Age-related changes in hemispherical specialization for attentional networks

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Abstract

Many cognitive functions face a decline in the healthy elderly. Within the cognitive domains, both attentional processes and executive functions are impaired with aging. Attention includes three attentional networks, i.e., alerting, orienting, and executive control that showed a hemispheric lateralized pattern in adults. This lateralized pattern could have a role in modulating the efficiency of attentional networks. For these reasons could be relevant to analyze the age-related change of hemispheric specialization of attentional networks. This study aims to clarify this aspect with a lateralized version of the ANTI-Fruit.

One hundred sixty-seven participants took part in this study. They are divided in three age groups: early adulthood (N=57; Range: 20-30); late adulthood (N=57; Range 31-64) and elderly/older people (N=57; Range: 65-87).

Results confirm the previous outcomes on the efficiency and interactions among attentional networks. Moreover, an age-related generalized slowness was evidenced.

These findings also support the hypothesis of a hemispheric asymmetry reduction in elderly/older adults. This pattern could partially explain the decrease in attentional functioning in elderly/older age.

Keywords: Attention; Attentional Networks; Alerting; Orienting; Executive Control; Aging; Lateralization;

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Introduction

Cognitive functions develop during life span [1,2]. In early adulthood, these processes reach their maximum expansion, which results in optimal performance in cognitive tests [1]. When aging advances, there is a physiological decline, which involves physical and cognitive dimensions, interfering with daily routines (e.g., executive functions) [1].

Some factors appear to compensate for this physiological decline, as a healthy lifestyle, characterized by adequate physical activity, good eating behaviors [3], absence of alcohol or smoking habits [4], optimal cognitive reserves [5], and optimal level of blood pressure [6].

Since the aging process is inter-individually different, the functional decline does not happen for all people in the same way. Some results underline that, generally, elderly people preserve some cognitive skills, such as language and crystallized intelligence (i.e., knowledge of general facts). Conversely, other cognitive processes deteriorate; i.e., processing speed [7], executive functions [8], memory [9], psychomotor skills [10], and attention [11].

Specifically, attention has a fundamental role in cognitive functioning, allowing to carry out some daily activities that request aware environmental information processing.

Posner and Petersen [12,13] identified three attentional networks involved in selective attention and associated with different anatomical brain regions (i.e., orienting, alerting, and executive control). Particularly the orienting system, located in the parietal cortex, involves direct attention toward space, focusing on specific stimuli (i.e., detecting environmental details). The executive control, located in the prefrontal cortex and anterior cingulate cortex, allows solving and controlling conflicts between expectations, stimuli, and responses. This network requires perceiving and recognizing the stimulus by selecting a single response among many possibilities. Finally, the alerting system, located in the right hemisphere, allows for greater activation and consequently higher responsiveness to stimuli. It is related to arousal systems and sustained attention favoring faster responses to stimuli.

To assess simultaneously the three different attentional systems suggested by Posner and Petersen's attention model, several authors adopted the Attention Network Test (ANT) [14]. The ANT combines the spatial cueing task [15] with the flanker task [16], helping in the analysis of the attentional functioning in its complex interactions with specific brain areas [12, 13, 17].

The ANT, or some of its variants, has been adopted in several populations (e.g., adults, adolescents, children, and clinical population; [18-25]. Considering aging, ANT has demonstrated that older people are less accurate and generally slower than younger [26-29].

Analyzing specifically each attentional network in aging, the results are inconsistent. The orienting network seems to be deeply conditioned by the typical slowdown of aging. Accordingly, studies

reported slower reaction times and a greater benefit of spatial cues in elderly people. However, once the reaction times were adjusted for the general slowdown, there were no significant differences in the performances between elderly and young people [30-32]. Moreover, no difference between elderly and young in their ability to re-orient attention was evidenced both adopting central versus spatial cue [27, 28, 29, 30, 32] and invalid versus valid cue [28]

Considering the executive control, elderly people appear to benefit more from the congruent condition [27, 29-32]. Nevertheless, this effect disappears when reaction times are corrected for the generalized slowdown.

Finally, concerning the alerting network, most studies have shown no advantage of the warning signal in increasing attentional performances in older people; on the contrary, they would seem disturbed by the acoustic signal [27, 29-32].

An aspect not properly investigated would seem the hemispheric lateralization of attentional networks, which could be affected by the aging process.

The first hypothesis about lateralization of the attentional systems has been proposed in studies on neglect. These studies had shown that front-parietal damage in the right hemisphere produced less attention to objects placed in the left visual field [33].

On this line, several authors have highlighted that healthy population experiences a similar pattern (i.e., pseudoneglect) [34] and tends to shift more attention to the left visual field, which involves activation of the right contralateral hemisphere [35, 36]. The preference for the left visual field, demonstrated mainly through visual-spatial tasks (e.g., [37, 38], would confirm the greater responsibility of the right hemisphere in spatial attention. Although, a superiority of the right hemisphere in sustained attention was also evidenced with tasks that did not involve visual stimuli [39-41].

To distinctly assess the three attentional networks in each hemisphere, Greene and his colleagues (2008) developed a lateralized version of the ANT: The Lateralized Attentional Network Task (LANT). In this task, targets were presented in the right or left visual field, providing a measure of the three networks in each hemisphere (according to Kornad et al., 2005 [42]). Additionally, invalid spatial cues were included to assess attentional costs and benefits of orienting, and the warning signal was acoustical, according to a revised version of the ANT [43].

This first study using LANT showed that both hemispheres sustain the three attentional networks [44]. Similar results were found by Poynter et al. (2010)[45]. Other studies proved the dominance of the right hemisphere in the attentional systems [46-48]. These results are consistent with clinical and imaging data showing clear right hemisphere dominance for attentional functions in both visual and auditory modalities [49-53]

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The nature of the stimuli can modulate the efficiency of attentional networks and differently involve the hemispheric control. Interaction between executive control and orienting reduces the interference of distractors when a spatial cue is present [48]. Using a different version of the ANT with non-directional stimuli, such as fruits (ANT-F) [24] instead of arrows, it has been demonstrated that directional stimuli can increase the difficulty in resolving the conflict [24]. Furthermore, a lateralized version of the ANT-F (LANT-F) revealed that the three attentional networks interact only when the stimuli are presented in the Left Visual Field (Right Hemisphere), but not when they are presented in the Right Visual Field (Left Hemisphere). These findings highlight the preeminent role of the right hemisphere in modulating the best attentional performance when all attentional networks are simultaneously involved.

For these reasons, the ANTI-F could be effective in assessing attentional systems in the elderly.

The brain organization changes over time [54-56], and these modifications can compromise the efficiency of attentional networks, to understand hemispheric lateralization changes in aging appear relevant.

A recent review by Friedrich and colleagues (2018) showed a decrease in the tendency to be more sensitive to stimuli presented in the left visual field in elderly people confirming brain changes related to aging with decreased right hemisphere specialization for spatial attention [57]. This finding demonstrates a reduction of hemispheric asymmetries in the elderly [58,59], which may be due to a neural reorganization and a decrease in right hemisphere dominance for attention in the elderly and older people.

Aims

This study aimed to explore the aging effects of the three attentional systems determining whether age influences all three attentional networks or specifically affects one of them. Moreover, we intended to verify age effects on the hemispheric asymmetry of attentional networks. Assuming that the use of non-directional stimuli might be more suitable to assess efficiency and interactions of attentional networks, LANTI-F was used to compare the role of the right and left hemispheres on the modulation of the attentional networks in young, middle-aged, and elderly/older adults. According to previous results [25], we expected to confirm an asymmetric attentional performance in young and middle-aged; according to recent data [57], this asymmetrical pattern should disappear in elderly/older people.

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2. Method

2.1 Participants

One hundred eighty-nine people voluntarily took part in the study. Considering LANTI-F accuracy, ten of them were excluded from the study. The final sample was composed by fifty-seven university students (female/male: 39/18; mean age =23.46 ± 2.08; Range: 20-30), fifty-seven middle-age adults (female/male: 39/18; mean age = 55.26 ± 7.54; Range: 31-64) and fifty-seven older adults (female/male: 39/18; mean age = 71.82 ± 5.88; Range: 65-87). Participants reported normal or corrected to normal vision, and all of them were naive to the purpose of the experiment.

2.2 Cognitive status

The Mini-Mental State Examination (MMSE) [60] was used to assess global cognitive status. Participants who scored ≤ 24 on the MMSE corrected by age and educational level were not included in the current study.

Lateralized Attention Network Test for Interaction-Fruit (LANTI-F)

2.3 Apparatus

Stimuli were programmed and displayed by E-Prime software on a 17" monitor with a screen resolution of 1024 × 768 pixels. Responses were collected through the mouse, and headphones were used to administer the auditory alerting tones. A chinrest was fixed at 56 cm from the monitor to guarantee the appropriate head position of participants.

2.4 Stimuli

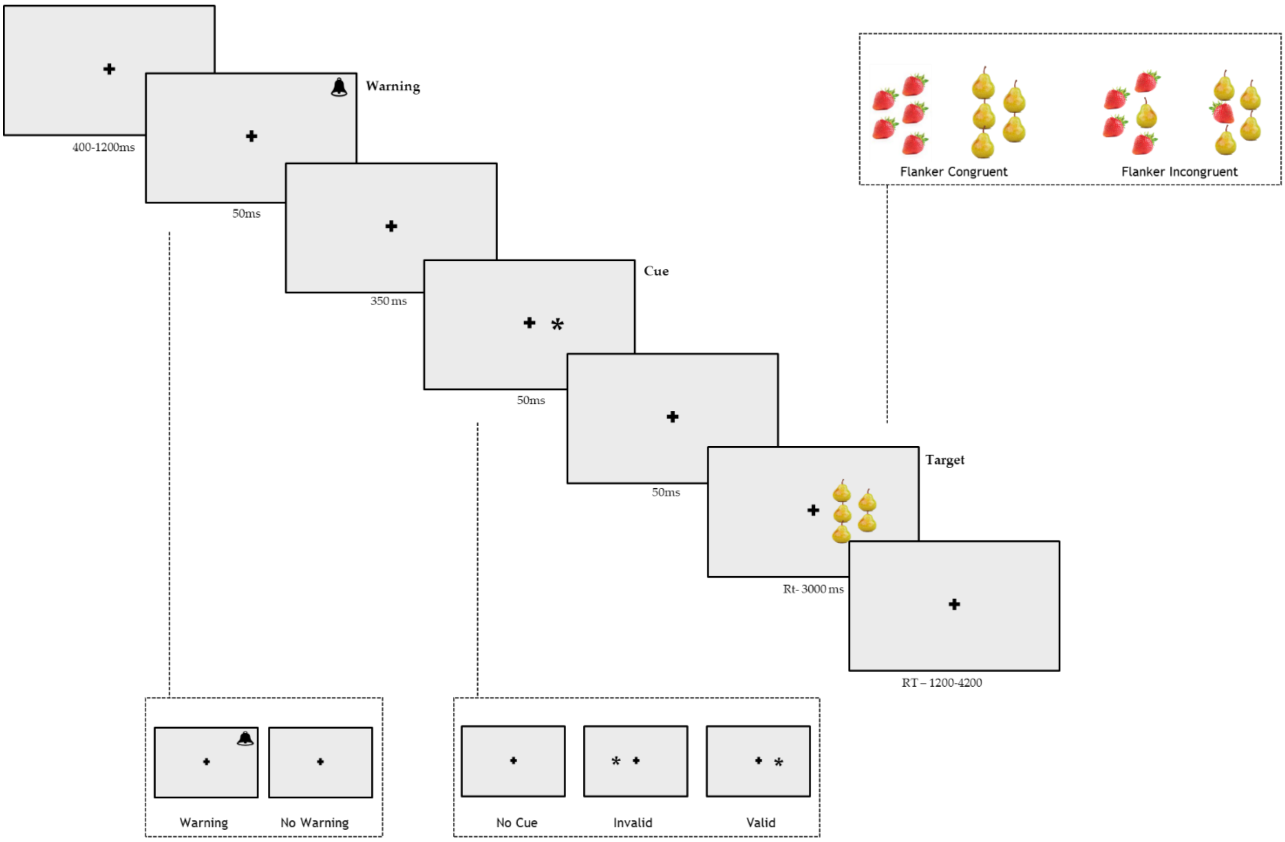
Each trial began with a central cross of 1° (degrees of visual angle). The stimuli consisted of red strawberries and yellow pears, presented on a grey background. They were positioned with the four flankers that overlapped the border of an imaginary semicircle where the target was at the centre [24,25]. This choice was made to ensure that all flankers appeared at the same distance in respect to the central target avoiding any distortion caused by the reduced efficacy of the leftmost and rightmost flanker stimuli in a row [25]. The flanker could be the same as the target (congruent condition) or different (incongruent condition). The cue was an asterisk of 1°, and it could be presented in the same position of the upcoming target (valid cue condition), in the opposite location (invalid cue condition), or it could be absent (no-cue condition). The auditory warning stimulus was 2000 Hz and lasted 50 ms.

2.5 Procedure

Subjects were tested individually in a silent and dimly lit room. Before each trial, the fixation cross was presented for a variable duration (400–1600 ms). The fixation period was followed by a warning stimulus lasting 50 ms in 50% of the trials. After a fixed interstimulus interval (ISI) of 350 ms, a cue of 50 ms was presented. In the valid condition (33% of the trials), an asterisk appeared in

the same position of the upcoming target; in the invalid condition (33%), the target appeared in the opposite position than the one signaled by the cue; in the no-cue condition (33%), no orienting stimulus was presented. The flankers were congruent with the target in half of the trials, while the trials were incongruent in the other half. After a stimulus onset asynchrony (SOA) of 400 ms, target and flankers were presented for 150 ms in the left or right visual field in order to isolate the information to one hemisphere, 5° from the fixation point. Participants had a limit of 1700 ms to respond. The fixation point was at the centre of the screen throughout the trial. The sequence of the events for each trial is shown in Figure 1.

Figure 1. Schematic of trial in the LANTI-F



Procedure

Participants performed one practice block of 16 trials, followed by four experimental blocks of 144 trials each. Overall, participants completed 48 valid trials, 48 invalid trials, and 48 no-cue trials for each flanker and warning condition. Trials were randomly presented within each block. The entire experiment comprised 576 trials, for a total duration of around 20 minutes.

Participants were instructed to fixate the central cross and discriminate the fruit on the semicircle center. Half of the participants responded with the left button of the mouse when the pear was the target and with the right button when the strawberry was the target, while the other half of the participants performed the opposite condition.

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General procedure

The experiment was performed following the ethical standards of the Declaration of Helsinki. The Institutional Review Board of the Department of Psychology (Protocol number 0001063) approved the study.

After participants signed the informed consent, the MMSE was administered. Then participants performed the LANTI-F.

2.6 Data Analysis

A power analysis a priori was conducted to define the total sample size, considering medium effect size. An average sample of 90 (30 for each group) participants was considered adequate for this study.

For the analyses of LANTI-F, only the RTs of correct responses ranging between 200 ms and 1400 ms were considered. People who reported accuracy lower than 50% were excluded from the analysis (1,5%).

An Age *group* (Early Adulthood, Late Adulthood, Elderly/Older) × *Visual Field* (Left, Right) x *Warning* (No-warning, Warning) × *Cue* (Invalid cue, No-cue, Valid cue) × *Flanker* (Congruent, Incongruent) analysis of variance (ANOVA) was conducted on RTs of the correct responses.

To estimate the lateralization of each attentional system, an Age group x Visual hemifield ANOVA was conducted on the *orienting effect* (RTs invalid-cue − RTs valid-cue), the *conflict effect* (RTs incongruent trials − RTs congruent trials), and the *alerting effect* (RTs no-warning − RTs warning) [14, 43, 61, 62]. A high score of orienting effect reflects the ability to rapidly orient the attention towards the targets appearing in the cued positions. A smaller conflict effect reflects the ability to inhibit the interfering effect of distractor stimuli (flankers). The alerting effect represents the benefit of alerting on the speed of the response to the target. To limit the more challenging conditions that could increase inter-hemispheric activity [63], the alerting effect was calculated excluding the invalid and incongruent conditions; the orienting effect was computed disregarding the incongruent conditions, and the conflict effect was estimated, without considering the invalid trials.

To analyze the relationship between age and lateralization of attentional effects, a correlation analysis (Pearson's r) was conducted between the attentional effects in the right and left visual field and age; while standard linear regression analyses have evaluated whether age influenced attentional effects differently in the right and left visual field.

ANOVAs and correlational analyses were conducted with Statistica 10.0, and an α value of 0.05 was used to establish statistical significance, while regression analysis was conducted using SPSS v.25.

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3. Results

The three groups significantly differ in age ($F_{2,168}$= 1078.4; p<0.0001; η2= 0.93), years of education $F_{2,168}$= 9.7; p<0.0001; η2= 0.19), and MMSE ($F_{2,168}$= 11.37; p<0.0001; η2= 0.12). The means and standard deviations of age, years of education and MMSE scores for each group are shown in Table 1.

Table 1. Means and standard deviations of age, year of education and MMSE for each group of participants.

Group	Age	Years of education	MMSE
Early adulthood	23.46 ± 0.75	16.39 ± 0.55	27.66 ± 0.17
Late Adulthood	55.26 ± 0.75	14.35 ± 0.55	27.85 ± 0.17
Elderly/Older	71.82 ± 0.75	13.16 ± 0.55	26.80 ± 0.17

3.1 Lateralized Attentional Network Test for Interaction- Fruit (LANTI-F)

The mean RTs for each experimental condition in both left and right visual fields are shown in Table 2, separately for the three age groups. The overall accuracy for the Left visual field was 93,74% (±7,13%) and for the Right Visual Field was 93,66% (±7,17%).

Table 2. Mean reaction times (in ms) and standard deviations of the three age groups of participants for each condition and each visual field.

			Early Adulthood		Late Adulthood		Elderly/Older	
			RVF	LVF	RVF	LVF	RVF	LVF
No-Warning	Congruent	Valid	643.04 ±17.9	610.9 ±16.15	742.89 ±17.9	736.58 ±16.15	815.36 ±17.9	817.95 ±16.15
		Invalid	650.03 ±15.04	645.13 ±14.79	765.56 ±15.04	779.87 ±14.79	855.51 ±15.04	857.44 ±14.8
		No-cue	648.64 ±14.86	635.56 ±15.57	776.61 ±14.86	763.4 ±15.57	838.16 ±14.8	834.87 ±15.57
	Incongruent	Valid	656.06 ±16.02	668.05 ±15.71	803.84 ±16.02	809.71 ±15.71	882.91 ±16.01	875.07 ±15.71
		Invalid	708.5 ±16.85	705.71 ±16.51	844.68 ±16.85	847.53 ±16.52	938.19 ±16.85	924.01 ±16.52
		No-cue	693.67 ±17.65	706.66 ±15.98	826.95 ±17.65	823.68 ±15.99	912.13 ±17.65	899.79 ±15.99
Warning	Congruent	Valid	573.28 ±15.07	585.23 ±16.06	696.09 ±15.07	713.58 ±16.05	759.4 ±15.07	761.34 ±16.05
		Invalid	608.13 ±14.88	617.36 ±15.22	754.77 ±14.88	730.55 ±15.23	824.2 ±14.8	815.33 ±15.23
		No-cue	577.61 ±16.39	580.80 ±15.17	693.28 ±16.39	686.44 ±15.17	779.1 ±16.39	756.6 ±15.17
	Incongruent	Valid	633.73 ±15.44	624 ±13.71	782.53 ±15.44	760.05 ±13.71	831.46 ±15.44	814.86 ±13.71
		Invalid	689.98 ±16.6	697.49 ±16.48	825.7 ±16.6	814.42 ±16.48	913.7 ±16.6	917.88 ±16.48
		No-cue	641.57 ±16.05	645 ±16.88	791.2 ±16.05	779.29 ±16.88	870.44 ±16.05	862.25 ±16.88

LVF: Left Visual Field; RVF: Right Visual Field

The ANOVA on RTs showed the significant main effects of *Age groups* ($F_{2,168}$=62.77; p<0.0001; η2= 0.43), *Warning* ($F_{1,168}$=289.16; p<0.0001; η2=0.62), *Cue* ($F_{1,168}$=144.77; p<0.0001; η2= 0.46), and *Flanker* ($F_{1,168}$=400.33; p<0.0001; η2= 0.70).

Planned comparisons revealed that the Early Adulthood group was faster than both Late Adulthood ($F_{4,165}$= 2,16; p<0.0001) and Elderly/Older ($F_{5,164}$= 1,17; p<0.0001) groups, and Late Adulthood group was faster than Elderly/Older group ($F_{4,165}$= 2.48; p<0.0001).

Furthermore, participants were faster in the warning than no-warning condition, and they were faster when the flanker was congruent than incongruent. Participants were also faster in valid compared to invalid ($F_{1,168}$=239.61; p<0.0001) and no-cue ($F_{1,168}$=45.27; p<0.0001) trials.

The main effect of *Visual Field* was marginally significant ($F_{1,168}$=3.18; p=0.08; η2= 0.02), showing a tendency of participants to be faster when stimuli were presented in the left than the right visual field (753 vs. 757 ms)

The *Cue* x *Flanker* ($F_{2,336}$= 5.71; p<0.005; η2=0.03) and the *Cue* x *Warning* ($F_{2,336}$=19.91; p<0.0001; η2=0.11), and the *Flanker x Warning* ($F_{1,168}$=15.66; p<0.0001; η2=0.08) interactions were significant. The *Visual Field x Warning x Flanker x Cue* interaction was significant too

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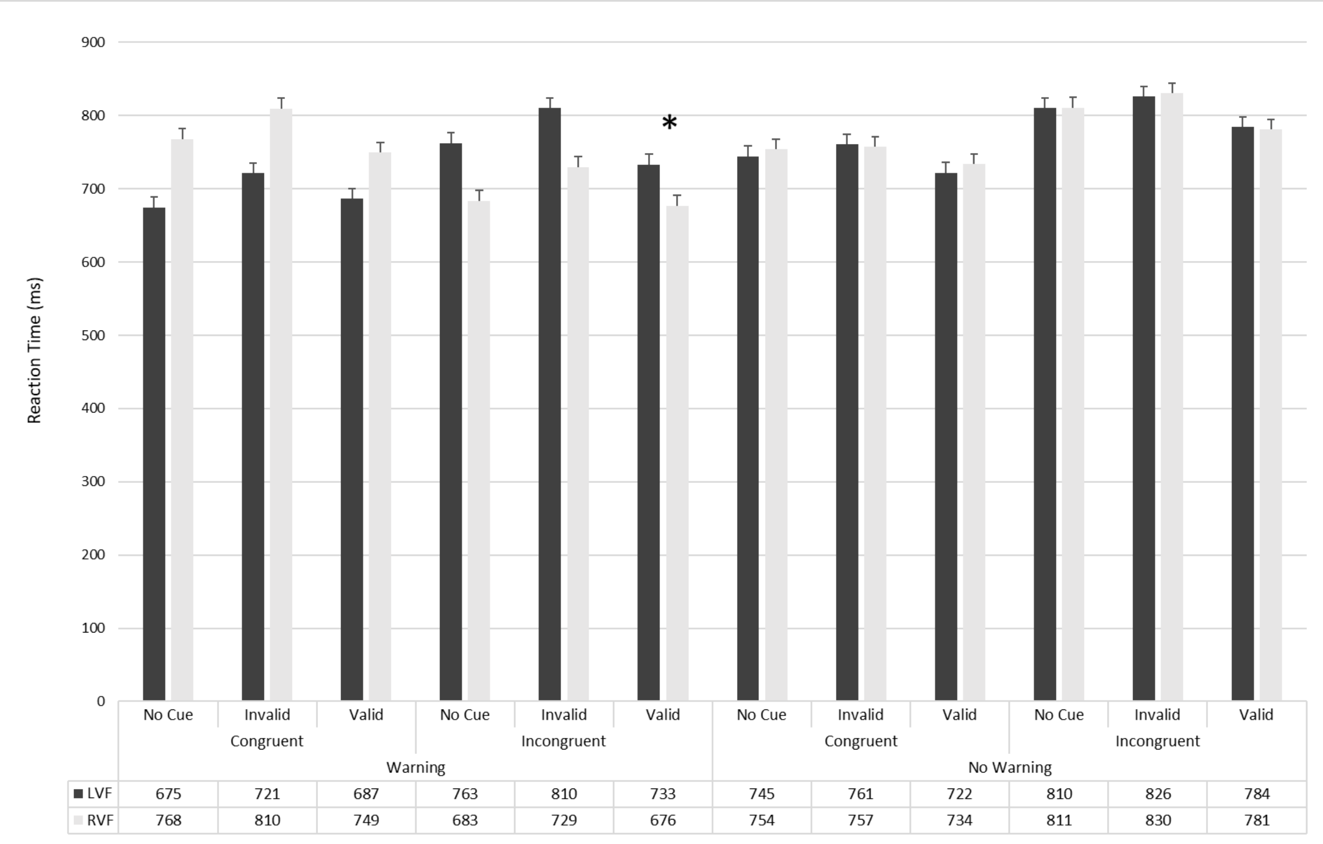
($F_{2,336}$=4.47; p<0.01; η2=0.03): participants were faster in the warning condition when the flanker was incongruent and the cue was valid for the stimulus presented in the left visual field compared to the right visual field (733 vs. 749 ms; $F_{1,168}$= 7.2; p<0.01; Figure 2).

Figure 2. Main reaction times (in milliseconds) for each condition of the LANTI-F, separately for the left (LVF) and right (RVF) visual field.



The *Age Groups* x *Cue* interaction was significant ($F_{4,336}$=3.16; p<0.01; η2=0.03), and showed that each group was faster in valid condition compared to both the invalid (Early Adulthood: $F_{1,168}$=59.9; p<0.0001; Late Adulthood: $F_{1,168}$=56.6; p<0.0001; Elderly/Older: $F_{1,168}$=133.3; p<0.0001) and the no-cue condition(Early Adulthood: $F_{1,168}$=13.7; p<0.002; Late Adulthood: $F_{1,168}$=6.8; p<0.01; Elderly/Older: $F_{1,168}$=28.5; p<0.0001). Each group was also faster in no cue condition, compared to the invalid one (Early Adulthood: $F_{1,168}$=25.88; p<0.0001; Late Adulthood: $F_{1,168}$=34.7; p<0.0001; Elderly/Older: $F_{1,168}$=60.3; p<0.0001). Moreover, Elderly/Older had a greater validity effect (*invalid trials- valid trials*) (880 vs. 820 ms; $F_{1,168}$=133.3; p<0.0001) than both Early Adulthood (665 vs. 624 ms; $F_{1,168}$=59.9; p<0.0001) and Late Adulthood groups (795 vs. 755 ms; $F_{1,168}$=56.6; p<0.0001).

The *Age Groups* x *Flanker type* condition was marginally significant ($F_{2,168}$=2.79; p=0.06). The *Age Groups* x *Warning* ($F_{2,168}$=0.30; p=0.74; η2=0.003) and *Age Groups* x *Visual Field* ($F_{2,168}$=0.84; p=0.43; η2=0.009) interactions were not significant.

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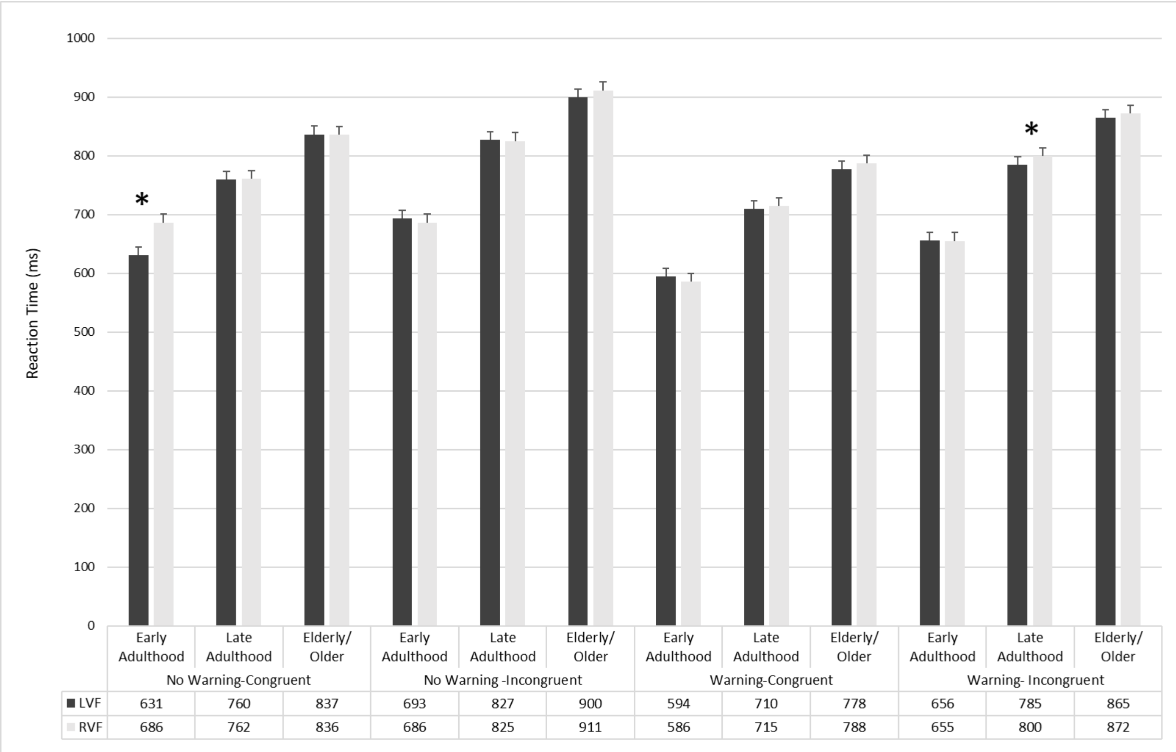
The *Age Groups x Visual Field x Warning x Flanker* interaction was significant ($F_{2,336}$=3.14; p<0.05; η2=0.05) and revealed that early adults were faster in the No-warning condition when a congruent-flanker trial was presented in the left than the right visual field (630 vs. 647 ms; $F_{1,168}$=5.79; p<0.01), while the middle-aged group was faster in the Warning condition when an incongruent flanker trial was presented in the left than the right visual field (784 vs. 800 ms; $F_{1,168}$=4.94; p<0.02). There were no hemispherical differences in the older group (see Figure 3).

Figure 3. Main reaction times (in milliseconds) for the three age groups in the left (LVF) and right (RVF) visual fields as a function of Warning and Flanker types.



3.2 Attentional Effects

To evaluate the age-related changes in the hemispheric lateralization of attentional effects, a preliminary correlational analysis was conducted (Table 3) showing that age correlated with alerting effect in the LFV (r=.19; p <0.01) and with conflict effect in the RVF (r.23; p <0.01; Table 3)

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Table 3. Correlations between age and the three attentional effects for the Left and Right visual field.

			Left Visual Field			Right Visual Field		
		Age	**Alerting**	**Conflict**	**Orienting**	**Alerting**	**Conflict**	**Orienting**
Left Visual Field	**Alerting**	**.19***	-					
	Conflict	.03	**.40***	-				
	Orienting	.01	.14	**.32***	-			
Right Visual Field	**Alerting**	.51	.15	.02	.01	-		
	Conflict	**.23***	.05	**.30***	.09	**.22***	-	
	Orienting	.09	.04	.14	**.17***	**.30***	**.21***	-

*p < 0.01

To further analyze the hemispheric lateralization of attentional effects, an *Age* (Early Adulthood, Late Adulthood, Elderly/Older) *x Visual Field* (Left, Right) ANOVAs were conducted on alerting, conflict, and orienting effects (see Figure 4).

Alerting effect. The *Age x Visual Field* was significant ($F_{2,168}$ =3.40; p=0.04; η2=0.039). Planned comparisons revealed that alerting effect was lateralized in Early Adulthood ($F_{1,168}$=7,54; p= 0.007), but not in Late Adulthood ($F_{1,168}$ =1,89; p=0.17) and Elderly/Older ($F_{1,168}$ =0.82; p=0.37) groups.

Conflict effect. The *Age x Visual Field* was significant ($F_{2,168}$ =3.85; p=0.02; η2=0.04). Planned comparisons revealed that conflict effect was lateralized in Early Adulthood ($F_{1,168}$=9,45; p= 0.002), but not in Late Adulthood ($F_{1,168}$ =0.94; p=0.33) and Elderly/Older ($F_{1,168}$ =0.73; p=0.39) groups.

Orienting effect. The *Age x Visual Field* was not significant ($F_{2,168}$ =0,77; p=0.46; η2=0.009).

Figure 4. The alerting, conflict and orienting effects as function of visual field and age.

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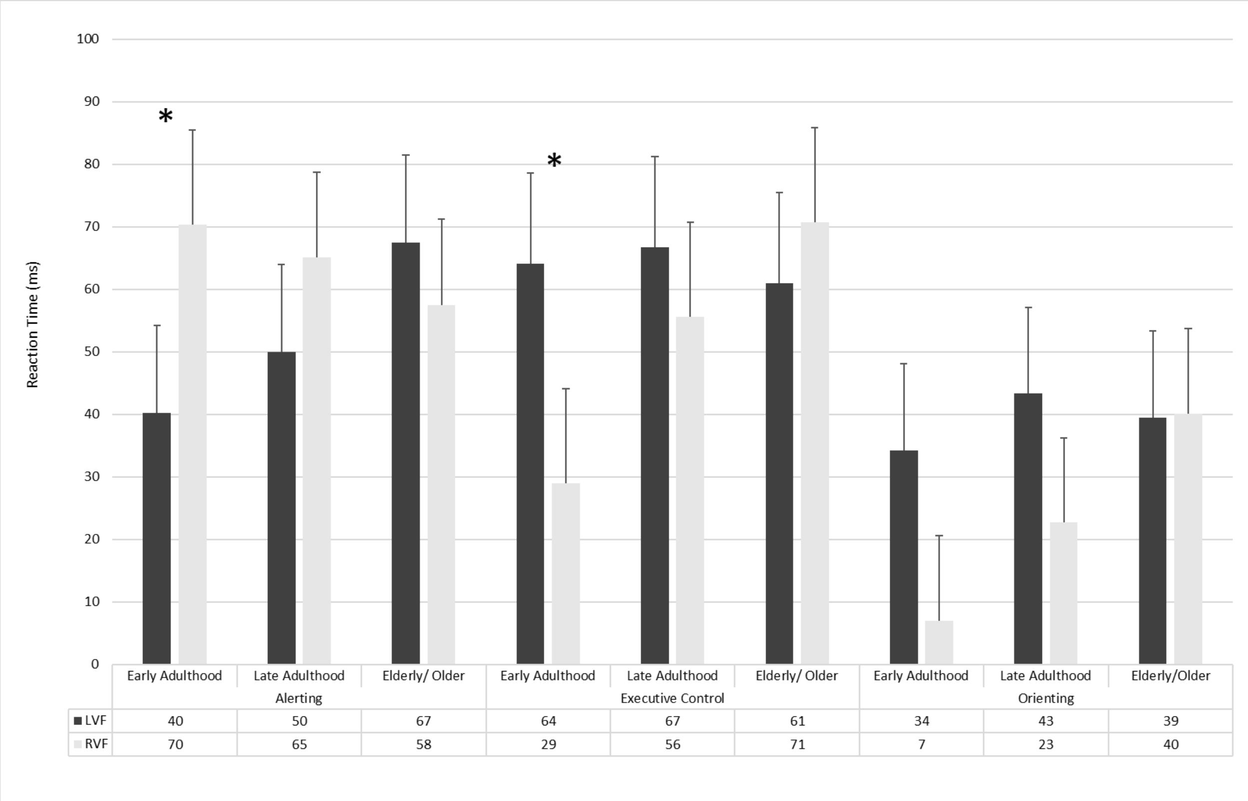

Finally, to examine the latent role of age, linear regressions were conducted by considering age as an independent variable and alerting, conflict, and orienting effects in both left and right visual field as the dependent variables (see Table 4). The regression model that considered the age as an independent variable, revealed a significant effect when alerting in LVF ($F_{1,169}$ =6,50; $p < 0.01$; $R^2 = 0.04$; Adjusted $R^2 = 0.03$) and conflict in the RVF were considered as dependent variables ($F_{1,169}$ =9.27; $p < 0.01$; $R^2 = 0.05$; Adjusted $R^2 = 0.05$).

Table 4. Regression analysis considering age as the independent variable and attentional effects in the left and right visual field as dependent variables

		Model	*B*	Standard error	Beta	*t*	Sign (p =)	95% CI lower	95% CI upper
LVF	**Alerting**	**Age**	**.58**	**.23**	**.19**	**2.55**	**.01**	**.13**	**1.03**
	Conflict	**Age**	-.12	.26	-.03	-.46	-65	-.63	.39
	Orienting	**Age**	-.04	.31	-.01	-.12	.91	-.64	.57
RVF	**Alerting**	**Age**	-.16	.24	-.51	-.66	.51	-.64	.32
	Conflict	**Age**	**.84**	**.27**	**.23**	**3.04**	**.003**	**.29**	**1.38**
	Orienting	**Age**	.48	.40	.09	1.20	.23	-.31	1.27

Discussion

Attentional networks in aging

In this study, we analyzed the age-related change in the hemispherical specialization of the attentional networks adopting a lateralized version of the ANTI, with non-imperative stimuli (i.e., fruits) [25]

The efficiency and interactions among the three attentional networks (i.e., alerting, orienting, and executive control)were confirmed (e.g., [24, 61]). As expected, faster reaction times were found in congruent than incongruent trials, valid than invalid cues, and warning than no-warning conditions. Moreover, an age-related generalized slowness of RTs was observed, confirming a general decline of attentional processes (e.g., [26, 64])

This study revealed a higher conflict effect in the older group, proving a worse executive functioning. Accordingly, conflict control seems to present a linear pattern characterized by a decline during aging, supporting previous evidence that adopted both imperative (i.e., arrow; [27, 29-32] or non-imperative stimuli (i.e., faces [26]).

Regarding orienting network, a linear decrease was underlined. Our results reveal significantly slower reaction times in the elderly than the younger groups in invalid trials, confirming that older people seem to be unable to disengage from an invalid spatial cue and re-orienting attention to an unexpected location. This effect could be due to a difficulty to shift attention to a new location or to a greater cost in disengaging [49, 65, 66].

Unexpectedly the presentation of an alerting stimulus seems not to affect the performance in aging. This result is in contrast to previous studies that identified either an improving [28] or a worsening [27, 29-32] in the performances of older people associated to the alerting stimulus. This difference could be due to the characteristics of the warning signal. In the studies mentioned above, the warning signal was a visual stimulus, while in our study, we adopt an auditory stimulus. Although the acoustic signal, as the visual one, induces a phasic increase of alertness [67], some authors suggested that the auditory modality might generate alertness more automatically than the visual modality [68]. For this reason, LANTI-Fruit may have helped the participants indiscriminately, flattening the differences due to age.

Hemispheric specialization of attentional networks in aging

Concerning hemispheric lateralization, participants tended to respond faster to stimuli presented in the left visual field than those presented in the right one, supporting the dominance of the right

contralateral hemisphere in attention [25,69]. Moreover, the results support the age-related changes of hemispheric specialization of attention observed by other authors [57-59].

The early and the late adulthood groups seem to resolve faster the congruent or incongruent conditions presented in the Left Visual Field. However, only the middle-aged group had an advantage due to the warning signal, supporting the hypothesis that increased alertness improves the ability to respond to stimuli presented in the left visual field [70]. Results of correlational and regression analyses confirmed the age-related changes on alerting effects, showing that alerting signals improve performance with increasing age, but only in the RH.

While the presence of a hemispheric asymmetry in young and middle-aged participants considering the W*arning x Flanker* interactions could support a right hemisphere dominance in the attentional process [46,47]; the absence of lateralization of the attentional network in the elderly would support the hypothesis that the structure and organization of the brain change during healthy aging [54-56].

Moreover, our results could support the hypothesis of decreased hemispheric asymmetry in the elderly due to a compensatory process of age-related physiological decline. Although the younger showed a dominance of the right hemisphere for the alerting system, the older group presented an opposite pattern. This result could be explained by the involvement of the analog area of the intact hemisphere to preserve the attentional process [58, 71, 72].

Our evidence could be explained according to the Right Hemi-Aging Model (RHAM), which hypotheses a faster decline in the right hemisphere compared to the left one [73]. Lower hemispheric specialization in the elderly could be confirmed by the preserved performance in tasks involving language (i.e., in the left hemisphere) [74]. Moreover, in line with the Hemispheric Asymmetry Reduction in Older Adults (HAROLD), this hemispheric asymmetry could be due to a compensatory or to a dedifferentiation process [58, 71,72]. Accordingly, the functions related to the right hemisphere deterioration could be recovered thanks to the involvement of the analog area of the intact hemisphere leading to a lower hemispheric specialization and a more bilateral pattern of hemispheric functioning.

Moreover, the LANTI-F could be not as easier for the elderly as the younger groups. Some studies [63] reported task-related hemispheric lateralization: the increased task complexity and cognitive load would determine bi-hemispheric processing in the elderly, for whom the unilateral processing, characterizing younger groups, would be not sufficient to solve the harder task.

Despite the reported evidence, this study is characterized by some limitations. Firstly, the absence of neurophysiological measures (e.g., EEG; fMRI) precludes us from determining the causal effect between the attentional networks and the neural mechanism. Moreover, it would have been helpful and interesting to compare the three age groups in task with imperative (i.e., LANTI-arrow) and non-imperative (i.e., LANTI-fruits) stimulus, to determine whether the task complexity could have a role in evidence different hemispheric lateralization in healthy aging.

Future studies could explore the hemispheric specialization in healthy aging and the pathological one, as Alzheimer's disease or Mild Cognitive Impairment, in which both executive functioning and attentional processes are compromised [64, 75].

The evidence of this study shows that the lateralization of attentional processes varies in aging. Aging would appear to reduce hemispheric specialization related to attentional processes; future studies could help identify if task-complexity could confirm or extend our results.

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