 to 75-79, whereas backward span declines 31%.

A number of studies have reported age differences in central executive tasks. In particular, an age decrement has been observed in a task that required subjects to continually monitor and update information in working memory (Van der Linden, Brédart & Beerten, 1994). Elderly subjects were also impaired in a random generation task in which subjects were required to generate random sequences of letters (Van der Linden, Beerten, & Pesenti, 1995). In this task, older subjects produced more alphabetical stereotypes (e.g., AB, KL, or YZ). These data suggest that some aspects of the central executive, other than global resources, are affected by age. More specifically, it appears that reduced central executive flexibility and/or decreased ability to inhibit overlearned procedures are involved.

In addition, some evidence suggests that backward digit span cannot involve the same phonological loop processes as forward digit span, but relies on a more important contribution from the central executive. A recent study suggests that immediate backward recall is supported by visual representation (Li & Lewandowsky, 1995). In that context, the strict comparison of forward and backward digit spans in order to examine the integrity of the phonological loop and the central executive, respectively, seems to be irrelevant. Furthermore, future studies should explore the specific nature of age-related differences in backward digit span.

Finally, the existence of a significant effect of education on both forward and backward span tasks, and minimally of sex on backward span, is consistent with the suggestion that many of the age-associated deficits in cognitive functioning could be better understood if different variables, especially subject variables (education, health status, intellectual activities, occupational status), were taken into account. For example, in a recent study, Arbuckle, Gold, Andres, Schwartzman, and Chaikelson (1992) showed that being younger, healthier, more educated, more introverted, more intellectually active, and more satisfied with social support predicted less intellectual decline and indirectly, better memory performance. Other studies have also suggested that the efficacy of a contextual support at encoding and retrieval on the memory performance of older subjects could depend on their level of schooling (Van der Linden, Wyns, Bruyer, Ansay, & Seron, 1993), verbal efficiency, and daily activity levels (Craik, Byrd, & Swanson, 1987). These data suggest that biological aging, environmental influence, and psychosocial variables interact in significant ways to affect memory performance in the elderly (Craik & Jennings, 1992).

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