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ORIGINAL INVESTIGATION

Differential age-related changes in localizing a target among distractors across an extended visual field

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Abstract Age differences in the spatial distribution of attention over a wide field of view have only been described in terms of the spatial extent, leaving the topographical aspect unexplored. This study examined age differences between younger and older adults in good general health in an important topographical characteristic, the asymmetry between the upper and lower visual fields. In Experiment 1, we found age differences across the entire attentional visual field. In addition, age differences were greater in the upper compared to the lower field. In Experiment 2, we examined whether the finding of a greater age difference in the ability to localize a target among distractors in the upper visual field in Experiment 1 was a result of possible differential age differences between the upper and lower visual fields in the ability to localize a target even when there was no distractor competing for attention. Our results suggested that the age differences we observed were linked to age differences in the ability to filter out distractors that compete with the target for attention rather than the ability to process only the target over a wide field of view. While younger adults demonstrated an upper visual field advantage in the ability to localize a target among distractors, there was no such field advantage in older adults. We discuss this finding of diminished upper visual field advantage in older adults in light of an account of pervasive loss of neural specialization with age. We postulate that one possible explanation of age differences in the asymmetry between the upper and lower visual fields may be an adaptation to age-related physical decline. We also discuss important implications of our findings in risks of falls and vehicle crashes.

Keywords Aging · Attentional visual field · Asymmetry · Adaptation

Introduction

Attentional functions such as the ability to select a target among distractors across an extended visual field ("spatial selective attention") decline with age (Ball et al. 1988; Sekuler et al. 2000). This decreased ability among older adults has been associated with higher risks in everyday tasks, such as collisions with obstacles during walking (Di Fabio et al. 2005), self-reported falls (Owsley and McGwin 2004), unsafe on-road driving, and increased self-reported motor vehicle crashes (Clay et al. 2005).

Spatial selective attention may be illustrated by parameters of the attentional visual field. This field represents the spatial coverage of selective attention within one fixation.

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Research on age-related changes in the attentional visual field has focused on the reduction of its field size with age (e.g., Ball et al. 1988; Clay et al. 2005). However, size is not the only parameter of the attentional visual field that predicts performance on cognitive and daily activities. The shape of the field could be asymmetrical and even irregular, making a significant negative impact on visual search (Chan and So 2007), and also possibly on daily functions. Given the same vertical extent, horizontally elongated attentional visual fields, as opposed to more symmetrical circular fields, have been associated with better performance on a range of visual and attentional tasks (Hassan et al. 2008). In addition, drivers with a smaller vertical extent of the attentional visual field were more likely to fail to stop at a red light (West et al. 2010). Despite the importance of understanding how aging affects the topography of the attentional visual field, research in this area remains sparse. It is still unclear whether there are age-related changes in the topography of the attentional field that can subsequently influence daily functioning. Among younger adults, the ability to detect a target among distractors is better when the target appears in the upper visual field compared to the lower field (Feng and Spence 2014), suggesting an upper field advantage in this age group. In the current study, we examine the effect of age on this upper visual field advantage in attention.

At the neural level, the upper visual field advantage among younger adults may be linked to distinctive cortical representations of the upper and lower visual fields in the ventral and dorsal processing streams (Previc 1990). Despite considerable cross-talk, the ventral and dorsal processing streams are dedicated to specific perceptual and attentional functions (Goodale and Milner 1992). Considering the distinctive functional specializations of the two visual fields, associations have been proposed between the upper visual field and the ventral stream, and between the lower visual field and the dorsal stream (Previc 1990). Referred to as the extrapersonal space, better performance in the upper visual field has been shown in tasks like visual search (Fecteau et al. 2000) and object recognition (Chambers et al. 1999); while the lower visual field, referred to as the intrapersonal space, has an advantage in visually guided movements and motion integration (Danckert and Goodale 2003).

The functional asymmetry resulting from distinctive brain processing may change with age. As we grow older, previously distinctive cognitive functions are more likely to overlap with each other (Hartley et al. 2001), more brain areas are recruited during cognitive processes (Grady et al. 1992), and the functions of different brain regions become less differentiated (Park et al. 2004). As a result, with advancing age, overlapping brain regions may be increasingly activated during previously distinctive cognitive functions. If the neural representations of the upper and lower visual fields also become more similar with age, it is possible that while younger adults show significantly better performance in the upper than the lower visual field (Feng and Spence 2014), older participants will demonstrate a diminished difference between the two fields.

In this study, we measured the ability to localize a target among distractors using the attentional visual field (AVF) task (Spence et al. 2013; Feng and Spence 2014). In the AVF task, the stimulus display consists of a target (a filled square inside an unfilled circle, Fig. 1a) presented among a group of homogenous distractors (unfilled squares). Participants were informed about the identities of the target and distractors which could provide top-down guidance on the deployment of attention (Wolfe et al. 2003). When looking for a singleton target (i.e., signal) among homogenous distractors (i.e., noise), two components are involved: processing of the signal (e.g., enhancing sensitivity to the target; Maljkovic and Nakayama 1994) and filtering out the noise (e.g., suppressing or inhibiting the processing of distractors which compete with the target for attention; Gaspar and McDonald 2014). Therefore, the upper visual field advantage in the AVF task among younger participants (Feng and Spence 2014) could be due to a greater capability in the upper visual field in processing of the signal, or filtering out the noise, or both.

Our first experiment compared the ability to localize a target among distractors in the upper and lower visual fields among younger and older adults. We hypothesized that while younger adults would demonstrate an upper field advantage in the ability to localize a target among distractors, older adults would show a much weaker or no advantage of the upper visual field. Our second experiment examined whether there is an upper field advantage in the ability to localize a target without distractors (thus, only signal processing but no noise filtering) in younger and older participants, which may contribute to an upper visual field advantage in the ability to localize a target when distractors are present (when both signal processing and noise filtering were needed). If younger and older participants do not differ in visual field advantage in finding a target without distractors, this cannot be a cause of the differential age differences in visual field advantage in the ability to localize a target among distractors.

Experiment 1

Methods

Participants

48 participants were recruited from the local community for this study. Half were younger adults (age range: 20–35;

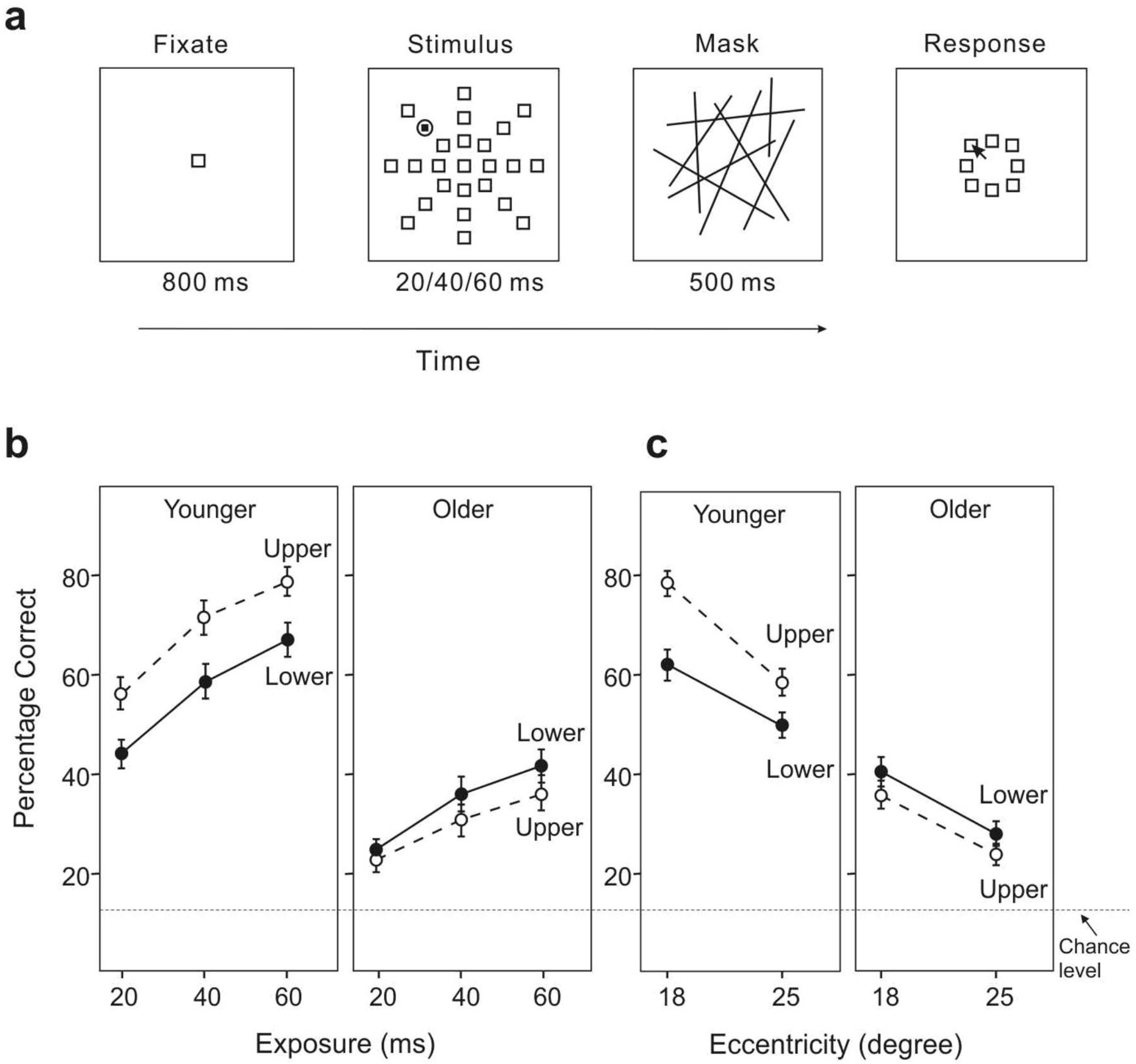

Fig. 1 **a** A sample trial of the attentional visual field (AVF) task. **b** Percentages correct as a function of exposure in the upper (U) and lower (L) halves of the visual field, for younger participants (*left panel*) and older participants (*right panel*). **c** Percentages correct as a function of eccentricity for younger and older participants. The *error bars* represent ±1 standard error. Chance level is 12.5 % (randomly selecting one direction among eight directions in the AVF task)

mean age: 25.0 years; 12 men and 12 women) and the other half were older adults (age range: 60–75; mean age: 68.1 years; 12 men and 12 women). Participants had a minimum of 12 years of education, normal or corrected-to-normal vision, and no self-reported history of neurological disorders or visual pathologies. When needed, participants used glasses or contact lenses. Only mono-focal lenses were used.

Tasks

In the AVF task (Fig. 1a), the stimuli were presented in a circular area (53.0° diameter) centered on a uniform light-gray screen. Participants viewed the screen at a distance of 40 cm restrained by a headrest which consisted of a chinrest and a head bar. Thus, both viewing distance and viewing angle (face being parallel to the plane of the display) were restrained. Each trial began with a centered, unfilled fixation square with a dark-gray border (2.7° × 2.7°). The fixation square was presented for 800 ms. Then the stimulus display appeared, which consisted of 15 identical distractors and one target, each uniquely localized at an eccentricity of 18° or 25° in one of eight equally spaced directions. The location of the target was randomly selected for each trial, subject to the restriction that the target appeared an equal number of times in each possible location. The target was a dark-gray filled square (1.4° × 1.4°) surrounded by an unfilled circle with a dark-gray circumference (2.7° × 2.7°). The distractor squares were unfilled squares with dark-gray borders (2.7° × 2.7°), identical to the fixation square. The stimulus display was presented for 20, 40, or 60 ms, followed by a mask of randomly oriented lines for 500 ms. The durations of the stimulus display were determined based on our previous research (Feng and Spence 2014) and results from pilot testing to ensure suitable difficulty levels for both younger and older participants. At the end, a response display appeared with eight buttons indicating the eight directions. Participants reported the direction of the target by clicking on the corresponding button after the mask disappeared (Fig. 1a). The next trial started 1000 ms after a response was made. Participants completed 288 experimental trials, which were divided into three equal blocks of 96 trials. Participants were instructed to be both accurate and fast.

Design

We adopted a mixed between–within repeated measure design. The within-participant design factors were stimulus exposure (20/40/60 ms), target eccentricity (18°/25°), and visual field (upper: directions ↖↑↗; lower: directions ↙↓↘). The between-participant factor was age (younger/older).

Results

The data were analyzed using a mixed between–within 2 × 3 × 2 × 2 repeated measures ANOVA (between-subject factor: age; within-subject factors: exposure × eccentricity × visual field).

Effect of age

There was a significant effect of age, with older participants performing less accurately than younger participants (older—32 %, younger—62 %; Fig. 1b, c), $F(1,46) = 64.55$, $p < 0.01$.

Effect of exposure

Results showed a significant effect of exposure, with accuracy being higher with increasing exposure (20 ms—36 %, 40 ms—49 %, 60 ms—56 %; Fig. 1b), $F(2,92) = 147.43$, $p < 0.01$. In addition, there was a significant interaction between age and exposure, with older participants benefiting less from increasing exposure (younger: 20 ms—49 %, 40 ms—64 %, 60 ms—72 %; older: 20 ms—24 %, 40 ms—33 %, 60 ms—39 %), $F(2,92) = 5.95$, $p < 0.01$. Subsequent analyses on each age group revealed a significant effect of exposure in both the older and younger groups, with both older and younger participants benefiting from increasing exposure: older, $F(2,46) = 41.96$, $p < 0.01$; younger, $F(2,46) = 121.33$, $p < 0.01$.

Effect of eccentricity

There was a significant effect of eccentricity, with overall accuracy decreasing with increasing eccentricity (18°—54 %, 25°—40 %; Fig. 1c), $F(1,46) = 96.07$, $p < 0.01$. There was no interaction between age and eccentricity, $F(1,46) = 1.56$, $p = 0.22$. Additional analyses showed a significant effect of eccentricity in both the older and younger groups: older (18°—38 %, 25°—26 %), $F(1,23) = 46.91$, $p < 0.01$; younger (18°—70 %, 25°—54 %), $F(1,23) = 50.03$, $p < 0.01$.

Effect of visual field

The main effect of visual field did not reach significance, $F(1,46) = 1.03$, $p = 0.32$. However, there was a significant interaction between age and visual field, with a differential pattern among older and younger participants (older: upper—30 %, lower—34 %; younger: upper—68 %, lower—56 %; Fig. 1b, c), $F(1,46) = 4.40$, $p < 0.05$. Subsequent analyses revealed that older participants were less accurate than younger participants in both the upper visual field, $F(1,46) = 50.71$, $p < 0.01$, and the lower visual field, $F(1,46) = 14.98$, $p < 0.01$. Among younger participants, there was a significant effect of visual field, with greater accuracy in the upper visual field, $F(1,23) = 5.24$, $p < 0.05$; but among older participants, no effect of visual field was found, $F(1,23) = 0.58$, $p = 0.47$.

Discussion

Results from Experiment 1 showed a greater age-related difference in target localization with the presence of distractors in the upper visual field. Compared to younger adults who demonstrated an advantage of localizing a target among distractors when the target appeared in the upper visual field, older adults did not show such an advantage. While this could be due to a greater age difference in filtering out the distractors in the upper visual field, it could also be a result of greater age difference in the ability to process the target in the upper visual field. As proposed by a signal detection theory model (Wolfe et al. 2003), when signal-to-noise ratio is much larger than 1.0, meaning that the signal and noise distributions are largely separate, attention would be almost always deployed to the target first, thus enhancing target processing. When there were no distractors, but only the target presented in the visual field, the signal-to-noise ratio is maximized. If the greater age difference in target localization in the upper visual field shown in Experiment 1 was due to a differential age difference in the upper and lower visual fields in the ability to process the target, we would observe a greater age difference in the upper visual field when only a target but no distractor is presented. However, if there is no age difference in the ability to process the target (without filtering out the distractors), or the age difference is comparable between the upper and lower visual fields, the greater age difference in target localization in the upper visual field is likely due to a greater age difference in the ability to filter out distractors that compete with the target for attention in the upper visual field.

In Experiment 2, we examined the ability to localize a target with distractors (involving both target processing and filtering of distractors) and without distractors (only target processing) between the upper and lower visual fields in both younger and older adults. Thus, in addition to the experiment trials where distractors were present (same as in Experiment 1), we added trials where only a target was shown without distractors. Performance on trials when only a target was presented reflects how well participants processed the target.

Experiment 2

Method

Participants

24 younger participants (age range: 18–23; mean age: 19.7 years; 15 men, 9 women) and 24 older participants (age range: 65–74; mean age: 68.4 years; 12 men, 12 women) were recruited from the local community. Participants had a minimum of 12 years of education, normal or corrected-to-normal vision, and no self-reported history of neurological or vision disorders. When needed, participants used glasses or contact lenses. Only mono-focal lenses were used.

Among the 24 older participants, 12 (age range: 66–74; mean age: 69.3 years; 6 men, 6 women) were recruited in the second phase of data collection of this experiment during which additional tests were administrated: Mini-Mental State Examination (MMSE) and a gaze test. The MMSE score was at least 28/30 for these participants, showing no sign of cognitive impairment. All participants completed the gaze test with ease. No participants in Experiment 2 had previously participated in Experiment 1.

Tasks

AVF The AVF task was identical to the one used in Experiment 1 except that (1) the stimulus display was presented for 30 or 60 ms, and (2) in addition to distractor-present trials (as used in Experiment 1), distractor-absent trials were also included (Fig. 2a). Due to the large number of combination of conditions, we reduced the levels of stimuli exposure from 3 levels in Experiment 1 to 2 levels in this experiment (30 or 60 ms). Participants completed 192 distractor-absent trials (only the target was presented) and 192 distractor-present trials (both the target and 23 distractors were presented), in four counterbalanced blocks.

MMSE The MMSE (Folstein et al. 1975) was administered to participants by the experimenter. The experimenter observed participants' responses and coded the score of each question accordingly.

Gaze Test Participants were first instructed to fixate at the center of the screen, and then directed their gaze toward instructed locations as quickly as possible. These locations were at the corners of the stimulus presentation area. They were above, below, left of, and right of the display center by 26.5° of eccentricity. The experimenter pointed to the instructed location and observed if participants were able to direct their gaze with ease.

Design

We adopted a mixed between–within repeated measure design. The within-participant design factors were distractor presence (absent/present), stimulus exposure (30/60 ms), target eccentricity (18°/25°), and visual field (upper: directions ↖↑↗; lower: directions ↙↓↘). The between-participant factor was age (younger/older).

Results

Accuracy was analyzed using a mixed between–within $2 \times 2 \times 2 \times 2 \times 2$ repeated measure ANOVA (between-subject factor: age; within-subject factors: distractor presence × exposure × eccentricity × visual field).

Effect of age

There was a significant main effect of age, with older participants performing less accurately than younger participants (older—59 %, younger—82 %; Fig. 2b–e), $F(1,46) = 56.10$, $p < 0.01$.

Effect of distractor presence

There was a significant main effect of distractor presence, with accuracy being higher when there was no distractors (distractor-present—45 %, distractor-absent—93 %), $F(1,46) = 719.97$, $p < 0.01$. In addition, there was a significant interaction between age and distractor presence, with older participants being more impacted by the presence of distractors (older: target only—90 %, with

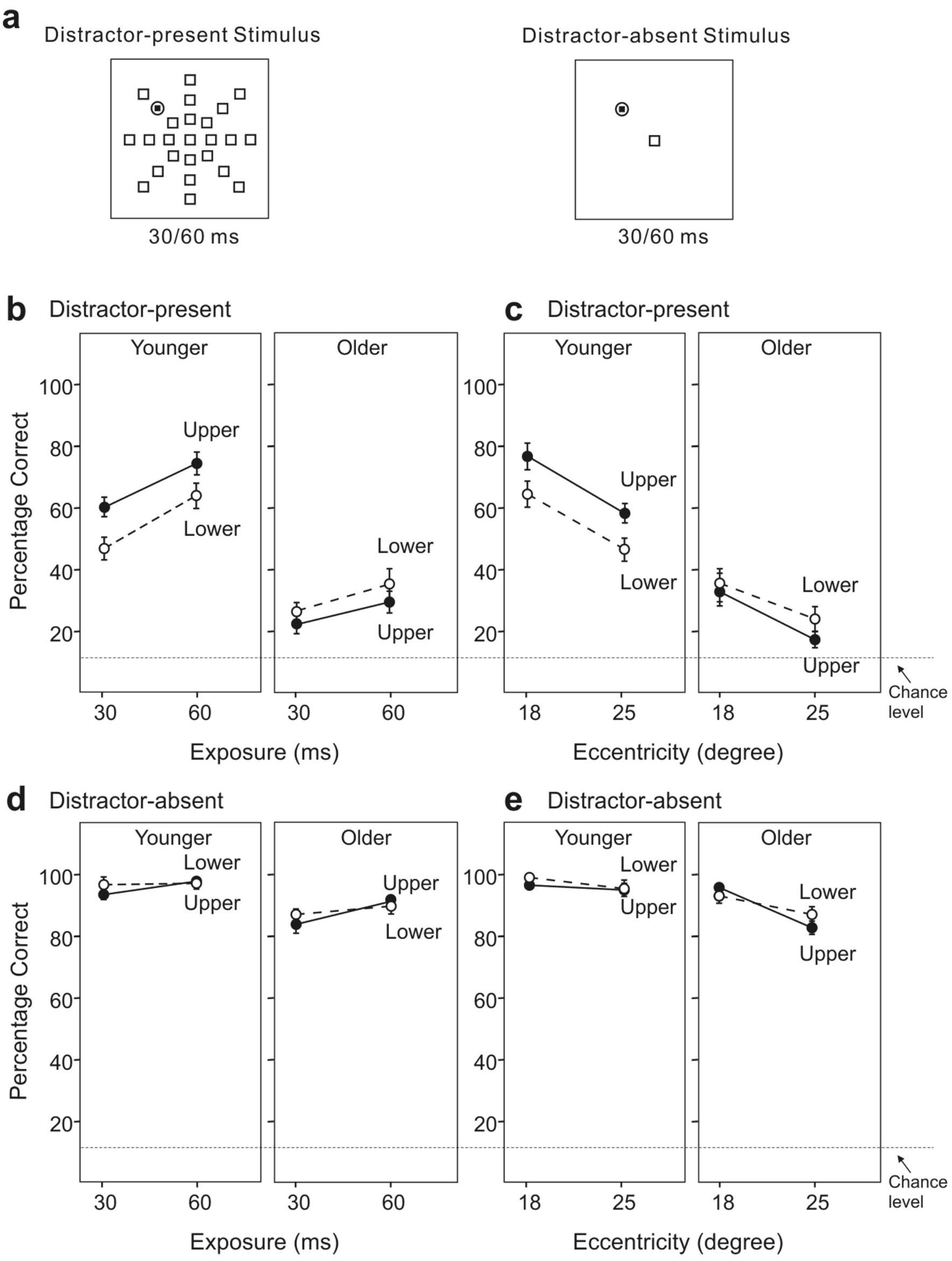

Fig. 2 **a** Sample stimuli of the distractor-absent condition and the distractor-present condition in the attentional visual field (AVF) task. **b** Percentages correct as a function of exposure in the upper (U) and lower (L) halves of the visual field, for the distractor-present condition in younger adults (*left panel*) and older adults (*right panel*). **c** Percentages correct as a function of eccentricity for the distractor-present condition in younger adults (*left panel*) and older adults (*right panel*). **d** Percentages correct as a function of exposure in the upper (U) and lower (L) halves of the visual field, for the distractor-absent condition in younger adults (*left panel*) and older adults (*right panel*). **e** Percentages correct as a function of eccentricity for the distractor-absent condition in younger adults (*left panel*) and older adults (*right panel*). The error bars represent ±1 standard error. Chance level is 12.5 % (randomly selecting one direction among eight directions in the AVF task)

distractor—28 %; younger: target only—96 %, with distractor—61 %), $F(1,46) = 56.14$, $p < 0.01$. Subsequent analyses on each age group showed a significant effect of distractor presence in both the older and younger groups, with both the older and younger adults performing less accurately when distractors were presented (Fig. 2b, c): older, $F(1,23) = 591.95$, $p < 0.01$; younger, $F(1,23) = 186.11$, $p < 0.01$.

Effect of exposure

Results also showed a significant main effect of exposure, with accuracy being higher with the longer exposure (30 ms—65 %, 60 ms—73 %; Fig. 2b, d), $F(1,46) = 159.09$, $p < 0.01$. There was no interaction between age and exposure, $F(1,46) = 2.64$, $p = 0.11$, suggesting that the effect of exposure was similar in younger and older participants (older: 30 ms—56 %, 60 ms—63 %; younger: 30 ms—74 %, 60 ms—83 %). There was a significant interaction between distractor presence and exposure (distractor-present: 30 ms—39 %, 60 ms—51 %; distractor-absent: 30 ms—91 %, 60 ms—95 %), $F(1,46) = 55.44$, $p < 0.01$, showing a greater effect of exposure when the distractors were present. In addition, there was a significant three-way interaction among age, distractor presence, and exposure, $F(1,46) = 26.26$, $p < 0.01$. In the older group, the effect of exposure was comparable when distractors were present or absent (distractor-present: 30 ms—24 %, 60 ms—32 %; distractor-absent: 30 ms—87 %, 60 ms—93 %), $F(1,23) = 2.39$, $p = 0.14$; while in the younger group, the effect of exposure was observed when distractors were present (30 ms—54 %, 60 ms—69 %), but not when distractors were absent (30 ms—95 %, 60 ms—98 %), $F(1,23) = 90.64$, $p < 0.01$.

Effect of eccentricity

There was a significant main effect of eccentricity, with accuracy being higher at the smaller eccentricity (18°—75 %, 25°—64 %; Fig. 2c, e), $F(1,46) = 112.69$, $p < 0.01$. There was no interaction between age and eccentricity, $F(1,46) = 0.47$, $p = 0.50$, suggesting that the effect of eccentricity was similar in younger and older participants (older: 18°—65 %, 25°—53 %; younger: 18°—84 %, 25°—74 %). There was a significant interaction between distractor presence and eccentricity (distractor-present: 18°—53 %, 25°—37 %; distractor-absent: 18°—96 %, 25°—90 %), $F(1,46) = 23.91$, $p < 0.01$, revealing a greater effect of eccentricity when the distractors were present. The three-way interaction among age, distractor presence, and eccentricity was also significant, $F(1,46) = 9.71$, $p < 0.01$. In the older group, the effect of eccentricity was comparable in both distractor-present (18°—35 %, 25°—21 %) and distractor-absent conditions (18°—95 %, 25°—85 %), $F(1,23) = 1.77$, $p = 0.20$; while in the younger group, the effect of eccentricity was quite visible when distractors were present (18°—71 %, 25°—52 %), but not when distractors were absent (18°—98 %, 25°—95 %), $F(1,23) = 28.90$, $p < 0.01$. The three-way interaction among distractor presence, exposure, and eccentricity was also significant, $F(1,46) = 6.79$, $p = 0.01$. Subsequent analyses revealed a greater effect of eccentricity at the shorter exposure when only the target was presented (30 ms: 18°—95 %, 25°—87 %; 60 ms: 18°—98 %; 25°—93 %), $F(1,47) = 10.44$, $p < 0.01$, while the effect of eccentricity was comparable between the two exposures when distractors were also present (30 ms: 18°—46 %, 25°—32 %; 60 ms: 18°—50 %; 25°—35 %), $F(1,47) = 1.64$, $p = 0.21$.

Effect of visual field

There was no overall effect of visual field (upper—70 %, lower—68 %), $F(1,46) = 0.43$, $p = 0.52$. However, the interaction between age and visual field was significant, $F(1,46) = 4.36$, $p = 0.04$, with older adults showing a general reduced accuracy difference between the upper and lower visual fields than the younger adults (older: upper—58 %, lower—61 %; younger: upper—82 %, lower—76 %). In addition, there was a significant three-way interaction among age, distractor presence, and visual field (Fig. 2b–e), $F(1,46) = 9.06$, $p < 0.01$. Subsequent analyses revealed that older participants were less accurate than younger participants in both the upper visual field, $F(1,46) = 73.28$, $p < 0.01$, and the lower visual field, $F(1,46) = 18.05$, $p < 0.01$. Older adults had comparable accuracy in the upper and lower visual fields when distractors were present (upper—26 %, lower—30 %), $F(1,23) = 1.15$, $p = 0.30$, and when distractors were absent (upper—90 %, lower—91 %), $F(1,23) = 0.18$, $p = 0.67$. In contrast, younger adults performed more accurately in the upper visual field when distractors were present (upper—71 %, lower—52 %), $F(1,23) = 6.64$, $p = 0.02$, while no differences were found between the visual fields when only the target was presented (upper—96 %, lower—97 %), $F(1,23) = 2.98$, $p = 0.10$. Furthermore, there was also a marginally significant three-way interaction among age, eccentricity, and visual field, $F(1,46) = 3.77$, $p = 0.06$. In the older group, the difference between the upper and lower visual fields was not comparable between the two eccentricities (18°: upper—65 %, lower—51 %; 25°: upper—51 %, lower—56 %), $F(1,23) = 4.42$, $p = 0.05$. In contrast, in the younger group, the difference between the upper and lower visual fields was comparable between the two eccentricities (18°: upper—87 %, lower—82 %; 25°: upper—77 %, lower—71 %), $F(1,23) = 0.18$, $p = 0.67$.

Comparing older adults recruited during two phases

As described earlier, half of the older participants in this experiment were recruited in the second phase of data collection during which MMSE and the gaze test were administered. The other half of the older participants were recruited in the first phase of data collection without MMSE and the gaze test. To ensure the homogeneity of our older participant group in this experiment, we compared the accuracies of two subgroups of older participants using a mixed between–within $2 \times 2 \times 2 \times 2 \times 2$ repeated measure ANOVA (between-subject factor: testing phase group; within-subject factors: distractor presence × exposure × eccentricity × visual field). There was no overall group difference (phase 1—62 %, phase 2—56 %), $F(1,22) = 1.89$, $p = 0.18$. While there were significant effects of distractor presence [$F(1,22) = 573.89$, $p < 0.01$], exposure [$F(1,22) = 48.56$, $p < 0.01$], and eccentricity [$F(1,22) = 53.84$, $p < 0.01$], there was no effect of visual field [$F(1,22) = 0.93$, $p = 0.35$]. None of the interactions with testing phase group were significant (p ranging from 0.22 to 0.93), suggesting no difference on attention between the two subgroups of older participants.

Discussion

Results from the target-present condition replicated our finding in Experiment 1 that younger adults were better at target localization in the upper visual field than in the lower field, while older adults showed no significant difference in their abilities to localize a target in the upper and lower fields. Older adults recruited in two phases in this experiment showed the same spatial distribution of attention (no difference between the upper and lower visual fields). When there were no distractors competing for attention with the target (thus, only target processing was involved while no filtering of distractors was needed), similar to younger adults, older adults performed comparably when the target appeared in the upper and the lower fields. This finding rules out the possibility that the greater age difference in target localization in the upper visual filed is due to differential age differences in the ability to process a target in the upper and lower visual fields. Rather, the greater age difference in target localization in the upper visual field suggests a greater age difference in the ability to filter out distractors (i.e., noise) that compete for attention with the target (e.g., an age-related decrement in the ability to suppress or inhibit the processing of distractors) in the upper visual field with age, compared to the lower visual field.

General discussion

Consistent with previous findings (Ball et al. 1988; McCalley et al. 1995; Sekuler et al. 2000; McCarley et al. 2012), our older participants did not perform as well as the younger participants on the AVF task. The upper field advantage that is generally observed among younger participants was not seen in the older group. The relatively greater age difference in localizing a target among distractors in the upper visual field reflects differential age differences in filtering out distractors when selecting a target for attentional processing rather than mere target processing.

Filtering out distractors can be achieved by both bottom-up suppression and top-down inhibition of distractors (Whiting et al. 2005). Bottom-up suppression refers to the decreased neuronal response to a strong stimulus when a weak stimulus is displayed in the same receptive field compared to the neuronal response to the strong stimulus when presented alone (Kastner and Ungerleider 2000). The suppression can take place at lower areas such as V1 and higher areas such as TEO of the temporal cortex in the ventral stream, and reflects competition of neuronal response among visual stimuli that are presented within the same neuron's receptive field. Therefore, when multiple stimuli are presented in close proximity, their interference could increase with less spatial separation (Kastner et al. 1998; Pinsk et al. 1999). Although the target and distractors in our AVF task were spatially separated (at least 11° of visual angle between any two stimuli), it is possible that bottom-up suppression could have taken place at a high-level processing area with large neuronal receptive fields. Top-down inhibition refers to the inhibitory effects on distractor features and locations (Braithwaite et al. 2005; Müller et al. 2007), when distractor identity or location information was provided. Findings on age differences in top-down inhibition have been mixed, with some studies showing significant age-related declines (Folk and Lincourt 1996; Lustig et al. 2007), while others suggesting preserved top-down control for older adults (Whiting et al. 2005; Costello et al. 2010) our experiment was not designed to parse out the bottom-up suppression ands top-down inhibition; therefore, the results cannot speak to whether either or both mechanisms contributed to our findings. Further investigation is needed to examine whether bottom-up and top-down mechanisms contributed to our finding of differential age differences in the upper and lower visual fields in the ability to localize a target among distractors.

Another construct that is relevant to our finding of age differences in localizing a target among distractors is visual crowding. Visual crowding refers to the phenomenon that recognition of a peripheral target is difficult due to the perceptual interference from surrounding stimuli (Whitney and Levi 2011), and its effect is strongly mediated by spatial separation between the target and the surrounding stimuli. According to Bouma's law of critical spacing (Bouma 1970), any surrounding stimulus within $0.5\phi^\circ$ of a target at an eccentricity of ϕ° could lead to crowding. In our experiment, for a target appearing at an eccentricity of 17°, an adjacent item could be 8° apart (the item in the same direction but the other eccentricity) or 14° apart (the item in a neighboring direction but the same eccentricity). If there is an effect from crowding, it is likely from the item that is at the same direction but of the other eccentricity, rather than items that are of the same eccentricity. While our current data cannot provide direct evidence on this, the speculation can be examined by presenting stimuli at one rather than two eccentricities (thus, the crowding effect should be largely reduced) and measure the age differences.

The relatively greater age difference in localizing a target among distractors in the upper visual field may be linked to similar observations from other tasks. For example, some studies reported a significant decline with age in spatial ability in the upper visual field (Aubrey and Dobbs 1989; Webber and Charlton 2001), while other studies showed no significant change with age in the lower visual field (Farver and Farver 1982; Mittenberg et al. 1989). This may be partially attributed to a greater decline of spatial attention in the upper visual field, given the important role that attention plays in spatial cognition (Böckler et al. 2011). If information in the upper visual field suffers from a greater loss of attentional processing with aging, it is not surprising that spatial ability is more significantly affected in this part of the visual field.

One possible explanation of the greater age difference in the ability to localize a target among distractors in the upper visual field may be a greater age-related decline in the ability to make upward than downward eye movements or attentional shifts. Older adults have more difficulty making upward saccades compared to downward saccades toward greater eccentricities (Yang and Kapoula 2006). During our tasks in both of our experiments, the short exposures of the stimulus (20–60 ms) did not allow participants to make any eye movement, since an eye movement would in general take at least 200 ms to prepare and execute (Liversedge et al. 2011). However, difficulties in upward eye movement may be associated with difficulties in an altered distribution of spatial attention, given the interactive relationship between attention and eye movements (Kristjánsson 2011). To explore this hypothesis, we reanalyzed our data by excluding the straight up (↑) and straight down (↓) directions. We compared younger and older participants' accuracies in localizing a target among distractors in the upper and lower visual fields by only including the diagonal directions (upper: directions ↖↗; lower: directions ↙↘). If accuracy difference between the straight up and straight down directions was the major contributing factor of our observation of differential age difference between the visual fields, we would expect the results from analyses including only the diagonal directions showing no difference between the two visual fields. However, our results suggested the contrary. In Experiment 1, there was a trend of interaction between age and visual field (younger: upper—72 %, lower—67 %; older: upper—35 %, lower—42 %), $F(1,46) = 3.11$, $p = 0.08$. In the distractor-present condition in Experiment 2, the interaction between age and visual field was significant (younger: upper—76 %, lower—67 %; older: upper—33 %, lower—38 %), $F(1,46) = 4.93$, $p = 0.03$. Results from our analyses do not support the hypothesis that possible age differences in the straight up and straight down directions were the particular cause, although age differences in these two directions may have contributed to the overall age difference.

Another possibility is that a greater age difference in the upper visual field may be an adaptation to physical and perceptual changes with age. With a continuous decline in gait and balance functions with increasing age (Salzman 2010), falling becomes increasingly common among older adults when encountering stair and floor obstacles, often leading to injury, disability, and poorer quality of life (Lord et al. 2001). Successful avoidance of these obstacles depends on detection and identification of hazardous objects in the lower visual field (Di Fabio et al. 2005). Thus, the lower visual field (intrapersonal space) becomes increasingly important for older adults when interacting with the environment (Desrocher and Smith 2005). However, greater age differences have been shown in contrast sensitivity and brightness perception in the lower visual field (McCourt et al. 2015), which could lead to more age-related declines in visual processing in the lower visual field. Less decline in spatial selective attention in the lower visual field may mitigate the effects from these age-related perceptual changes.

A third possible explanation is that the differential aging effect may be attributed to a general reduction of neural specificity in the aging brain (Park et al. 2004). The reduced difference between the upper and lower fields may relate to the decrease of specificity between the dorsal and ventral streams (Grady et al. 1992), and within individual streams (Park et al. 2004) of the visual cortex. Alternatively, the differential aging effect may simply reflect a continuous selective loss of attentional function in the upper visual field as a function of asymmetrical age-related neural losses. Further investigation is necessary to distinguish between these two hypotheses.

In addition to a differential effect of aging on spatial attention between the upper and lower visual fields, our results demonstrated an interesting observation concerning age differences across eccentricity. Our result of no interaction between age and eccentricity when distractors were present from both Experiments 1 and 2 suggests that the effect of age on the ability to identify a target among distractors remains stable across eccentricities. The age-related decline in the spatial distribution of attention has been conceptualized in the literature as a constriction of the attentional visual field (Scialfa et al. 1987; Ball et al. 1988). According to this perspective, there is a greater age-related decline at wider eccentricities, and older adults are only able to attend to a much smaller area of the visual field with each fixation. To support this view, a significant interaction between age and eccentricity factors should be found. However, in both Experiment 1 and the distractor-present condition in Experiment 2, we found a significant effect of age that was independent of eccentricity. Our result supports an alternative view that age-related changes in the attentional visual field represent a reduction of the ability to extract information from the cluttered visual environment (Seiple et al. 1996; Sekuler et al. 2000). Of course, in addition to this reduction, there are other age-related declines in abilities to orient attention in time (Zento et al. 2011), to switch attention from one task to another (Kramer et al. 1999; Kray et al. 2002), and to divide attention among multiple tasks (Ball et al. 1988; Hartley 2001). These changes in various aspects of attention collectively place a negative impact on performance of older adults on daily tasks.

The ability to find a target among distractors across an extended visual field is associated with walking and driving performances. It has been shown that individuals with a decline in attentional abilities have higher risks of falling and motor vehicle collisions (Clay et al. 2005; Di Fabio et al. 2005). Our finding of differential age-related decline in attentional abilities between the upper and lower visual fields provides a further relevant perspective on this issue. It is not yet known how such an uneven decline in attentional functions may affect driving performance, but it seems possible, for example, that older drivers with reduced attentional ability in the upper visual field may experience more difficulty noticing highly placed traffic signs. Future work should seek connections between the observed age-related topographical changes and daily activities such as driving, particularly those driving situations that are most vulnerable to the topographical changes.

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