Age-related changes in ERP correlates of visuospatial and motor processes.

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ABSTRACT

Although previous ERP studies have demonstrated slowing of visuospatial and motor processes with age, such studies frequently included only young and elderly participants, and without information about age-related changes across the adult lifespan. The present research used a Simon task with two irrelevant dimensions (position and direction of an arrow) to study visuospatial (N2 posterior contralateral, N2pc) and motor (response-locked lateralized readiness potential, LRP-r) processes in young, middle-aged and elderly adults. The reaction time and motor execution stage (LRP-r) increased gradually with age, while visuospatial processes (N2pc latency) were similarly delayed in the older groups. No age-related increase in interference was observed, probably related to a delay in processing the symbolic meaning of the direction in older groups, which was consistent with age-related differences in distributional analyses and N2pc amplitude modulations.

Descriptors: Event-related potentials (ERPs); Simon task; Age-related slowing; Visuospatial attention; Motor processes.

Introduction

Early research on the effect of aging on cognitive processes focused on behavioural measures (mainly the reaction time, RT) obtained in different experimental tasks (Cerella, 1985; Salthouse, 1985). Aging was associated with longer RTs (Salthouse, 1985). These findings led to the development of models that described the aging process as a progressive decline in cognitive functions (Birren, Woods, & Williams, 1980; Myerson, Hale, Wagstaff, Poon, & Smith, 1990).

However, subsequent cross-sectional studies provided some insight into the evolution of different subsets of cognitive processes and revealed different patterns in the effects of aging in cognitive functioning, which led to the proposal of models to explain the heterogeneity in the effects of aging on specific cognitive processes (Park et al., 2002). In this context, some processes revealed a progressive decline throughout the adult lifespan (e.g. reasoning, spatial visualization, memory, speed); however, cognitive skills like the amount of vocabulary known, increase up to 60 years old (Salthouse, 2009).

Longitudinal studies involving fluid cognitive skills, as visual processing, spatial orientation or speed of processing (Finkel, Reinolds, McArdle, & Pedersen, 2003; McArdle, Ferrer-Caja, Hamagami, & Woodcock, 2002; Willis & Schaie, 2005) showed that aging was associated with a decline in these cognitive skills, starting at around 50 years old, followed by a period of relative stability and a subsequent progressive decline after 65 years old. In relation to these cognitive skills, some authors suggested that the main age-related change in brain function was the decline in the inhibition of irrelevant information, which resulted in longer RTs when irrelevant information had to be suppressed for successful performance of a task (Hasher & Zacks, 1988).

Stimulus-Response Compatibility tasks (SRC) (Zhang, Zhang, & Kornblum, 1999) require processes associated with fluid cognitive skills (e.g. selection of the target stimulus and inhibition of the non-targets, suppression of the irrelevant features of the target stimulus, etc.). The Simon task, where the participants respond to lateralized visual stimuli, was proposed for the study of age-related differences in such processes (Simon, 1990), as participants carry out a processing of the visual features of the display, the visuospatial orientation to the target stimulus, and a suppression of a contralateral non-target stimulus as well as of the irrelevant dimensions of the target stimulus, among other processes. In the Simon task, participants must respond to spatially lateralized stimuli by pressing one of two buttons. The response buttons are also lateralized in the same spatial arrangement as the stimuli, with the position of the stimuli being irrelevant to the task. In those cases in which the required response is on the opposite side to the stimulus (incompatible condition), a type of interference known as the Simon effect is produced (for reviews see Leuthold, 2011, Lu & Proctor, 1995, and Simon, 1990). The interference is manifested by a longer reaction time (RT) in the incompatible condition than in the compatible condition, in which the response side is ipsilateral with respect to the stimulus position.

Some evidence about the stages when cognitive decline appears in performing a Simon task was obtained. Bialystok, Craik, Klein, and Viswanathan (2004), who recruited participants between 30-80 years old, observed that RT and Simon effect increased from the age of 60 years onward. Moreover, Juncos-Rabadán, Pereiro, and Facal (2008) found a greater interference and increased RT in participants of 50-59 years old relative to younger adults, maintenance in groups between 50-59 and 60-69 years old, and a subsequent decline, at 70-82 years old. Age-related differences in Simon-type tasks are a common finding (for a review, see Proctor, Vu, & Pick, 2005).

Nonetheless, other studies did not find age-related differences in the Simon effect (Proctor, Pick, Vu, & Anderson 2005; Kubo-Kawai & Kawai, 2010). Such discrepancies are usually attributed to factors related to the experimental design. Specifically, Proctor et al. (2005) suggested that the difficulty for older participants lay in the suppression of the irrelevant dimension when it came from the same source of stimulation as the relevant dimension. Thus, when relevant and irrelevant dimensions belonged to different physical stimuli, age-related differences were not present. Moreover, Kubo-Kawai and Kawai (2010), in a study combining Simon and go/no go tasks, suggested that greater task difficulty slowed RTs and cancelled the age-related differences.

However, the RT measure is the final outcome of many cognitive processes involved in performing a task (e.g. different subprocesses associated with stimulus processing, selection of an appropriate response and execution of the selected response). Event-related brain potentials (ERP) provide a high-resolution measure of brain activity and appear suitable for studying the electrophysiological correlates of cognitive processes to establish which processes decline with age. Moreover, ERP technique is an appropriate approach in the study of cognitive control and enable age-related differences in correlates of cognitive control to be demonstrated even when decline in behavioural performance is still not evident (Vallesi & Stuss, 2010).

ERP studies have demonstrated that behavioural slowing is not the result of a homogeneous decline in cognitive processes, supporting the above concept of heterogeneity in the decline pattern of the cognitive processes (Park et al., 2002). In fact, no differences between young adults and healthy elderly participants in ERP correlates of perceptual processes were found in studies using a variety of cognitive tasks, such as the oddball task (Amenedo & Díaz, 1998), facial recognition tasks

(Chaby, George, Renault, & Fiori, 2003; Galdo-Álvarez, Lindín, & Díaz, 2009; Pfütze, Sommer, & Schweinberger, 2002) and SRC tasks (Falkenstein, Yordanova, & Kolev, 2006; Kolev, Falkenstein, & Yordanova, 2006).

Furthermore, an important locus of age-related slowing was manifested in the motor-generating system using SRC tasks (Falkenstein et al., 2006; Kolev et al., 2006; Roggeveen, Prime, & Ward, 2007; Wild-Wall, Falkenstein, & Hohnsbein, 2008; Yordanova, Kolev, Hohnsbein, & Falkenstein, 2004) and mental rotation tasks (Band & Kok, 2000). Electrophysiological evidence for this was provided by measurement of the lateralized readiness potential (LRP), a component that, through a subtraction procedure, isolates an increase of activity at electrode sites contralateral to the hand involved in preparing a movement. The time from stimulus presentation to the LRP onset (LRP-s) can be used as a measure of the stimulus processing prior to the moment when response activation starts. Likewise, the interval between the LRP onset and the overt response (LRP-r) can be considered as an index of the duration of the response activation (Smulders & Miller, 2012).

Some studies showed that the LRP amplitude was larger in elderly than in young participants (Roggeveen et al., 2007; Wild-Wall et al., 2008; Yordanova et al., 2004). It was proposed that larger LRP amplitudes in elderly participants are related to decline in inhibitory control (Roggeveen et al., 2007). Moreover, other studies (Wild-Wall et al., 2008; Yordanova et al., 2004) suggested that larger LRP amplitudes might be related to an increased threshold of response activation due to dysregulation in high-level control systems. In addition, some studies have reported earlier response-locked LRP (LRP-r) latencies in elderly than in young participants (Falkenstein et al., 2006; Kolev et al., 2006; Roggeveen et al., 2007; Wild-Wall et al., 2008; Yordanova et al., 2004). This finding may reflect a need for a longer activation of the motor cortex in elderly participants to enable the response to be executed (Kolev et al., 2006). Alternatively, prolonged execution of the motor response has also been related to an age-related strategy emphasizing response accuracy (Osman et al., 2000).

Visuospatial processes are considered another important source of age-related slowing, as manifested in delayed N2pc latencies in SRC tasks (Van der Lubbe & Verleger, 2002) and visual search tasks (Amenedo, Lorenzo-López, & Pazo-Álvarez, 2012; Lorenzo-López, Amenedo, & Cadaveira, 2008; Lorenzo-López et al., 2011). The N2pc is a negative ERP component recorded at parietal sites contralateral to the visual hemifield where the target stimulus is located, with maximum amplitude between 200-300 ms after stimulus presentation (Eimer, 1996; Luck & Hillyard, 1994; Woodman & Luck, 1999, Woodman & Luck, 2003). N2pc has been associated with visuospatial processing of the target stimulus and with inhibition of the non-target (see Hickey, Di Lollo, & McDonald, 2009).

Despite the above evidence, very few ERP studies have attempted to study the modulation of the cognitive processes throughout the lifespan, and most studies have simply compared groups of young and elderly adults.

The present study included a Simon-like task, in which participants were required to respond to the colour of a lateralized arrow but to ignore the position of the arrow and the direction indicated by the arrow (see Figure 1). Thus, four experimental conditions were generated according to the compatibility or incompatibility between the two irrelevant dimensions and the required response: Compatible Direction and Compatible Position (CDCP), Incompatible Direction and Compatible Position (IDCP), Compatible Direction and Incompatible Position (CDIP), Incompatible Direction and Incompatible Position (IDIP). This task enabled examination of the electrophysiological correlates of visuospatial processing of the target stimulus (N2pc). The task also provides a correlate of the execution of the motor response: the response-locked LRP (LRP-r). The LRP-r onset and amplitude may provide information about the interference elicited by the irrelevant dimensions.

The inclusion of two irrelevant dimensions was expected to increase task difficulty, which according to previous studies (Juncos-Rabadán, Pereiro, & Facal, 2008) would lead to increased age-related differences. Moreover, as in the IDCP and CDIP conditions the arrow conveys contradictory spatial information (i.e. the arrow points towards the opposite hemifield regarding where it is located) (see Figure 1), the present task enables the study of the perceptual conflict. On the basis of a previous study in a sample of young participants (Cespón, Galdo-Álvarez, & Díaz, 2013) and consistently with studies that used N2pc as a tool to study the strength of irrelevant stimuli to attract attentional resources (Eimer & Kiss, 2007; Hickey, McDonald, & Theeuwes, 2006), perceptual conflict would be related to smaller N2pc amplitude in IDCP and CDIP conditions (where the two irrelevant dimensions conveyed contradictory spatial information) than in CDCP and IDIP conditions (where the two irrelevant dimensions conveyed the same spatial information) (see Figure 1).

According to the cognitive slowing theory (Salthouse, 2009), age-related slowing in ERP correlates of visuospatial (N2pc latency) and motor (LRP) processes was expected (see Figure 2.1a and 2.2a). According to the inhibitory deficit hypothesis (Hasher & Zacks, 1988), age-related increases in S-R interference (revealed by RTs and LRP data) and perceptual conflict (revealed by N2pc amplitude) were expected (see Figure 2.3a and 2.4a).

As far as we know, this is the first ERP study focusing on effects of aging on ERP correlates of visuospatial and motor processes including a sample of middle-aged participants. Nonetheless, previous behavioural reports related to cognitive slowing

(Salthouse, 2009) and the interference effect (Juncos-Rabadán et al., 2008) in middle-aged participants led us to expect a decline in the cognitive functioning in middle-aged relative to young participants, which would be more evident in the elderly group.

Method

Participants

Forty five participants (30 women, 15 men) between 19 and 84 years old were divided into 3 age groups: young group, 19-22 years old (mean age 20.5 years); middle-aged group, 50-64 years old (mean age 56.0 years); elderly group, 65-84 years old (mean age 71.1 years). Each group comprised 15 participants. The participants were recruited from the general population (for more details about the sample, see Table 1) and volunteered to take part in the study. The study received prior approval by the local ethical review board. Forty-four of the participants were right-handed and one was ambidextrous (evaluated by the Edinburgh Handedness Inventory: Oldfield (1971)). All participants had normal or corrected to normal vision. The participants had no history of neurological or psychiatric disorders according to self-report.

Table 1 about here

Task

A series of red or blue arrows pointing either left or right was displayed on a screen against a black background. The screen was placed 100 cm in front of the participants. The arrow stimuli subtended 2.87º horizontally and 1.72º vertically in the visual field, and the arrows were presented in the parafoveal region (the internal edge was 2.29º and the external 5.16º of visual angle regarding a central cross: see Bargh & Chartrand, 2000). A grey geometric figure of similar morphology and eccentric position (two orthogonally superimposed bars, the vertical thicker than the horizontal, see Figure 1) was presented in the opposite hemifield to the target stimulus. The arrows (and the contralateral stimulus) were presented for 125 ms, with 2000 ms inter-trial intervals. The participants were instructed to direct their gaze towards the central cross throughout the task, which, together with the short interval during which the stimuli were presented, minimized the likelihood of ocular movements towards the area where the arrow appeared (see Abrahamse & Van der Lubbe, 2008).

Figure 1 about here

Procedure

Each participant carried out the task while seated in a comfortable chair in a dimly lit, sound-attenuated, electrically shielded chamber. The participants were instructed to respond to the colour of a blue or red arrow by pressing one of two horizontally positioned buttons (blue or red), but to ignore the position and the direction indicated by the arrow (Figure 1). The arrow was presented on either side of the central cross (where the participants were asked to direct their gaze throughout the task) and pointed either to the left or to the right. The two irrelevant dimensions (position and direction indicated by the arrow) gave rise to four experimental conditions, depending on whether the dimensions were compatible or incompatible with the response to the colour: compatible direction-compatible position (CDCP), incompatible direction-compatible position (IDCP), compatible direction-incompatible position (CDIP) and incompatible direction-incompatible position (IDIP) (Figure 1). The same numbers of trials were run for all four conditions (80 per condition).

After a practice block of 24 trials, a total of 320 trials (80 per condition) were presented in two blocks, with an inter-block interval of 90 s. The response hand assigned to each colour of the stimulus was counterbalanced among the participants, who were instructed to respond as quickly and accurately as possible.

EEG recordings

In total, 47 active electrodes were used for the EEG recordings, in accordance with the 10-10 International System: AFz, AF7, AF8, Fz, F3, F4, F5, F6, F7, F8, FCz, FC1, FC2, FC3, FC4, FT7, FT8, FT9, FT10, Cz, C1, C2, C3, C4, C5, C6, T7, T8, CPz, CP3, CP4, TP7, TP8, TP9, TP10, Pz, P3, P4, P7, P8, P9, P10, PO7, PO8, Oz, O1 and O2. The EEG signal was passed through a 0.01–100 Hz analog band-pass filter and was sampled at 500 Hz. The reference electrode was placed on the tip of the nose and the ground electrode at Fpz. Simultaneously to EEG recordings, ocular movement (EOG) recordings were obtained with two electrodes located supra- and infraorbitally to the right eye (VEOG) and another two electrodes at the external canthus of each eye (HEOG). All impedances were maintained below 10 kΩs.

After signal storage, a two-step procedure was used to remove epochs with horizontal ocular artifacts, following a procedure used in previous studies (e.g. Woodman & Luck, 2003). Firstly, trials with large horizontal eye movements (larger than ± 35 µV) were removed. Secondly, averaged HEOG waveforms showing residual eye movements (HEOG activity exceeding ± 3 µV) were eliminated. Also, blinks were corrected off-line by use of the algorithm of Gratton, Coles, and Donchin (1983).

The signal was passed through a 0.01–30 Hz digital band-pass filter. One-second epochs were extracted: 200 ms pre-stimulus in stimulus-locked ERPs (N2pc, LRP-s) and 700 ms pre-response in response-locked ERPs (LRP-r). Epochs with signals exceeding ±100 µV were automatically rejected, and all remaining epochs were inspected individually to identify those still displaying artifacts; the artifact epochs were also excluded from subsequent averaging. Epochs were then corrected to the mean voltage of the baseline (-200 to 0 in stimulus-locked ERPs, -700 to -500 in response-locked ERPs). For stimulus-locked ERPs, the number of averaged epochs per condition for each group was as follows: 63 (young group), 61 (middle-aged group), 62 (elderly group). For each hemifield and condition, only those participants with a minimum of 26 epochs after artifact rejection were included in the analyses (range: 26-40). The number of averaged epochs per condition for response-locked ERPs was as follows: 65 (young group), 69 (middle-aged group), 69 (elderly group).

Data analysis

Trials with incorrect responses or reaction time (RT) outside the 100-1000 ms range were excluded from the behavioural and the ERP analyses. The percentages of trials excluded because of responses that were too slow were as follows: 0.003% young; 0.006% middle-aged; 0.29% elderly.

The RT, the subtracted interference on each incompatible condition (i.e. IDCP-CDCP, CDIP-CDCP, and IDIP-CDCP) and the percentage of errors (PE) were analyzed. To determine whether the magnitude of the interference depended on the speed of response, distributional analysis (DA) of the RTs was carried out (Ratcliff, 1979) for each group (young, middle-aged, elderly) and type of interference (IDCP, CDIP, IDIP). For this purpose, the RTs were ordered by length, and for each participant, the RTs at the 4 Quintile Intersection Points that divided the distribution into 5 equal parts (quintiles) were selected.

In order to obtain the LRP waveforms (LRP-s and LRP-r), the difference in contralateral-ipsilateral activation for C3 and C4 electrode pairs in each hemisphere was calculated. The differences were then averaged (Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988). The method can be summarised by the following formula: $[(C4 - C3)_{\text{left hand movements}} + (C3 - C4)_{\text{right hand movements}}] / 2]$. The N2pc component was obtained on the basis of the hemifield of presentation of the stimulus by the following formula: $[(PO8 - PO7)_{\text{left hemifield}} + (PO7 - PO8)_{\text{right hemifield}}] / 2]$.

The N2pc component was identified as the larger negative peak between 200-350 ms after the stimulus presentation at the PO7/PO8 electrode pair. The N2pc amplitude was calculated as the mean amplitude within ±30 ms around peak latency for each participant. In order to study possible differences in the N2pc onset, a procedure similar to that used by Van der Lubbe and Verleger (2002) was used. Specifically, the averaged amplitudes in three consecutive temporal windows of 25 ms (i.e., 125-150, 150-175, and 175-200) were obtained.

The onset latency of the correct preparation in the LRP-r was determined by the method of Schwarzenau, Falkenstein, Hoormann and Hohnsbein (1998), which assumes that the onset of correct preparation corresponds to the intersection point of two straight lines, one fitted to the baseline and another to the rising slope of the LRP.

LRR-r onsets were subtracted as follows: IDCP-CDCP, CDIP-CDCP, and IDIP-CDCP to study if possible delays in LRP-r onset for S-R incompatible (IDCP, CDIP, and IDIP) relative to compatible condition (CDCP) were increased with age.

Effects of the irrelevant dimensions on the peak latency of the stimulus-locked LRP (LRP-s), measured as the maximum negative peak between 300-650 ms after stimulus presentation, were studied. The LRP-s amplitude was measured as the mean amplitude within ±30 ms around peak latency. The onset of the stimulus-locked LRP (LRP-s) could not be reliably measured in the present study because when lateralized stimuli are presented in horizontal arrangement, a central contralateral negativity (N2cc) overlaps with the LRP-s onset (Cespón, Galdo-Álvarez, & Díaz, 2012; Praamstra, 2007). However, LRP-r onset can be studied because N2cc is a stimulus-related component, and therefore it is not expected to affect response-related averages (Praamstra & Plat, 2001). Simon tasks designed with the aim of studying the LRP-s onset usually present the stimuli in a vertical arrangement, although this setting does not allow study of the N2pc component.

Statistical analysis

RTs were analyzed and linear regression analyses were conducted to test age-related slowing. In addition, LRP-r onset latency, LRP-s peak latency and N2pc onset and peak latencies were studied to provide information about age-related slowing in correlates of motor and visuospatial processes. Moreover, age-related differences in S-R interference were studied by subtracting the compatible from the incompatible conditions (i.e. IDCP-CDCP, CDIP-CDCP, and IDIP-CDCP) in RTs and LRP-r onset. Also the PE was studied. The DA also enabled study of the temporal dynamic of the interferences on each group. In addition, perceptual interference was studied by means of N2pc amplitude modulations.

In order to determine any differences in RTs, PE, LRP-r onset latency, N2pc onset latency and in the latencies and amplitudes of N2pc and LRP-s components based on the experimental conditions and the age, mixed ANOVAs were carried out with two within-subject factors, Position (two levels: Compatible and Incompatible) and Direction (two levels: Compatible and Incompatible), and one between-subject factor, Age (three levels: young, middle-aged and elderly).

To evaluate the LRP-r positive deflection observed in young participants, one sample t-tests were applied to the mean values of five consecutive windows of 50 ms each, with a step size of 10 ms between windows (i.e. each window had an overlap of 40 ms with the prior window) and starting 45 ms before the LRP positive peak. If all the windows reached a significant value, we can conclude that the waveforms deviated significantly from baseline.

To evaluate the magnitude of the interference in RTs and LRP-r onset latency, mixed ANOVAs were carried out with one within-subject factor, Condition (three levels: IDCP, CDIP, and IDIP), and one between-subject factor, Age (three levels: young, middle-aged and elderly). In addition, to study whether the interference was significant in each QIP, one-sample t-tests were carried out for each type of interference on each group of participants.

Linear regressions were conducted for each condition separately in middle-aged and elderly participants, with the age of the participants as the independent variable and RT, LRP-r onset latency (using absolute values) and N2pc peak latency as dependent variables. Linear regression analysis was also carried out with the age of the participants as the independent variable and the averaged values among the four conditions of RT, LRP-r onset latency and N2pc peak latency as dependent variables. Coefficients of determination and F significant values are reported.

Pearson correlation analysis between RT and the latency of each component was conducted separately for each experimental condition in the middle-aged and elderly groups, to study correlations between delays in RT and delays in visuospatial (N2pc) and/or motor execution (LRP-r) processes (using absolute values). Pearson correlation analysis was also carried out by averaging the values of RT and ERP latencies among the conditions. The group of young participants was not included in linear regression and correlation analyses since this would require a group of participants between 30 and 49 years old.

The Greenhouse-Geisser ε correction value for the degrees of freedom was used when necessary and the corresponding α levels were determined. When the ANOVAs revealed significant effects due to the factors and their interactions, post hoc comparisons of the mean values were carried out by paired multiple comparisons (adjusted to Bonferroni).

Figure 2 about here

Results

Behavioural measures

Slowing:

For the RT (see Table 2), the mixed ANOVA (Position x Direction x Age) revealed a significant effect of Age (F (2, 42) = 23.3, $p < 0.001$) as the RT was shorter in young than in middle-aged ($p < 0.001$) and elderly groups ($p < 0.001$). The RT was also shorter in middle-aged than in elderly participants ($p = 0.029$). Position had a significant effect (F (1, 42) = 311.0, $p < 0.001$), as the RTs were shorter for trials with compatible position than for trials with incompatible position ($p < 0.001$). The Direction x Age interaction was significant (F (2, 42) = 4.0, $p = 0.026$), as the RT was shorter when Direction was compatible than when it was incompatible ($p = 0.002$) in the young adults, whereas no differences were found in middle-aged ($p = 0.115$) and elderly ($p = 0.479$) groups.

Linear regression showed a significant linear relationship between RT and age of the participants for each experimental condition: CDCP [$R^2 = 0.271$ (F (1, 29) = 10.4, $p = 0.003$]; IDCP [$R^2 = 0.308$ (F (1, 29] = 12.5, $p = 0.001$]; CDIP [$R^2 = 0.358$ (F (1, 29) = 15.6, $p < 0.001$)]; IDIP [$R^2 = 0.375$ (F (1, 29] = 16.8, $p < 0.001$]. Linear regression also revealed a significant linear relationship between RT (averaged among the four experimental conditions) and age of the participants [$R^2 = 0.336$ (F (1, 29] = 14.2, $p = 0.001$] (see Figure 7).

Table 2 about here

S-R Interference:

For the magnitude of the interference on RTs (see Figure 2.4b), the mixed ANOVA (Interference x Age) revealed an effect of the type of interference (F (2, 84) = 142.7, $p < 0.001$, $\varepsilon = 0.875$), as the interference on RTs was greater when position was incompatible with the response than when it was not (CDIP > IDCP, p = 0.001; IDIP > IDCP, $p < 0.001$). The interference x Age interaction was significant (F (4, 84) = 6.7, $p < 0.001$, $\varepsilon = 0.875$), although pairwise comparisons revealed the same task effects for all age groups; CDIP > IDCP: young ($p < 0.001$), middle-aged ($p < 0.001$) and elderly ($p < 0.001$); IDIP > IDCP: young ($p < 0.046$), middle-aged ($p < 0.001$) and elderly ($p < 0.001$).

The distributional analysis (Figure 3) revealed the following effects:

In young adults, IDCP interference was significant in QIP1 (t (14) = 3.6, p = 0.003), QIP2 (t (14) = 3.1, p = 0.007) and QIP3 (t (14) = 3.5, p = 0.004); CDIP interference was significant in QIP1 (t (14) = 9.3, $p < 0.001$), QIP2 (t (14) = 7.1, $p < 0.001$), QIP3 (t (14) = 7.1, $p < 0.001$) and QIP4 (t (14) = 4.8, $p < 0.001$); and IDIP interference was significant in QIP1 (t (14) = 6.3, $p < 0.001$), QIP2 (t (14) = 6.2, $p < 0.001$), QIP3 (t (14) = 7.3, $p < 0.001$) and QIP4 (t (14) = 5.5, $p < 0.001$).

In middle-aged adults, IDCP interference was significant in QIP3 ((t (14) = 3.0, p = 0.009) and QIP4 (t (14) = 2.5, p = 0.024); CDIP interference was significant in QIP1 (t (14) = 7.6, $p < 0.001$), QIP2 (t (14) = 9.4, $p < 0.001$), QIP3 (t (14) = 7.3, $p < 0.001$) and QIP4 (t (14) = 4.0, p = 0.001); and IDIP interference was significant in QIP1 (t (14) = 8.7, $p < 0.001$), QIP2 (t (14) = 7.7, $p < 0.001$), QIP3 (t (14) = 8.1, $p < 0.001$) and QIP4 (t (14) = 2.9, p = 0.001).

In elderly adults, CDIP interference was significant in QIP1 (t (14) = 13.1, $p < 0.001$), QIP2 (t (14) = 14.1, $p < 0.001$), QIP3 (t (14) = 12.8, $p < 0.001$) and QIP4 (t (14)

= 6.2, $p < 0.001$); and IDIP interference was significant in QIP1 ($t (14) = 10.7$, $p < 0.001$), QIP2 ($t (14) = 8.9$, $p < 0.001$), QIP3 ($t (14) = 5.0$, $p < 0.001$) and QIP4 ($t (14) = 5.0$, $p < 0.001$).

Figure 3 about here

For the PE (see Table 2), the mixed ANOVA (Position x Direction x Age) revealed a significant effect of the Position ($F (1, 42) = 41.5$, $p < 0.001$), as the PE was greater in trials with incompatible Position than with compatible Position ($p < 0.001$). Direction also had a significant effect ($F (1, 42) = 4.9$, $p = 0.033$), as the PE was greater when the Direction was incompatible than when it was compatible with the response to the colour ($p = 0.033$). Position x Direction x Age showed a significant interaction effect ($F (2, 42) = 3.6$, $p = 0.035$). In young adults, the PE was greater when position was incompatible than when it was compatible, regardless of whether direction was compatible (CDIP > CDCP) ($p = 0.002$) or incompatible with the response (IDIP > IDCP) ($p < 0.001$), whereas a direction effect was only observed when position was incompatible with the response, i.e. IDIP > CDCP ($p = 0.007$). On the other hand, in the middle-aged group, when the stimulus position was compatible, the PE was greater when the Direction was incompatible than when it was compatible ($p = 0.038$) (IDCP > CDCP). In elderly adults there were no differences between conditions in the PE.

ERPs

Slowing:

For the onset latency of the LRP-r (see Table 2, Figure 4, and Figure 2.2b), the mixed ANOVA (Position x Direction x Age) revealed a significant effect of the factor Age ($F (2, 42) = 17.7$, $p < 0.001$) as earlier LRP-r onset was observed in elderly than in middle-aged ($p = 0.022$) and young participants ($p < 0.001$) and in middle-aged than in young participants ($p = 0.009$). Position also exerted an effect ($F (1, 42) = 113.1$, $p < 0.001$), as the LRP-r onset was earlier when the Position was compatible than when it was incompatible with the response ($p < 0.001$). The ANOVA also revealed a significant effect of the interaction Direction x Age (F (1, 42) = 3.33, p = 0.046). In young adults only, the LRP-r onset was earlier when the Direction was compatible than when it was incompatible (p = 0.001).

Figure 4 about here

For the LRP-s peak latency (see Table 2 and Figure 5), the mixed ANOVA (Position x Direction x Age) revealed an effect of the Age (F (2, 42) = 14.5, $p < 0.001$), as LRP-s latencies were longer in elderly participants than in middle-aged (p = 0.050) and young ($p < 0.001$) participants. LRP-s latencies were also longer in middle-aged participants than in young participants (p = 0.018). Position also had a significant effect (F (1, 42) = 62.0, $p < 0.001$) as LRP-s latencies were delayed when the Position was Incompatible than when it was Compatible with the response ($p < 0.001$). The ANOVA also revealed a Direction x Age interaction effect (F (2, 42) = 5.05, p = 0.011). In young adults only, the LRP-s peak latency was longer when the Direction was Incompatible than when it was Compatible ($p < 0.001$).

For the LRP-s amplitude, the mixed ANOVA (Position x Direction x Age) revealed an effect of the Age (F (2, 42) = 7.94, $p < 0.001$), as the LRP-s amplitude was larger in elderly than in young (p = 0.010) adults, and it was larger in middle-aged than in young (p = 0.002) participants. Position also had a significant effect (F (1, 42) = 5.84, p = 0.020) as the LRP-s amplitude was larger when the Position was Compatible than when it was Incompatible with the response.

Figure 5 about here

For the N2pc peak latency (see Table 2, Figure 6, and Figure 2.1b), the mixed ANOVA (Position x Direction x Age) revealed an effect of Age (F (2, 42) = 41.4, p <

0.001) as the N2pc peak latency was shorter in young than in middle-aged participants ($p < 0.001$), and it was shorter in young than in elderly participants ($p < 0.001$). The mixed ANOVA (Position x Direction x Age) conducted for the N2pc onset did not reveal any significant effect.

Figure 6 about here

Linear regression between LRP-r onset latency and age of the participants (middle-aged and elderly) showed a significant linear trend in CDCP [$R^2 = 0.346$ (F (1, 29) = 14.8.6, p = 0.001)], IDCP [$R^2 = 0.165$ (F (1, 29) = 5.5, p = 0.26)], CDIP [$R^2 = 0.173$ (F (1, 29) = 5.8, p = 0.022)] and IDIP [$R^2 = 0.353$ (F (1, 29) = 15.3, p = 0.001)] . The average LRP-r values among the conditions also revealed a significant linear trend [$R^2 = 0.310$ (F (1, 29] = 12.6, p = 0.001] (see Figure 7). No linear relationships between N2pc peak latency and age of the participants were found (see Figure 7).

The correlations between LRP-r onset latency and RT were significant in the four conditions: CDCP (r = 0.51, p = 0.004); IDCP (r = 0.45, p = 0.013); CDIP (r = 0.68, $p < 0.001$) and IDIP (r = 0.70, $p < 0.001$). The correlation between the average RT and LRP-r onset latency values among the conditions was significant (r = 0.67, $p < 0.001$). Correlation analyses between RT and N2pc peak latency did not reveal any significant effects.

Figure 7 about here

S-R interference:

The mixed ANOVA (Condition x Age), carried out to study age-related differences in delays of the preparation of the correct response onset, revealed an effect of the Condition (F (2, 84) = 31.52, $p < 0.001$, $\varepsilon = 0.786$), as the LRP-r onset was less delayed in IDCP than in CDIP and IDIP ($p < 0.001$). The age factor was not significant.

The positive dip observed in LRP-r (Figure 4) was statistically significant for the young participants in those conditions where the interference was manifested: IDCP (t1 (14) = 2.6, $p = 0.019$; t2 (14) = 2.9, $p = 0.011$; t3 (14) = 3.1, $p = 0.008$; t4 (14) = 3.0, $p = 0.010$; t5 (14) = 2.3, $p = 0.040$), CDIP (t1 (14) = 6.9, $p < 0.001$; t2 (14) = 6.7, $p < 0.001$; t3 (14) = 5.7, $p < 0.001$; t4 (14) = 4.4, $p < 0.001$; t5 (14) = 3.5, $p = 0.040$), and IDIP (t1 (14) = 6.0, $p < 0.001$; t2 (14) = 6.6, $p < 0.001$; t3 (14) = 6.8, $p < 0.001$; t4 (14) = 6.0, $p < 0.001$; t5 (14) = 4.3, $p = 0.001$) conditions.

Perceptual conflict:

For the N2pc amplitude (see Figure 6, and Figure 2.3b), which indicates the amount of attentional resources allocated to a target, the mixed ANOVA (Position x Direction x Age) revealed an effect of the Position x Direction x Age (F (2, 42) = 4.19), $p = 0.022$), as differences among conditions were only observed in young adults. Specifically, N2pc amplitudes were larger in young participants when the Direction and Position conveyed the same information as when they conveyed the opposite information (CDCP>CDIP, $p =0.001$; CDCP>IDCP, $p < 0.001$; IDIP>CDIP, $p = 0.039$; IDIP>IDCP, $p = 0.041$). Also, when the Position was Compatible and the Direction Incompatible (i.e., in IDCP), the N2pc amplitude was smaller in young participants than in middle-aged ($p = 0.054$) and elderly ($p = 0.042$) participants.

Discussion

The overall aim of the present study was to shed light on the modulation of ERP correlates of motor execution (LRP-r) and visuospatial processing (N2pc) in a sample of young, middle-aged and elderly participants who performed an SRC task. The results revealed the following: a) age-related slowing in RTs; b) progressive slowing with age in the response execution stage (LRP-r onset) and similar slowing in visuospatial processes (N2pc peak) in middle-aged and elderly relative to young participants; c) similar position interference in the three age groups and direction interference only in the young group (and also in middle-aged for slower responses); d) increased LRP amplitudes in the older groups relative to young participants; e) perceptual conflict by contradictory spatial information, conveyed by the irrelevant dimensions, only in young participants (smaller N2pc amplitude in IDCP and CDIP than in CDCP and IDIP).

An age-related slowing of the RT was observed (longer RT in the elderly than in the middle-aged and young, and longer RT in the middle-aged than in the young participants). Those results are consistent with the age-related slowing in the performance of a Simon task demonstrated in previous studies (Castel, Balota, Hutchison, Logan, & Yap, 2007; Juncos-Rabadán et al., 2008; Proctor, Vu, & Pick, 2005; Van der Lubbe & Verleger, 2002). Therefore, the data from the present study support the well-known report of age-related slowing in the speed of response (Salthouse, 2009). Importantly, ERP correlates provided evidence about differences in the pattern of slowing in each particular process, which supported the concept of heterogeneity of the cognitive processes in the pattern of slowing (Park et al., 2002).

The LRP-r onset, an ERP correlate of the motor execution of the response, revealed a gradual slowing in the motor execution stage, i.e. the slowing was greater in middle-aged and elderly relative to the young group, and it was also greater in elderly than in middle-aged participants. These results are consistent with the findings of previous studies (Falkenstein et al., 2006; Kolev et al., 2006; Roggeveen et al., 2007; Wild-Wall et al., 2008; Yordanova et al., 2004) and with the suggestion that the motor response execution stage represents a main source of the age-related slowing observed in RTs (Falkenstein et al., 2006; Kolev et al., 2006), which is also supported by the correlation between RT and duration of the response execution stage.

The results also showed that execution of the motor response represents a locus of age-related slowing that is already manifested in the middle-aged participants and that is further increased in the elderly participants, as also revealed by the linear regression analyses (see Figure 7b). Thus, the slower execution of the response may explain the slowing observed in RT in the elderly and middle-aged groups with respect to the young group, as well as the slowing in RT for the elderly group relative to the middle-aged group.

On the other hand, the N2pc onset did not show differences with age. However, the N2pc peak latency was slower in middle-aged and elderly than in young participants. These results are consistent with the results of Van der Lubbe and Verleger (2002) and suggest that age-related slowing did not occur at the moment when attentional shift starts (N2pc onset), but at the time when the discrimination of the target stimulus is most pronounced (N2pc peak latency). The age-related slowing in N2pc peak latency was also consistent with results of visual search tasks (Amenedo et al., 2012; Lorenzo-López et al., 2008, Lorenzo-López et al., 2011). Therefore, these results suggest that, in the Simon task, processes associated with visuospatial processing of the target stimulus slow down in healthy elderly and also in middle-aged participants compared to young participants, contributing to the slowing observed in RT in the two older groups. However, and consistently with linear regression and correlation analyses, slowing in the latencies of response in elderly relative to middle-aged participants may be explained by delays in response-related processes but not by delays in visuospatial processes.

It cannot be entirely excluded that N2pc was shortened in young participants due to the positive wave observed after 250 ms. This positive wave might be related with the temporal contralateral component (Ptc), which was involved in isolating the target once it was already identified (see Hillimire et al., 2009, 2010). Therefore, it would represent a later process. Importantly, the observed age-related differences in N2pc latency are consistent with the results obtained by Van der Lubbe and Verleger (2002) with a similar task. In addition, the present results show that the N2pc latency was not delayed in elderly relative to middle-aged participants and it can be reliably stated since the above positivity was not present in any of the older groups.

The present results support the existence of different patterns of age-related changes for each particular process, which is consistent with the notion of heterogeneity of the cognitive functions in the pattern of age-related decline (Park et al., 2002). In fact, onset of attentional shift to the target stimulus was preserved. However, the time at which attentional shift to the target stimulus is most pronounced was delayed in middle-aged and elderly relative to young participants, whereas there were no differences between the older adult groups. The response execution stage was also gradually slowed with age although, in contrast to the pattern of decline in discrete stages suggested by studies on fluid cognitive skills (Finkel et al., 2003; McArdle et al., 2002; Willis & Schaie, 2005), the results of the linear regression analysis suggest a gradual slowing from 50 years of age, up to 84 years.

Regarding the interference effect, the RT was shorter and the PE was higher when the stimulus position was incompatible with the response, which was consistent with previous findings in young (Lu & Proctor, 1995) and elderly (Proctor, Vu, & Pick, 2005) participants. However, age-related increase in interference was not observed, which is not consistent with the findings of previous studies (Bialystok et al., 2004; Castel et al., 2007; Juncos-Rabadán et al., 2008; Proctor, Vu, & Pick, 2005; Van der Lubbe & Verleger, 2002) that supported the inhibitory deficit hypothesis (Hasher & Zacks, 1988; Zacks & Hasher, 1997). Nonetheless, evidence for an absence of age-related differences on the Simon effect has previously been reported (Kubo-Kawai & Kawai, 2010; Proctor, Pick, Vu, & Anderson, 2005) and was attributed to the experimental design.

In the present study, the absence of increased interference with age may be related to age-related differences in the effect of direction. Specifically, the direction of the arrow interfered in the responses of young participants (slower RT and greater PE in the IDCP than in the CDCP condition), which is consistent with previous findings (Masaki, Takasawa, & Yamazaki, 2000; Wittfoth, Schardt, Fahle, & Herrmann, 2009); however, it only affected slower responses in middle-aged participants and the effect was totally absent in elderly participants. If the direction of the arrow does not produce interference in the task used in the present study, then position-direction interaction (in IDIP) is probably absent as well as the perceptual conflict conveyed by contradictory spatial information (in IDCP and CDIP conditions). Therefore, interference in the three incompatible conditions is attenuated in the older groups.

Stimulus position is known to attract attentional resources more quickly than the direction of the stimulus (Klein & Ivanoff, 2011). This has been attributed to mandatory semantic processing of the direction (Iani, Baroni, Pellicano, & Nicoletti, 2011; Symes, Ellis, & Tucker, 2005; Vainio, Ellis, & Tucker, al., 2007). In accordance with the model of the temporal overlap (see Hommel, 2000), if an irrelevant dimension is processed after the response, then it does not affect the performance. In the present study, the distributional analysis showed that the direction interfered throughout the distribution of RTs in young participants (i.e., from shorter to longer RTs). However, the direction only interfered in slower responses in middle-aged participants and it did not interfere in elderly participants. Thus, on the basis of the distributional analysis, it may be hypothesized that aging affects the speed of processing of the arrow direction (due to its symbolic nature) more than it affects processing of the arrow position and colour. This interpretation is also consistent with greater age-related decline in effortful than in automatic processes (Hasher & Zacks, 1979).

ERP correlates of interference in response-related processes (LRP) and perceptual conflict in allocating attention to the target stimulus (N2pc) provided additional information.

The interference from the stimulus position similarly affected the motor execution stage, delaying LRP-r onset in the three age groups, which was consistent with similar levels of behavioural interference. Interference in the response execution stage by stimulus position was consistent with previous findings (Vallesi, Mapelli, Schiff, Amodio, & Umiltà, 2005). In addition, the incompatibility of the arrow direction also delayed the LRP-r onset, which is consistent with behavioural data and with a previous study in a sample of young participants (Masaki et al., 2000). Moreover, the LRP-s latency was delayed when interference was manifested (i.e. in IDCP, CDIP, IDIP for the young; in CDIP/IDIP for the older groups) and consistently with RTs, an age-related slowing in LRP-s latency was observed.

The amplitude of LRP-s was greater in middle-aged and elderly participants than in the young group. Similar results were reported in previous studies (Roggeveen et al., 2007; Wild-Wall et al., 2008; Yordanova et al., 2004), in which the increased LRP amplitudes were associated with declined inhibitory control (Roggeveen et al., 2007) and dysregulation in high-level control systems (Wild-Wall et al., 2008). In the present study, increased LRP amplitudes were not accompanied by increased interference. Therefore, on the basis of the compensation hypothesis (Reuter-Lorenz & Cappell, 2008), the present results suggest that larger LRP amplitudes may be related to additional mechanisms recruited for maintaining the performance.

Age-related differences in the shape of the LRP-r waveform were also observed. Specifically, the young participants showed a positive dip related to transitory preparation of the incorrect response in all the conditions in which S-R incompatibility was present (i.e. IDCP, CDIP, and IDIP). However, this positive wave was not present in the older groups, possibly because of delayed activation of the automatic response based on the position in the older groups, in accordance with the possible delay in the incorrect preparation/N2cc complex observed for the CDIP and IDIP conditions in LRP-s waveforms. However, future studies are required to test this hypothesis since incorrect preparation and N2cc could not be isolated under the present experimental design.

The direction of the arrow only elicited an effect of interference in young participants. This may explain why ERP evidence of a perceptual conflict related to contradictory spatial information conveyed by both irrelevant dimensions was only obtained in young participants. In the IDCP and CDIP conditions, the arrow was on the opposite side with respect to where it was indicating. In these conditions, the N2pc amplitudes were smaller in the young, but not in the older participants, relative to the CDCP/IDIP conditions. This effect suggests that the contradictory information reduced the amount of attentional resources devoted to the target stimulus. This finding is consistent with data obtained by Cespón et al. (2013) in a sample of young participants and with N2pc modulations generated by high-level properties of the display (Eimer & Kiss, 2007; Telling, Kumar, Meyer, & Humphreys, 2009). Nonetheless, it must to be noted that perceptual conflict is always accompanied by S-R incompatibility (from the direction of the arrow in IDCP and from the arrow position in CDIP), which constitutes a limitation of the present experimental design.

The N2pc amplitude was larger in middle-aged and elderly groups than in the young group, for the IDCP condition. These differences may also be related to the contradictory information conveyed by both irrelevant features, which reduced the N2pc amplitude in young but not in middle-aged and elderly participants. Moreover, studies involving visual search tasks found smaller N2pc in elderly than in young participants (Amenedo et al., 2012; Lorenzo-López et al., 2008; Lorenzo-López et al., 2011, but see also Lien, Gemperle, & Ruthruff, 2011), which was related to differences in activity to suppress the distractor stimuli. Experimental manipulations have linked the N2pc with processing of the target as well as suppression of the distractor/s (Hickey et al., 2009). Thus, in the present study, non-target suppression-related activity, which occurs when various stimuli that fall within the same receptive field compete for cortical representation (Luck, Girelli, Mc Demortt, & Ford, 1997), cannot be entirely excluded. However, considering that in the present study target and non-target appeared in opposite hemifields and separate by 7.5º, it is possible that N2pc basically reflects activity related to target processing. Importantly, differences between age-related modulations of target processing and distractor suppression might be found. Future studies could be specifically designed to explore this possibility.

In summary, the results of the present study using an SRC task showed an age-related slowing in RT. Importantly, the ERP results provided support for the heterogeneity in the patterns of cognitive slowing on each particular process. In fact, although the onset of the attentional shift to the target stimulus (N2pc onset) was preserved with age, the time when that attentional shift is more pronounced (N2pc peak) was delayed in middle-aged and elderly participants relative to the younger group. By contrast, execution of the response (LRP-r) gradually slowed with increasing age. Moreover, although no evidence for declined inhibitory control was found, increased

LRP amplitudes suggested compensatory mechanisms to maintain performance. The lack of differences in interference was related to greater masking of the direction effect by the stimulus position in the older groups. Also, only the younger participants were affected by the perceptual conflict due to the contradictory spatial information conveyed by both irrelevant dimensions in IDCP and CDIP conditions, as revealed by modulations in the N2pc amplitude.

Acknowledgements

This study was financially supported by funds from the Spanish Government: *Ministerios de Educación (Beca FPU AP2007-04362)* and *Economía y Competitividad (PSI2010-22224-C03-03)*, and from the Galician Government: *Consellería de Economía e Industria (10 PXIB 211070 PR), and Consellería de Educación e Ordenación Universitaria (Axudas para a Consolidación e Estruturación de unidades de investigación competitivas do sistema universitario de Galicia. Modalidade: Grupos con potencial de crecemento. Ref: CN 2012/033)*.

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Figure 1: Stimuli presented and response buttons. Participants were instructed to respond by pressing the left button with the left hand when a red arrow appeared, and the right button with the right hand when a blue arrow appeared, so that the conditions presented (from top to bottom rows) were, respectively, as follows: compatible direction and compatible position (CDCP); incompatible direction and compatible position (IDCP); compatible direction and incompatible position (CDIP), and incompatible direction and incompatible position (IDIP). The response buttons were counterbalanced between participants.

Figure 2: The main hypotheses and results are graphically represented through diagrams (light bar chart: young participants; grey bar chart: middle-aged participants; dark bar chart: elderly participants). It was hypothesized an age-related slowing in visuospatial (2.1a) and motor (2.2a) processes. The results showed that the motor execution stage (LRP-r onset) was progressively lengthened with age (2.2b), whereas visuospatial attention processes (N2pc latency) were slowed in middle-aged and elderly regarding young participants but differences were not present between the older groups (2.1b). On the other hand, it was hypothesized an age-related reduction of N2pc amplitude in those conditions where perceptual conflict was present (i.e., IDCP and CDIP) (2.3a) as well as an increased motor interference with age (2.4a). The results showed that only in young participants the N2pc was smaller in those conditions where perceptual conflict was present (2.3b), probably because the arrow direction only affected the performance in the young group (2.4b). S-R interferences did not increase with age (2.4b).

Figure 3: Distributional analyses (DA) of the reaction times are shown for each group of participants. Interference from the CDIP and IDIP conditions was present independently of the speed of response for the three groups of age. In IDCP, interference was present for young participants in QIP1, QIP2, and QIP3. For middle-aged participants interference in the IDCP was manifested at slow responses (QIP3, and QIP4). Interference in IDCP was not observed in elderly participants.

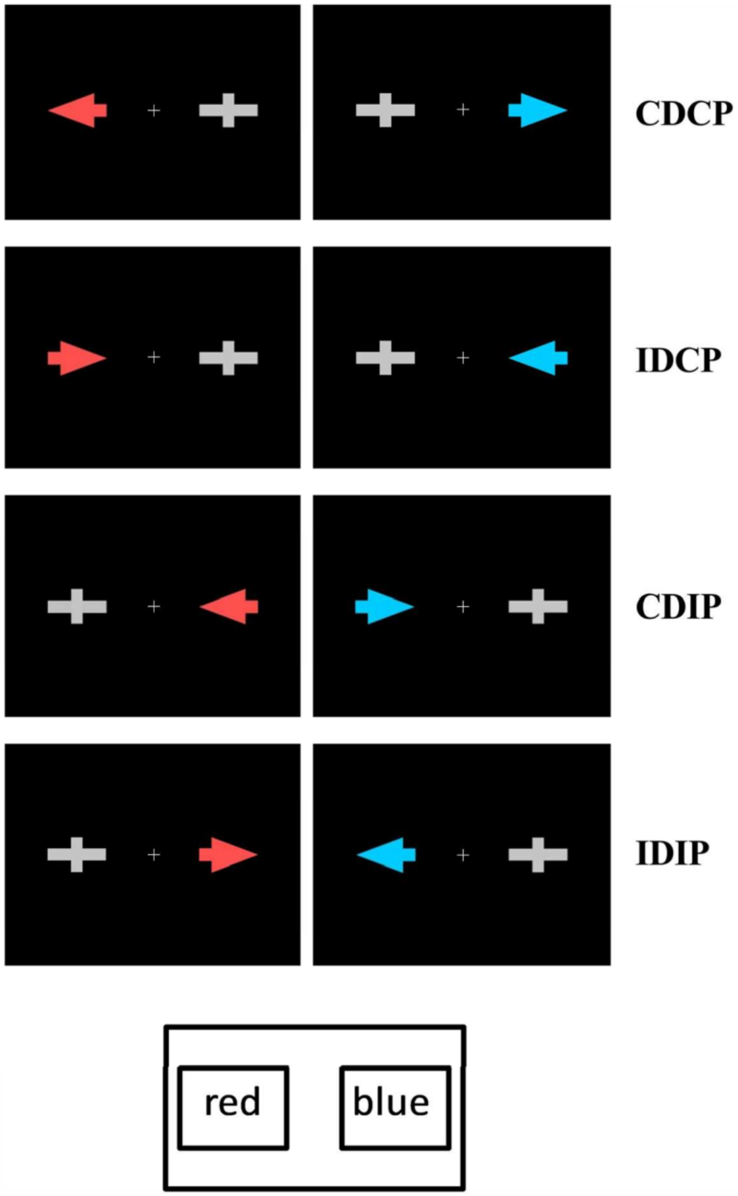
Figure 4: Response-locked lateralized readiness potential (LRP-r) is represented for the three groups of participants: young (grey solid waveform), middle-aged (black solid waveform), and elderly (black dashed waveform) in the four conditions of the task (CDCP, IDCP, CDIP and IDIP). The LRP-r onset latency was recorded (as the point

where the negative trend in the waveform begins). The LRP-r onset was earlier in middle-aged and elderly than in young participants, as indicated by longer time for response execution in middle-aged and elderly than in young participants. The LRP-r onset was also earlier in elderly than in middle-aged participants, indicating prolonged response execution in elderly relative to the middle-aged participants.

Figure 5: Stimulus-locked lateralized readiness potential (LRP-s) at the C3/C4 electrode pair is represented for the three groups of participants: young (grey solid waveform), middle-aged (black solid waveform) and elderly (black dashed waveform) in the four conditions of the task (CDCP, IDCP, CDIP and IDIP). LRP-s latency (300-650 ms) was slower in conditions in which behavioural interference was observed. The LRP-s latency also slowed with aging in accordance with the behavioural data.

Figure 6: Negativity posterior contralateral (N2pc) at the PO7/PO8 electrode pair is represented for the three groups of participants: young (grey solid waveform), middle-aged (black solid waveform), and elderly (black dashed waveform) in the four conditions of the task (CDCP, IDCP, CDIP and IDIP). The N2pc peak latency was longer in middle-aged and elderly than in young participants, indicating that the electrophysiological activity associated with visuospatial processing of the target stimulus was delayed in middle-aged and elderly relative to young participants. There were no differences in N2pc latency between middle-aged and elderly participants. In young participants, the N2pc amplitude was smaller in IDCP/CDIP than in CDCP/IDIP, which suggests interference in processing stimuli with conflictive spatial information. HEOG was also graphically represented (light waveforms: right side ocular movements; dark waveforms: left side ocular movements).

Figure 7: Scatter plots and regression lines for RT (top), LRP-r (middle) and N2pc (bottom) values on the age of each participant in the middle-aged and elderly groups. The corresponding coefficient of correlation between years of age and respectively RT, LRP-r and N2pc is shown at the top right hand side of each graph.



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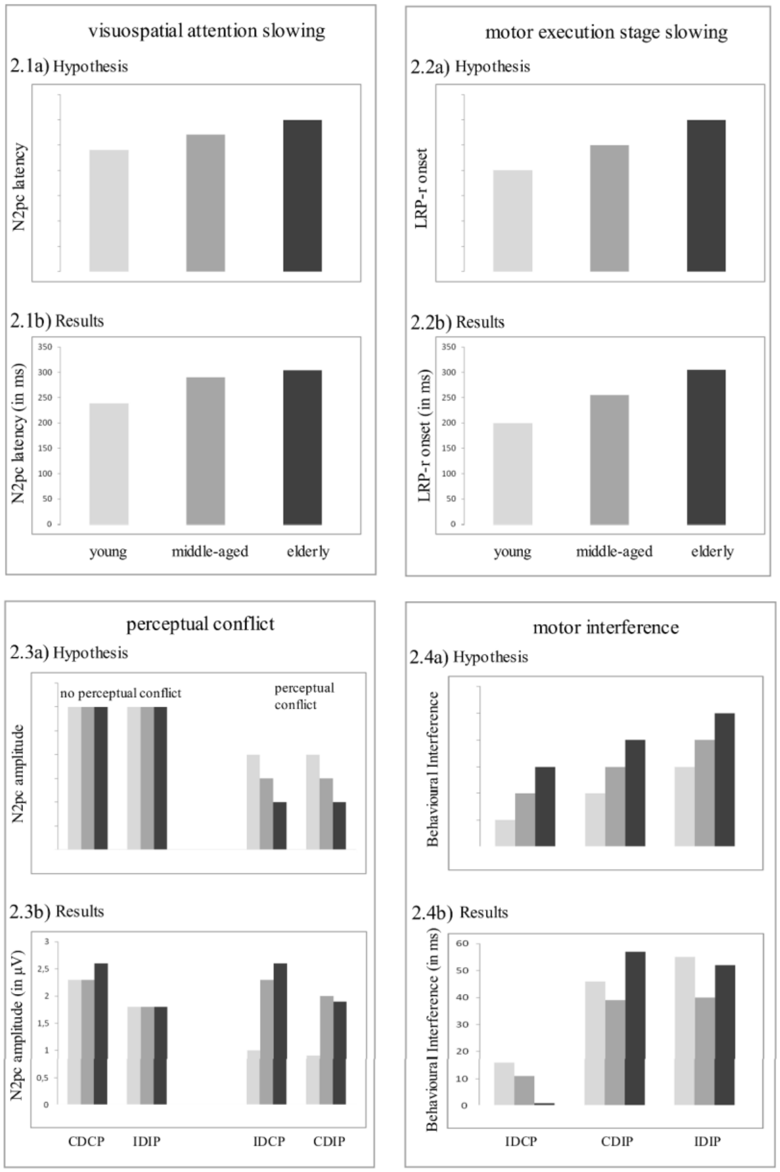

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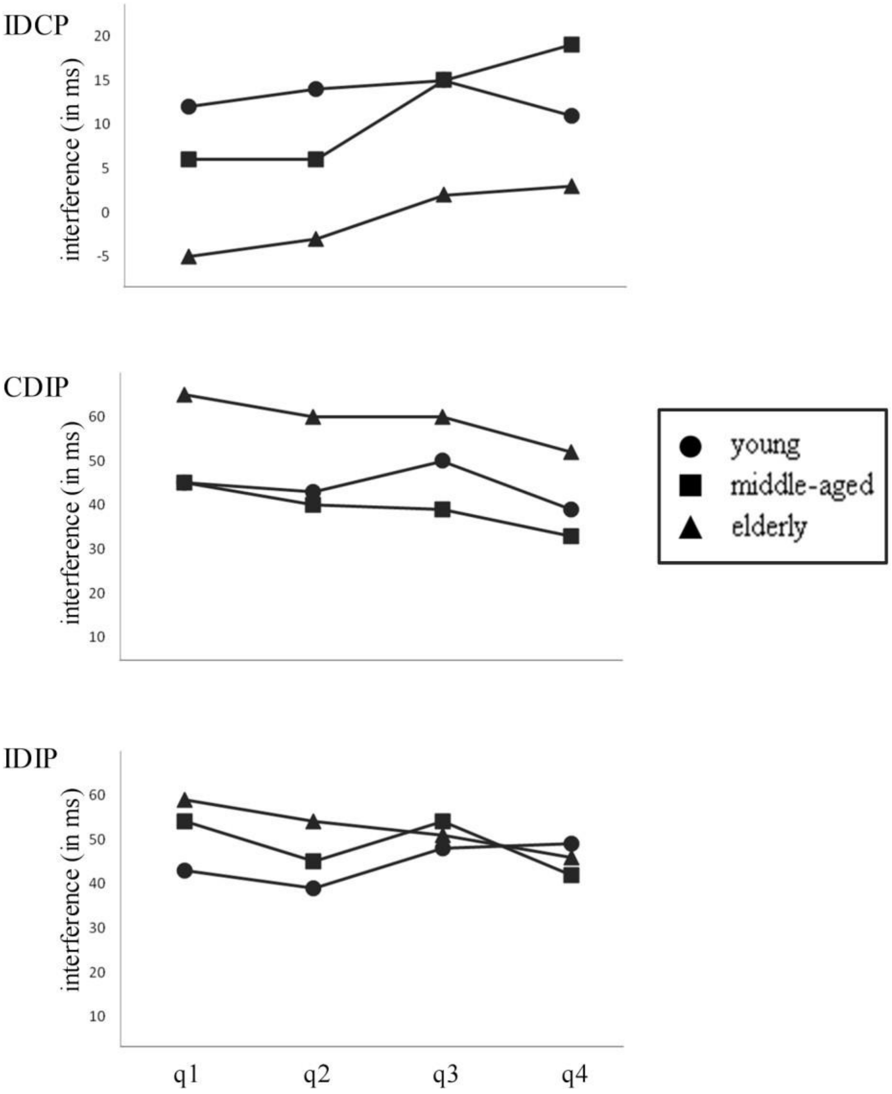

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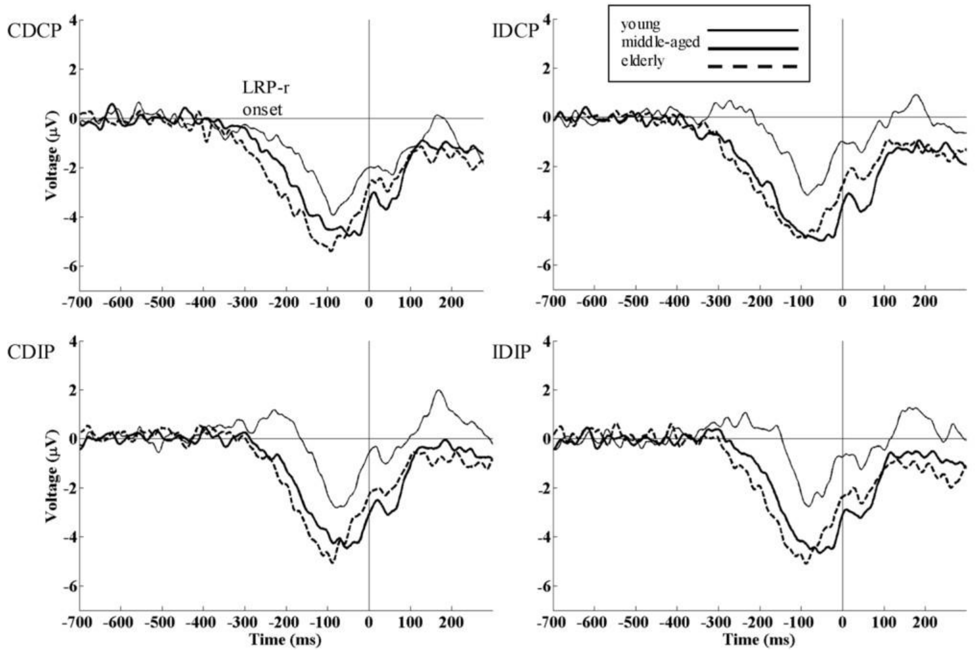

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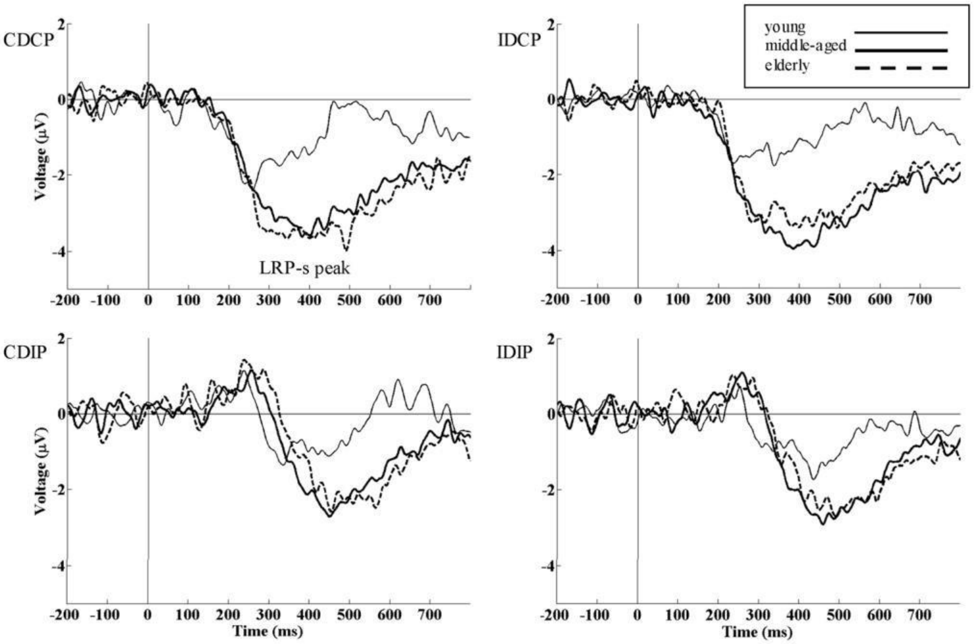

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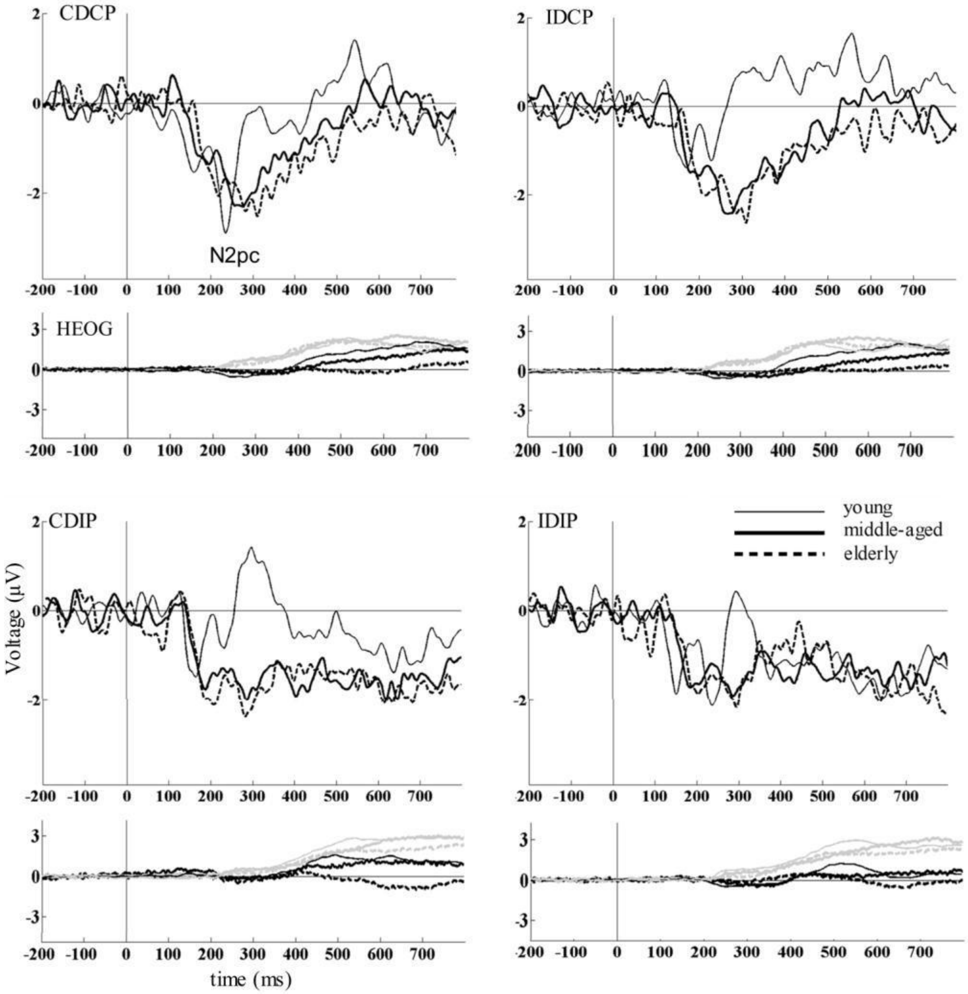

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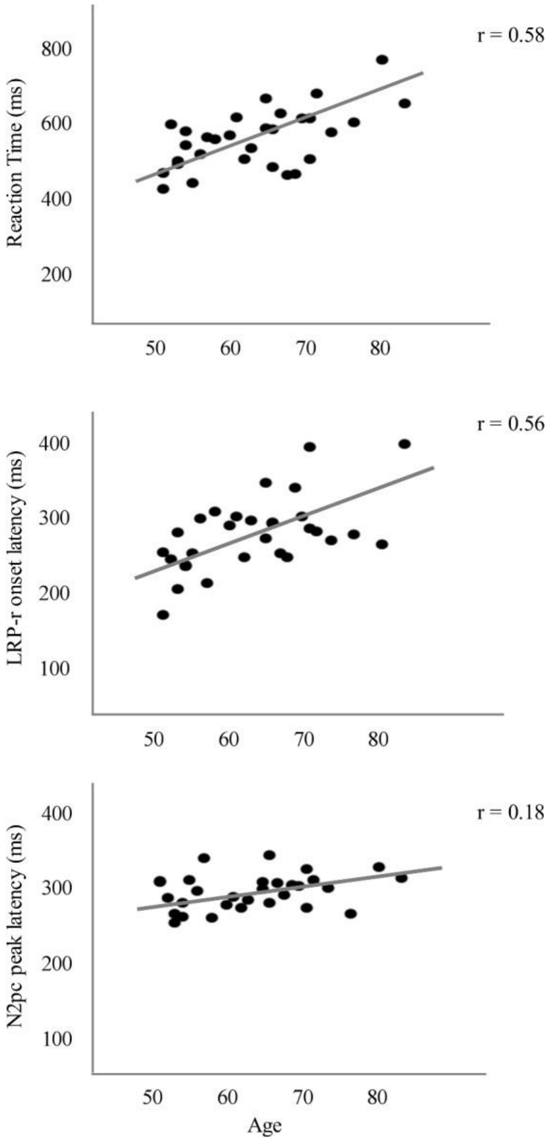

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277x553mm (300 x 300 DPI)

	Sample size	**Females / Males**	**Range age**	**Average age**	**Years of schooling**
Young	15	10 / 5	19-23	20.5 (1.2)	14.4 (4.3)
Middle-aged	15	10 / 5	51-63	56.0 (4.5)	14.4 (1.2)
elderly	15	10 / 5	65-84	71.1 (5.9)	13.4 (3.5)

Table 1- The Table recaps the main characteristics of the sample: size of the sample in each group of participants, number of females and males (respectively), and range of age used in each group. Mean and standard deviation values are provided for age and years of schooling.

	RT	**PE**	**N2pc lat**	**N2pc amp**	**LRP-r onset**	**LRP-s lat**	**LRP-s amp**
CDCP young	404 (41)	2.9 (2.7)	240 (26)	-2.3 (1.5)	-245 (60)	349 (36)	2.2 (1.7)
IDCP young	420 (50)	4.0 (2.9)	233 (31)	-1.0 (0.9)	-211 (53)	398 (66)	2.0 (1.1)
CDIP young	450 (42)	6.4 (5.0)	241 (28)	-0.9 (1.2)	-174 (59)	404 (76)	1.9 (1.4)
IDIP young	459 (47)	9.4 (4.7)	240 (19)	-1.8 (1.0)	-168 (47)	412 (80)	1.9 (1.9)
CDCP middle-aged	511 (70)	1.5 (1.5)	277 (29)	-2.3 (1.8)	-290 (56)	402 (59)	4.1 (1.4)
IDCP middle-aged	522 (62)	2.8 (3.1)	295 (26)	-2.3 (1.5)	-280 (50)	409 (58)	4.3 (1.3)
CDIP middle-aged	550 (69)	3.9 (4.2)	289 (31)	-2.0 (1.4)	-228 (50)	472 (54)	3.4 (1.6)
IDIP middle-aged	551 (59)	4.5 (7.2)	299 (43)	-1.8 (1.4)	-222 (37)	487 (64)	3.6 (1.5)
CDCP elderly	573 (92)	1.3 (2.0)	310 (35)	-2.6 (1.5)	-341 (59)	457 (74)	4.2 (2.3)
IDCP elderly	573 (87)	1.9 (2.9)	302 (22)	-2.6 (1.9)	-326 (82)	458 (75)	3.7 (1.9)
CDIP elderly	630 (86)	6.1 (5.3)	300 (31)	-1.9 (2.5)	-273 (56)	539 (76)	3.2 (1.6)
IDIP elderly	625 (85)	5.0 (3.4)	304 (36)	-1.8 (1.8)	-279 (55)	536 (92)	3.1 (1.8)

Table 2- Mean and standard deviation, for each Condition (Compatible Direction-Compatible Position (CDCP), Incompatible Direction-Compatible Position (IDCP), Compatible Direction-Incompatible Position (CDIP) and Incompatible Direction-Incompatible Position (IDIP)) and group of Age: young (19-23 years old), middle-aged (50-64 years old) and elderly (older than 65 years old) of Reaction Time (in milliseconds); Percentage of Errors (PE); peak latency and averaged amplitude (±30 ms around peak) of N2pc at PO7/PO8 electrodes pair; onset of the response-locked lateralized readiness potential (LRP-r) at C3/C4 electrodes pair; peak latency and averaged amplitude (±30 ms around peak) of the stimulus-locked lateralized readiness potential (LRP-s) at C3/C4 electrodes pair.