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Age-dependent distractor suppression across the vision and motor domain

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The ability to inhibit distracting information—distractor suppression—is a fundamental process for the visual and motor systems. Whereas aging is typically linked to a general decline in cognitive processing, a specific impairment in distractor suppression is found during visual attention tasks. Despite this, the effect of aging on a human's capacity to inhibit distracting information during a motor task is currently unknown. Therefore, we tested the ability of young and older adults to inhibit distracting information during a visual attention (global–local) and a motor (reaching) task. When faced with distractors, younger and older adults displayed significant behavioral impairments (accuracy and speed) across both tasks. However, these deficits were substantially enhanced in older adults. Intriguingly, the amount of distractor impairment observed within each participant was correlated across the visual and motor tasks, irrespective of age group. Thus, while all participants' ability to inhibit distractors was correlated across the visual and motor domain, older adults displayed a generalized distractor inhibition deficit. We propose that a shift from proactive to reactive control in older adults could explain such impairment. These results may have important implications regarding the ability of older adults to effectively deal with distractors during complex visuomotor tasks such as driving.

Introduction

Normal aging is known to be associated with a degree of cognitive decline. Theories describing age-related cognitive changes differ in the level of specificity they ascribe to the aging effects. For instance, aging is thought to incorporate a general decline in speed of processing (Salthouse, 2000), which therefore has an overarching impact on performance by older adults. However, evidence for more specific decline in attention mechanisms has been extensively documented. First, it has been shown that older adults may have reduced inhibition, as they seem less susceptible to negative priming (where a previously ignored item tends to be inhibited when it subsequently becomes a target; Hasher, Stoltzfus, Zacks, & Rypma, 1991). Other more direct examples of reduced inhibition are demonstrated in tasks where participants are required to focus on a subset of the visual input throughout the experimental condition. For instance, when a series of faces and houses are presented consecutively and participants are asked to monitor only the faces or houses, older adults show a reduced capacity for suppressing the irrelevant stimuli (Gazzaley, Cooney, Rissman, & D'Esposito, 2005). Similarly, when the faces and houses are superimposed on one another, eliminating the effects of memory, older participants were shown to exhibit reduced inhibition for the irrelevant stimulus, which also resulted in increased recognition memory for the irrelevant items compared with young adults (Schmitz, Cheng, & De Rosa, 2010). A comparable behavioral effect has also been documented when older adults have been shown to encode and process irrelevant words that are presented together with relevant images (Campbell, Hasher, & Thomas, 2010). Indeed, such impaired inhibition is not tied to a specific visual

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attention paradigm or stimulus type and can be seen in visual search tasks, where there is an age-related decline in the ability of older adults to inhibit a subset of distractors (preview search; Kramer, Hahn, Irwin, & Theeuwes, 2000).

These behavioral effects are also linked to reduced top-down modulation of brain-related activity representing target and distractor processes (Gazzaley et al., 2005). For instance, when "target" faces are superimposed on "distractor" houses, older adults show reduced tuning for the faces in the fusiform face area (FFA), while at the same time activation in the parahippocampal place area (PPA) for the house is more sensitive to bottom-up salience (Schmitz, Dixon, Anderson, & De Rosa, 2014). Similarly, while young adults show top-down modulation of steady state visually evoked potentials (SSVEP) when instructed to attend to one of two sets of random dot kinematograms based on their color, older adults show no such modulation (Quigley, Andersen, Schulze, Grunwald, & Muller, 2010). Interestingly, this reduced top-down modulation in perceptual areas in older adults is seemingly complemented by later increase in prefrontal activity, perhaps as a late compensatory mechanism driven by the lack of early top-down perceptual modulation (Quigley et al., 2010; Schmitz et al., 2010; Schmitz et al., 2014).

The detrimental effect of aging has also been well documented in the motor domain (Seidler et al., 2010). Healthy aging has been linked with a host of motor control deficits such as increased movement variability (Contreras-Vidal, Teulings, & Stelmach, 1998), movement slowing (Seidler-Dobrin, He, & Stelmach, 1998), difficulties in movement coordination (Seidler, Alberts, & Stelmach, 2002), and, additionally, motor learning and motor memory impairments (Hardwick & Celnik, 2014; Trewartha, Garcia, Wolpert, & Flanagan, 2014). Interestingly, when older adults perform a motor task, they display increased activation in the prefrontal areas of the brain (dorsolateral prefrontal cortex, dorsal premotor cortex, inferior frontal gyrus), possibly reflecting a greater reliance on cognitive control (Heuninckx, Wenderoth, & Swinnen, 2008). Consistent with this view, motor control is thought to be attentionally more demanding for older adults (Li & Lindenberger, 2002; Seidler et al., 2010). Consequently, on tasks that require cognitive control, motor impairments are disproportionately higher in older compared with younger adults (Heuninckx et al., 2008).

So how might an older adult's reduced capacity to inhibit distractors during visual attention tasks (e.g., Schmitz et al., 2010) relate to their ability to inhibit distractors within a motor task? When making simple reaching movements, target-orientated visual distractors have a detrimental effect on motor performance in young adults (Howard & Tipper, 1997; Reichenbach, Franklin, Zatka-Haas, & Diedrichsen, 2014; Tipper, Howard, & Houghton, 1998; Welsh & Elliott, 2004; Welsh, Elliott, & Weeks, 1999). As older adults show reduced motor performance during cognitively demanding tasks, one might expect them to exhibit greater deficits (relative to younger adults) when encountering distractors during a simple motor task, as a consequence of their reduced capacity for inhibition. In addition, it is possible that an older adult's ability to inhibit distractors is correlated across the visual and motor domain, indicating a generalized distractor inhibition deficit in old age. In support of this idea, when preparing to perform a grasping movement, brain activity within a specialized parietal–occipital inhibition network is only evident when obstacles (distractors) had to be avoided (Chapman, Gallivan, Culham, & Goodale, 2011). A similar inhibition network has also been associated with distractor suppression in the visual domain, specifically during a Global-Local task in which participants had to ignore a salient global or local feature while responding to the nonsalient one (Mevorach, Hodsoll, Allen, Shalev, & Humphreys, 2010; Mevorach, Humphreys, & Shalev, 2006). It was also documented that older adults show specific suppression impairment in such global-local tasks (Tsvetanov, Mevorach, Allen, & Humphreys, 2013). Taken together, these findings may point to a similar suppression mechanism that is involved in both visual and motor control tasks, which is susceptible to age-related decline. However, contrary to this prediction, there is evidence to suggest that normal aging impairments in inhibitory processes across the visual attention and motor domains are unrelated (Anguera & Gazzaley, 2012).

Therefore to examine this question further, we tested the ability of young and older adults to inhibit distractors during a visual attention (global–local) and a motor (reaching) task. We hypothesized that older adults would show specific deficits during conditions in which they were required to inhibit distractors across both domains, and that their level of impairment would be correlated across tasks.

Methods

Participants

Twenty older and 30 younger adults with no current health problems participated in the study. One participant was removed from each group for either not following written instructions (e.g., responding to global instead of local) or due to a technical fault with the motor task, leaving 19 (mean: 71, range: 63–85, 10 male) older and 29 (mean: 23, range: 18–36, 11 male)

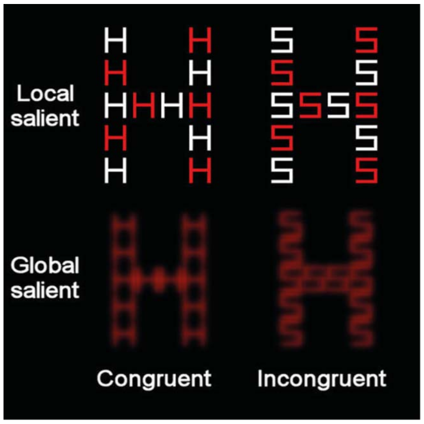

Figure 1. Example stimuli for the global–local task. Two displays were used representing local more salient (top) or global more salient (bottom) conditions. In half of the trials the letters on the global and local levels matched (congruent, left column) and on the other half they did not match (incongruent, right column).

younger participants. All participants provided written informed consent, and the study was approved by the research ethics committee at the University of Birmingham and adhered to the Declaration of Helsinki. Participants were given either course credit or £7 cash for their involvement in the study. Elderly participants were recruited through advertisements in the local press or through the School of Psychology older adults database. Younger participants were recruited through an internal recruitment system and personal invitations. All participants had normal or corrected-to-normal vision. Elderly participants were screened for cognitive decline using the MoCA test (Montreal Cognitive Assessment) with a threshold score of $\geq$25.

General procedure

The visual attention distractor (global–local) task and motor distractor task were performed in a single session lasting approximately 1 hr. For all participants, the global–local task was performed first, followed by the motor distractor task. Although practice effects across experiments were possible, we maintained this experimental order (across participants) so that our main comparison of interest between groups (young vs. old) was not contaminated by the order in which they performed the two tasks.

Global–local task

The visual attention task used here utilized hierarchical letters (Navon, 1977) similar to Tsvetanov et al. (2013). In this task an array of small (local) letters constitutes a large (global) letter (Figure 1). In different blocks of trials participants are required to identify either to local or the global letters while inhibiting the other (either local or global). In this particular version, the relative saliency of the local or global levels is orthogonally manipulated with respect to which level should be reported. Previously (Tsvetanov et al., 2013) we have shown during such a task that older adults demonstrate a specific impairment in distractor inhibition.

Stimuli

The stimuli were presented on a 17-inch monitor using Matlab (MathWorks, Natick, MA) and the Psychophysics toolbox. Participants were seated approximately 60 cm away from the screen, so that each centimeter on the screen represented 0.968° of visual angle. All stimuli appeared against a black background. The relative saliency of the global and local elements was manipulated using two sets of displays representing high global saliency and high local saliency. In both sets the hierarchical letters were created from the orthogonal combinations of the letters H and S (Figure 1). For the displays with a relative high local saliency the local elements alternated colors (white and red; Figure 1). Each local letter subtended $1.348° \times 1.068°$ of visual angle (in height and width, respectively) with the global letter subtending $8.268° \times 5.388°$ of visual angle (in height and width, respectively). The interelement distance was 0.388° in visual angle. For the display with relative global salience similarly sized local letters were used but they were all red. The interelement distance was 0.0968° of visual angle. This then yielded a global letter subtending $5.688° \times 4.518°$ of visual angle (in height and width, respectively). These letters underwent a blur procedure in Paint Shop Pro 7.0 with factor = 7. These hierarchical letters appeared at the center of the screen. A white cross (0.578°) served as fixation and appeared at the center of the screen.

Procedure

In different blocks of trials, participants were instructed to identify either the global (large letter formed of the small letters) or local letter (small letters that form the larger figure) while ignoring the letter on the other level (Figure 1). Each block represented one of four possible conditions: identify global in global salient displays; identify global in local salient displays; identify local in global salient displays and identify local in local salient displays. Each block was repeated three times to form a series of 12 blocks randomly

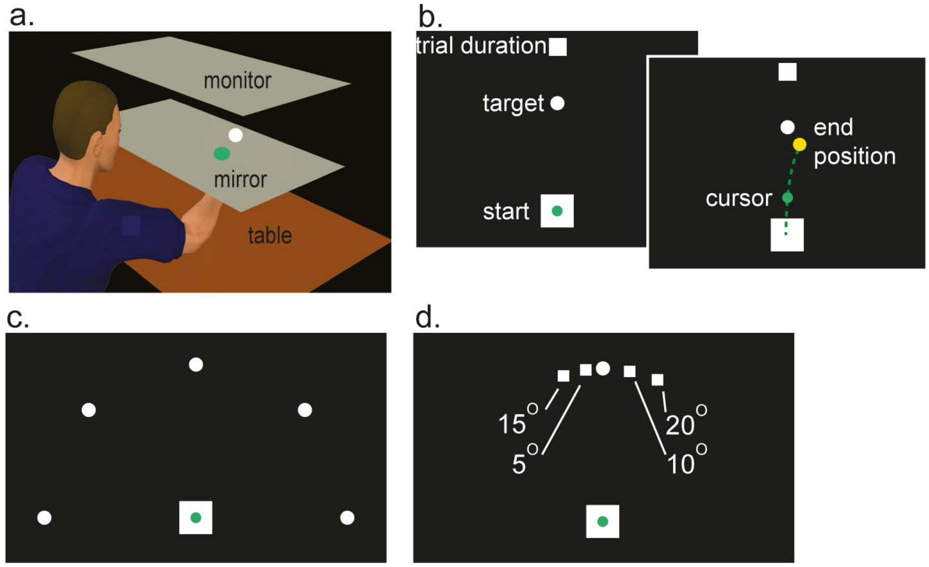

Figure 2. Motor distractor task. (a) Task apparatus. Participants were seated with their semipronated right index finger attached to a Polhemus motion tracking system underneath a horizontally suspended mirror. The mirror prevented direct vision of the hand and arm, but showed a reflection of a computer monitor mounted above that appeared to be in the same plane as the hand. (b) Task procedure. Participants made reaching movements (green circle representing index finger position) toward visual targets displayed on the screen (white circle). Feedback regarding trial duration was displayed at the top of the screen (white square). Participants could either receive online feedback (green) of their movement on simply endpoint feedback (yellow). (c) Target positions. The target could be positioned in one of five positions arrayed radially at 8 cm from the central starting position. (d) Distractor positions. The distractor (white or red square) could be placed 5°, 10°, 15°, or 20° clockwise or counterclockwise to the target.

ordered. Each block was preceded by a visual instruction (Identify Global/Identify Local), which was presented for 2 s. Each block contained 12 trials, half of which contained congruent displays (the same letter features in the local and global levels) and the other half incongruent ones (the letters in the local and global levels differed). Each trial began with a fixation cross which appeared for 1500 ms. This was followed by a 200-ms interval, after which a target was presented for 250 ms. Participants were instructed to respond by pressing the "1" and "2" keys on the keyboard using their index and middle fingers (with 1 representing H and 2 representing S). Both accuracy and speed were emphasized. Reaction time (RT; ms) was measured from stimulus onset until response.

Data analysis and statistics

As older participants may show general slowing (Lindenberger & Baltes, 1994; Salthouse, 2000) we also calculated ratio measures for the effects of interests. For instance, a congruency ratio was computed whereby the congruency difference (RT incongruent – RT congruent) was divided by average RT across both conditions. This enabled us to test for level bias, salience suppression, and distractor interference regardless of overall slowness.

Motor distractor task

The goal of this task was to examine the influence visual distractors have on motor accuracy. Participants were seated with their forehead supported on a headrest. Their semipronated right index finger was attached to a Polhemus motion tracking system underneath a horizontally suspended mirror. The mirror prevented direct vision of the hand and arm, but showed a reflection of a computer monitor mounted above that appeared to be in the same plane as the hand (Figure 2a). Participants controlled a cursor on the screen by moving their finger (which was attached to a motion tracking sensor) across the table. They were told to never lift their finger off the table and to make pointing movements (i.e.) apart from their index finger, the rest of their hand should be clenched into a fist. The visual display consisted of a 1-cm-diameter central white starting box, a green cursor (0.3 cm diameter) representing the position of the index finger and a circular white target (0.5 cm diameter; Figure 2b). The target could be positioned in one of five positions arrayed radially at 8 cm from the central starting position (Figure 2c). Participants had to make a movement toward the target either with no distractors (Figure 2b) or with a single white or red square (0.5 cm in width and height) distractor. This distractor could be placed 5°, 10°, 15°, or 20° clockwise or counterclockwise to the target (Figure 2c). We pre-

	Trials	Online or endpoint feedback	Distractors	Distractor color
Block 1	80	40 = online 40 = endpoint	No	—
Block 2	90	Endpoint	Yes	White
Block 3	90	Online	Yes	White
Block 4	90	Endpoint	Yes	Red
Block 5	90	Online	Yes	Red

Table 1. Motor distractor task procedure.

dicted that the color and distance of the distractor (relative to the target) would manipulate distractor suppression difficulty. Specifically, a red distractor would be easier to suppress than a white distractor due to its reduced similarity with the target (Duncan & Humphreys, 1989), whereas a distractor closer to the target (5°) would be harder to suppress than a distractor placed further away (20°; Eriksen & Hoffman, 1972). In addition, participants either had online vision (online) where they could see the cursor representing their hand position throughout the movement, or endpoint feedback (end point) where participants only received visual feedback relating to the end position of their movement (see following material). Visual feedback was manipulated so that movement accuracy was either based entirely on feedforward control (endpoint) or a combination of feedforward and feedback control (online; Heath, 2005; Tseng, Diedrichsen, Krakauer, Shadmehr, & Bastian, 2007). We hypothesized that this would allow us to disentangle proactive (feedforward) and reactive (feedback) distractor suppression. Finally, a square (0.5 cm in width and height) at the top of the screen provided movement speed feedback (see following material).

A trial started by participants moving the cursor into the start position. A target then appeared. If this was a distractor trial then a distractor also appeared simultaneously with the target. Participants were instructed to make a movement toward the target and stop as close as possible to it, while ignoring all distractors. The end of each movement was defined by movement velocity falling below 0.05 cm/s (note movement length had to exceed 4 cm). At this point, a yellow circle appeared (Figure 2b), which indicated the movement endpoint. Therefore, the goal of each trial was to get the yellow circle as close as possible to the target. To ensure participants reacted and moved at a similar speed, trial duration feedback was provided at the top of the screen. Once the target (and distractor) had appeared, participants had 1200 ms to execute the movement. Therefore, this incorporated both reaction time (RT) and movement time (MT). If this was achieved the box at the top of the screen remained white (Figure 2a). However, if this was exceeded then the box turned red.

The task contained five blocks, which involved different variations of the task (Table 1). Block 1 was a training block in which participants made 40 movements (eight movements to each target) with either online or endpoint feedback without distractors. Blocks 2–5 involved 90 trials, with 18 movements towards each target. As distractors could be positioned 5°, 10°, 15°, or 20° clockwise or counterclockwise to the target (eight positions in total), the 18 trials for each target involved two repetitions of each distractor position (16 trials) plus two trials, which involved no distractors. The order of these trials within each block was randomized but remained constant across participants. Blocks 2 and 3 involved white distractors with endpoint and online feedback, respectively. Blocks 4 and 5 involved red distractors with endpoint and online feedback, respectively.

The order of the blocks was maintained across participants. Although practice effects across the blocks may influence our ability to compare between blocks, our main comparison of interest was between groups (young vs. old). Therefore, we wanted to be able to compare groups at the same time point in the experiment with the same task constraints. To emphasize any differences, we decided to place the blocks in order of presumed difficulty (except block 1, which was training). For instance, block 2 was thought most difficult as a result of participants having only endpoint feedback and the target and distractor being the same color (white). However, to examine whether practice effects distorted the within-subject differences between visual feedback and distractor color, we recruited an additional 10 young, healthy participants (mean: 25, range: 21–39, five male) who experienced blocks 2–5 in the reverse order: block 2 = online feedback, red distractor; block 3 = endpoint feedback, red distractor; block 4 = online feedback, white distractor; block 5 = endpoint feedback, white distractor.

Data analysis and statistics

The two-dimensional position (x, y) of the hand was continuously recorded at a rate of 60 Hz using a custom Matlab program and the Psychophysics toolbox. Our main parameter of interest was the radial distance between the movement end position and target (radial error; cm). In addition, reaction time (RT; ms) and movement time (MT; ms) were calculated for each trial. RT was defined as the time between the target appearing and the participant's finger leaving the start position. MT was defined as the time between the participant's finger leaving the start position and movement velocity falling below 0.05 cm/s (note

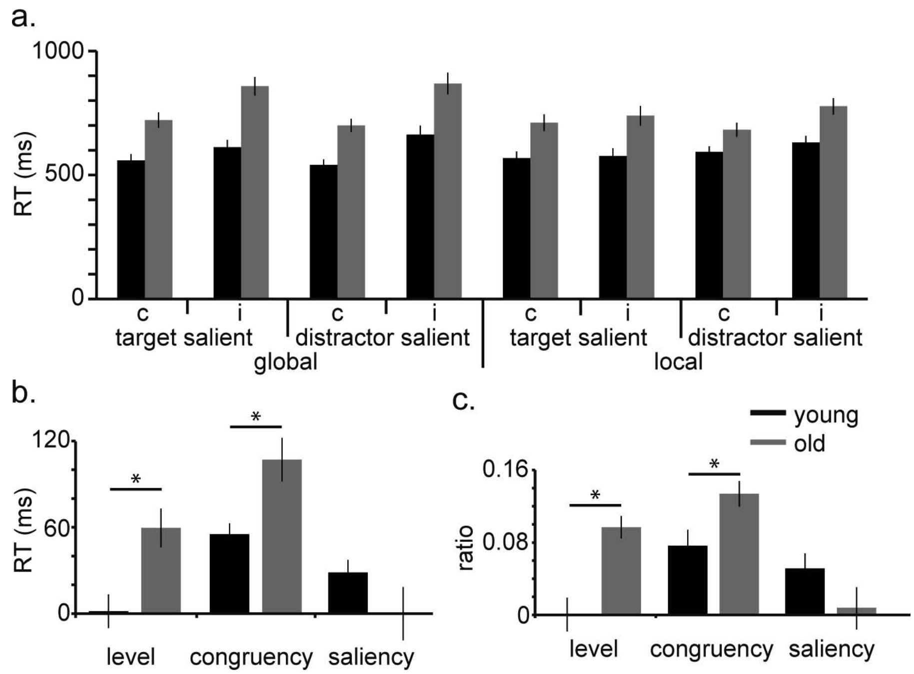

Figure 3. RT data for the global-local task. (a) RT (ms) performance for the young (black) and old (gray) groups. Data are presented according to the target level (global/local), the relative saliency (target salient/distractor salient) and congruency (c = congruent/i = incongruent). (b) Interaction data showing the level (global–local), congruency (incongruent–congruent) and saliency (distractor salient–target salient) differences between the two groups. (c) Interaction data for ratios. Presented are the level, congruency, and saliency differences transformed to a ratio (the difference divided by overall performance). Data is mean ± *SEM*. *$p < 0.045$.

movement length had to exceed 4 cm). We removed any trial in which radial error exceeded 5 cm or RT and MT exceeded 1500 ms. This accounted for 1.7% of all trials. We regarded block 1 as a training block in which participants became accustomed to the task. Therefore, we used the no distractor trials within blocks 2–5 as our measure of no distractor performance. As these trials were interspersed with the distractor trials, they would provide us with a true measure of "baseline" performance across blocks 2–5. For each participant, we obtained a global value for no distractor performance by averaging across blocks 2–5; this meant that both online (block 2, 3) and endpoint feedback (blocks 4, 5) performance was included (two trials for each target [5] from each block were included; total amount of trials included = 40 trials). This average no distractor value was compared between the young and old groups for radial error, RT, and MT using two-tailed independent *t* tests. Next, we compared performance across distractor position (5°, 10°, 15°, or 20°), distractor color (red, white) and visual feedback (online, endpoint). In order to reduce statistical complexity, distractor performance was averaged across target position (1–5) and distractor placement (clockwise/counterclockwise). To measure participants' performance in relation to the cost of adding a distractor to their performance, the subsequent data was analyzed subtracted from the no distractor condition (Δ). Separate 4 (distractor position) × 2 (distractor color) × 2 (visual feedback) × 2 (age group) repeated-measures ANOVAs compared Δ distractor performance for radial error, RT, and MT. Significance level was set at $p < 0.05$. Effect sizes are reported as partial eta squared (η_p^2) for ANOVAs and Hedges' *g* (Hedges, 1981; Hentschke & Stuttgen, 2011) for *t* tests. This is a measure of effect size, which is similar to Cohen's *d* but controls for different group sizes. All data are reported as mean ± standard error of the mean (across subjects; *SEM*).

Results

Global–local task

Reaction time

Our initial objective was to replicate the impairments observed in older adults during distractor suppression within the global–local visual search paradigm. First, older adults were slower (757 ± 30 ms) than young adults, 593 ± 25; $F(1, 46) = 18.2$, $p < 0.001$, $\eta_p^2 = 0.28$, in identifying both local and global letters (Figure 3a). Generally, global identification was slower than local identification ($F_{(1,46)} = 11.5$, $p = 0.001$, $\eta_p^2 = 0.20$) and congruent displays were responded to quicker than incongruent ones, $F(1, 46) = 112.3$, $p < 0.001$, $\eta_p^2 = 0.71$.

	$F(1, 46)$	p	n_p^2
Reaction time			
Level × Congruency	28.4	<0.001	0.39
Saliency × Congruency	17.1	<0.001	0.27
Accuracy			
Level × Congruency	8.0	0.007	0.15

Table 2. ANOVA results for the Global/Local task—non-age related significant interactions.

However, level and congruency also interacted with age, $F(1, 46) = 10.7$, $p = 0.002$, $n_p^2 = 0.18$, and $F(1, 46) = 11.2$, $p = 0.001$, $n_p^2 = 0.20$. In particular, the level difference (global–local) for young adults was considerably smaller than for the older adults, $t(46) = 3.2$, $p = 0.003$, $g_{\text{Hedges}} = 1.0$, which may suggest a local precedence in older (but not in younger) adults (Figure 3b). Moreover, the congruency effect (incongruent–congruent) for young adults was significantly smaller than for the older adults, $t(46) = 3.4$, $p = 0.002$, $g_{\text{Hedges}} = 1.0$, which is indicative of reduced distractor suppression in the older participants (Figure 3b). In contrast, saliency and group did not significantly interact, $F(1, 46) = 2.4$, $p = 0.127$, $n_p^2 = 0.05$, as the saliency effect (Distractor salient–Target salient) did not differ across the groups (29 ± 9 and 0 ± 18 for young and old adults, respectively; Figure 3b). No other significant interactions involving age were found. (For significant interactions not involving age, see Table 2.)

To verify that the effects of age were not due to the overall slow responses in the older adults, we also compared the level ratio and congruency ratio across the two groups (by dividing the level difference and congruency difference by overall performance in each participant). Independent t tests verified that both level ratio, $t(46) = 2.7$, $p = 0.01$, $g_{\text{Hedges}} = 0.79$, and congruency ratio, $t(46) = 2.0$, $p = 0.043$, $g_{\text{Hedges}} = 0.61$, differed significantly across the two groups (Figure 3c).

Accuracy

Overall, older adults were also less accurate (0.91 ± 0.01) than young adults, 0.96 ± 0.01; $F(1, 46) = 11.0$, $p = 0.002$, $n_p^2 = 0.19$; Figure 4a. Whereas congruent displays were generally more accurate than incongruent ones, $F(1, 46) = 43.9$, $p < 0.001$, $n_p^2 = 0.49$; Figure 4a, the interaction between congruency and age approached statistical significance, $F(1, 46) = 4.0$, $p = 0.051$, $n_p^2 = 0.08$. This indicates that the congruency effect for older participants was significantly larger than for the young adults, $t(46) = 2.05$, $p = 0.046$, $g_{\text{Hedges}} = 0.61$; Figure 4b. Thus, reduced distractor suppression in the old group was evident in both RTs and accuracy. No other significant interactions involving age were found. (For another significant interaction not involving age, see Table 2.)

Motor distractor task

No distractor performance

Younger (0.85 ± 0.04 cm) and older (0.90 ± 0.05) adults showed similar radial error during no distractor performance, $t(46) = 0.67$, $p = 0.51$, $g_{\text{Hedges}} = 0.22$. However, as expected, older adults displayed slower reaction times, young = 434 ± 13 ms, old = 543 ± 25; $t(46) = 4.3$, $p = 0.0005$, $g_{\text{Hedges}} = 1.3$, and movement times, young = 364 ± 14 ms, old = 449 ± 30; $t(46) = 2.8$, $p = 0.007$, $g_{\text{Hedges}} = 0.8$.

Distractor performance

Our objective was to evaluate the difference between young and old adults when inhibiting a distractor during motor (reaching) behavior. To measure participants' performance in relation to the cost of adding a distractor, the subsequent data was analyzed after subtracting no distractor performance (Δradial error). Although there

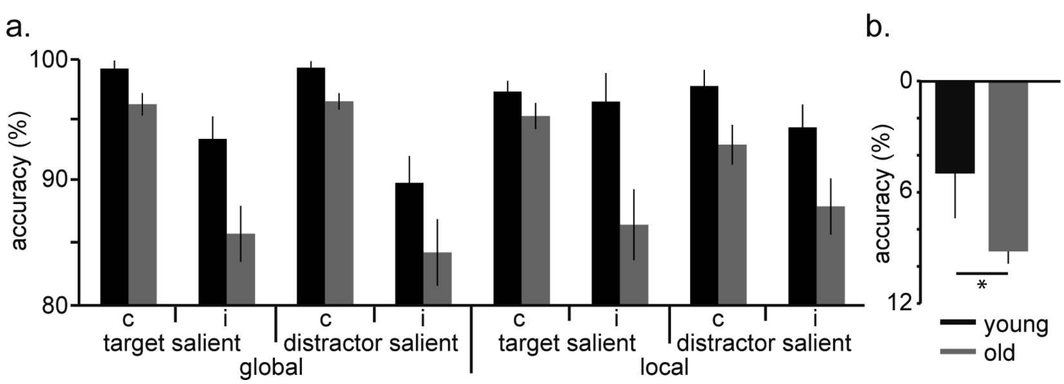

Figure 4. Accuracy data for the global–local task. (a) Accuracy (%) performance for the young (black) and old (gray) groups. Data are presented according to the target level (global/local), the relative saliency (target salient/distractor salient) and congruency (c = congruent/i = incongruent). (b) Interaction data showing the congruency (incongruent–congruent) difference between the two groups. Data is mean ± *SEM*. *$p < 0.047$.

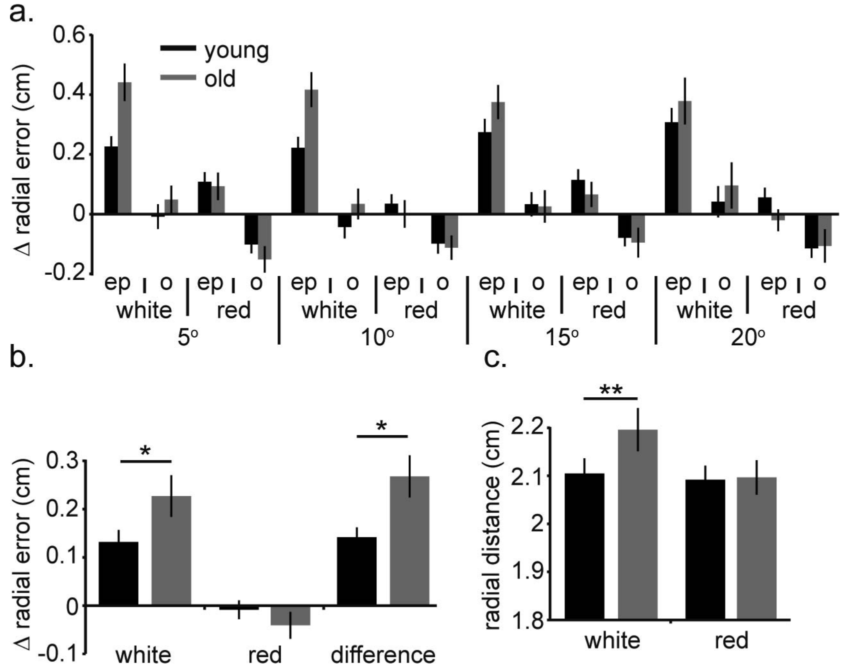

Figure 5. Δradial error for the motor distractor task. (a) Δradial error (distractor–no distractor; cm) performance for the young (black) and old (gray) groups. Data are presented according to distractor position (5°/10°/15°/20°), distractor color (white/red), and visual feedback (online/endpoint). (b) Interaction data showing the distractor color (white − red) difference between the two groups. (c) Interaction data showing the distractor color (white − red) difference between the two groups for radial distance (cm) from distractor. Data is mean ± *SEM*. $^*p < 0.046$. $^{**}p = 0.10$.

were clear and significant differences for distractor color, $F(1, 46) = 89.1$, $p = 0.0005$, $n_p^2 = 0.66$, and visual feedback, $F(1, 46) = 73.3$, $p = 0.0005$, $n_p^2 = 0.61$; Figure 5a, the only significant effect relating to age (group) was its interaction with distractor color, $F(1, 46) = 8.4$, $p = 0.006$, $n_p^2 = 0.16$. Specifically, older adults showed increased Δradial error in the presence of white distractors, $t(46) = 2.1$, $p = 0.046$, $g_{\text{Hedges}} = 0.59$; Figure 5b. In contrast, red distractors had no effect on Δradial error and performance was similar between age groups, $t(46) = 0.9$, $p = 0.35$, $g_{\text{Hedges}} = 0.27$. Although the interaction between age, distractor color, and visual feedback did not reach significance, $F(1, 46) = 2.9$, $p = 0.097$, $n_p^2 = 0.06$, the age-dependent white distractor impairment seems to be driven by the participant's behavior during endpoint visual feedback trials (Figure 5a).

However, as block order was maintained across participants, the within-subject differences between visual feedback and distractor color could be driven by a practice effect (see Methods). Therefore, we recruited an additional 10 young, healthy participants and exposed them to blocks 2–5 in the reverse order. We found a significant effect for distractor color, $F(1, 9) = 6.44$, $p = 0.032$, $n_p^2 = 0.42$; visual feedback, $F(1, 9) = 10.93$, $p = 0.009$, $n_p^2 = 0.55$; and interaction between distractor color and visual feedback, $F(1, 9) = 6.95$, $p = 0.027$, $n_p^2 = 0.44$. Despite the block order being flipped, Δradial error was still significantly greater in the block involving endpoint feedback and white distractors (0.34 ± 0.09 cm; block 5) relative to online feedback/white distractors (–0.01 ± 0.06; block 4; $t_{(9)} = 3.4$, $p = 0.08$, $d_{\text{Cohen}} = 1.4$), endpoint feedback/red distractors (0.05 ± 0.04; block 3; $t_{(9)} = 2.7$, $p = 0.026$, $d_{\text{Cohen}} = 1.3$), and online feedback/red distractors (–0.03 ± 0.04; block 2; $t_{(9)} = 3.6$, $p = 0.005$, $d_{\text{Cohen}} = 1.6$). This provides strong evidence that the within-subject differences between visual feedback and distractor color were independent of block order.

It is possible that older adults were simply confusing the white distractor with the target. If true, then the older adults' radial end position should be closer to the white distractor relative to young adult performance. To investigate this, we calculated radial distance relative to the distractor (rather than the target). Although not significant, older adults showed increased radial distance from the white distractor relative to young adults, $t(46) = 1.67$, $p = 0.10$, $g_{\text{Hedges}} = 0.50$; Figure 5c). This indicates that older adults were not simply moving toward the white distractor, but showing a rebound effect in that they were ending up further away from the distractor.

Reaction time

Older adults were generally slower to react across all distractor conditions. There was a significant main

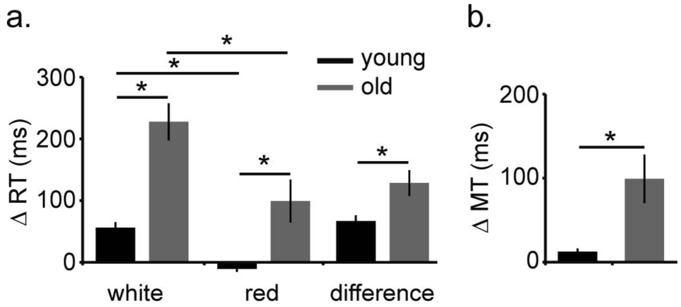

Figure 6. ΔRT and ΔMT for the motor distractor task. (a) ΔRT (distractor–no distractor; ms) performance for the young (black) and old (gray) groups. Interaction data showing the distractor color (white − red) difference between the two groups. (b) ΔMT (distractor–no distractor; ms) performance for the young (black) and old (gray) groups. Data showing main effect for group. Data is mean ± *SEM*. $^*p < 0.013$.

effect for group, $F(1, 46) = 30.0$, $p = 0.0005$, $n_p^2 = 0.40$, and also a significant interaction between distractor color and group, $F(1, 46) = 9.1$, $p = 0.004$, $n_p^2 = 0.17$. Both young, $t(28) = 7.2$, $p = 0.0005$ two-tailed, $d_{\text{Cohens}} = 1.8$, and old, $t(18) = 6.2$, $p = 0.0005$, $d_{\text{Cohen}s} = 0.86$, showed greater ΔRT when faced with a white distractor compared with a red distractor (Figure 7a).

However, the difference between white and red distractor performance was significantly greater for the older group, $t(46) = 2.7$, $p = 0.012$, $g_{\text{Hedge}s} = 0.61$; Figure 6a. This suggests that older adults took longer to react across distractor conditions; however, they were particularly affected by white distractors.

Correlation between reaction time and distance from distractor

Within the saccade literature, reaction time has been used as a proxy to determine the underlying mechanisms of distractor inhibition. In general, slower responses (longer RT) are associated with movements away from the distractor, thus suggesting the distractor location has been inhibited over time (Campbell, Al-Aidroos, Pratt, & Hasher, 2009; Van der Stigchel, 2010; Van der Stigchel, Meeter, & Theeuwes, 2007).

To examine this relationship in the motor task, we correlated each participant's RT (ΔRT) with their average endpoint distance from the distractor (when faced with a white distractor). We found a positive correlation across groups, irrespective of age (partial correlation: $r = 0.32$, $p = 0.028$), suggesting that longer reaction times were associated with greater movements away from the distractor. However, this relationship was driven by a strong correlation in the older group ($r = 0.53$, $p = 0.02$), which was not seen in the young group ($r = -0.01$, $p = 0.95$).

Movement time

Older adults also demonstrated slower movement speed across distractor conditions. There was a significant main effect for group, $F(1,46) = 13.4$, $p = 0.001$, $n_p^2 = 0.23$; Figure 6b. However, all interactions relating to group were not significant, $p > 0.079$, $n_p^2 < 0.048$. This suggests that older adults moved slower in

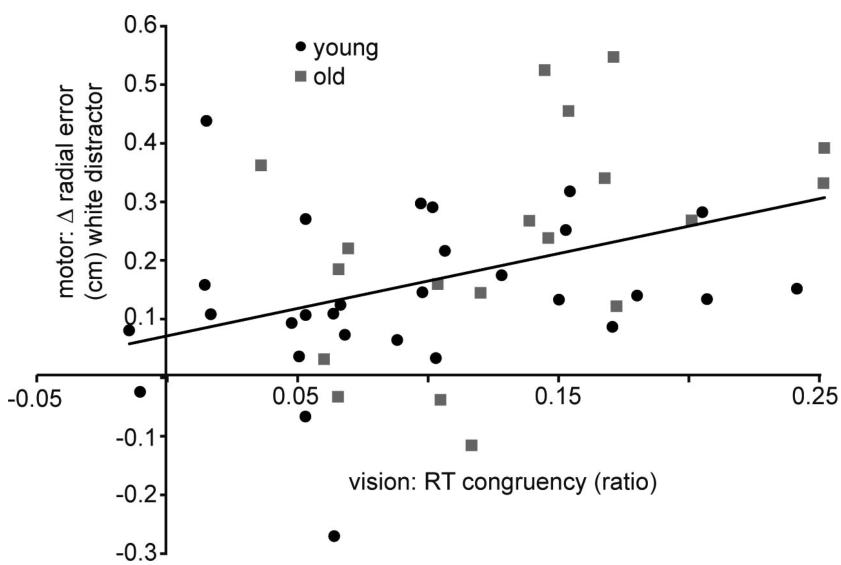

Figure 7. Correlation between visual and motor distractor performance. Data showing a positive correlation (partial correlation controlling for age group; $p = 0.024$) between a participant's RT congruency ratio in the visual global–local task and their Δradial error with white distractors in the motor distractor task, across the young (black) and old (gray) groups.

the presence of distractors; however, this was consistent across all other task parameters.

Correlation between visual and motor distractor performance

For both the vision and motor tasks, only specific parameters were affected by both distractor and age (in the vision task: RT congruency, whereas for the motor task: Δradial error and ΔRT [white distractor performance]. We examined whether participants' behavior across these parameters were correlated. We found a positive correlation between a participant's RT congruency ratio (Figure 3c) in the visual global–local task and their Δradial error with white distractors (Figure 5b) in the motor distractor task (partial correlation controlling for age group; $r = 0.33$, $p = 0.024$; Figure 7). This correlation was maintained within each age group, but did not reach significance (young: $r = 0.24$, $p = 0.21$, old: $r = 0.45$, $p = 0.052$). Although it appears the correlation was stronger in the older adult group, this conclusion could not be supported statistically (Fisher's $Z = 0.76$, $p = 0.45$, $k_{\text{Cohen}} = 0.24$, two-tailed). In other words, the Fisher's test indicates that the correlation in the young and old groups was not significantly different.

To ensure this relationship was specific to participants' response to distractors rather than, for instance, a general effect of task difficulty, we compared RT level ratio (which highlights task difficulty—global versus local—rather than sensitivity to distractors) in the visual task with white distractor Δradial error in the motor task. This partial correlation, controlling for age group, was not significant ($r = 0.10$, $p = 0.49$). In addition, the correlation between a participant's RT saliency ratio in the visual global-local task (which again may reflect sensitivity to task difficulty rather than distractor suppression) and their Δradial error with white distractors (Figure 5b) in the motor task was also not significant (partial correlation controlling for age group; $r = 0.017$, $p = 0.91$). Finally, ΔRT for white distractors in the motor task was not correlated with any parameter in the visual task ($r < 0.16$, $p > 0.27$).

Discussion

Summary

We found that younger and older adults showed behavioral impairments when faced with distractors across the visual and motor domain; however, these deficits were significantly enhanced in the old. Specifically, during a global–local (visual attention) task, older adults displayed a reduced capacity to suppress distractors. In addition, they exhibited less accuracy during a reaching (motor) task but only in the presence of a white distractor. Crucially, the degree of distractor impairment observed within each participant was correlated across the visual and motor tasks, irrespective of age group.

Older adults' display reduced distractor suppression during a global–local task

Overall the performance of older adults was slower and less accurate than young adults on the visual attention task when they were required to respond to global or local levels of a compound letter while ignoring the other irrelevant level. Interestingly, older adults showed a specific decrease in a measurement of distractor inhibition (congruency effect) in this task whereby the identity of the irrelevant level had a more pronounced effect on their performance. This finding fits with the idea that older adults are less effective in inhibiting task-irrelevant distractors (Gazzaley et al., 2005; Schmitz et al., 2010; Tsvetanov et al., 2013). The effect of aging on distractor suppression in the current study is in contrast to the findings reported by Tsvetanov et al. (2013). These authors reported an increase in the congruency effect for older adults especially for conditions when the distractor level was more salient. However, the task used within the current study differs from the one used in Tsvetanov et al. (2013). The main methodological difference was the use of shorter blocks, which were mixed (compared with longer blocks with less repetition); therefore, the need to switch between levels and displays was more pronounced. It is therefore likely that this design made the competition between the target and distractor level more pronounced across all blocks and displays, for both the distractor salient and the target salient conditions. The other difference between the age groups occurred with respect to the level difference, where old participants showed an overall local bias (overall local targets were responded to quicker than global ones) whereas no level difference was found for younger participants. Previous studies have reported conflicting effects regarding level precedence in aging, but often a change from global precedence in young adults to local precedence in older adults have been documented (Lux, Marshall, Thimm, & Fink, 2008). In summary, age effects on performance in the global–local task were in accordance with a reduced inhibition of perceptual distractors and fit with previous accounts of cognitive aging (Lustig, Hasher, & Zacks, 2007).

Older adults' reduced accuracy with white distractors during reaching task

During a simple reaching (motor) movement toward visual targets, older adults were able to perform at a comparable level of accuracy as young adults, but they executed the movement at a significantly slower speed. All participants showed similar trends in the presence of visual distractors. Specifically, relative to no distractor performance, distractors that were the same color as the target (white) caused a small but significant increase in movement error, whereas distractors that were a different color (red) had no effect. There was also an interaction between distractor color and the visual feedback provided during the movement. When participants had online vision, distractors had little effect on the error observed at the end of movement, and in fact, it appears red distractors could be used to slightly improve end point error (relative to no distractor performance). In contrast, when participants were restricted to end point vision, white distractors caused a significant increase in error whereas red distractors had little effect. This suggests that movement accuracy was mainly impaired when the distractor was a similar color to the target and visual feedback was restricted. In the presence of distractors, we did not observe any global deficit for older adults in terms of their movement accuracy. Despite this, they did display a specific impairment in the presence of a white distractor. Although not supported by the statistics, it appears this deficit was mainly observed when older adults were restricted to endpoint vision.

These results fit nicely within the context of previous literature relating to motor control and aging. Specifically, older adults motor impairments are often more visible during complex tasks that require some level of cognitive control even in young adults (Heuninckx et al., 2008). Recent work suggests that increased reaction times within a motor task may represent a greater requirement of cognition-based processes relating to action planning (Wong, Haith, & Krakauer, 2015). It is clear from our reaction time data that both younger and older adults found motor performance significantly more demanding (increased reaction time) in the presence of a white distractor. Even though older adults displayed an even greater elongation of reaction time, they were still unable to inhibit the distractor and perform at a similar accuracy as younger adults.

The simplest explanation is that older adults mistook the square-shaped white distractor for the circular-shaped white target. However, if this was the case then older adults' endpoint position ought to be closer to the white distractor than the younger adults. In other words, older adults would be further away from the target but closer to the distractor. In contrast to this prediction, older adults' end position was further away from the white distractor relative to younger adults. This suggests that older adults were not moving toward the white distractor, but away (rebound effect). Such a response to distractors has been well documented in previous literature investigating reaching movements (Howard & Tipper, 1997; Tipper, Howard, & Jackson, 1997). Specifically, the path of a movement veers away from a distracting stimulus (but see Welsh et al., 1999); with this phenomenon being explained through the response vector model (Tipper et al., 1997; Welsh & Elliott, 2004). Tipper et al. (1997) proposed that the presentation of multiple visual stimuli resulted in the initiation of independent movement plans for each stimulus (Cisek & Kalaska, 2010). It is well known that motor cortex (M1) cells code for specific directions of a reaching movement, firing most when the planned reach is in that preferred direction and less frequently as the movement direction deviates (Georgopoulos, 1995). Tipper et al. (1997) suggested that although the independent (competing) movement plans code for reaches to different directions, their representations may share some M1 neuron populations. When the neurons coding for the competing response are inhibited as selection occurs (selective inhibition), the neuronal pools shared by both response processes are affected (Welsh & Elliott, 2004). Therefore, the result of distractor inhibition is a biased movement direction that veers away from the distractor location (Tipper et al., 1997; Welsh & Elliott, 2004). Within the current study, older adults displayed an exaggerated movement direction away from the white distractor, with slower reaction times being associated with larger movements away from the distractor (only in older adults). Somewhat similar results have been found in the saccade literature, where longer reaction times are often found to be followed by a movement away from a distractor, whereas shorter reaction times lead to movements toward the distractor. It has been suggested that this reflects the distractor location being inhibited over time (Campbell et al., 2009; Van der Stigchel et al., 2007; Van der Stigchel, 2010). In the motor task, younger adults' reaction times were significantly shorter, movement accuracy was greater and the relationship between reaction time and distance from distractor was not observed. This may indicate that older adults had a reduced ability to proactively inhibit white distractors, which would lead to the development of a stronger competing movement plan and a greater requirement to inhibit this response. Based on the saccade literature, this would explain the slower reaction time, the greater movement away from the distractor, but also increased error relative to the target.

Distractor suppression correlated across the visual and motor domain

One of the most interesting results of this study was the positive correlation between a participant's ability to inhibit distractors across the global–local and reaching task, which was irrespective of age groups. Therefore, whereas all adults' ability to inhibit distractors was correlated across visual and motor domains, older adults displayed a generalized distractor inhibition deficit. The correlation between distractor performance across the two domains seems to go against previous work, which showed visual and motor inhibition to be unrelated in aging (Anguera & Gazzaley, 2012). However, the inhibition processes used in Anguera and Gazzaley (2012) were fundamentally different regardless of the sensory domain. Specifically, the authors compared the inhibition of an already triggered motor action in a stop signal task with sensory filtering during a delayed visual recognition task. In contrast, the present study used tasks that both measured distractor suppression but differed in their modality. As previously mentioned, it has been shown that distractor suppression during a global–local task has been associated with a parietal–occipital inhibition network (Mevorach et al., 2006; Mevorach et al., 2010) that is also active when performing grasping movements requiring the avoidance of an obstacle (distractor) (Chapman et al., 2011). These findings may point to a similar suppression mechanism that is involved in both the visual and motor tasks, which is susceptible to age-related decline.

One possibility is that this reflects a shift in the dominant control mechanism used by older adults to inhibit distractors. Within the visual domain, a proactive mechanism is thought to set up the system to suppress distractors in advance of their appearance. In contrast, a reactive mechanism operates as a late correction mechanism that reflexively suppresses visual distractors after they appear (Braver, 2012; Braver et al., 2001). Critically, individuals differ in their ability to utilize either mode of control and in particular it has been suggested that a shift from proactive to reactive control occurs with age (Braver, 2012; Braver et al., 2001). Interestingly, Tsvetanov et al. (2013) reported reduced distractor suppression in old age during a global–local task that has been shown to rely on proactive suppression (Mevorach, Humphreys, & Shalev, 2009). In addition, previous work has used brain stimulation (TMS) to indicate a specific role of the intraparietal sulcus for proactive control during visual distractor suppression (Mevorach et al., 2009). It is tempting to suggest that such a shift from proactive to reactive control could also explain the deficit observed in older adults within the motor task. As previously discussed, older adults showed an exaggerated movement direction away from the white distractor. This could suggest that older adults were unable to proactively inhibit the distractor, leading to the development of a stronger movement plan within the motor system. As a result, they would then have to rely (to a greater extent) on reactively inhibiting this plan through selective inhibition. A more powerful selective inhibition response would likely lead to an exaggerated movement direction away from the distractor.

Conclusions

When faced with distractors, younger and older adults displayed significant behavioral impairments within the visual and motor domain, with these deficits being substantially enhanced by age. Interestingly, the degree of distractor impairment observed within each participant was correlated across the visual and motor tasks, irrespective of age group. Therefore, while all adults' ability to inhibit distractors was correlated across the visual and motor domains, older adults displayed a generalized distractor inhibition deficit. Such a deficit in older adults raises important future research questions regarding the ability of older adults to effectively deal with distractors during complex visuomotor tasks such as driving.

Keywords: aging, cognitive control, distractors, motor control, suppression, visual attention

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