Evidence for an Age-related Decline in Feature-based Attention

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Abstract

The impact of aging on selective attention has been a topic of investigation for decades. Feature-based attention allows to efficiently guide attention to relevant information in the visual scene, but unambiguous empirical evidence on age-related effects is still limited. In this study, 38 young and 38 older participants performed a two-alternative forced choice task in which a response was selected based on a task-relevant number (= target) presented alone or together with a task-irrelevant letter (= neutral distracter) or number (= compatible or incompatible distracter). Participants were required to select the target based on color. Task data were modelled with a hierarchical drift-diffusion model to compare the behavioral interference of the distracters between the age groups while accounting for differences in the speed-accuracy trade-off, sensory encoding and the execution of a motor response. The hierarchical drift-diffusion model revealed that decreases in the rate at which information was collected in the conditions with compared to without a distracter were more pronounced in the older than young age group when the distracter was compatible or incompatible. Furthermore, these decreases were more pronounced in the older than young age group when the distracter was incompatible compared to neutral. Our findings are consistent with an age-related decline in the ability to filter out distracters based on features.

Public significance statement

The present study indicates that the ability to filter out distracters based on features declines with age. This decline likely occurs due to a general decrease in the top-down suppression of distracters and can attribute to age-related declines in other cognitive functions such as working memory.

Keywords

Aging; Cognition; Neuropsychology; Selective attention; Feature-based attention

Introduction

A major challenge in neuroscience is to gain insight in the cognitive changes that occur with normal aging. Developing tools to optimize cognitive function and quality of life of older adults has recently grown in importance considering that the global population is aging. Furthermore, increasing the knowledge on cognitively healthy aging is a crucial step towards understanding how pathological processes can disrupt this process.

Research has shown that multiple cognitive functions decline with age (Grady, 2012; Salthouse, 2010). Such age-related declines might originate from a lower availability of processed information for high-level cognitive functions (Cerella, 1985; Salthouse, 1996) due to deficits in sensory processes (e.g., visual acuity) (Lindenberger & Baltes, 1994; Schneider & Pichora-Fuller, 2000) and a general slowing of cognitive processes (Li, 2005; Li, Lindenberger, & Sikström, 2001; O'Sullivan et al., 2001; Rabbitt, Mogapi, et al., 2007; Rabbitt, Scott, et al., 2007). Multiple studies have highlighted the importance of other age-related changes since declines in cognitive performance were also observed when controlling for these impairments (e.g., Quigley, Andersen, Schulze, Grunwald, & Müller, 2010; Zanto, Toy, & Gazzaley, 2010). Notably, the decline in cognitive speed with age might lead to an impaired inhibitory control (Gazzaley et al., 2008), in which older adults display difficulties in deleting no longer relevant information, inhibiting prepotent responses and suppressing irrelevant information (Comalli Jr, Wapner, & Werner, 1962; Dempster, 1992; Williams, Ponesse, Schachar, Logan, & Tannock, 1999). More specifically, an age-related deficit in inhibiting irrelevant information is consistent with impaired performance on the Stroop task (West & Alain, 2000) and the Flanker task (Zeef, Sonke, Kok, Buiten, & Kenemans, 1996) with age, as well as with stronger priming effects to irrelevant information (Campbell, Grady, Ng, & Hasher, 2012; Gazzaley, Cooney, Rissman, & D'esposito, 2005; Rowe, Valderrama, Hasher, & Lenartowicz, 2006). Thus, in older adults, distracters can capture attention more easily (Hasher, Lustig, & Zacks, 2007; Hasher & Zacks, 1988) and subsequently overload working memory (Clapp & Gazzaley, 2012; Schmitz, Cheng, & De Rosa, 2010). This is supported by studies reporting that older adults have more difficulties in locating a target among distracters than young adults (Hommel, Li, & Li, 2004; Kramer, Hahn, Irwin, & Theeuwes, 2000; Phillips & Takeda, 2010). In contrast, other studies found that cueing the target location reduces the attentional capture of distracters to a similar extent in young and older adults (Gottlob & Madden, 1998; Hartley, Kieley, & Slabach, 1990; Haupt, Napiórkowski, Sorg, Müller, & Finke, 2019; Madden, Whiting, Cabeza, & Huettel, 2004). The latter evidence offers a more nuanced perspective by highlighting that older adults are impaired when relying solely on bottom-up attention, or when exceeding the limit to recruit additional top-down resources to compensate for declines in sensory regions (Cabeza, 2002; Grady et al., 1994; Madden et al., 2007; Park & Reuter-Lorenz, 2009; Reuter-Lorenz & Cappell, 2008; Reuter-Lorenz & Lustig, 2005; Stern, 2002; Talsma, Kok, & Ridderinkhof, 2006; Whiting, Madden, & Babcock, 2007).

In line with the aforementioned evidence, processes of spatial-based attention (i.e., selecting targets based on their locations) have been reported to decline with age when accounting for task difficulty (Hommel et al., 2004; Madden & Whiting, 2004; Wang, Fu, Greenwood, Luo, & Parasuraman, 2012) and individual differences in cognitive reserve (see Zanto & Gazzaley, 2019). Similar age-related effects could be expected in feature-based attention (i.e., selecting targets based on their features) since spatial-based (Gillebert et al., 2012; Gitelman et al., 1999; Nobre et al., 1997) and feature-based (Lanssens, Pizzamiglio, Mantini, & Gillebert, 2020; Shulman et al., 1999) attention rely on a core fronto-parietal network. However, neural differences have been reported that might be affected differentially by aging. For instance, compared to spatial-based attention, feature-based attention relies less on the superior parietal cortex (Giesbrecht, Woldorff, Song, & Mangun, 2003; Greenberg et al., 2010; Schenkluhn, Ruff, Heinen, & Chambers, 2008) and recruits other regions outside the fronto-parietal network (e.g., the inferior frontal junction: Bedini & Baldauf, 2021; Meyyappan, Rajan, Mangun, & Ding, 2021). In addition, feature-based attention is complicated by age-related changes in feature perception, such as color (Nguyen-Tri, Overbury, & Faubert, 2003), and declines in feature selectivity in sensory regions due to dedifferentiation (Park et al., 2012; Schmolesky, Wang, Pu, & Leventhal, 2000). A limited number of studies has reported that older adults are slower and less capable than young adults to discriminate target from distracter feature values when correcting for sensory differences (Quigley et al., 2010; Quigley & Müller, 2014; Zanto et al., 2010). Notably, these studies only had a limited sample size (Quigley et al., 2010; Quigley & Müller, 2014) or administered a working memory task (Zanto et al., 2010). An early meta-analysis also suggested an age-related decline in feature-based attention based on smaller negative priming effects in older compared to young adults (Verhaeghen & De Meersman, 1998). However, meta-analyses that included more recent studies with negative priming tasks suggested a preserved ability to filter out distracters based on features with age (Gamboz, Russo, & Fox, 2002; Verhaeghen, 2011). The heterogeneity in the results of the meta-analyses might be caused by changes in other cognitive processes with age, such as in the retrieval from working memory when seeing the same stimulus in consequent trials and in the speed-accuracy trade-off (Salthouse, 1979; Smith & Brewer, 1995; Starns & Ratcliff, 2010), as well as by age-related changes in sensory encoding (Zanto et al., 2010) and executing a motor response (e.g., see Seidler et al., 2010). To this end, analyzing the performance of older adults on a feature-based attention task with a drift-diffusion model holds promise for resolving the ambiguity in the literature because the model allows to decompose the observable behavior (choices and RTs) into separate latent variables with unique cognitive interpretations (e.g., see Theisen, Lerche, von Krause, & Voss, 2021). The drift-diffusion model (Ratcliff, 1978; Ratcliff & Rouder, 1998) assumes that evidence for a decision accumulates over time from a starting point at a drift rate towards one of two decision boundaries, by which a response is initiated when one of the boundaries is reached. The drift rate reflects the speed at which information is gathered and depends on the quality of the information, with higher drift rates leading to faster responses and fewer errors. The separation of the decision boundaries controls the speed-accuracy trade-off, in which higher boundary separations lead to slower responses since more information is required to terminate the decision process, but fewer errors since the probability to terminate at the correct boundary is higher. A non-decision parameter accounts for the time consumed by processes unrelated to the decision, such as the encoding of stimuli and the execution of the motor response. Because the drift-diffusion model decomposes behavior into dissociable latent parameters, it allows to disambiguate changes in feature-based attention with age (captured by the drift rate parameter) from age-related changes in the speed-accuracy trade-off (captured by the boundary separation parameter) and in sensory and motor processes (captured by the non-decision time).

The current study aimed to elucidate the impact of aging on feature-based attention by comparing task performance between two age groups with a drift-diffusion model. More specifically, we administered a two-alternative forced choice task to groups of young and older participants in which one or two colored stimuli were presented. One stimulus was the target, i.e., a number in which a response had to be selected based on its identity. The other stimulus (if present) was the distracter. The distracter could be a letter, which was neutral with the response to the target since letters were irrelevant to task performance, or a number that was either compatible (linked with the same response) or incompatible (linked with the other response) with the target. We hypothesized that a distracter would interfere with responses to the target (regardless of the distracter's identity) (e.g., Gillebert et al., 2012). In this context, given that feature-based attention is expected to influence the drift rate and that the most recent evidence suggests an age-related decline in feature-based attention (Gamboz et al., 2002; Quigley et al., 2010; Quigley & Müller, 2014; Verhaeghen, 2011; Zanto et al., 2010), we hypothesized corresponding decreases in drift rate which would be more pronounced for older than young adults. Further, consistent with a congruency effect (see MacLeod, 1991), we hypothesized that an incompatible distracter would be more difficult to suppress and would interfere more with responses to the target than a neutral or compatible distracter. Considering that increased task difficulty can attenuate age-related effects (Hommel et al., 2004; Madden & Whiting, 2004; Wang et al., 2012), we hypothesized corresponding decreases in drift rate which would be more pronounced for older than young adults. In addition, boundary separations and non-decision times were estimated to account for differences in the speed-accuracy trade-off and in sensory and motor processes, respectively. Considering the more conservative response style of older adults (Salthouse, 1979; Smith & Brewer, 1995; Starns & Ratcliff, 2010) and the slowed sensory encoding (Zanto et al., 2010) and execution of a motor response (e.g., see Seidler et al., 2010) with age, we hypothesized higher boundary separations and non-decision times for older than young adults.

Materials and methods

Participants

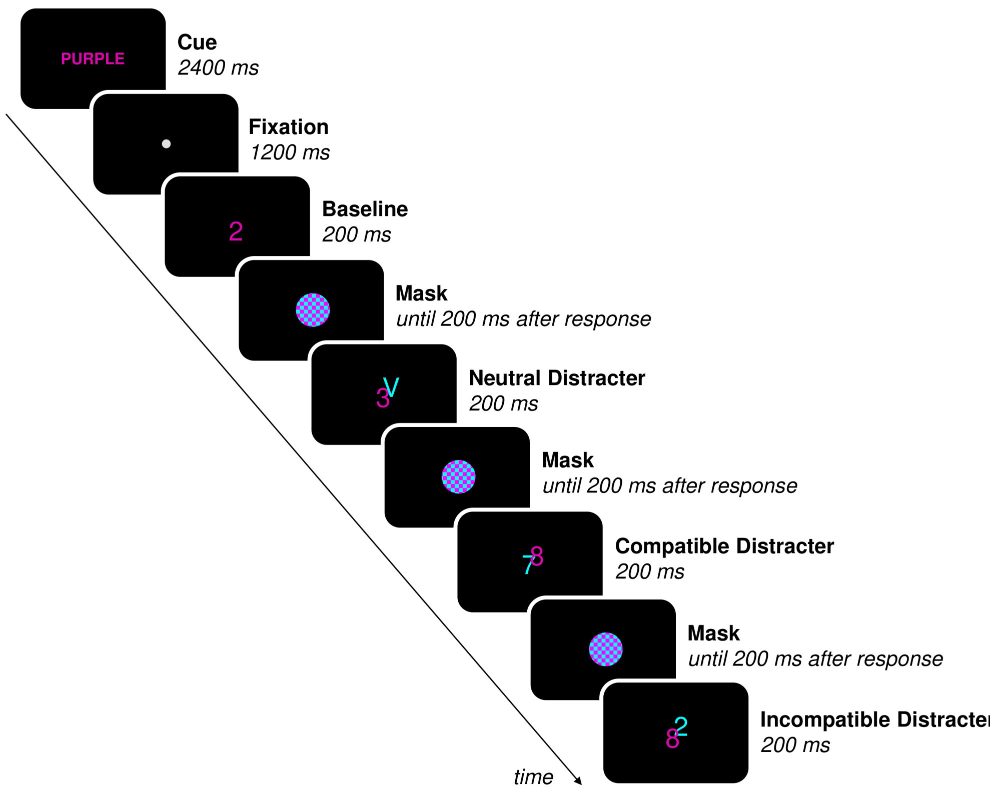
38 cognitively healthy young volunteers (Age: 18-25 years, *M* = 20.6 years, *SD* = 2.3 years; Education level: 13-18 years, *M* = 15.0 years, *SD* = 1.8 years) and 38 cognitively healthy older volunteers (Age: 60-85 years, *M* = 69.7 years, *SD* = 6.4 years; Education level: 10-20 years, *M* = 15.6 years, *SD* = 2.4 years) participated in the current study. The age groups were matched for gender (21 female, 17 male) and education level (two-sample *t*-test: $t(72) = 1.30$, $p = .20$). Participants were required to be right-handed to eliminate a possible effect of handedness on task performance (Dehaene, Bossini, & Giraux, 1993). All participants had normal or corrected-to-normal vision and reported not to suffer from color blindness. Participants reporting a neurological history (e.g., stroke, traumatic brain injury), psychiatric history (e.g., schizophrenia) and/or diagnosis of attention deficit (hyperactivity) disorder were not eligible to participate. The study was approved by the Social and Societal Ethics Committee (reference number: G-2017 12 1036). All participants gave written informed consent in accordance with the Declaration of Helsinki.

Task and stimuli

Stimuli were presented on a 24-inch Dell monitor (60 Hz, 1920 × 1200 pixel resolution) controlled by a personal computer running Presentation 19.0 (Neurobehavioral Systems, Berkeley, CA, United States). Eye tracking data were collected for fixation control using the Tobii Pro Fusion eye tracking system (250 Hz; Tobii Technology AB, Sweden). Participants were seated in a semi-dark room and their heads were stabilized by a chin rest placed at approximately 70 cm from the screen. Participants performed a two-alternative forced choice task (Fig. 1). In each trial, one or two partly overlapping equiluminant stimuli (size = ~0.80°) were displayed in the center of a black screen for 200 ms (similar to the feature-based paradigm in Lanssens, Pizzamiglio, Mantini, & Gillebert, 2020). One stimulus was a number (between 1 and 9, except 5), while the other (if present) was a letter (A, F, H, K, N, R, U or V) or also a number. Co-presented numbers were never the same. One stimulus was colored in magenta or cyan, the other (if present) was colored in cyan or magenta.

Figure 1

Two-Alternative Forced Choice Task



Note. Blocks consisted of 32 trials in which one task-relevant number (= target) was presented without a task-irrelevant stimulus (= distracter) (baseline condition), with one task-irrelevant letter (neutral with the response to the target), or with one task-irrelevant number either compatible or incompatible with the response to the target. The conditions occurred an equal amount of times per block in random order. The target color was cued by the respectively colored word at the start of each block. Participants were instructed to press one of two buttons depending on whether the target was smaller or larger than five.

We used a mixed experimental design, with each participant completing four runs each consisting of four blocks. In half of the runs, the target was the magenta number, while in the other half, the target was the cyan number. The order of the runs was counterbalanced across participants. Each block started with a cue-only trial, in which the target color was presented as a colored word in the center of the screen for 2400 ms ("PURPLE" or "BLUE", indicating magenta or cyan respectively; font size: Arial 24 pt). The cue was followed by a fixation interval of 1200 ms. Each block had 32 trials in which the target number was presented without a distracter (baseline condition), co-presented with a distracter letter that was neutral compared to the response to the target, or co-presented with a distracter number that was either compatible or incompatible with the response to the target. These four conditions occurred an equal amount of times per block in random order, in which each of eight possible numbers/letters occurred once per color and per condition. To avoid a (micro-)spatial bias while performing the task, the magenta and cyan stimuli randomly switched locations from trial to trial, which was counterbalanced per condition. The overlap of stimuli (left stimulus presented on top of right, or vice versa) also randomly switched from trial to trial, which was counterbalanced per condition as well. The presentation of stimuli was followed by a mask, which was a cyan and magenta colored noise patch (size = ~1.60° visual angle) that was presented until 200 ms after participants responded. Each block was followed by a rest period of 12 s.

Participants were instructed to indicate whether the target number was smaller or larger than five. To this end, the upwards (↑) or downwards (↓) arrow on the keyboard (positioned on the vertical axis and corresponding with < 5 and > 5 respectively) had to be pressed with the index finger of the dominant hand. Participants were asked to fixate the center of the screen and to pay attention to speed and accuracy while performing the task.

Procedure

Prior to performing the task, all older participants were screened for cognitive impairments with version 7.1 of the Montreal Cognitive Assessment (MoCA) (MoCA score: 24-30, $M = 27.5$, $SD = 1.5$) (Nasreddine et al., 2005). Subjects with a MoCA score lower than 23 were excluded from the study (Carson, Leach, & Murphy, 2018).

Data analysis

Behavioral and eye tracking data were analyzed using R (R 3.5.3, R Core Team (2021). R Foundation for Statistical Computing, Vienna, Austria. URL: https://www.R-project.org/) and the lme4 package (version 1.1.21) (Bates, Mächler, Bolker, & Walker, 2014), and using Python (version 3.6.12) and the HDDM package (version 0.8.0) (Wiecki, Sofer, & Frank, 2013).

One (female) participant of each age group was excluded from all analyses since the chains of their hierarchical drift-diffusion models did not converge, in which multiple individual parameters and one group-level parameter had a Gelman-Rubin statistic ($\hat{R}$) larger than 1.02. Visual inspection revealed that their RT distributions were more positively skewed than those of other participants. Thus, the final sample on which the analyses were performed consisted of 37 participants per age group.

Task. Trials with anticipatory RTs of 100 ms or less (< 0.001% of trials) and trials with RTs above the 99^{th} percentile of the sample (= ~1766 ms) were excluded from the analysis.

The averaged accuracy and RTs on correct trials were analyzed with a Poisson and linear mixed-effects model respectively. Each of these models included independent variables for age group, condition and their interaction, as well as a random intercept. The goodness of fit of the models was consistently better without a random slope. The effects of the independent variables were assessed by performing Wald chi-square tests. If an interaction was not significant, the mixed-effects model was re-fitted without it to estimate the main effects of the independent variables.

Next, the behavioral data of participants in both age groups were fitted with a hierarchical version (Wiecki et al., 2013) of the drift-diffusion model (Ratcliff, 1978; Ratcliff & Rouder, 1998). The hierarchical drift-diffusion model is a specific version of a drift diffusion model which assumes that individual estimates are normally distributed around a group mean (Wiecki et al., 2013). The hierarchical drift-diffusion model uses Markov-chain Monte Carlo sampling to generate posterior distributions over parameter estimates. We used a model with accuracy coding, in which the decision boundaries were associated with the correct and incorrect response respectively (i.e., assuming unbiased starting points). We allowed the model to estimate drift rate, boundary separation and non-decision time separately for each age group, condition and their interaction. Parameters for the conditions with a distracter were estimated relative to the baseline condition in which no distracter was present. We drew 30.000 samples from the posterior distribution, in which the first 15.000 samples were discarded as burn-in with a thinning of 20. To ensure model convergence, we visually inspected the group-level chains and the model was run three times to compute the $\hat{R}$. All group-level parameters were required to have a $\hat{R}$ between 0.98 and 1.02. The three model fits were then concatenated to obtain a model based on 90.000 samples. We also performed a posterior predictive analysis in which 500 samples were used to simulate the performance of each participant across conditions. A strong correlation was found for both age groups between the empirical and simulated accuracy (Young: $r(35) = .87$, $p < .001$; Older: $r(35) = .87$, $p < .001$), and between the empirical and simulated mean correct RTs (Young: $r(35) = .997$, $p < .001$; Older: $r(35) = .998$, $p < .001$) and standard deviation in correct RTs (Young: $r(35) = .92$, $p < .001$; Older: $r(35) = .93$, $p < .001$) (Cohen, 1988, 1992). We evaluated the impact of aging on feature-based attention by assessing whether the estimated posterior distribution of the drift rates differed between age groups. To this end, we calculated the overlap between the respective posterior distributions.

Fixation control. The eye tracking data were preprocessed by selecting samples recorded during stimulus presentation. Trials in which 30% or more of the samples were lacking were classified as being not successfully recorded and excluded from the analyses. Runs were required to have samples of at least 25% of the trials to be included in the eye tracking analysis. As a result, 16 young participants and 16 older participants were excluded from the eye tracking analysis since no data were present for at least one condition[1]. The eye movements of participants were inspected by counting saccades with a minimal duration of 10 ms outside a radius of 2.50° around fixation. A Poisson mixed-effects model was fitted on the proportion of trials with at least one saccade. The model included independent variables for condition, age group and their interaction, as well as a random intercept. The goodness of fit of the model was consistently better without a random slope. If the interaction was not significant, the model was re-fitted without it to estimate the main effects of the independent variables.

Transparency and openness

All methods developed by others were appropriately cited in the text and listed in the references section. The study data have been made publicly available at the Open Science Framework, URL: https://osf.io/2k49x/. The code that was used during the data analysis is available upon request. This study's design and its analysis were not pre-registered.

[1] The low quality of the eye tracking data in a subset of the participants is likely related to a suboptimal set-up (e.g., lighting < 300 lux) and individual factors (e.g., glasses, cataract surgery)

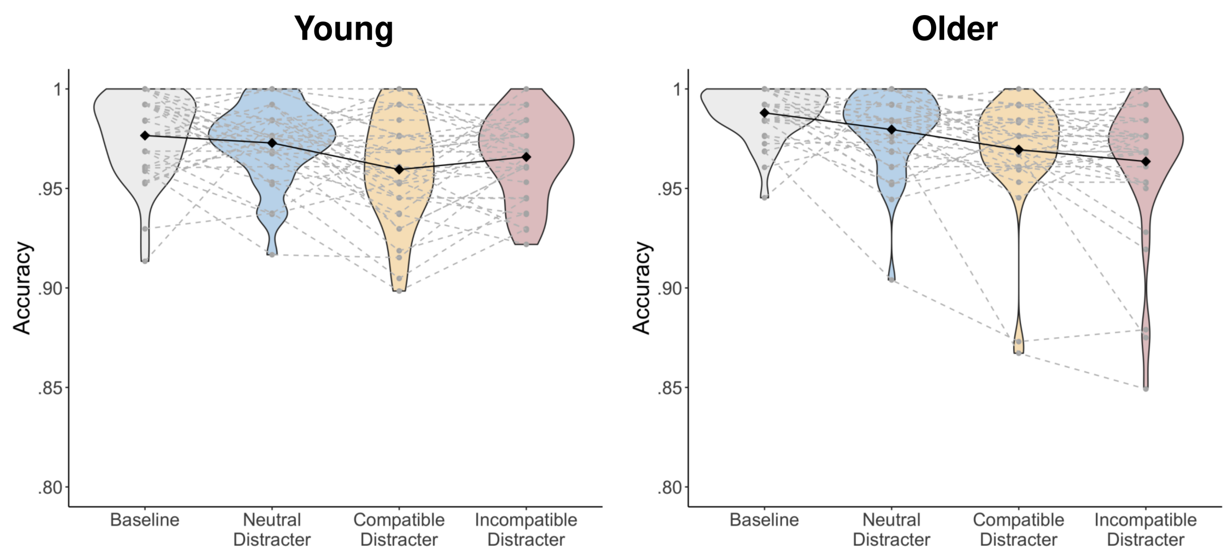
Results

Accuracy

The accuracy was high and no significant effects of age group ($\chi^2(1) = 0.41$, $p = .52$), condition ($\chi^2(3) = 2.12$, $p = .55$) or their interaction ($\chi^2(3) = 0.26$, $p = .97$) were found (Fig. 2).

Figure 2

Accuracy



Note. The accuracy is reported for each participant of the young and older age group per condition: a target presented without a distracter (= baseline), or with a neutral, compatible or incompatible distracter. Grey dots reflect the individual participants, black dots represent the group means.

Reaction time

Significant effects of age group, condition (Young: $\chi^2(3) = 52.48$, $p = 2.36 \times 10^{-11}$; Older: $\chi^2(3) = 236.29$, $p = 6.04 \times 10^{-51}$) and their interaction ($\chi^2(3) = 35.46$, $p = 9.75 \times 10^{-8}$) were found on the RTs on correct trials (Fig. 3).

First, for the effect of age group, the RTs were significantly higher for the group of older compared to young adults in the baseline condition in which the target was presented without a distracter (Δ = 110.57 ms, 95% CI [68.50 ms, 152.64 ms], $t(76.99) = 5.15$, $p = 1.94 \times 10^{-6}$), and in the conditions in which the target was presented with a neutral (Δ = 132.19 ms, 95% CI [90.12 ms, 174.26 ms], $t(76.99) = 6.16$, $p = 3.10 \times 10^{-8}$), compatible (Δ = 146.05 ms, 95% CI [103.98

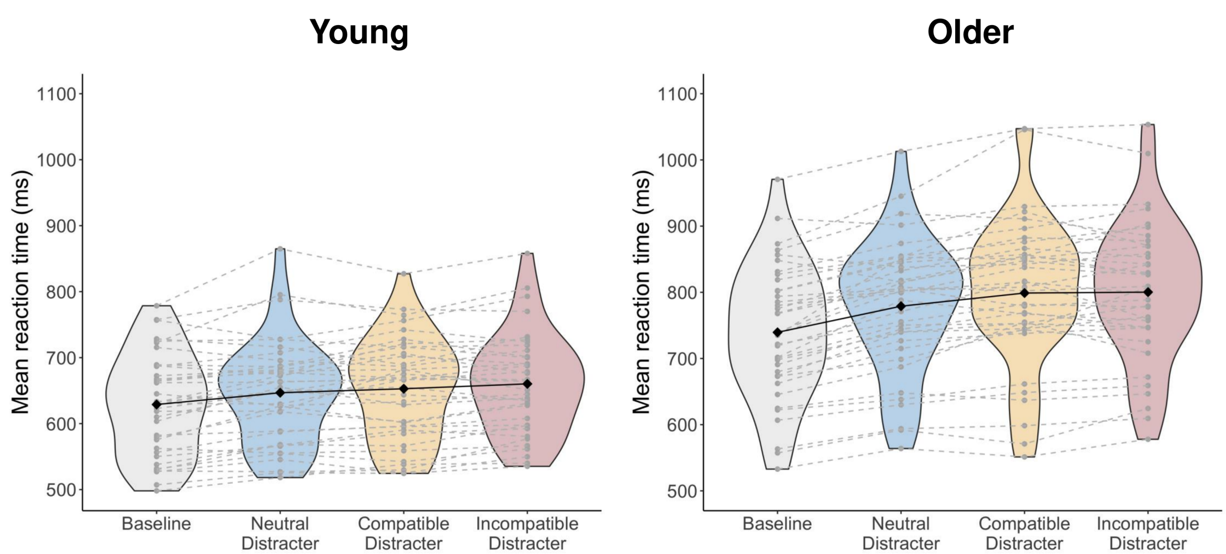
ms, 188.12 ms], $t(76.99) = 6.80$, $p = 1.95 \times 10^{-9}$) or incompatible ($\Delta = 140.08$ ms, 95% CI [98.01 ms, 182.15 ms], $t(76.99) = 6.53$, $p = 6.47 \times 10^{-9}$) distracter.

Second, for the effect of condition, the RTs of young adults were significantly higher when the target was presented with a neutral ($\Delta = 17.89$ ms, 95% CI [9.05 ms, 26.74 ms], $t(216) = 3.97$, $p = 9.98 \times 10^{-5}$), compatible ($\Delta = 23.81$ ms, 95% CI [14.97 ms, 32.66 ms], $t(216) = 5.28$, $p = 3.19 \times 10^{-7}$) or incompatible ($\Delta = 31.30$ ms, 95% CI [22.45 ms, 40.14 ms], $t(216) = 6.94$, $p = 4.62 \times 10^{-11}$) distracter compared to the baseline condition in which the target was presented without a distracter. The RTs were also significantly higher when the target was presented with an incompatible compared to neutral distracter ($\Delta = 13.41$ ms, 95% CI [4.56 ms, 22.25 ms], $t(216) = 2.97$, $p = .003$), but did not differ significantly when the target was presented with a compatible versus neutral ($\Delta = 5.92$ ms, 95% CI [-2.93 ms, 14.76 ms], $t(216) = 1.31$, $p = .19$) or incompatible ($\Delta = -7.49$ ms, 95% CI [-16.33 ms, 1.36 ms], $t(216) = 1.66$, $p = .10$) distracter. In the group of older adults, the RTs were significantly higher when the target was presented with a neutral ($\Delta = 39.51$ ms, 95% CI [30.67 ms, 48.36 ms], $t(216) = 8.76$, $p = 5.90 \times 10^{-16}$), compatible ($\Delta = 59.30$ ms, 95% CI [50.45 ms, 68.14 ms], $t(216) = 13.14$, $p = 2.27 \times 10^{-29}$) or incompatible ($\Delta = 60.81$ ms, 95% CI [51.97 ms, 69.66 ms], $t(216) = 13.48$, $p = 1.86 \times 10^{-30}$) distracter compared to the baseline condition in which the target was presented without a distracter. The RTs were also significantly higher when the target was presented with a compatible ($\Delta = 19.78$ ms, 95% CI [10.94 ms, 28.63 ms], $t(216) = 4.38$, $p = 1.82 \times 10^{-5}$) or incompatible ($\Delta = 21.30$ ms, 95% CI [12.45 ms, 30.14 ms], $t(216) = 4.72$, $p = 4.24 \times 10^{-6}$) compared to neutral distracter, but did not differ significantly when the target was presented with an incompatible versus compatible distracter ($\Delta = 1.51$ ms, 95% CI [-7.33 ms, 10.36 ms], $t(216) = 0.34$, $p = .74$).

Third, for the interaction between age group and condition, the RTs increased significantly more for the group of older compared to young adults when the target was presented with a neutral (Δ = 21.62 ms, 95% CI [9.11 ms, 34.13 ms], $t(216) = 3.39$, $p = 8.36 \times 10^{-4}$), compatible (Δ = 35.49 ms, 95% CI [22.98 ms, 47.99 ms], $t(216) = 5.56$, $p = 7.89 \times 10^{-8}$) or incompatible (Δ = 29.51 ms, 95% CI [17.01 ms, 42.02 ms], $t(216) = 4.63$, $p = 6.46 \times 10^{-6}$) distracter compared to the baseline condition in which the target was presented without a distracter. The RTs also increased significantly more for the group of older compared to young adults when the target was presented with a compatible compared to neutral distracter (Δ = 13.86 ms, 95% CI [1.36 ms, 26.37 ms], $t(216) = 2.17$, $p = .03$), but did not differ significantly when the target was presented with an incompatible versus neutral (Δ = 7.89 ms, 95% CI [-4.62 ms, 20.40 ms], $t(216) = 1.24$, $p = .22$) or compatible (Δ = -5.97 ms, 95% CI [-18.48 ms, 6.53 ms], $t(216) = -0.94$, $p = .35$) distracter.

Figure 3

Reaction Time on Correct Trials



Note. The mean reaction time on correct trials is reported for each participant of the young and older age group per condition: a target presented without a distracter (= baseline), or with a neutral, compatible or incompatible distracter. Grey dots reflect the individual participants, black dots represent the group means.

Hierarchical drift-diffusion model

The estimated drift rates, boundary separations and non-decision times of the hierarchical drift-diffusion model are reported per condition for each age group in Figure 4.

Drift rate. The drift rate did not differ significantly between the age groups in the baseline condition ($p = .20$), indicating that young and old participants did not differ significantly in their overall drift rate in the absence of distracters.

First, we compared the drift rate between the conditions in which the target was presented with versus without a distracter. In both age groups, the drift rates were significantly lower when the target was presented with a neutral (Young: $p = .02$; Older: $p = .001$), compatible (Young: $p < .001$; Older: $p < .001$) or incompatible (Young: $p = .001$; Older: $p < .001$) distracter compared to the baseline condition. The decrease in drift rate relative to the baseline condition did not differ significantly between the age groups for the condition with a neutral distracter ($p = .15$), but the decreases were significantly stronger in the group of older compared to young adults for the conditions with a compatible ($p = .03$) or incompatible ($p < .001$) distracter.

Second, we compared the change in drift rate from the baseline condition between the conditions with a distracter. The decrease in drift rate relative to the baseline condition was significantly stronger for the condition with a compatible compared to neutral distracter in both age groups (Young: $p = .001$; Older: $p < .001$) and this did not differ significantly between the age groups ($p = .24$). The decrease in drift rate relative to the baseline condition was significantly stronger for the condition with an incompatible compared to neutral distracter in the older ($p < .001$) but not young ($p = .10$) age group. This effect differed significantly between the age groups ($p < .001$). The decrease in drift rate relative to the baseline condition was significantly stronger for the condition with an incompatible compared to compatible distracter in the older age group

($p = .03$) and significantly lower in the young age group ($p = .01$). The latter effect also differed significantly between the age groups ($p = .002$).

In summary, all distracters interfered significantly with the rate at which information was accumulated in both age groups, but the impact of the compatible and incompatible distracters was significantly stronger in the older than young age group. The drift rate decreased significantly more in the older age group when the distracter was compatible or incompatible compared to neutral and incompatible compared to compatible, while this was not consistently observed in the young age group. The decrease in drift rate due to the incompatible compared to neutral distracter was significantly stronger in the older than young age group, while the decrease in drift rate due to the compatible compared to neutral distracter in the older age group differed significantly from the respective increase in drift rate in the young age group.

Boundary separation. The boundary separation was significantly higher for the group of older compared to young adults in the baseline condition ($p < .001$), indicating that older participants were on average more cautious in their responses.

First, we compared the boundary separation between the conditions with a distracter and the baseline condition in which the target was presented without a distracter. In the group of young adults, the boundary separation was significantly lower when the target was presented with a compatible distracter compared to the baseline condition in which the target was presented without a distracter ($p = .001$), but not significantly lower when the target was presented with a neutral ($p = .09$) or incompatible ($p = .32$) distracter. In the group of older adults, the boundary separation was significantly lower when the target was presented with an incompatible distracter compared to the baseline condition ($p = .02$), but not significantly higher ($p = .19$) or lower ($p = .38$) when the target was presented with a neutral or compatible distracter. Further, the effects on boundary separation relative to the baseline condition did not differ significantly between the age groups for the conditions with a neutral (p = .10) or compatible (p = .15) distracter, but the decrease in boundary separation relative to the baseline condition for the condition with an incompatible distracter was significantly stronger in the group of older compared to young adults (p = .047).

Second, we compared the change in boundary separation from the baseline condition between the conditions with a distracter. Relative to the baseline condition, the boundary separation was significantly more decreased for the condition with a compatible compared to neutral distracter in the group of young adults (p = .03), but did not differ significantly in the group of older adults (p = .11). This effect did not differ significantly between the age groups (p = .35). Further, relative to the baseline condition, the boundary separation was not significantly more decreased for the condition with an incompatible compared to neutral distracter in the group of young adults (p = .18), but it was significantly different in the group of older adults (in which it decreased and increased, respectively) (p < .001). The latter effect differed significantly between the age groups (p < .001). The decrease in boundary separation relative to the baseline condition was significantly weaker for the condition with an incompatible compared to compatible distracter in the group of young adults (p = .004), but significantly stronger in the group of older adults (p = .02). This effect also differed significantly between the age groups (p < .001).

In summary, the compatible and incompatible distracter led to decreases in boundary separation, but the effects were not consistently significant in the age groups. The decrease in boundary separation caused by the incompatible distracter was significantly stronger in the older than young age group, although the boundary separation of the older age group was still higher considering the substantial difference in the baseline condition. The identity of the distracter significantly modulated the boundary separation in both age groups, although the effects differed within and between the age groups. The decrease in boundary separation caused by the incompatible relative to neutral distracter in the young age group differed significantly from the respective difference in the older age group, and the increase in boundary separation due to the incompatible relative to compatible distracter in the young age group differed significantly from the respective decrease in the older age group.

Non-decision time. The non-decision time did not differ significantly between the age groups in the baseline condition ($p = .13$), indicating that young and old participants did not differ significantly in their overall non-decision time in the absence of distracters.

First, we compared the non-decision time between the conditions with a distracter and the baseline condition in which the target was presented without a distracter. In the group of young adults, the non-decision time was significantly higher when the target was presented with a neutral ($p < .001$), compatible ($p < .001$) or incompatible ($p < .001$) distracter compared to the baseline condition in which the target was presented without a distracter. In the group of older adults, the non-decision time was significantly higher when the target was presented with an incompatible distracter compared to the baseline condition ($p = .009$), but not significantly higher when the target was presented with a neutral ($p = .28$) or compatible ($p = .27$) distracter. Further, the increase in non-decision time relative to the baseline condition was significantly stronger in the group of young compared to older adults for the condition with a neutral ($p = .04$) or compatible ($p = .047$) distracter, but not for the condition with an incompatible distracter ($p = .31$).

Second, we compared the change in non-decision time from the baseline condition between the conditions with a distracter. In the group of young adults, the increase in non-decision time relative to the baseline condition was not significantly different for the conditions with a compatible versus neutral distracter in both age groups (Young: $p = .43$; Older: $p = .48$) and this effect did not differ significantly between the age groups ($p = .48$). The increase in non-decision time relative to the baseline condition was significantly stronger for the conditions with an incompatible compared to neutral distracter in the group of older ($p = .04$) but not young ($p = .36$) adults. This effect also did not differ significantly between the age groups ($p = .09$). The increase in non-decision time relative to the baseline condition was significantly stronger for the conditions with an incompatible compared to compatible distracter in the group of older ($p = .045$) but not young ($p = .43$) adults. Similarly, this effect did not differ significantly between the age groups ($p = .08$).

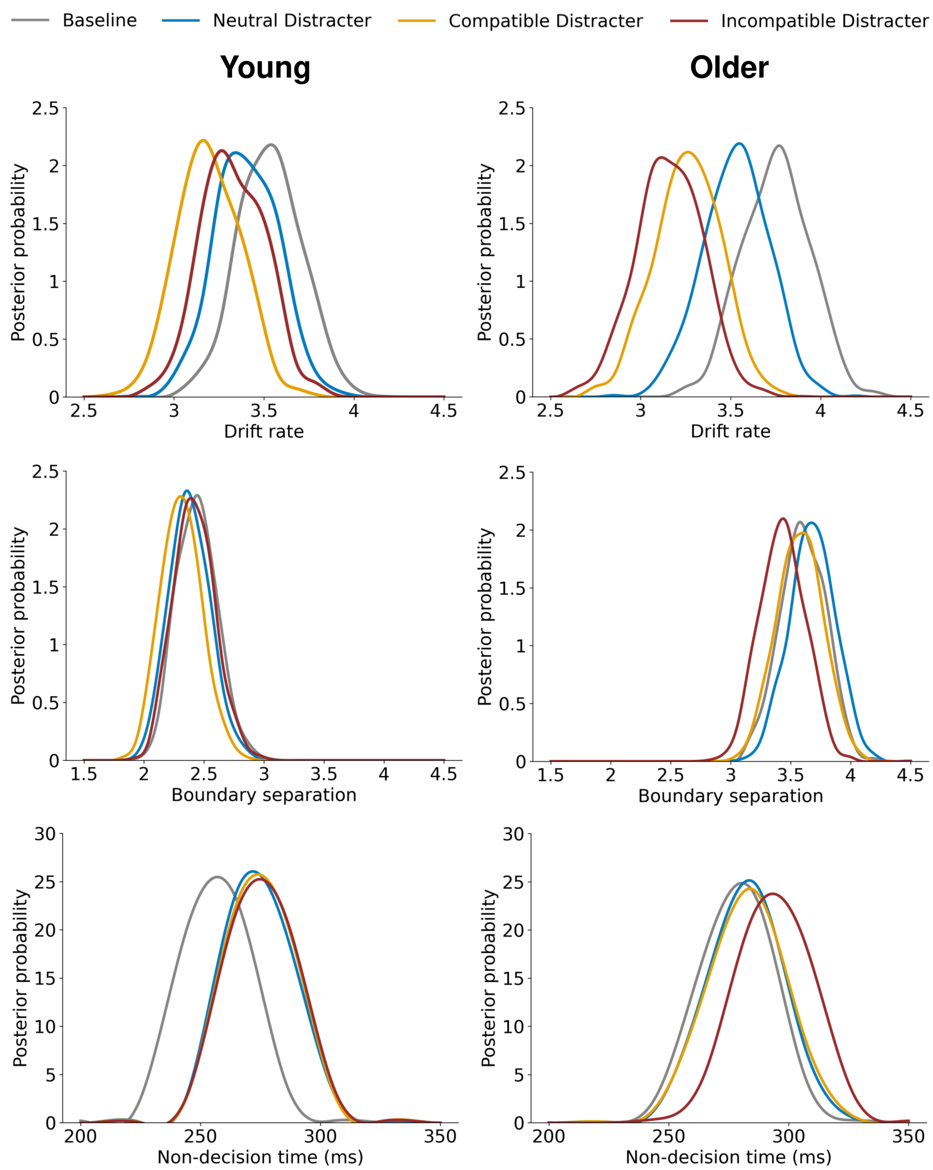
In summary, all distracters led to increases in non-decision time in both age groups, but these increases were only consistently significant in the young age group. Furthermore, the increases in non-decision time caused by the neutral and compatible distracter were significantly stronger in the young than older age group. The non-decision times were modulated by the identity of the distracter in the group of older adults, with significant increases in non-decision time when the distracter was incompatible instead of neutral or incompatible instead of compatible, but no significant increases were observed in the group of young adults. None of these effects differed significantly between the age groups.

Fixation control

The results of the eye tracking analysis were added as supplementary results. A significant effect of condition, but not of age group was found on the proportion of trials with at least one saccade outside a 2.50° radius from fixation. The interaction between age group and condition was also not significant.

Figure 4

Hierarchical Drift-Diffusion Model Parameters



Note. The posterior probability of the parameters of the hierarchical drift diffusion model (drift rate, boundary separation and non-decision time) is reported for the group of young and older adults per condition: a target presented without a distracter (= baseline), or with a neutral, compatible or incompatible distracter. The parameters of the conditions with a distracter were estimated relative to the baseline condition. In order to visualise within- and between-group differences, the absolute values of the parameters of conditions with a distracter were computed by adding their estimates to those of the baseline condition.

Discussion

The current study assessed the impact of aging on feature-based attention by comparing the behavioral interference of distracters in a two-alternative forced choice task between two age groups. Results showed that the accuracy did not differ significantly within or between age groups, while overall the RTs on correct trials were significantly higher for the group of older than young adults. The RTs of both age groups were significantly higher when the target was presented with compared to without a distracter, and these increases were significantly stronger in the older than young age group. Although not consistently significant, the RTs of both age groups were higher when the target was presented with an incompatible compared to neutral or compatible distracter, and with a compatible compared to neutral distracter. The latter RT increase was significantly stronger in the older than young age group. Next, the data were analyzed with a hierarchical drift-diffusion model to decompose the averaged RTs into different underlying parameters in order to disambiguate differences in feature-based attention (captured by drift rate) from differences in the speed-accuracy trade-off (captured by boundary separation), sensory encoding and the execution of a motor response (captured by non-decision time). The drift rate did not differ significantly between the age groups in the condition without a distracter, indicating no significant differences in evidence accumulation in the absence of distracting information. The drift rates of both age groups were significantly lower when the target was presented with compared to without a distracter, but the decreases were significantly stronger in the older than young age group when the distracter was compatible or incompatible. Further, in the older age group, these decreases in drift rate were significantly stronger when the distracter was compatible or incompatible compared to neutral and incompatible compared to compatible, while in the young age group, these decreases were only significantly stronger when the distracter was compatible compared to neutral. The decrease in drift rate was significantly stronger in the older than young age group when the distracter was incompatible compared to neutral. Jointly, our observations indicate that feature-based attention declines with age. Significant within- and between-group differences in boundary separation and non-decision time were observed as well, which are discussed in one of the following sections.

Feature-based attention declines with age

We observed that the task performance of both age groups decreased when the target was presented with compared to without a distracter. This was reflected by significantly higher RTs on correct trials. These RT increases were significantly stronger in the older than young age group. This could be due to an age-related decline in the ability to suppress a distracter, but might as well result from a constant proportional relation between the age groups since the RTs of older adults were slower overall (Salthouse, 2000). Furthermore, stronger RT increases for older than young adults in conditions with compared to without a distracter can be (partially) attributed to age-related differences in the speed-accuracy trade-off. Older adults prioritize accuracy over speed, while young adults tend to prioritize speed over accuracy (Salthouse, 1979; Smith & Brewer, 1995). Congruently, older adults require more information to initiate a response than young adults (Ratcliff, Thapar, Gomez, & McKoon, 2004; Starns & Ratcliff, 2010). This implies that the slowed responding of older adults (Der & Deary, 2006; Dykiert, Der, Starr, & Deary, 2012; Fortenbaugh et al., 2015) cannot be solely attributed to age-related declines in processing speed (Cerella, 1985; Salthouse, 1996), sensory encoding (Zanto et al., 2010) and motor processes (e.g., see Seidler et al., 2010), but also to a more conservative response style which leads to similar or even better accuracy levels than young adults (e.g., see Vallesi, Tronelli, Lomi, & Pezzetta, 2021). Analyzing the data with a hierarchical drift-diffusion model allowed us to estimate the rate at which information to make a decision is collected (i.e., drift rate) while accounting for, among other factors, the speed-accuracy trade-off (i.e., boundary separation). We observed that the rate at which information was gathered was indeed affected by the presence of a distracter since the drift rates of both age groups were significantly lower in the conditions with compared to without a distracter. These decreases in drift rate were significantly stronger in the older than young age group when the distracter was compatible or incompatible, which suggests that the ability to suppress distracters based on features declines with age. Some studies have interpreted lower drift rates in older than young adults as a slowed information processing speed (e.g., see Theisen, Lerche, von Krause, & Voss, 2021). Thus, the stronger decrease in drift rate for the older than young age group when the target was presented with a compatible or incompatible distracter compared to without a distracter could be argued to result from a slower processing of information from two stimuli compared to one stimulus. However, it is unlikely that this underlies our findings since under such an account we would also expect a significant between-group difference in drift rate when the target was presented with a neutral distracter compared to without a distracter, and possibly even when the target was presented without a distracter. We also note that the link between processing speed and drift rate is less straightforward than is sometimes assumed, as the concept of processing speed is closely related to the sensory encoding of information by which it would also map onto non-decision time.

The identity of the distracter modulated task performance as well. The RTs of both age groups were significantly higher when the target was presented with an incompatible compared to neutral distracter, with no significant difference between the age groups. This finding is consistent with typical congruency effects in the literature (see MacLeod, 1991). The RTs of both age groups were also higher when the target was presented with a compatible compared to neutral distracter, but this RT increase was only significant in the older age group and significantly higher in the older than young age group. Further, the RTs were not significantly different within or between age groups when the target was presented with an incompatible compared to compatible distracter. The latter findings differ from typical congruency effects in which a compatible distracter interferes less with responses to a target than a neutral or incompatible distracter (see MacLeod, 1991). Although the reason of this effect is unclear, we note that our paradigm manipulated a feature that requires more high-level processing (i.e., identity) than those in typical conflict tasks (e.g., color in the Stroop task). Hence, distracters of the relevant response set (= numbers) could have interfered more with task performance than distracters of the irrelevant response set (= letters), but their exact identity required further processing and affected the averaged RTs less. Likewise, we did not observe typical congruency effects on the drift rate in the analysis of the data with a hierarchical drift-diffusion model. Adding to the presumption that feature-based attention might decline with age, we found that the decrease in drift rate due to the incompatible compared to neutral distracter was significantly stronger in the older than young age group.

In summary, consistent with the most recent empirical evidence (Quigley et al., 2010; Quigley & Müller, 2014; Verhaeghen, 2011; Zanto et al., 2010), our findings indicate a decline in feature-based attention with advancing age. In this way, the current study contributes to resolving the ambiguity that has pervaded the literature on the impact of aging on feature-based attention (Gamboz et al., 2002; Verhaeghen & De Meersman, 1998). Notably, our conclusions seem to hold a greater reliability since we combined a feature-based attention task with a drift-diffusion model to account for age-related changes in other cognitive, sensory and motor processes (in contrast to Gamboz et al., 2002; Verhaeghen, 2011; Verhaeghen & De Meersman, 1998; Zanto et al., 2010) in a substantial sample of young and older adults (in contrast to Quigley et al., 2010; Quigley & Müller, 2014). An important question for future research remains the origin of the age-related decline in feature-based attention. Our findings demonstrate that this decline is unlikely to be related to eye movements since stimuli were presented near fixation and no significant between-group differences in fixation were found. It is also unlikely that declines in sensory processes (Nguyen-Tri et al., 2003; Park et al., 2012; Schmolesky et al., 2000) can fully explain impaired feature-based attention abilities since these would be captured by the non-decision time rather than the drift rate and considering that age-related effects were modulated by the identity of the distracter. Therefore, it seems plausible that top-down attentional processes decline with age, in which empirical evidence indicates an impaired ability to suppress distracters (see Zanto & Gazzaley, 2019) but preserved ability to enhance targets (see Deiber et al., 2010; Geweke, Li, & Störmer, 2018). A declined ability to inhibit distracters would affect all mechanisms of selective attention, which is consistent with reports of age-related impairments in spatial-based attention (Hommel et al., 2004; Madden & Whiting, 2004; Wang, Fu, Greenwood, Luo, & Parasuraman, 2012). Notably, feature-based attention might be less efficient than spatial-based attention due to additional impairments in feature perception and selectivity with age (Nguyen-Tri, Overbury, & Faubert, 2003; Park et al., 2012; Schmolesky et al., 2000), explaining why older adults would rely less on feature-based attention than young adults when a spatial strategy is possible (Pehlivanoglu, Duarte, & Verhaeghen, 2020; Talsma et al., 2006).

Age-related differences in the speed-accuracy trade-off and non-decisional factors

Not only significant differences in drift rate were observed, but also in boundary separation and non-decision time. The boundary separation was significantly higher in the group of older compared to young adults when the target was presented without a distracter, while the non-decision time was not significantly higher. The boundary separations and non-decision times of the older age group were also consistently higher in the conditions with a distracter than those of the young age group. These findings are congruent with earlier studies attributing the slowed responding of older adults to higher boundary separations and non-decision times (Theisen et al., 2021) due to a more conservative response style (Salthouse, 1979; Smith & Brewer, 1995; Starns & Ratcliff, 2010), a slowed sensory encoding (Zanto et al., 2010) and a slowed execution of the motor response (e.g., see Seidler et al., 2010). Noteworthy, our model mainly attributed the slower responses of older adults to a difference in boundary separation.

The boundary separations of the young and older age group were significantly lower when the target was presented with a compatible or incompatible distracter respectively compared to presenting the target without a distracter. In the group of young adults, the decreases in boundary separation relative to the condition without a distracter were significantly stronger when the distracter was compatible compared to neutral or incompatible. In the group of older adults, the decrease in boundary separation was significantly stronger when the distracter was incompatible compared to compatible. Taken together, these decreases in boundary separation seem in part responsible for the incorrect responses on the task. The boundary separation only increased when the target was presented with a neutral distracter compared to without a distracter in the older age group, which led to significant within- and between-group differences versus the condition with an incompatible distracter. Between-group differences in boundary separation were also observed. The decrease in boundary separation relative to the condition without a distracter was significantly stronger in the older than young age group when the distracter was incompatible. This decrease in boundary separation was also significantly stronger in the group of older compared to young adults when the distracter was incompatible compared to compatible. Thus, this suggests that older adults adjusted their decision boundaries to a lesser extent than young adults when an incompatible distracter was present.

The non-decision times of both age groups were higher when the target was presented with compared to without a distracter, in which all increases were significant in the young age group while only the increase associated with the incompatible distracter was significant in the older age group. This can be explained by the necessity to encode two instead of one stimuli (Zanto et al., 2010). The increases in non-decision time were not significantly different between the conditions with a distracter in the group of young adults, but the increase was significantly stronger when the distracter was incompatible compared to neutral or compatible in the group of older adults. Further, the increases in non-decision time were significantly stronger in the young compared to older age group when the distracter was neutral or compatible. It is currently unclear what underlies the latter within- and between-group differences in non-decision time. Notably, since stimuli and conditions were presented in a random order in each block, it is unlikely that differences in non-decision time can be attributed to a response repetition advantage considering that this occurred at random within each participant and would be balanced across participants.

Conclusion

The findings of the current study indicate an age-related decline in the ability to filter out distracters based on features. This decline likely occurs due to a general decrease in the top-down suppression of distracters, which might attribute to an age-related deficit in working memory since this results in a decreased ability to prevent access of distracting information that can interfere with the completion of a goal (Park et al., 2002). Further research is required to elucidate the relative contributions of bottom-up and top-down processes in the decline in feature-based attention with age, in which it is important that tasks are sufficiently challenging and that individual differences in cognitive reserve are considered (Robertson, 2013, 2014; Wilson et al., 2002).

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Declaration of interest

The authors report there are no competing interests to declare.

Data availability statement

The study data have been made publicly available at the Open Science Framework, URL: https://osf.io/2k49x/.

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