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Verbal forward digit span in Spanish population

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Abstract

Background: Older people complain of difficulties in recalling telephone numbers and being able to dial them in the correct order. This study examined the developmental trend of verbal forward digit span across adulthood and aging in a Spanish population, as an index of one of the components of Baddeley's working memory model—the phonological loop—, which illustrates these two aspects. **Method:** A verbal digit span was administered to an incidental sample of 987 participants ranging from 35 to 90 years old. The maximum length was defined that participants could recall of at least two out of three series in the same order as presented with no errors. Demographic variables of gender and educational level were also examined. **Results:** The ANOVA showed that the three main factors (age group, gender and educational level) were significant, but none of the interactions was. Verbal forward digit span decreases during the lifespan, but gender and educational level affect it slightly. **Conclusion:** Phonological loop is affected by age. The verbal forward digit span in this study is generally lower than the one reported in other studies.

Keywords: Phonological loop, working memory, aging, verbal digit span.

Resumen

Amplitud verbal de dígitos en orden directo en población española. **Antecedentes:** las personas mayores se quejan con frecuencia de las dificultades que tienen para recordar números de teléfono o para marcarlos en el orden correcto. Este estudio investiga el desarrollo de la amplitud verbal de dígitos en orden directo en adultos y personas mayores en población española, como índice de uno de los componentes del modelo de memoria operativa de Baddeley: el lazo fonológico, que precisamente ilustra estos dos aspectos. **Método:** la tarea verbal de amplitud de dígitos en orden directo se administró a una muestra incidental de 987 participantes, entre 35 y 90 años. Se definió como la longitud mayor de series de dígitos repetidas correctamente en, al menos, dos de las tres series. Variables demográficas, género y nivel educativo también se examinaron. **Resultados:** el ANOVA mostró que los tres factores principales (grupo de edad, género y nivel educativo) fueron significativos, pero ninguna de las interacciones alcanzó la significación. La amplitud verbal de dígitos en orden directo desciende durante el ciclo vital, pero tanto género como nivel educativo afectaron ligeramente. **Conclusiones:** el lazo fonológico está afectado por la edad. La amplitud verbal de dígitos en orden directo fue, en general, menor que la encontrada en otros estudios.

Palabras clave: lazo fonológico, memoria operativa, envejecimiento, amplitud verbal de dígitos.

One of the complaints of older people is having difficulties in carrying out everyday activities, such as correctly remembering a telephone number to be able to dial it successfully. This everyday activity may indicate how human memory temporarily stores information. In this sense, short-term memory development during the lifespan can contribute to reach an integrated perspective of the structure and processes that take place while performing diverse everyday activities.

Short-term memory was first considered as opposed to long-term memory (Atkinson & Shiffrin's model), and was characterized as a passive store that presented a limited capacity to retain information for a brief period of time (see the critiques of Baddeley, Eysenck, & Anderson, 2014). Later on, and in contrast to previous conceptions, Baddeley and Hitch (1974) developed a multi-component model named the working memory model, which emphasizes the active process of the short-term memory. Broadly, this model comprises four components: The *phonological loop*, which is responsible for the temporary storage of speech-based information; the *visuospatial sketchpad*, responsible for visual-spatial information; the *episodic buffer* characterized by its capacity to integrate information from a variety of sources into episodes and by the limited capacity of its temporary storage system; and finally, the *central executive*, a component of attention that controls and coordinates the activities of the other three components, and of the available processing resources.

Baddeley's working memory model has been of great value in characterizing the temporal memory in children, adult, aged and demented patients (e.g., Sebastián & Hernández-Gil, 2010, 2012). It would be interesting to observe not only at what point the functions that characterize working memory appear, but also the developmental pattern and the differences that are found in the progression of the working memory's components across the life span. Moreover, the current study examines the changes of the phonological loop that occur across adulthood and aging.

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As mentioned, this auxiliary system is responsible for the temporary storage of speech-based information and is, in turn, divided into two subcomponents: The *phonological store*, where small amounts of verbal information are passively retained and the *subvocal rehearsal*, which is an active process that facilitates the execution of other strategies (e.g., chunking or recoding), resulting in the retention of items for longer periods of time.

To illustrate the phonological loop, it has been compared to dialling a telephone number where subjects have to recall the different numbers and their order to dial it correctly, and to recall them, we usually repeat them aloud or subvocally (e.g., Baddeley et al., 2014). To evaluate the phonological loop, simple verbal span tasks (e.g., digit span task) are commonly used, as they require the participant to retain auditorily-presented information in a correct serial order. The digit sequence recall task depends on the phonological loop because the two subcomponents —the phonological store and the subvocal rehearsal— require remembering what the items are on the one hand, and the correct order in which they were presented, on the other. The simplest verbal span task is the forward digit span, consisting of random sequences of digits read aloud by the experimenters with the participants having to recall them in the same order as they were presented.

In relation to the development of the phonological loop in childhood and adolescence, Anglo-Saxon data show that forward digit span increases with age, until age 15, where it reaches adult levels (e.g., Gathercole & Alloway, 2008). As opposed to these results, Sebastián & Hernández-Gil (2012) found lower forward digit span than Anglo-Saxon data in a Spanish wide sample, which increases until age 17, probably because the number of syllables of the digits in Spanish is longer than in English.

In relation to the changes of the phonological loop in adults and aging, most studies showed a significant age effect in forward digit span (Aparecida & Rocha de Vasconcellos, 2010; Choi et al., 2014; Hale et al., 2011; Kumar & Priyadarshi, 2013; Monaco, Costa, Caltagirone, & Carlesimo, 2013; Peña-Casanova et al., 2009; for a meta-analysis see Bopp & Verhaeghen, 2005), although there are a few that did not find it (e.g., Fisk & Warr, 1996). However, some studies have indicated that age affects forward digit span slightly until 65 or 70 years (e.g., Hickman, Howieson, Dame, Sexton, & Kaye, 2000), while others showed that there were no age differences between 75 and 96 year old (e.g., Ryan, López, & Paolo, 1996).

In several of them, some methodological issues have to be taken into account. First, the ranges of age are very wide. For example, Fisk and Warr's (1996) oldest group had a range of 20 years (from 60 to 80); there was a similar problem in Aparecida and Rocha de Vasconcellos' (2010) study, whose oldest age group was reported as "more than 60 years old", without specifying the upper limit of age. Second, the oldest group was not very old, as in Kaufman, McLean and Reynolds' (1988) study, whose oldest participants were less than 76 years old. Finally, the sample sizes in the different age groups were not very big in various studies, for example, in Kumar and Priyadarshi's (2013) study, there were only l6 participants in each age group.

Most of the studies (e.g., Chen, Cowell, Varley, & Wang, 2009; Choi et al., 2014; Gregoire & Van der Linden, 1997; Hickman et al., 2000; Myerson, Emery, White, & Hale, 2003; Olazarán, Jacobs, & Stern, 1996; Peña-Casanova et al., 2009; Ryan et al., 1996; Wilde, Strauss, & Tulsky, 2004) followed the procedure of the Wechsler Adult Intelligence Scales (WAIS-R, Wechsler, 1981; WAIS-III, Wechsler, 1997a) or the Wechsler Memory Scales (WMS-III, Wechsler, 1997b). In most of them, forward digit span consisted of presenting two series of two digits, followed by two series of one more digit until nine digits. Participants were asked to recall them in the same order as they heard it. When they recalled at least *one* of two series correctly, a new series of an additional digit was given. The final score was the number of series correctly recalled (from 0 to 16 series). So, forward digit memory span was not reported, except in the original Wechsler Adult Intelligence Scale (WAIS, Wechsler, 1955) and in the latest one, the WAIS-IV (Wechsler, 2008). In other studies, however, forward digit span was taken as the maximum length at which participants could recall at least *two* out of three series with no errors (e.g., Della Sala, Cocchini, Logie, Allerhand, & MacPherson, 2010; Fisk & Warr, 1996; Kumar & Priyadarshi, 2013; Sebastián & Hernández-Gil, 2012).

Demographic variables seem to influence forward digit span. For instance, educational level affects forward digit span in the elderly (e.g., Gregorie & Van der Linden, 1997; Kaufman et al., 1988; Peña-Casanova et al., 2009), but in some studies, it has not been examined (e.g., Aparecida & Rocha de Vasconcellos, 2010). Regarding gender, the data are quite controversial. Several studies indicated a slightly better performance in males (Chen et al., 2009; Choi et al., 2014; Kumar & Priyadarshi, 2013), while others did not find significant differences (Gregorie & Van der Linden, 1997; Kaufman et al., 1988; Peña-Casanova et al., 2009).

The main objective of the present study is to examine forward digit span in a wide sample of Spanish young, older, and very old adults (from 35 to 90 years old), following a procedure more restrictive —and, therefore, more informative— than the one used in the Wechsler Scales. This method was the same as the one used in children and adolescents (Sebastián & Hernández-Gil, 2012) and in people with neurocognitive disorders (see, for example, Della Sala et al., 2010; Sebastián and Hernández-Gil, 2010), in order to present a whole picture of the phonological loop during the lifespan and to compare the data with patients with neurocognitive and emotional disorders. A significant decrease of verbal forward digit span with age is expected. The influence of demographic variables of gender and educational level on digit span is also examined, predicting an effect of level of education and a slight effect of gender.

Method

Participants

An incidental sample of 987 voluntary participants carried out the experiment. All participants were born in Spain and came from the Community of Madrid. They were recruited from Centres for the Elderly, Day Centres or they were students' and experimenters' relatives or friends. Students received course credit for their contribution. They were arranged into eight age groups, 35-44 years, 45-54 years, 55-64 years, 65-69 years, 70-74 years, 75-79 years, 80-84 years, and 85-90 years, and were also organized by gender (males and females) and educational level (primary and secondary studies). None of them were under any kind of psychiatric medication (e.g., antidepressants). Reliable information was given about participants. In the case that they were authors' or students' relatives or friends, informers corroborated the absence of any cognitive impairment (e.g., memory, orientation, language, etc.). If they were suspected of any, the participant was not included. In the case of Centres for the Elderly or Day Centres, the professionals verified that they did not suffer any cognitive or emotional alterations. None of them were illiterate or had university education. They did not present any difficulties in reading or writing. In case of problems in seeing or hearing, they were allowed to wear glasses or hearing aids. The research was complete in accordance with the Helsinki Declaration. The characteristics of participants can be seen in Table 1. From 65 to 90 years age ranges were narrower than 35 to 64 to reduce the within-group variability in old and very old groups.

Instruments

The digit span material consisted of random sequences of digits read aloud by the experimenters at the rate of one per second. An item was added gradually to increase the sequence of digits.

Procedure

The task started with three sequences of three digits. Participants were asked to listen carefully to them and to recall them in the same order as they were presented. An additional digit progressively increased the length of the sequence. An example was given in order to check that they had understood the instructions. Digit span was taken as the maximum length at which participants could recall at least two out of three series with no errors. The task was administered individually to all participants.

Data analysis

The results were analysed by age group, gender and educational level. A trend analysis was performed in order to check whether the digit span decreased by age group and whether such decrease was linear, quadratic or cubic. Due to the fact that the number of samples was uneven among the age groups, and because of the unequal variance in the digit span, the Games-Howell Pairwise Comparison Test was computed.

Results

An 8 (Age group: 35-44 years, 45-54 years, 55-64 years, 65-69 years, 70-74 years, 75-79 years, 80-84 years, and 85-90 years) × 2 (Gender: male, female) × 2 (Educational level: primary and secondary studies) ANOVA was carried out. The results of the ANOVA indicated that the three main factors age group, $F(7, 987) = 14.58$, $MSE = 10.71$, $p<.0001$, $\eta^2_p = .097$, gender, $F(1, 987) = 4.26$, $MSE = 3.13$, $p<.039$, $\eta^2_p = .004$ and educational level, $F(1, 987) = 26.30$, $MSE = 19.31$, $p<.0001$, $\eta^2_p = .027$, were significant, but none of the interactions reached significance ($p>.05$), Age group × Gender, $F(7, 987) = 1.82$, $MSE = 1.34$, Age group × Educational level, $F(7, 987) = 1.69$, $MSE = 1.24$, Gender × Educational level, $F(1, 987) = .36$, $MSE = .26$, Age group × Gender × Educational level, $F(7, 987) = 1.08$, $MSE = .79$. Post hoc comparisons show that all participants with primary studies ($M = 4.86$; $SE = .039$) had a lower digit span than with secondary studies ($M = 5.33$; $SE = .085$). Males had a higher digit span ($M = 5.19$; $SE = .078$) than females ($M = 5.00$; $SE = .051$).

A trend analysis was performed to check whether forward digit span decreases in linear, quadratic, or cubic terms by age group. The analysis showed that only linear contrast was significant, $F(1, 986) = 300.88$, $MSE = 237.30$, $p<.0001$, but not the quadratic, $F(1, 986) = .001$, $MSE = .001$, or the cubic, $F(1, 986) = .188$, $MSE = .15$, contrasts ($p>.05$).

As can be seen in Table 2, digit span clearly decreased with age. Post-hoc comparisons (Games-Howell) confirmed this developmental trend. From 35 to 64 years old, a similar forward digit span was found and the age groups did not differ from each other; but, they differed from the older groups. The decrease in one digit (from 5 to 4 digits) started at 65 years old, and it diminished, in general, smoothly until 79 years. Finally, the decrease of the digit span was more accentuated in the oldest groups (80-84 years and 85-90 years), but these two very old groups did not differ from each other.

When comparing our data on forward digit span with the Wechsler Intelligence Scale for Adults IV (Spanish WAIS-IV) in a broad Spanish population, some differences are observed (see Table 2). The Spanish WAIS-IV has different range groups. Some of them are very wide, for example, from 55 to 64 years and from 70 to 79 years. Neither the American nor the Spanish WAIS-IV reported about gender, so the comparison is made in total forward digit span. The results are generally similar in the sense that

Table 1
Characteristics of participants by age group (standard deviations in parenthesis)

Age group	N	Gender: M / F	Mean of years	Educational level: Primary / Secondary
35-44 years	182	67 / 115	39.5 (2.8)	65 / 117
45-54 years	225	87 / 138	48.9 (2.9)	97 / 128
55-64 years	141	53 / 88	57.7 (2.8)	83 / 58
65-69 years	48	18 / 30	66.8 (1.4)	38 / 10
70-74 years	76	23 / 53	71.6 (1.5)	58 / 18
75-79 years	57	21 / 36	76.5 (1.2)	48 / 9
80-84 years	138	41 / 97	81.9 (1.1)	127 / 11
85-90 years	120	32 / 88	87.1 (1.6)	110 / 10
Total	987	342 / 645	61.93 (17.1)	626 / 361

Table 2
Verbal forward digit span in our study and in Spanish and American WAIS-IV (standard deviations in parenthesis)

Age group	Forward digit span in our study	Forward digit span in Spanish WAIS-IV	Forward digit span in American WAIS-IV
35-44	5.62 (.94)	6.3 (1.1)	6.8 (1.4)
45-54	5.52 (.94)	6.2 (1.2)	6.8 (1.4)
55-64	5.38 (.93)	5.9 (1.3) [a]	6.5 (1.3)
65-69	4.88 (.93)		6.5 (1.3)
70-74	4.92 (.96)	5.1 (1.2) [b]	6.2 (1.4)
75-79	4.67 (.66)		6.3 (1.3)
80-84	4.45 (.81)	4.4 (1.0)	6.1 (1.3)
85-90	4.25 (.74)	4.3 (1.0)	6.0 (1.2)

[a] Age group: 55-69
[b] Age group: 70-79

digit span decreases with age; however, our data showed a lower digit span than that of the Spanish WAIS-IV in all age groups. The American WAIS-IV had the same range groups as ours, but its forward digit span is greater than the Spanish WAIS-IV, and consequently much higher than our results.

Discussion

The present investigation supports the finding that verbal forward digit span decreases during the lifespan, which is in keeping with other studies (e.g., Aparecida & Rocha de Vasconcellos, 2010; Choi et al., 2014; Hale et al., 2011; Kumar & Priyadarshi, 2013; Monaco et al., 2013; Peña-Casanova et al., 2009; for a meta-analysis see Bopp & Verhaeghen, 2005). Comparing our results with other data, the verbal forward digit span in our study is generally lower. For example, Gregoire and Van der Linden (1997) found slightly higher scores than ours; Hickman et al., (2000) indicated a span of almost 6 digits in their oldest group (from 84 to 93 years old), while in our study, the mean forward digit span is 4.25; in the Bopp and Verhaeghen's meta-analysis (2005), participants over 60 years old had a 7 digit span, while it was less than 5 digits for over 65 years old participants in ours; Monaco et al., (2013) showed higher forward digit span than ours in each age group, although the decreasing trend is similar.

In a previous study (Sebastián & Hernández-Gil, 2012), it was also found that the forward digit span assessed in children and adolescents was lower than the one reported in English samples, and it was pointed out that this difference in the developmental pattern of verbal span could be due to the word length effect. Baddeley, Thomson and Buchanan (1975) formulated that memory span was more affected by lists that contained long words as compared to lists containing short words. This effect has been related to subvocal rehearsal and recall processes. In the first case, it is understood that the greater the word length, the longer it takes to perform the rehearsal and, therefore, the easier it is to lose information during the rehearsal of a succession of long words (Baddeley et al., 1975). Moreover, the second case states that the longer it takes to utter a word (within a sequence), the greater the chance that the stored information will fade before fully recalling the complete sequence of words. Overall, both effects could explain the differences found between the Anglo-Saxon study and ours, as Spanish digits are longer (most of them are composed of two syllables, e.g., 'cuatro', 'cinco', 'siete', etc.) than English digits (most of which consist of just one syllable, e.g., 'one', 'two', 'three', etc.) (e.g., Olazarán et al., 1996). Curiously enough, the forward digit span in the American WAIS-IV is greater than that in the Spanish WAIS- IV in all age groups, with the highest difference observed in the oldest age group.

Thus, if the word length effect is related to the process of subvocal rehearsal, the age-related decrease in forward digit span could be explained by the articulation rate (i.e., subvocal rehearsal). In fact, it has been shown that older and younger adults' performances were equal when none of them were allowed to subvocally rehearse the digits (Gerhand, 1994; cited in Phillips & Hamilton, 2001). Other authors have interpreted that the processing speed might be a critical factor in age-related decrease of forward digit span (e.g., Salthouse, 1996). But, a general reduction in processing speed with aging may be related to a decrease in articulation rate, and as Philips and Hamilton (2001) highlighted, this relationship has not yet been fully explored in the elderly.

Besides the word length effect on the repetition process, other strategies that underlie the working memory were also speculated upon to explain span differences between different spoken language populations, such as recoding or chunking (Sebastián & Hernández-Gil, 2012; Stuart-Hamilton, 2012). For example, when having to remember a code or a record locator flight, associations between each letter with a town or a country are commonly used strategies. In Spain, the words that are most frequently associated are long words with three or four syllables (for example, Barcelona, for "B", Italia, for "I", or Pamplona, for "P", instead of short Spanish words such as Berna, Innsbruck or Paris), a strategy that probably results in a "word length effect" and in a poorer memory-span performance compared to short-word associations. The Anglo-Saxon subjects are used to spelling the words since childhood. This poor strategy of using long words in Spanish is further accentuated in adults and old people as compared to children and adolescents because they have been using them their whole lives.

Demographic variables seem to influence forward digit span. Males show a slightly better performance than females, although the effect is lower than 1% of explained variance (for similar results, see Chen et al., 2009; Choi et al., 2014; Kumar & Priyadarshi, 2013). Although type of occupation has not been considered, one might speculate that more men than women have carried out jobs related to numbers, and then could have developed abilities associated to this particular task.

Educational level is also related to forward digit span, showing that the higher the education, the better the performance in the task as it was found in the present study. One possible explanation could be that the memory strategies that improve the performance of the digit span task (such as chunking process) benefit from formal education, so that participants with secondary studies have learnt and memorized more information over their academic years than participants with primary studies. This cognitive training of holding mental information or serial processing (see, for example, Banken, 1985) might improve mental processes related to digit span task.

Although this relationship between digit span and education level has been previously reported, some authors (e.g., Kaufman et al., 2008; Peña-Casanova et al., 2009) have found larger effects than the 3% of the current one. Furthermore, Otrosky-Solís and Lozano (2006) concluded that educational level was a better predictor of forward digit span than age. Because the present study excluded illiterate participants and university students or graduates, a low educational level effect could be expected.

In fact, Otrosky-Solís and Lozano (2006) informed of a differential effect of age on this task, that is, illiterate participants showed a lower reduction of digit span with age than primary or high school graduates. The exclusion of participants with very high or very low education could explain the lack of statistical interaction between age and education level reported in our study. So, one might conclude that the phonological loop is affected by age regardless of the educational level of the participants because education modulates the performance of verbal forward digit span task in the same manner across age ranges.

Regarding the procedure and correction of the verbal forward digit span used in Wechsler scales, two important issues have to be taken into account: The final score and the number of trials of each series. The first issue (the final score) involves sixteen trials, starting from two trials of 2-digit series going up to two trials of 9-digit series, for example, in the WMS-III (Wechsler, 1997b). The subject's final score is the number of trials correctly recalled. In case one subject correctly recalls the two trials of 6 digits, his or her final score is 10 (ten trials correctly recalled), because he or she would have correctly recalled the previous eight trials of, 2- to 5-digit series. However, this final score of 10 trials does not indicate the forward digit span of this subject. This problem has been solved in the WAIS-IV (Wechsler, 2008), because it allows the experimenter to calculate the forward digit span, besides reporting the number of series correctly recalled, as in WMS-III. However, a second issue related to the number of trials still remains in the WAIS-IV, namely, with only *two* trials in each series of digits, one subject could obtain a particular forward digit span recalling only *one* of the two trials. In the present study, three trials were administered and the participants had to correctly recall 67% of the trials (*two* of the three) of each series, thereby reducing chance probability and making our results more reliable. It is important to emphasize that WMS-IV (Wechsler, 2009) eliminated the digit span (both forward and backward) tasks, their absence being justified by the fact that WAIS-IV already assessed them. So, as the WMS-IV technical manual indicates, WAIS-IV provides verbal working memory measures while WMS-IV provides visual-spatial working memory measures (Wechsler, 2009). In our opinion, both measures should be taken together in the same test to fully understand working memory.

As mentioned before, the present investigation did not consider participants' occupations. Hence, it is difficult to know if participants activate strategies when recalling a digit sequence that could be related to the demands of different jobs. In a similar line, the inclusion of participants with primary and secondary studies makes more difficult to generalize our results to other populations with different levels of education. However, the conclusion that the phonological loop is affected by age is strongly supported by two aspects: the wide and heterogeneous sample and the restrictive assessment of the forward digit span, which also provides valuable data for future comparisons to other age ranges and patients with neurocognitve and psychiatric disorders.

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