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Does dual-task coordination performance decline in later life?

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Abstract

Background: This cross-sectional study examined whether changes occur in people's capacity to coordinate two simultaneous tasks (dual-task) when transitioning from adulthood to later life. The central executive, Baddeley's working memory model component, is responsible for this coordination. Contradictory results have been reported regarding the relationship between ageing and dual-task performance; but these seem to be related to methodological issues that have been addressed in this study. **Methods:** Nine hundred and seventy-two participants, aged between 35 and 90 years old, volunteered to carry out a verbal digit span task, followed by single and concurrent (dual-task) tests: first, a box crossing task, then, the digit recall task in relation to their memory span, and finally, both these tests simultaneously. **Results:** We found no difference in people's capacity to coordinate their attention when doing two tasks in adulthood or healthy later life, including those in the oldest age groups. Furthermore, gender and educational level were not related to dual-task performance. **Conclusions:** The results support the normal functioning of the central executive in very old people. These data contrast with research with patients suffering from different types of dementia, which show a decrease in their dual-task performance.

Keywords: ageing, dual-task, working memory, psychogeriatrics.

Resumen

¿Desciende la capacidad para realizar dos tareas simultáneas en las personas mayores? **Antecedentes:** este estudio transversal examina la capacidad para realizar dos tareas de forma simultánea desde la edad adulta hasta la vejez. El ejecutivo central del modelo de memoria operativa de Baddeley es el responsable de esta coordinación. Existe cierta polémica respecto a la relación entre edad y rendimiento en la tarea doble, que podría explicarse por algunos aspectos metodológicos abordados en este estudio. **Método:** novecientos setenta y dos participantes entre 35 y 90 años participaron voluntariamente en el estudio. Realizaron una tarea de amplitud verbal de dígitos, seguida de una tarea de cruces y una tarea de recuerdo de dígitos en función de la amplitud de cada sujeto, y ambas tareas de forma simultánea (doble tarea). **Resultados:** no se encuentran diferencias en función de la edad en la doble tarea, ni siquiera en los grupos de personas más mayores. Tampoco existe relación entre esta capacidad y el género o el nivel de educación. **Conclusiones**: los resultados muestran que la capacidad del ejecutivo central para coordinar dos tareas de forma simultánea está preservada en la edad adulta y la vejez. Ello contrasta con los hallazgos obtenidos en personas con diferentes tipos de demencia, que sí presentan un deterioro en esta capacidad.

Palabras clave: envejecimiento, doble tarea, memoria operativa, psicogerontología.

People's ability to perform two tasks, first separately and then together, depends on the capacity to coordinate attention. The difference between performance in each of the single tasks and the dual-task provides an index of dual-tasking ability (Logie, Cocchini, Della Sala, & Baddeley, 2004). This dual-task coordination capacity is a measure of the executive function in Baddeley's working memory model and has been invaluable in characterizing temporal memory (working memory) of children, adults, aged people, and Alzheimer's disease (AD) patients (e.g., Baddeley, Eysenck, & Anderson, 2014). Baddeley's working memory model is a multi-component model with four components: the phonological loop, the visuospatial sketchpad, the episodic buffer, and the central executive. The phonological loop controls the temporary storage of speech-based information and is divided into two subcomponents, the phonological store and the rehearsal process. The visuospatial sketchpad manages visual-spatial information. The episodic buffer has a temporary storage system with a limited capacity and integrates information from a variety of sources into episodes. Lastly, the central executive controls and coordinates the activities of the other three components and the available processing resources. It enables high-level, goal-directed behaviour with multiple processes, called executive functions, such as focusing attention, cognitive flexibility (rapidly switching or shifting attention), inhibiting responses, and the division of attention and coordination between two tasks performed simultaneously (dual-tasking), amongst others (see also Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000).

The dual-task performance test is a valid method to measure the central executive, as it requires participants to coordinate their attention to multiple tasks (Baddeley et al., 2014; Logie et al., 2004). Some authors have suggested that dual-task performance is significantly higher in younger than older adults (Allen, Lien, Ruthruff, & Voss, 2014; Hartley, 2001; Naveh-Benjamin, Craik, Guez, & Kreuger, 2005; for a meta-analysis, see Riby, Perfect, & Stollery, 2004), whereas others have indicated that dual-task

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abilities are not affected in ageing individuals free from dementia or any psychiatric disorders (Anderson, Bucks, Bayliss, & Della Sala, 2011; Logie et al., 2004; Sebastián & Hernández-Gil, 2016; for a meta-analysis, see Verhaeghen, Steitz, Sliwinski, & Cerella, 2003). Thus, the relationship between ageing and dual-task performance needs to be explored in more depth to explain these contradictory results. Beforehand, some theoretical and methodological issues need consideration.

First, it is important to isolate the specific process that is being examined: the capacity to coordinate attention between two tasks. Therefore, the focus should not be on participants' performance of each task alone, as that would measure a discrete ability (for example, box crossing measures motor ability, and digit recall tasks measure verbal memory). A more accurate way to measure dual-task coordination is to calibrate single-task performances for each participant so that under dual-task conditions, the test captures their capacity to coordinate attention between each task (Baddeley et al., 2014; Logie, Horne, & Pettit, 2014). In other words, each participant takes a dual-task test that is adjusted for their single-task ability (e.g., Hartley & Little, 1999). Further, some of the studies that reported small age-related differences have highlighted that this calibration seems to contribute to the maintenance of dual-task performance (Anderson et al., 2011; Logie et al., 2004).

Second, the processing mechanisms that each task requires must be considered. Logie et al. (2014) recently postulated that choosing two tasks that do not require the same processing mechanism might be a good way to guarantee accurate measurement of dual-tasking capacities. In fact, Logie et al. (2004) demonstrated this with two tasks that used 'different, domain-specific systems within working memory' to ensure they did not interfere with one another. Alternatively, Hartley (2001) employed two tasks that did not require the same response mechanisms (manual versus oral responses). Both studies found similar dual-task performance levels in younger and older adults, and concluded that choosing two tasks that were not in competition with each other affected the results.

Third, different results might be obtained depending on whether or not reaction times were tested. Given that processing speed is affected by age (e.g., Salthouse, 2009), a worse dual-task performance might be expected if quick responses (i.e., short latencies) are required. In fact, Riby et al. (2004) indicated that age-related effects are less pronounced when accuracy is tested, rather than response times. Verhaeghen et al. (2003) went even further, pointing out that those effects disappeared when the tasks did not test processing speed (see also Hartley & Little, 1999).

Finally, some problems regarding participants' characteristics have been found across many investigations. For example, some studies (e.g., Logie et al., 2004) compared Alzheimer's disease (AD) patients with a control group and did not include oldest-old participants because age had to be matched, as the onset of this disease is between 60 and 80 years (McKhann et al., 2011). In other studies, the age ranges used were often broad; for example, Hartley and Little (1999) conducted seven experiments with groups of older participants with an average age range of 22 years (the age of one group of people ranged from 60 to 85 years). Lastly, the sample sizes of the age groups were small in some studies; for instance, Allen et al. (2014) formed two groups with only 12 participants.

The present cross-sectional investigation examined whether dual-task coordination is affected by age. For this purpose, we recruited a broad sample of Spanish people (35-90 years), in which oldest-old participants were well represented, and we controlled the three main methodological issues found in previous research: 1) Tasks did not compete for the same processing resources, and the output modes differed. 2) Participants were matched according to their baselines scores. 3) Accuracy was tested (rather than processing speed). The effect of gender and years of education on dual-task performance was also examined.

Method

Participants

An incidental sample of 972 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 were students' and experimenters' relatives or friends. Students received course credit for their contribution. They were arranged into eight age groups (35-44, 45-54, 55-64, 65-69, 70-74, 75-79, 80-84, and 85-90 years), and were also organized by gender (males and females) and educational level (primary and secondary studies). We decided to only include participants who had been educated to primary and secondary level because they represent almost 90% of people over 65 in Spain (Abellán & Pujol, 2016). None of them were on any kind of psychiatric medication (e.g., antidepressants). 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 any impairment was suspected, 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. 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 completed 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 at 35 to 64, to reduce the within-group variability in old and oldest-old groups.

Instruments

The digit span of each individual was estimated as follows: The participants heard a list of digits at a rate of one digit per second.

Table 1
Number of participants, gender, mean age and mean of years of education, by age group (standard deviations in parentheses)

Age group	Participants	Male / Female	Age	Years of education
35-44	182	67 / 115	39.5 (2.8)	10.93 (3.2)
45-54	225	87 / 138	48.9 (2.9)	9.84 (2.9)
55-64	141	51 / 90	57.7 (2.8)	8.89 (2.9)
65-69	45	17 / 28	66.8 (1.4)	7.20 (2.4)
70-74	76	23 / 53	71.6 (1.5)	7.42 (2.6)
75-79	57	21 / 36	76.5 (1.2)	6.98 (2.3)
80-84	132	39 / 93	81.9 (1.1)	6.69 (1.9)
85-90	114	30 / 84	87.2 (1.6)	6.52 (1.5)
Total	972	335 / 637	61.6 (17.1)	8.61 (3.1)

They were then asked to repeat these digits in the same order as they heard them. The task started with the presentation of three sequences of three digits. The participants were asked to recall them verbally in the same order as they were presented, and an additional digit progressively increased the length of the sequence. The digit span was taken as the maximum length at which the participants could recall at least two out of three series with no errors (see Sebastián & Hernández-Gil, 2012). This estimate was then used in the digit recall tasks.

The tracking task was a pencil-and-paper test designed by Della Sala, Baddeley, Papagno and Spinnler (1995), consisting of 80 boxes linked on a chain. Participants were asked to begin at one end of the chain, and to draw a cross on each square for 2 minutes. Additional pages were given, if necessary, to reach the 2-minute time limit. The total number of boxes crossed was taken as the score for each participant.

In the digit recall task, the participants heard a series of sequences, at an individual digit span length, for immediate oral serial-ordered recall over a period of 2 minutes. The number of lists that each participant heard and recalled during the 2-minute period varied depending on their digit span, and thus, the performance measure was the proportion of correctly recalled digits.

Procedure

All tasks were administered to all participants individually in the following order: 1) The digit span test. 2) The box-crossing task separately (single condition). 3) A short rest. 4) The digit recall task separately (single condition). 5) The box-crossing and the digit recall tasks simultaneously for a 2-minute period (dual condition).

Data analysis

First, proportional measures of dual-task performance were computed, following Della Sala, Foley, Beschin, Allerhand and Logie (2010). Proportional performance in box-crossing was calculated by measuring the change in box-crossing between single- and dual-task conditions [index p_t = 100 - (box-crossing in single condition - box-crossing in dual condition) × 100/box-crossing in single condition]. The proportional performance in correct digit recall was calculated by measuring the change in correct digit recall sequences between single- and dual-task conditions [index p_m = 100 - (correct recall of sequences of digits in single condition - correct recall of sequences of digits in dual condition) × 100/correct recall of sequences of digits in single condition]. Finally, an index of dual-task performance was calculated (μ), considering the proportional loss in the digit recall task (p_m) and the box-crossing task (p_t): $\mu = (p_m + p_t)/2$. This μ index was considered an indicator of the person's ability to coordinate his or her attention. For all three measures, scores nearer 100% indicate a lower loss (i.e., a better performance) in dual as compared to single condition.

Then, the results were analysed by age group (35-44, 45-54, 55-64, 65-69, 70-74, 75-79, 80-84 and 85-90) and test condition (single-task and dual-task). First, two ANOVAS were executed to test the effect both of age and test condition on the box-crossing task and the digit recall task. Second, three ANOVAS were performed to see whether the loss in box-crossing (p_t), digit recall (p_m), or dual-coordination index (μ) was affected by age. Trend analysis was also carried out to determine whether this μ index decreases with age. Finally, correlation analyses were completed to check whether gender or years of education were associated with any of the three main indexes (p_t, p_m or μ). Significance level was set at .05 for all tests.

Results

The mean values of the box-crossing task and digit recall tasks, in the single and dual conditions, by age group are shown in Table 2. For the box-crossing task, an 8 × 2 (Age Group × Condition) ANOVA with repeated measures in the second factor was conducted. The results showed that age group, $F(7, 964) = 133.38$, $MSE = 358276.63$, $p<.0001$, $\eta^2_p = .492$, and condition, $F(1, 964) = 289.79$, $MSE = 96490.54$, $p<.0001$, $\eta^2_p = .231$, were significant, but not the Age group × Condition interaction, $F(7, 964) = 0.868$, $MSE = 289.012$, $p = .531$, $\eta^2_p = .006$. Pairwise comparisons (Bonferroni) revealed that the number of crosses decreased significantly with increasing age, although this decline was the same in both conditions. For the digit recall task, an 8 × 2 (Age Group × Condition) ANOVA with repeated measures in the second factor was also conducted. The analysis showed similar results: Both

Table 2
Mean numbers of crosses and proportion of digits correctly recalled in single and dual conditions, p_t and p_m, by age group (standard deviations in parentheses)

Age troup	Crosses		Digits		p_t (%)	p_m (%)
	Single	Dual	Single	Dual		
35-44	172.23 (37.12)	156.10 (39.74)	.79 (.14)	.72 (.18)	91.09 (16.21)	91.82 (20.47)
45-54	158.18 (39.81)	144.46 (41.52)	.80 (.14)	.73 (.17)	92.34 (19.38)	91.00 (18.35)
55-64	147.89 (41.92)	132.48 (40.20)	.76 (.15)	.70 (.17)	90.16 (16.29)	92.44 (21.22)
65-69	122.40 (46.98)	103.07 (38.84)	.80 (.15)	.72 (.19)	86.79 (16.66)	90.22 (17.51)
70-74	106.99 (39.58)	88.17 (35.93)	.75 (.14)	.70 (.17)	83.31 (17.33)	93.24 (15.77)
75-79	100.47 (36.12)	83.35 (34.88)	.72 (.13)	.67 (.16)	82.58 (15.96)	92.70 (15.55)
80-84	94.26 (42.12)	77.66 (37.59)	.76 (.14)	.69 (.18)	83.01 (19.89)	91.18 (18.94)
85-90	67.31 (32.56)	55.38 (30.51)	.74 (.15)	.68 (.21)	82.25 (19.82)	91.49 (22.58)
Total	130.94 (53.19)	115.48 (52.47)	.77 (.14)	.71 (.18)	87.80 (18.47)	91.68 (19.39)

age group, $F(7, 964) = 3.19$, $MSE = 0.137$, $p<.002$, $\eta^2_p = .023$, and condition, $F(1, 964) = 164.44$, $MSE = 1.56$, $p<.0001$, $\eta^2_p = .146$, were significant, but the Age Group × Condition interaction was not, $F(7, 964) = 0.383$, $MSE = 0.004$, $p<.912$, $\eta^2_p = .003$. However, post-hoc tests (Bonferroni) revealed that the correct digit sequence recall was quite stable across the age groups in both conditions because the only significant difference was between the 45-54 and 75-79 age groups (younger individuals performed better than older adults). As in the box-crossing task, digit recall performance was greater in the single than in the dual condition.

The proportional measures of dual-task performance (changes between single and dual conditions) are also reported in Table 2. Regarding the change in the box-crossing task (p_t), the univariate ANOVA indicated that age group was significant, $F(7, 964) = 7.48$, $MSE = 2438.20$, $p<.0001$, $\eta^2_p = .052$. Post hoc comparisons (Bonferroni) showed that the middle-aged groups (35-64 years) achieved similar performances and did not differ from each other, but they differed significantly from the older groups (70-90 years). The other age groups did not differ from each other. In relation to the change in the digit recall task (p_m), the univariate ANOVA did not show significant differences across the age groups ($p = .982$). As shown in Table 2, the decline was quite similar across the age groups.

A trend analysis was performed to determine whether the dual-task coordination decreased with age in linear, quadratic or cubic terms. It showed that only the linear contrast was significant, $F(1, 964) = 19.57$, $MSE = 3487.20$, $p<.0001$, $\eta^2_p = .023$, but not the quadratic or the cubic contrasts ($p = .724$ and $p = .421$, respectively) (see Figure 1). Post hoc comparisons (Bonferroni) indicated no significant differences across the age groups. In order to understand this contradiction, we performed an alternative analysis, taking the three younger age-groups as one group (35-64 years), and the five older age-groups as the other group (65-90 years). This contrast test revealed that the older group had a lower index of coordination of attention than the younger participants, $t(964) = 41.812$, $p<.0001$, showing that differences in dual-task coordination are found when the sample is divided into two broad categories, but not when narrower age groups are arranged.

Point-biserial correlation analyses showed that the dual-task performance of the box-crossing task (p_t) correlated weakly with years of education ($\varrho = .08$, $p = .016$), whereas the dual-task

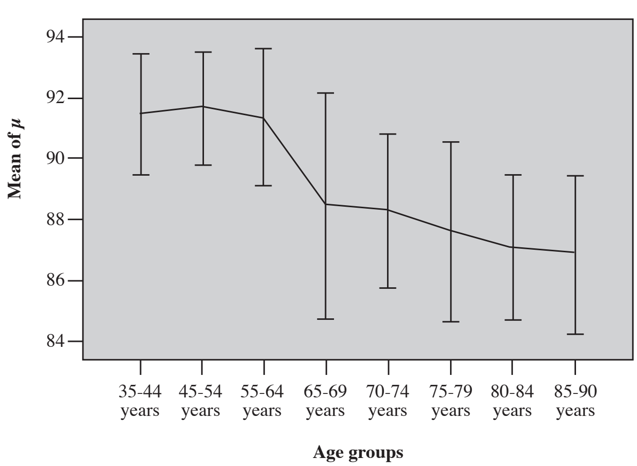

Figure 1. Mean of the index of coordination of attention (μ) by age group

performance on the digit recall task (p_m) and the coordination of attention index (μ) did not ($\varrho = -.02$ and $\varrho = .04$, respectively). None of these three measures (p_t, p_m, and μ) were correlated with gender ($\varrho = .04$, $\varrho = .04$ and $\varrho = .06$, respectively).

Discussion

There are five main results in reference to dual-tasking and ageing. First, single-task performance was better than dual-task performance, both in box-crossing and in digit recall tasks. These results were expected, as they reflect the increased attention required in the dual-task coordination task, which is the case regardless of the participants' age. Second, age had an effect on the box-crossing task performances, both in single and dual conditions. If lower scores for older participants had been even lower under dual rather than under single-task conditions, a statistical interaction between age group and condition would have been found, confirming the hypothesis that dual-task coordination is affected in later life. However, our results show that older people performed worse than younger adults in the box-crossing task, regardless of whether they were under single or dual-task conditions. Thus, this cannot be explained by the coordination mechanism being damaged in healthy older adults. Instead, deterioration of motor skills and the concern older people expressed about marking outside of the square might explain these results. Third, the scores of the digit sequence recall were similar among younger and older participants, both in single and dual conditions, as the digit recall task was adjusted to each participant's span. Fourth, the dual-task cost in the box-crossing task was slightly higher in the older and oldest age groups. But age accounts for just 5% of the variance, and no interactions between age and test condition were found in any analysis, so this is not a very consistent finding. Finally, the index of coordination of attention, based both on the box-crossing and the digit recall measures, was the same across all age groups, indicating that dual-tasking ability remains constant from age 35 to 90.

With regard to studies that reported higher dual-task costs in older adults (e.g., Naveh-Benjamin et al., 2005), our study sampled participants from a wide age-range to determine whether decline is restricted to the oldest age groups. Despite the decreasing trend from early to later life, no significant differences were found, not even between the youngest and the oldest participants. By contrast, when data were reanalysed using only two broad age groups, slight differences in dual-task coordination between younger (35-64 years old) and older (65-90 years old) participants emerged. This is because individual differences are greater in older age groups, and within-group variance is increased. Therefore, an age group from 65 to 90 does not seem appropriate (Baltes & Lindenberger, 1988), and the arrangement of narrower, representative age groups may contribute to more reliable results. In this sense, the current investigation formed age groups with ranges of five years for participants between 65 and 90 years old and ten years for those aged 35 to 64. Nevertheless, all groups included an adequate number of participants, with an average of 85 people in the five-year age groups and an average of 183 participants in the ten-year age groups.

The fact that older people maintained their capacity to coordinate their attention can be explained by the conservative method we applied in this study. For example, our approach in relation to baselines (i.e., performances under a single condition) was to adjust them so older participants would not be penalized by their relatively lower single-task abilities. Thus, the digit recall task was calibrated according to the digit recall span of each participant, as verbal memory span is affected by age (see Sebastián & Mediavilla, 2015). In addition, proportional measures of dual-task costs (such as the ones in p_t and p_m) are more specific than absolute differences (single performance *minus* dual performance) in the detection of any age-related differences, as they reduce the effect of the single-task performance (Riby et al., 2004). Taking this consideration into account, our results show that the dual task performance levels of the old and the oldest-old were between 82 and 93% of the single performance for both tasks. Furthermore, responses were not timed in our study because processing speed is affected in later life (Salthouse, 2009; Verhaeghen et al., 2003). Instead, participants were instructed to mark the sequence of chained boxes in the box-crossing task and to pay attention to the series of numbers in the digit sequence task. Finally, the tasks differed in their output mode; the digit sequences required oral responses, whilst the box-crossing performance required manual ones. Thus, they were non-competitive tasks and did not interfere with one another in the response-generation processing stage. As potential interference between different tasks seems to be limited to response-generation processes in older adults, the design of this study has avoided disadvantaging them (see Hartley, 2001).

Neither gender nor years of education were correlated with the index of coordination of attention. The only significant finding was that people who have received more years of formal education also achieve a better proportional performance in the box-crossing task. Although Vallesi (2015) suggested that educational level is the best predictor of overall dual-task performance, he also noticed that younger participants usually had University degrees, which made it difficult to separate the effects of age and formal education. We did not include people who were illiterate or who had attended university in our study because a sample of participants with primary and secondary studies was more homogeneous and representative of the Spanish old population (see Abellán & Pujol, 2016).

Some studies using a similar method have reported that older patients with AD (Della Sala, Cocchini, Logie, Allerhand, & MacPherson, 2010), frontal variant of frontotemporal dementia (fvFTD) (Sebastián & Hernández-Gil, 2010) and vascular dementia (VaD) (Inasaridze, Foley, Logie, & Della Sala, 2009) show worse dual-task performance than the control groups. Nevertheless, these results seem to be in line with our findings: The mechanism that coordinates the attention required for dual-task is preserved in healthy older people (e.g., Anderson et al., 2011), but is impaired by some forms of dementia. Additionally, although Mild Cognitive Impairment (MCI) does not seem to affect dual tasking capacities (Foley, Kaschel, Logie, & Della Sala, 2011), MCI is thought to be a precursor of AD (Petersen et al., 2014). Therefore, it would be interesting to see if this study's method could develop into a validated tool to identify MCI patients who might develop AD, or patients in the first stages of AD (Kirova, Bays, & Lagalwar, 2015).

In conclusion, contrary to the classical picture of ageing, where increased age is associated with worse cognitive performance, this study shows that older people can preserve their ability to simultaneously perform two tasks. Thus, 'the dull hypothesis' (i.e., the prediction that older people will naturally perform worse than younger people on a particular cognitive task), which was postulated by Perfect and Maylor (2000) and recently reviewed by Logie et al. (2014), can be rejected. They suggest that, given the amount of data available to support the decline in cognitive performance with age, research should move towards examining capacities that are preserved in ageing and developing theoretical explanations and methods to support them, rather than conduct further studies that investigate the capacities that diminish with age.

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