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Older yet Sharp: No General Age-Related Decline in Focusing Attention

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Attention is a multifaceted mechanism operating on space, features, and memory. Previous studies reported both decline and preservation of attention in aging. Yet, it is unclear if healthy aging differentially affects attentional selection in these domains. To address these inconsistencies, we evaluated the ability to focus attention using a battery of 11 tasks in a large sample of younger and older adults ($n = 172/174$). We addressed whether (a) individual differences and aging effects are consistent across different attention tasks and (b) there is a domain-specific or domain-general age-related decline in focused attention. Both younger and older adults benefited from focusing attention on space, features, and memory representations. Confirmatory factor analysis showed substantial commonalities in baseline performance across all tasks, indicating shared variance in decision-making and memory processes. Focused-attention effects, however, formed separate factors reflecting spatial-, feature-, and memory-based attentional efficiency. Correlations between these factors were generally low and inconsistent for both age groups. This supports the view that focused attention is not a single ability. Within the same domain, some tasks showed a decline, whereas others showed improvement with aging, and, on average, attentional benefits were similar across age groups. Accordingly, our results are inconsistent with the claim that aging is associated with either domain-specific or domain-general decline in focused attention.

Public Significance Statement

Longevity has boomed, confronting society with the need to foster the quality of life of the growing aging population. Being able to independently perform daily tasks is essential for well-being, and this depends critically on the fitness of our attentional abilities. Well-tuned perceptual attention abilities are needed to efficiently navigate our crowded sensory environment, and we also need an attention mechanism to select among thoughts, memories, and actions. Studies have pointed either to decline or preservation of attention in aging, creating an inconsistent picture. Our study provides a comprehensive assessment of the ability to focus attention on spatial locations, features, and memory representations in a large sample of younger and older adults. We found no evidence that attentional functions decline as people age: Younger and older adults could efficiently focus attention on all domains assessed, thereby improving their performance. The focus of attention remains sharp as people age.

Keywords: cognitive aging, attention, working memory, Bayesian mixed-effects models, orienting

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Controlled attention (also known as top–down attention) involves the selection of information guided by our current task goals (Oberauer, 2019; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977; Zanto & Gazzaley, 2014). This cognitive ability is essential for several activities of daily living, such as safely crossing a street, finding someone in a crowd, or even sorting through arguments in our minds. Selective attention is among the cognitive functions assumed to decline during healthy aging (Braver & Barch, 2002; Hasher & Zacks, 1988; Madden, 2007; West, 1996; Zanto & Gazzaley, 2014), and reductions in this ability could gradually and steadily hinder independent living in old age. Accordingly, assessing how aging affects attention abilities has become a salient issue in psychological research and the focal point of cognitive training programs (Belchior et al., 2013; Cheng et al., 2018; Park & Bischof, 2013; Rolle et al., 2017; Zendel et al., 2016).

Yet, the evidence for an attentional decline in aging is mixed (Madden, 2007; Veríssimo et al., 2022; Zanto & Gazzaley, 2014). Because attention is not a monolithic concept (Petersen & Posner, 2012; Posner & Petersen, 1990), one possibility to explain the mixed results is that different attentional mechanisms follow diverging trajectories across the life span: Some decline, while others remain preserved or even improve with age (Veríssimo et al., 2022). One classification schema proposes that attentional processes vary depending on the targets of selection (Chun et al., 2011). At one end, attention can operate on perceptual information to select and enhance relevant sensory inputs for ongoing processing, with selection occurring in a region of space or based on features. On the other end, attention may operate upon ideas, memories, and goals, selecting information to guide our thoughts and actions. Comparing the impact of age in these different types of domains is therefore essential to map how attentional functions develop and to determine which functions are more prone to age-related decline. So far, we lack a targeted evaluation of age differences across different attention paradigms. This evaluation is central to identifying which subcomponents of attention are at risk and should become the targets of interventions to prevent cognitive decline and which ones remain preserved and can provide a buffer against age-related impairment.

Research on attention in aging has predominantly concentrated on specific attentional functions linked to the inhibition of irrelevant information, broadly categorized as executive attention or attentional control. Findings in this literature exhibit a mixed pattern, with some studies indicating decline and others suggesting preserved ability. Recent large-scale studies assessing performance in paradigms commonly employed for inhibition assessment, such as the Simon or Stroop tasks, have contradicted the notion of attention decline in aging (Erb et al., 2023; Rey-Mermet et al., 2018; Rey-Mermet & Gade, 2020; Veríssimo et al., 2022). This evidence aligns with meta-analytic reviews of the extant literature (Rey-Mermet & Gade, 2018; Verhaeghen, 2011). However, it is noteworthy that large-scale studies, thus far, have not addressed selective attention tasks beyond the scope of these traditional executive control tasks.

Accordingly, the main goal of the present study was to provide a systematic evaluation of age differences in the ability to focus selective attention on perceptual representations, on one hand, and memory representations, on the other hand. Our study evaluated attentional focusing using a set of 11 tasks covering three domains—spatial attention, feature-based attention, and attention to working memory (WM) contents—in a large sample of younger (n = 172) and older adults (n = 174) providing a large-scale comparison of age effects across different attention paradigms. This allowed us to assess the possibility of domain-specific versus domain-general changes in the ability to focus attention in aging.

Spatial Attention

Spatial attention selects perceptual stimuli in one region in space for enhanced processing (Anton-Erxleben & Carrasco, 2013). Spatial attention can be assessed by comparing conditions in which a target stimulus appears at uncertain locations with conditions in which a cue highlights one spatial location as relevant (Posner, 1980), as illustrated in Figure 1A. Cues can be exogenous (e.g., a flash) attracting attention to salient changes in the visual field or endogenous (e.g., an arrow) requiring voluntarily control of spatial attention. In our study, we focused on endogenous cues because they more closely reflect top–down attentional selection (Carrasco & Yeshurun, 2009).

Spatial attention is relatively preserved in aging (for a review, see Zanto & Gazzaley, 2014). Older participants seem as able to orient spatial attention with endogenous cues as young adults (e.g., Waszak et al., 2010), provided that the cues are easy to interpret (Folk & Hoyer, 1992). Spatial attention, however, not only improves detection but also enhances the sensory signal at the cued location, increasing visual resolution (Carrasco & Barbot, 2014; Intriligator & Cavanagh, 2001; Montagna et al., 2009). Moreover, focusing spatial attention may require adjusting the size of the selected area (Greenwood & Parasuraman, 2004). Changes in spatial resolution and the resizing of the focus of attention have been less often evaluated in aging. Therefore, although a large portion of the literature seems to show preserved spatial attention in aging, the selection of tasks examined has been narrow. Hence, more evidence is needed from different spatial attention paradigms to determine to what extent aging affects spatial attention. In the present study, we included spatial attention tasks that measured detection ability, the resizing of the selection area, the time course of spatial focusing, as well as changes in visual resolution.

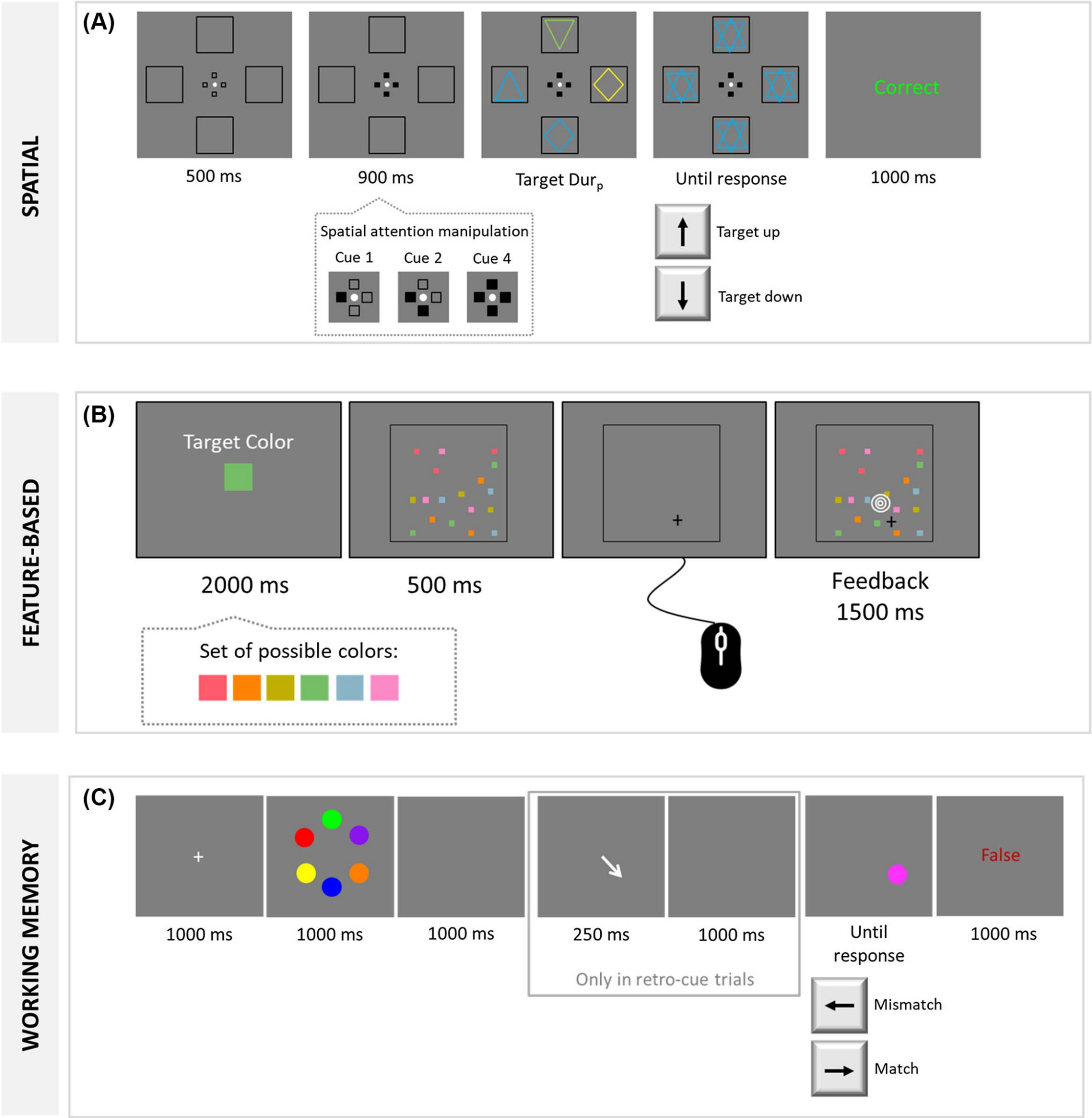
Feature-Based Attention

Feature-based attention enhances responses to the attended feature at the expense of nonattended ones (Carrasco, 2011) by creating attention filters that specify which features will be selectively processed and the extent of attenuation of nonattended features (Sun et al., 2016a, 2016b). Feature-based attention has been traditionally studied with visual search tasks, and a wealth of data has indicated age-related decrements in visual search performance (Ball et al., 1990; Zanto & Gazzaley, 2014). Nonetheless, visual search tasks have been criticized because they do not clearly isolate the attentional filters guiding feature-based selection (Inverso, 2017): Participants can sometimes solve the task on the basis of other variables (such as local contrast). Furthermore, because visual search tasks are reaction-time-based and older adults are generally slower to respond than younger adults, visual search speed may conflate age differences in feature-based selection with age differences in processing speed or response caution—both of which may account for differences in response times (Krause et al., 2021; Ratcliff et al., 2010a; Schubert et al., 2019).

Recently, a centroid paradigm has been proposed as an alternative to measure feature-based attention (Drew et al., 2010; Inverso, 2017; Sun et al., 2016a, 2016b). In this task, participants have to locate the

Figure 1

Illustration of Key Features of the Attention Paradigms Used to Measure Attention in Each Relevant Domain: A. Spatial, B. Feature-Based, and C. Working Memory



Note. In the spatial capacity task illustrated in Panel A, participants had to report the orientation (up or down) of the blue triangle. In the feature-based centroid task illustrated in Panel B, participants had to determine the center of gravity of the dots in the cued color. In the change detection retro-cue task illustrated in Panel C, participants had to report whether a probe matched or mismatched the color presented at the same location in the memory array. See the online article for the color version of this figure.

center of gravity (also known as centroid) of a briefly displayed cloud of dots varying in one feature dimension (e.g., color). A cue indicates one feature as relevant (e.g., green dots), such that only the centroid of dots with the cued feature should be evaluated, as illustrated in Figure 1B. This task assesses the degree to which the cued feature is weighted compared to the remaining features. Previous studies have shown that younger adults can develop efficient attention filters to give more weight to the cued category compared to the noncued ones (Lu et al., 2019; Sun et al., 2016a, 2016b, 2021). To the best of our knowledge, there are no studies that assessed how aging affects the ability to form feature-based attention filters. One goal of the present study was to assess the degree of age-related change in this ability.

Attention to Representations in Working Memory

Working memory is the cognitive system that maintains, in an accessible state, the mental representations that are currently relevant for completing our task goals. Selection of mental representations in working memory is accomplished by a focus of attention

(Cowan, 2011; Oberauer & Hein, 2012). The *retro-cue paradigm* has been used to assess the focus of attention in working memory (Souza & Oberauer, 2016). In a typical retro-cue task, participants study a set of memoranda for a later recognition or recall test, as illustrated in Figure 1C. In retro-cue trials, a cue (e.g., an arrow) during the retention interval points to the location of one memory item ahead of testing, thereby allowing participants to focus attention on retrieving this item. Accuracy (and response speed) improves in retro-cue trials compared to no-cue trials (Griffin & Nobre, 2003; Landman et al., 2003).

A handful of studies assessed retro-cue effects in old age, with mixed results: Some observed age-related decline in the ability to use retrocues (Duarte et al., 2013; Newsome et al., 2015), whereas others found preserved ability (Gilchrist et al., 2016; Loaiza & Souza, 2018; Mok et al., 2016; Souza, 2016; Strunk et al., 2019). Reduced retro-cue benefits have been found under time pressure (e.g., response deadline; Duarte et al., 2013) or with a short time to use the retrocue (Newsome et al., 2015). Given that old age is associated with slowing of processing (Cerella, 1985; Verhaeghen & Salthouse, 1997), it may be that old adults just need more time than younger adults to efficiently focus attention on working memory representations. Additionally, the type of memory test could be an important factor: A reduced attentional benefit in older adults was only observed in change detection (CD) tasks (Duarte et al., 2013; Newsome et al., 2015), whereas in recall tasks, older adults showed similar benefits as young adults (Loaiza & Souza, 2018; Souza, 2016). So far, studies have not assessed older adults in multiple retro-cue tasks simultaneously, and hence, we have no evidence regarding the robustness of the ability to use attention to modulate memory representations in aging across different types of retro-cue tasks and memory tests.

The Present Study

The present study was designed to provide a systematic assessment of the ability to focus attention in three domains: spatial attention, feature-based attention, and attention to working memory contents. For each domain, we assessed performance in multiple tasks to avoid conflating task-specific effects with changes in the general ability to focus attention. Our participants completed three tasks that measured the ability to focus spatial attention, four tasks measuring feature-based attention, and four tasks measuring attention to working memory contents (see summary in Table 1). We collected data of two age groups: younger ($n = 172$, $M = 23.7$ years) and older adults ($n = 174$; $M = 71.5$ years).

Using generalized Bayesian mixed-effects models (Bürkner, 2017, 2018) tailored to the respective performance indicator in each task, we evaluated focused attention benefits in each of the 11 tasks. Specifically, focused attention was measured by contrasting performance across two conditions: a control condition that did not require focused attention and a focus condition requiring selective attention to a subset of the information. The *focus effect*, defined as the difference between the control and the focus condition in each task, provides an index of the effect of selective attention. In some tasks (i.e., the spatial and the working memory tasks), selective attention in the focus condition afforded better performance than in the control condition, and hence, a larger focus effect reflects better selective attention. In other tasks (i.e., the feature tasks), the focus condition was harder than the control condition, and selective attention served to mitigate that increase in difficulty. Hence, in these tasks, a smaller focus effect reflects better selective attention. We assessed whether the focus effect indicated better, comparable, or worse ability to focus attention for older adults compared to young adults in each task. To test our hypotheses, we assessed whether the effects of all tasks within each domain of attention warranted the assumption that aging consistently changed focusing ability in that domain. Finally, we tested the hypothesis that aging consistently affected attention across all three domains.

Method

Participants

Participation criteria were as follows: (a) age between 18 and 35 years old (younger sample) or between 65 and 80 years old (older sample), (b) fluent in German, and (c) physically and mentally healthy as evaluated by self-report; in addition, older adults underwent the Mini-Mental State Examination (Folstein et al., 1975) to screen for dementia (score > 25). The older adults were community-dwelling individuals. The younger adults were students from the Zurich area. Participants received 15 Swiss francs (ca. 16 U.S. dollars) per hour, or in the case of students, they could opt for partial course credits. The study protocol was approved by the institutional review board (Approval Number 16.12.12). All participants signed an informed consent form in the beginning of the study and were debriefed in the end.

The study consisted of two laboratory sessions lasting between 2.5 and 4.5 hr. Responses to the tasks were not time-limited; hence, older adults took generally longer to complete the tasks. Two 10-min breaks were scheduled per session. Participants were offered drinks (tea, coffee, water, juice) and snacks (cake, cookies, chocolate, fruit, nuts) during these breaks. Participants completed 20 tasks that were evenly distributed across sessions. The tasks measured attention, multiple object tracking, working memory, reasoning, and perceptual ability. Only the 11 attention tasks are reported in the present article. A single task order for the 20 tasks was constructed, evenly distributing the type of material (e.g., color, orientation, spatial frequency) and the type of task over sessions and session blocks (see additional online material at https://osf.io/nf4dp/).

We aimed for at least 150 participants per age group. A total of 213 younger and 195 older adults registered to participate in the study. Thirty-eight younger adults did not show for any of their sessions, and three completed only the first session. Sixteen older adults did not show up for any of the sessions; three completed only one session, and four had to be excluded because their Mini-Mental State score was below 25. Hence, our final sample size consisted of 172 younger adults ($M = 23.7$ years old, $SD = 3.81$; 133 women, 39 men) and 174 older adults ($M = 71.5$ years old, $SD = 4.3$; 97 women, 77 men).

Stimuli and Procedure

Difficulty Calibration

For most tasks reported here, we ran pilot studies to determine the difficulty level of the task for each age group. Our aim was to equate task difficulty across age groups. In the pilot study, younger ($n = 30$) and older ($n = 30$) completed a version of the reported tasks in which a task parameter affecting performance (e.g., duration of stimulus

Table 1

Brief Description of the 11 Attention Tasks

Task	Description	Dependent variable	Adjustment
	Spatial attention		
1. Capacity	To find, across four locations, the blue triangle (target) and report its orientation (up or down). A central cue indicated, ahead of stimuli presentation, the possible target locations (1, 2, or 4).	Accuracy in the control (four cued) versus focus (one cued) conditions	*Target duration:* younger 160 ms, older 380 ms
2. Time course	To find, across four locations, a rotated *T* (among crosses) and report whether it was rotated left or right. A cue indicated the possible target locations (1 or 4), and after a cue–target interval of either 100, 150, or 400 ms, the target display appeared.	Accuracy in the control (four cued) versus focus (one cued) conditions	*Target duration:* younger 50 ms, older 200 ms
3. Resolution	Four squares with a small gap were presented. The size of the gap was varied based on ongoing performance (to maintain 75% accuracy). Ahead of stimulus presentation, a cue indicated which locations (1, 2, or 4) could be probed at the end of the trial.	Average size of the gap in the control (four cued) versus focus (one cued) conditions	
	Feature-based attention		
4. Color centroid	A cloud of 18 colored squares was shown scattered on the screen (three squares for each of six colors). The task was to determine the centroid of the squares in the cued color (control condition: determine the centroid of only three squares with the cued feature).	Estimation error in the control (only three squares) versus focus (filter three squares amid 15 distractors) conditions	
5. Gabor centroid	A cloud of 12 Gabors was shown scattered on the screen (three Gabors for each of four spatial frequencies). The task was to determine the centroid of the Gabors in the cued spatial frequency (control condition: determine the centroid of only three dots with the cued feature).	Estimation error in the control (only three dots) versus focus (filter three dots amid nine distractors) conditions	
6. Letter enumeration	Two clouds of letters (X and O mixed randomly) were presented left and right on the screen. A cue indicated which letter to attend to. The task was to indicate which cloud (left or right) had the larger number of cued letters.	Accuracy in the control (all letters) versus focus (cued letters) conditions	*Cloud duration:* younger 200 ms, older 320 ms
7. Shape enumeration	Two clouds of shapes (circles and triangles mixed randomly) were presented left and right on the screen. A cue indicated which shape to attend to. The task was to indicate which cloud (left or right) had the larger number of cued shapes.	Accuracy in the control (all shapes) versus focus (cued shapes) conditions	*Cloud duration:* younger 220 ms, older 390 ms
	Attention to working memory		
8. Color change detection	Participants memorized an array of colored dots and, after a brief delay, decided whether a probe matched the color in the same location in the array. In 50% of the trials, a retrocue indicated the probed location ahead of testing.	Accuracy in the control (no-cue) versus focus (retrocue) condition	*Memory load:* younger six items, older five items
9. Orientation change detection	Participants memorized an array of rotated triangles and, after a brief delay, decided whether a probe matched the orientation of the item in the same array location. In 50% of the trials, a retrocue indicated the probed location ahead of testing.	Accuracy in the control (no-cue) versus focus (retrocue) condition	*Memory load:* younger 5.4 items, older 4.6 items
10. Color delayed estimation	Participants memorized colored dots and, after a brief delay, reproduced the color of a probed item on a color wheel. In 50% of the trials, a retrocue indicated the probed location ahead of testing.	Mixture model parameters (P_{mem} and κ) in the control (no-cue) versus focus (retrocue) condition	*Memory load:* younger 5.8 items, older 4.5 items
11. Orientation delayed estimation	Participants memorized an array of rotated triangles and, after a brief delay, reproduced the orientation of one probed item by rotating it. In 50% of the trials, a retrocue indicated the probed location ahead of testing.	Mixture model parameters (P_{mem} and κ) in the control (no-cue) versus focus (retrocue) condition	*Memory load:* younger six items, older four items

Note. Noninteger values of memory load reflect a mix of two loads. For example, 5.4 indicates that 60% of the trials consisted of five items and 40% of six items. Variables presented in italics were adjusted in an attempt to equate task difficulty between age groups (e.g., to compensate for age-related slowing or lower working memory capacity).

presentation, memory load) was individually adjusted using a staircase procedure (using the QUEST procedure by Watson & Pelli, 1983) to yield 75% accuracy in the baseline without a manipulation of attention. We used the average value of the task parameter obtained in this pilot to determine the parameter value for each age group in the main study (see Table 1 for adjusted parameter values for each age group).

Feedback

For tasks in which responses were binary, feedback was provided by presenting the German words for "correct" (Richtig) and "incorrect" (Falsch) in green and red, respectively, in the middle of the screen. For trials requiring responses that vary continuously or the recall of several items, feedback was presented by indicating the match between the response and the true target value. Trials were computer-paced, but brief self-paced pauses were allowed every 10 trials.

Eye Tracking

During the spatial tasks, participants were instructed to maintain fixation in the screen center before and during stimulus presentation. To ensure that participants maintained fixation, we monitored their gaze location online by the eye tracker (150 Hz Gaze-Point connected to iMotions). Participants were seated 60 cm away from the computer with their heads supported by a chinrest. Calibration of the eye tracker was performed before the start of the relevant task. Only when eye-tracking calibration consistently failed for a given participant, the task was conducted without eye tracking. If fixation was not maintained in the screen center (within 3° around it), the trial was aborted and repeated at the end of the task. When a trial was aborted, a red circle frame (3° of visual angle) was shown around the screen center, and the fixation dot turned red, indicating to participants that they failed to maintain fixation in this region.

Spatial Attention Tasks

Participants completed three spatial attention tasks requiring the resizing of the focused area and the detection of a target stimulus (i.e., spatial capacity task), the rapid shifting of attention in response to a cue (i.e., the time-course task), and fine visual resolution (i.e., resolution task). A summary of the main features of these tasks is presented in Table 1. Figure 1A illustrates the flow of events in one representative task (i.e., the spatial capacity task). For all spatial tasks, we contrasted performance in one condition in which attention was distributed to all possible stimulus locations (i.e., Cue 4; hereinafter the control condition) to a condition in which spatial attention was guided to a single location (Cue 1; hereinafter the focus condition). A detailed description of each task, alongside an illustration of the flow of events in all the spatial attention tasks, is available in Figure S1 in the additional online material at https://osf.io/nf4dp/.

Feature-Based Attention Tasks

Participants completed four tasks that required feature-based attentional selection: two centroid tasks requiring attention to colors and spatial frequencies (Gabor stimuli), respectively, and two enumeration tasks requiring attention to letters and shapes, respectively. Table 1 presents a summary of these tasks. Figure 1B illustrates the flow of events in one representative task (i.e., the color centroid task). For all feature-based attention tasks, we contrasted performance in a condition in which only the cued feature was presented, and hence, no attentional selection was required (control condition) to a condition in which an attention filter had to be formed to select information about objects of a given category amid distractors (focus condition). A detailed description of each task, alongside an illustration of the flow of events in all the feature-based attention tasks, is available in Figure S2 in the additional online material at https://osf.io/nf4dp/.

Attention to Working Memory Contents

Participants completed four retro-cue tasks to measure attention to working memory contents varying in the paradigm (change detection vs. delayed estimation [DE]) and material (colors vs. orientations). Table 1 presents a summary of these tasks. Figure 1C illustrates the flow of events in one representative task (i.e., the color change detection task). For all retro-cue tasks, we contrasted performance in a no-cue condition (also known as control condition) to a retro-cue condition in which attention was directed to the relevant memory item ahead of testing (focus condition). A detailed description of each task, alongside an illustration of the flow of events in all retro-cue tasks, is available in Figure S3 in the additional online material at https://osf.io/nf4dp/.

Additional Tasks

Participants also completed three tasks in which they were required to reproduce the feature of a visually displayed stimulus: (a) a color patch, (b) the orientation of a triangle, or (c) the spatial frequency of a Gabor stimulus (along a continuum from 17 values). We also administered three time-restricted reasoning tests: Letter Sets (Ekstrom et al., 1976), Diagramming Relationships (Ekstrom et al., 1976), and the short version (Arthur et al., 1999) of the Raven's Advanced Progressive Matrices. Finally, participants also completed two tasks to measure working memory capacity from the battery developed by Lewandowsky et al. (Lewandowsky et al., 2010): the *Spatial Short-Term Memory* and the *Memory Updating* tasks, and a multiple object tracking task (Souza & Oberauer, 2017). Results of these tasks are not reported here.

Data Analysis

Data Preprocessing

For all tasks, we modeled trial-wise performance as a function of condition and age group. Some participants experienced computer crashes that prevented them from completing all trials in a given task. As we modeled the data of each trial, we could still include all these participants, applying the statistical model to their available trials. For the spatial tasks, trials in which eye movements deviated from the screen center were aborted and repeated at the end of the session. Aborted trials were excluded from analysis. For some participants, calibration of the eye tracker failed (six young participants and 34 older adults), and the spatial tasks were conducted without eye tracking.

Bayesian Hierarchical Generalized Mixed Models

We ran Bayesian hierarchical generalized linear mixed models (BGLMs) to estimate performance changes from the control to the focus conditions separately for each attention task. Specifically, in the BGLMs, the main performance indicator (proportion correct, recall error, or gap size) was predicted by the experimental condition (control vs. focus) and the age group of the participant. In most domains, we included two similar task versions (e.g., spatial capacity and spatial time course for the spatial domain; the two enumeration tasks for attention to features domain; the two change detection tasks for memory, and so on). In these cases, we modeled performance in these tasks simultaneously and included task as an additional predictor. There was only one instance in which a task was modeled alone, namely for the spatial resolution task, because this task has a unique dependent variable (the size of the gap in a square). The models estimated performance in the baseline condition for each task and its difference to the focus condition, reflecting the focus effects. We included random intercepts and random slopes separately for younger and older adults. The random intercepts reflect variation between individuals in overall task performance; the random slopes reflect variation in the experimental effects across individuals. The posterior means of the *SD* of each random effect are presented in the additional online material at https://osf.io/nf4dp/.

To evaluate if age groups differed in their ability to focus attention, we computed the difference between conditions, that is, performance changes from the control to the focus condition, as an index of focusing efficiency and compared it between younger and older adults for each task. To assess the credibility of the effect of attention and for age differences in this effect, we evaluated whether the highest density interval (HDI) of the posterior distribution (i.e., the range of values that cover 95% of the posterior) included zero. If the HDI included zero, then differences were regarded as not credibly different from zero. Otherwise, the direction of the difference was interpreted as favoring stronger focus ability for either younger or older adults, depending on which age group showed a focus effect indicating more effective attentional focusing.

The BGLMs were estimated using the *brms* package (Bürkner, 2017). The data distribution of the BGLMs was chosen depending on the task's performance indicator. For all tasks using accuracy as a performance indicator (i.e., spatial capacity and time course, feature letter enumeration and shape enumeration, color change detection, and orientation change detection), we modeled the number of correct responses over all trials with a binomial distribution and a logit link function. For the spatial resolution task, we modeled gap size in the last 10 trials in each of the two calibration blocks using a Gaussian distribution and a logit link function. Specifically, gap size was rescaled by dividing the gap size by the maximally allowed gap size in the calibration procedure, yielding a variable ranging from 0 to 1. The logit link function in the model ensured that the predicted values were restricted to that range. For the Color and Gabor centroid tasks, we modeled the centroid reproduction error in each trial with a γ distribution and a logarithmic link function. For the delayed estimation tasks, we modeled recall performance as a mixture of random guessing (represented by a uniform distribution on the circle) and recall from memory (represented by a von Mises distribution centered on the target location; Frischkorn & Popov, 2023; Zhang & Luck, 2008). For all models, we used the default priors suggested by brms. Parameters were estimated with four Markov chain Monte Carlo chains, each containing 1,000 warmup samples and 2,000 samples after warmup, except for the spatial resolution tasks that used twice the number of samples. To ensure convergence of the Markov chain Monte Carlo chains, we checked that all *R*-hat values were below 1.05.

Bayesian Confirmatory Factor Analyses

We ran Bayesian confirmatory factor analyses (CFAs) to evaluate the amount of covariance between tasks from the same domain and across domains. To estimate the models, we used the posterior median of the estimated model parameters from the Bayesian GLMs for the performance in the baseline conditions and the focus effect of each subject in each task. We rescaled the posterior estimates of the baseline performance and the focus effects in the spatial resolution task as well as for the two centroid tasks so that larger values reflect better performance. The full pattern of correlations across tasks in these conditions is available in the additional online material at https://osf.io/nf4dp/.

The advantage of using the estimated parameters from the BGLMs over aggregated behavioral performance is that the estimated parameters were separated from trial noise and thus more adequately capture true variations between participants (Rouder & Haaf, 2019). We fit CFAs separately for the performance in the baseline conditions and the focus effects, allowing us to estimate the degree of common variance in performance between tasks, on one hand, and of common variance in the ability to focus attention across different domains, on the other hand.

The Bayesian CFAs were estimated using the package *blavaan* (Merkle & Rosseel, 2018) implemented in *R* (R Core Team, 2018). The benefit of using Bayesian estimation methods is that, in combination with adequate priors, they provide more robust parameter estimation than frequentist methods (McNeish, 2016). In our analyses, we set the following priors: γ priors with a shape of 1 and rate of .05 for variance parameters, β priors with $\alpha = 1$ and $\beta = 1$ extended in range from -1 to $+1$ for covariance parameters, and normal priors with $\mu = 0$ and $\sigma = 10$ for factor loadings. The parameters were sampled using the *no U-turn* sampler implemented in STAN (Carpenter et al., 2017) with four Markov chain Monte Carlo chains each consisting of 5,000 warmup samples and 20,000 postwarmup samples. To verify convergence of the parameter estimation, we checked that all the R-hat values were below 1.05.

We evaluated model fit of the CFA models using a Bayesian implementation of the root-mean-square error of approximation (BRMSEA) and a Bayesian implementation of the comparative fit index (BCFI). Additionally, we report posterior predictive *p* values (PP*p*).[1] As cutoff criteria to assess model fit, we considered BRMSEA $< .05$ and BCFI $> .95$ as good model fits and BRMSEA $< .08$ and BCFI $> .90$ as acceptable model fits. For both BRMSEA and BCFI, we report the posterior mean and the 95% HDI.

Transparency and Openness

This study was not preregistered. The anonymized data, the analysis scripts, and the materials to run all tasks reported here are available on the Open Science Framework at https://osf.io/nf4dp/ (Souza et al., 2023).

Results

Descriptive statistics for the control and focus conditions in the 11 attention tasks are summarized in Table 2. Figure 2 illustrates the changes in performance across the different attention tasks by plotting

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[1] PP *p* values close to zero indicate a bad model fit, whereas values close to 0.5 indicate a good model fit.

Table 2
Descriptive Statistics for the 11 Attention Tasks

Domain	Task	Performance indicator	Age group	Condition	Mean	(*SD*)	Min.	Max.	*N*
Spatial	Capacity	Proportion correct	Older	Control	0.85	0.13	0.43	1.00	168
				Focus	0.94	0.12	0.43	1.00	169
			Younger	Control	0.71	0.12	0.35	0.98	171
				Focus	0.86	0.12	0.45	1.00	171
	Time course	Proportion correct	Older	Control	0.69	0.16	0.33	1.00	171
				Focus	0.78	0.17	0.22	1.00	171
			Younger	Control	0.76	0.12	0.42	0.98	172
				Focus	0.89	0.13	0.43	1.00	172
	Resolution	Gap size (pixels)	Older	Control	25.59	4.47	6.95	29.70	165
				Focus	13.61	8.89	2.30	29.65	166
			Younger	Control	12.65	5.35	4.10	28.70	169
				Focus	5.86	3.66	2.60	29.50	169
Feature	Color centroid	Response error (pixels)	Older	Control	30.51	18.40	13.10	113.69	174
				Focus	54.73	21.67	25.59	132.77	174
			Younger	Control	19.25	8.48	10.69	75.57	171
				Focus	29.51	10.86	17.72	108.20	171
	Gabor centroid	Response error (pixels)	Older	Control	29.80	18.22	12.86	134.15	174
				Focus	70.56	17.01	41.75	150.65	174
			Younger	Control	19.56	9.13	9.62	97.94	170
				Focus	54.85	14.49	23.70	120.36	170
	Letter enumeration	Proportion correct	Older	Control	0.70	0.10	0.38	0.90	174
				Focus	0.60	0.06	0.45	0.79	174
			Younger	Control	0.77	0.08	0.54	0.98	172
				Focus	0.63	0.06	0.48	0.76	172
	Shape enumeration	Proportion correct	Older	Control	0.78	0.09	0.40	0.94	173
				Focus	0.62	0.05	0.47	0.76	173
			Younger	Control	0.80	0.08	0.44	0.98	172
				Focus	0.64	0.06	0.48	0.78	172
Attention working memory	Color change detection	Proportion correct	Older	Control	0.76	0.10	0.28	0.98	174
				Focus	0.83	0.10	0.43	0.98	174
			Younger	Control	0.78	0.10	0.45	0.98	171
				Focus	0.86	0.10	0.38	1.00	171
	Orientation change detection	Proportion correct	Older	Control	0.68	0.09	0.40	0.85	174
				Focus	0.71	0.11	0.45	0.93	174
			Younger	Control	0.76	0.09	0.40	0.98	172
				Focus	0.84	0.09	0.43	1.00	172
	Color delayed estimation	Response error (degrees)	Older	Control	51.99	13.77	18.54	91.38	173
				Focus	31.05	11.79	11.66	77.12	173
			Younger	Control	43.79	11.34	22.37	85.62	172
				Focus	24.06	8.86	9.15	74.95	171
	Orientation delayed estimation	Response error (degrees)	Older	Control	47.45	12.11	18.40	81.38	173
				Focus	35.48	12.68	12.54	75.12	173
			Younger	Control	45.18	12.39	15.76	84.78	171
				Focus	32.69	12.51	8.40	81.56	171

the behavioral performance for the control and the focus conditions for both younger and older adults. The focus effect—the difference between the control and the focus condition in each task—reflects the effectiveness of focused attention.

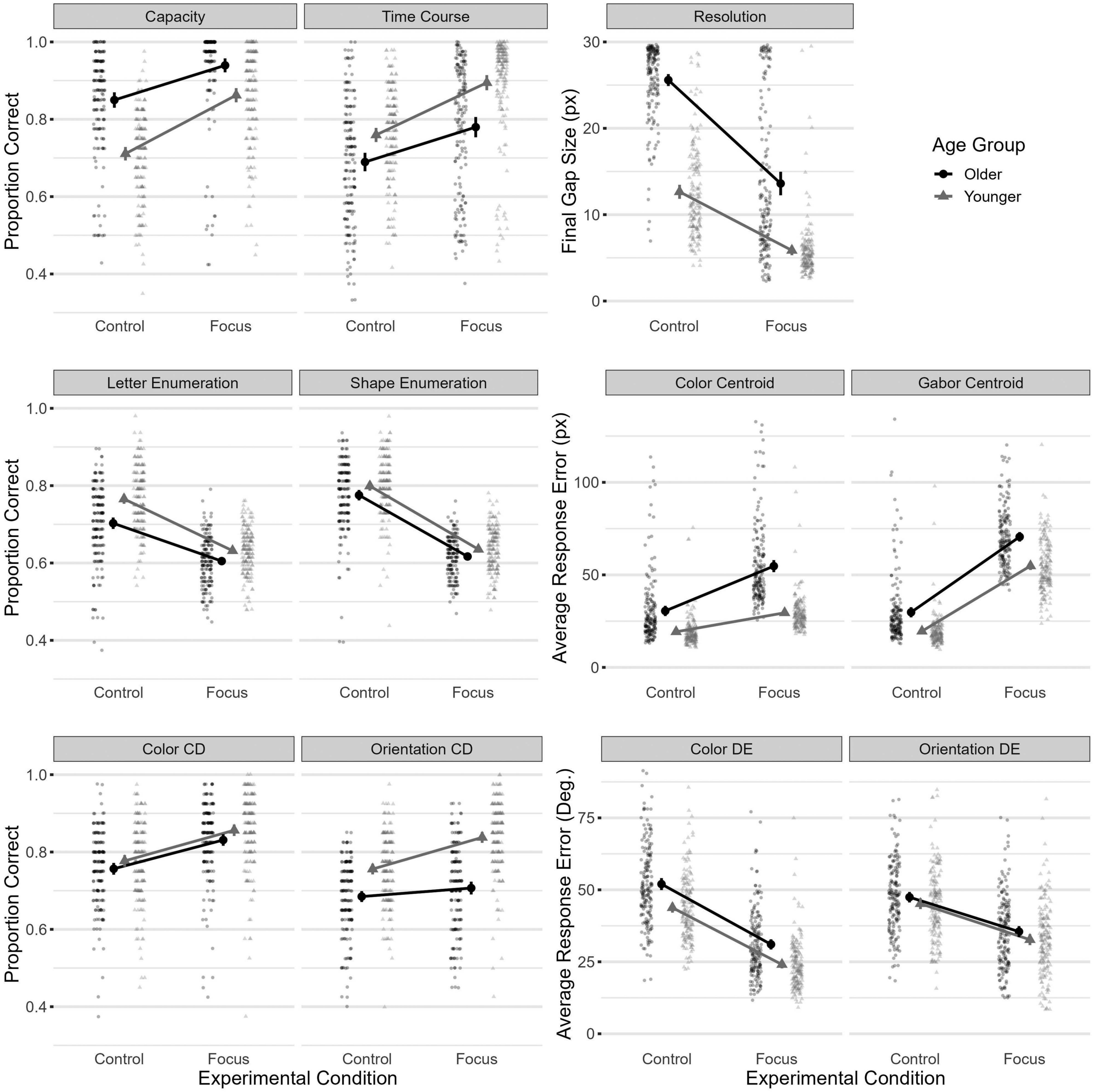
Table 3 presents the posterior estimates from Bayesian hierarchical mixed-effects models for the age effect in the control condition, the age effect in the focus effect, and the focus effect in each age group separately. Figure 3 plots the standardized posterior estimates of age differences (i.e., Glass Δ) in the focus effect across the 11 different tasks. Our results indicate that both older and younger adults were able to focus attention on the 11 tasks. Moreover, as evident from Figure 3 and Table 3, in some tasks, older adults were better able to focus attention, in others, younger adults, and in some, there were no credible differences between the age groups. All in all, there were no systematic age differences in how attention modulated performance across the 11 attention tasks. In the following section, we will first discuss age differences in the control condition of each task. Then, we will discuss the effects of aging on the attentional effects observed in the tasks measuring spatial and feature-based perceptual attention and attention to working memory.

Age Differences in the Control Conditions

Aging has been associated with changes in several cognitive abilities, from motor control and processing speed to memory processes involved in episodic, semantic, and working memory, as well as fluid intelligence (Craik & Bialystok, 2006; Hartshorne & Germine, 2015; Ratcliff et al., 2006; Rönnlund et al., 2005; Schaie & Willis, 2010). One issue in measuring attentional abilities therefore is how to best dissociate changes in attention from changes in other core cognitive abilities. Given the well-known age-related slowing effect (Finkel et al., 2007; Hertzog & Bleckley, 2001; Salthouse, 2000),

Figure 2

Behavioral Performance in Control and Focus Condition in Each of the 11 Attention Tasks



Note. Performance of each participant was plotted (younger = cloud of gray triangles; older = cloud of black circles) alongside the group mean performance (large triangles and circles) and within-subject standard errors (error bars). The top row shows the spatial attention tasks, the middle row the feature attention tasks, and the bottom row the working memory attention tasks. px = pixels; deg = degrees; CD = change detection; DE = delayed estimation.

we aimed to reduce the contribution of this variable for the measurement of performance in our tasks by relying on accuracy and by not imposing a time limit to enter a response. Yet, accuracy could also be influenced by the speed of uptake of information (i.e., encoding time) and the capacity to hold information in working memory. Hence, we attempted to reduce the impact of age differences in the control condition by adapting the difficulty of our tasks to the expected ability level of our age groups.

We conducted a pilot study (n = 30) in which we calibrated the difficulty level of the tasks (e.g., how long a target stimulus was displayed; the memory load) on an individual basis to achieve 75% correct responses in the control condition. In our pilot, we observed

Table 3

Posterior Estimates of the Age Effect in the Control Condition and Age Effect in the Focus Effect in Each Task, as Well as the Posterior Estimates of the Focus Effect for Each Age Group Separately

		Δ Aging control (older–younger)		Δ Aging focus (older–younger)			Focus effect	
Task (DV—scale)	Task order	Post. mean	95% HDI	Post. mean	95% HDI	Age group	Post. mean	95% HDI
				Spatial attention tasks				
Capacity (PC—logit)	2	**1.11**	**[0.91, 1.32]**	**0.49**	**[0.17, 0.83]**	Younger	1.20	[1.05, 1.36]
						Older	1.69	[1.43, 1.99]
Time course (PC—logit)	1	*−0.32*	*[−0.50, −0.13]*	*−0.76*	*[−0.95, −0.57]*	Younger	1.43	[1.27, 1.59]
						Older	0.67	[0.56, 0.78]
Resolution (gap size—logit)	3	*2.58*	*[2.32, 2.84]*	**−1.13**	**[−1.52, −.74]**	Younger	−1.18	[−1.25, −1.02]
						Older	−2.29	[−2.67, −1.18]
				Feature-based attention tasks				
Letter enumeration (PC—logit)	1	*−0.32*	*[−0.40, −0.24]*	**0.21**	**[0.12, 0.29]**	Younger	−0.65	[−0.71, −0.59]
						Older	−0.44	[−0.50, −0.38]
Shape enumeration (PC—logit)	4	*−0.15*	*[−0.23, −0.06]*	0.06	[−0.02, 0.15]	Younger	−0.83	[−0.90, −0.77]
						Older	−0.77	[−0.83, −0.71]
Color centroid (Abs. error—log)	2	*0.40*	*[0.33, 0.47]*	*0.20*	*[0.15, 0.25]*	Younger	0.43	[0.40, 0.45]
						Older	0.63	[0.59, 0.67]
Gabor centroid (Abs. error—log)	3	*0.37*	*[0.30, 0.44]*	**−0.11**	**[−0.17, −0.06]**	Younger	1.05	[1.01, 1.08]
						Older	0.93	[0.89, 0.98]
				Attention to working memory tasks				
Color CD (PC—logit)	4	*−0.14*	*[−0.27, −0.00]*	−0.10	[−0.24, 0.05]	Younger	0.60	[0.49, 0.71]
						Older	0.50	[0.41, 0.60]
Orientation CD (PC—logit)	1	*−0.37*	*[−0.48, −0.26]*	*−0.45*	*[−0.58, −0.32]*	Younger	0.56	[0.46, 0.67]
						Older	0.11	[0.03, 0.20]
Color DE (pMem—logit)	2	*−0.33*	*[−0.50, −0.17]*	0.01	[−0.19, 0.20]	Younger	1.37	[1.23, 1.52]
						Older	1.38	[1.24, 1.52]
Color DE (Kappa—log)		*−0.46*	*[−0.57, −0.33]*	**0.15**	**[0.02, 0.29]**	Younger	0.18	[0.09, 0.27]
						Older	0.34	[0.24, 0.44]
Orientation DE (pMem—logit)	3	−0.06	[−0.22, 0.11]	−0.04	[−0.19, 0.12]	Younger	0.73	[0.63, 0.83]
						Older	0.69	[0.58, 0.81]
Orientation DE (Kappa—log)		*−0.49*	*[−0.61, −0.37]*	−0.08	[−0.20, 0.05]	Younger	0.38	[0.30, 0.47]
						Older	0.31	[0.21, 0.40]

Note. Effect estimates are given on the parameter scale that is indicated for each task. DV = dependent variable; scale = measurement scale of the parameter; Post. = Posterior; CI = credibility interval; PC = proportion correct; Abs. = Absolute; CD = change detection; DE = delayed estimation; pMem = probability of having an item in memory; kappa = precision of the memory distribution; HDI = highest density interval. Parameter estimates marked in gray and italic font indicate credible age differences favoring younger adults; estimates marked in bold font indicate credible age differences favoring older adults. Task order: Order of exposition to tasks of the same domain within the battery.

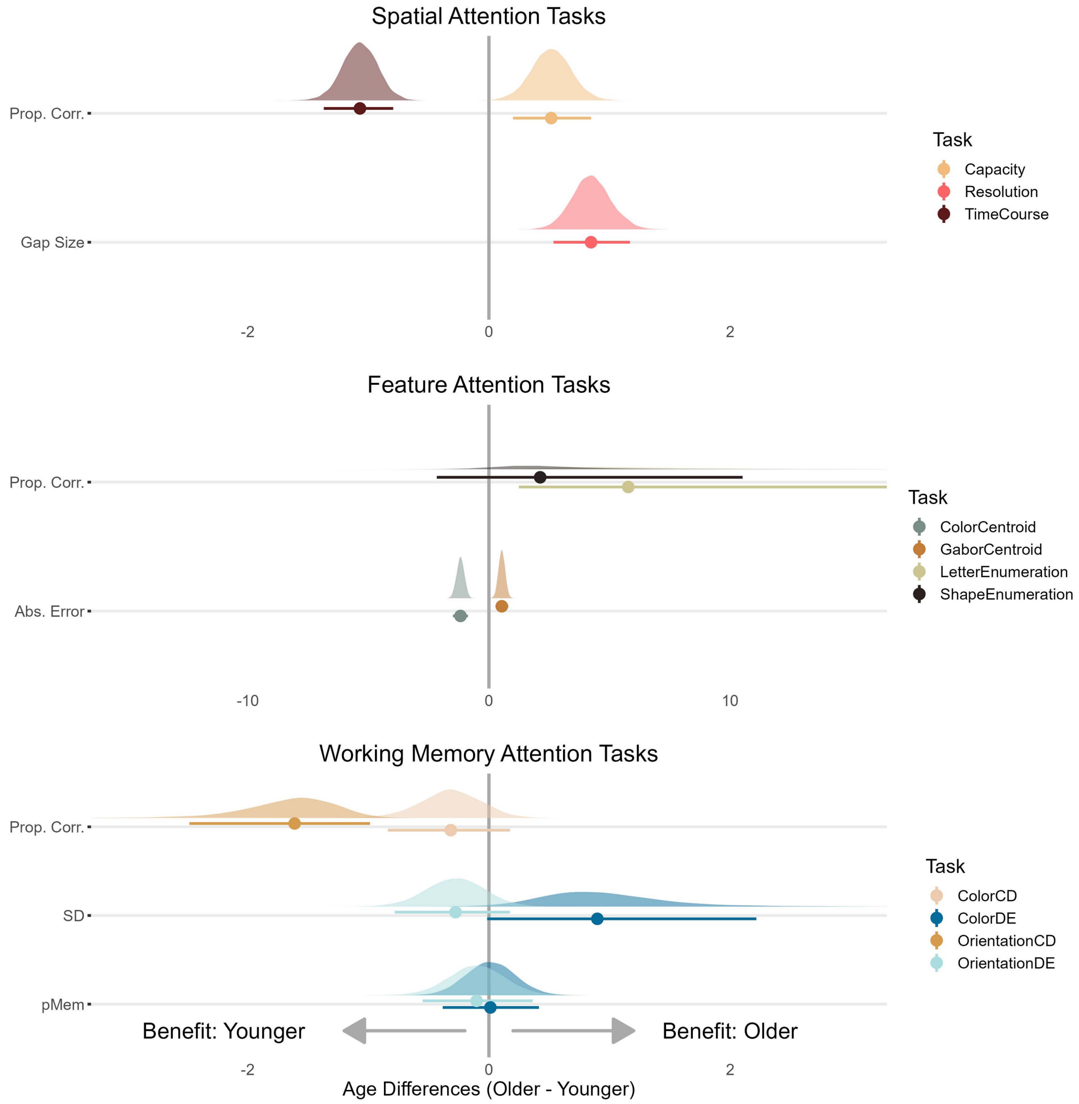
consistent age differences in the calibrated values, with older adults requiring longer presentation times (Gottlob & Madden, 1998) and lower values of memory load (Loaiza & Souza, 2018). We used these values to set the parameters of the tasks used in the present study (see adjusted values in Table 1). Despite this prior adaptation, our age groups still differed in control condition performance, and these differences most often favored the younger adults. An overview of the age effect on performance in the control condition is provided in Table 3. All in all, our sample of older adults struggled more to perform most of the cognitive tasks (nine out of 11 tasks) than the younger adults. Although the adaptation did not entirely remove age differences, it reduced them sufficiently to bring performance into the same range of the measurement scale for the two age groups on most tasks. This mitigates the risk that age differences in the focus effect are artifactually created (or masked) by being measured at different levels of the performance scale (Loftus, 1978). Evidence against the possibility of systematic scaling artifacts comes from the fact that age differences in the control condition were not correlated with age differences in the focus effect (see Table 3). As will be demonstrated in the following section, regardless of whether older adults performed worse, comparably, or better than younger adults in the control condition, the benefits of focused attention were similar between younger and older adults.

Spatial Attention

Older and younger adults benefited from spatial cues in all three tasks (see Table 3 for parameter estimates of the focus effect for older and younger adults, as well as the age effect in the focus benefit). Specifically, when a single location was spatially cued, both age groups improved their accuracy in the capacity and time-course tasks and were able to detect smaller gaps in a Landolt stimulus in the resolution task. Compared to younger adults, older adults showed larger benefits of spatial cues in the capacity task, $\Delta b_{\text{focus}} = 0.49$, HDI = [0.17, 0.83], and the resolution task, $\Delta b_{\text{focus}} = 1.13$ [0.74, 1.52], but smaller benefits in the time-course task, $\Delta b_{\text{focus}} = -0.76$ [−0.95, −0.57]. All in all, this pattern suggests that older adults are not less able to focus spatial attention than their younger counterparts.

Figure 3

Overview of Posterior Estimates of Standardized Age Differences (Glass Δ) in the Focus Effect in the 11 Attention Tasks



Note. For each task, we computed the age difference such that positive values reflect better attentional-focusing ability of older adults. The distributions illustrate the posterior differences in the focus effects between older and younger adults. Points indicate the median differences, and the horizontal bars are the 95% highest density intervals for the age difference in focus effects. Prop. Corr. = Proportion Correct; Abs. = Absolute; SD = Standard Deviation; pMem = Probability the Item is in Memory; CD = change detection; DE = delayed estimation. See the online article for the color version of this figure.

Feature-Based Attention

The focus conditions of the feature attention tasks demanded participants to focus attention on a subset of three stimuli (i.e., the cued category) while ignoring other stimuli not matching the to-be attended feature. To control for general differences in task performance, our control conditions in these tasks required participants to process only three target stimuli that were shown on screen without additional distractors to give a response. As focusing on a single feature amid distractors is typically harder than processing all stimuli, performance in the focus conditions in these tasks is generally poorer than in the control condition. Hence, in these tasks—different from the spatial attention tasks—smaller differences between control and focus conditions imply more effective selective attention.

Both older and younger adults showed worse performance in the focus conditions than the control conditions (see Table 3). Younger adults showed smaller performance costs—reflecting better ability to focus selectively on the cued feature—than older adults in the color centroid task, $\Delta b_{\text{focus}} = 0.20$ [0.15, 0.25]. For the letter enumeration task, $\Delta b_{\text{focus}} = 0.21$ [0.12, 0.29], and the Gabor centroid task, $\Delta b_{\text{focus}} = -0.11$ [−0.10, −0.06], older adults showed smaller performance costs in the focus condition compared to their younger counterparts, consistent with the claim that they were more effective in focusing attention on the cued feature. There was no credible age difference in the shape enumeration task, $\Delta b_{\text{focus}} = 0.06$ [−0.02, 0.15]. All in all, the pattern of age differences favored older adults in two of the tasks, young adults in one task, and it was absent in the last one. This pattern was not related to any characteristics of the tasks. Hence, similarly to the tasks in the spatial domain, feature-based attention tasks did not show consistent evidence of age-related decline in the ability to form an attention filter.

Attention to Representations in Working Memory

With regards to the benefits of attending to memory representations, both older and younger adults showed cueing benefits in the change detection and the delayed estimation tasks (see Table 3). In fact, for most of the tasks and performance indicators, there were no credible age differences in the focus effect (see Figure 3 and Table 3): proportion correct in the color change detection task, $\Delta b_{\text{focus}} = -0.10$ [−0.24, 0.05]; the probability of having an item in memory in both the color, $\Delta b_{\text{focus}} = 0.01$ [−0.19, 0.20], and orientation delayed estimation tasks, $\Delta b_{\text{focus}} = -.04$ [−0.19, 0.12]; and precision of memory representation in the orientation delayed estimation task, $\Delta b_{\text{focus}} = -0.08$ [−0.20, 0.05]. Only in the orientation change detection task, younger adults benefited more from focused attention than older adults, $\Delta b_{\text{focus}} = -0.45$ [−0.58, −0.32], whereas older adults benefited more than younger adults from focused attention with respect to memory precision in the color delayed estimation task, $\Delta b_{\text{focus}} = 0.15$ [0.02, 0.29].

CFA: Commonalities Between Tasks and Domains

To evaluate if tasks from the same domain tapped similar processes and were related to the tasks from other domains, we ran a Bayesian CFA on the estimated performance in the baseline conditions of the different tasks, as well as on the performance benefits achieved in the focus conditions (i.e., the focus effects). The posterior estimates as well as the model fit for these CFAs are illustrated in Figure 4.

Shared Variance in Baseline Performance

Figure 4A shows the CFA model for the baseline performance. The CFA had an acceptable fit for both age groups: younger: BRMSEA = .060, 95% HDI [.047, .072] and BCFI = .944, 95% HDI [.919, 966]; older: BRMSEA = .021, 95% HDI [.000, .042] and BCFI = .991, 95% HDI [.974, 1.000]. For both the spatial attention domain and the attention to memory domain, we could form a single factor capturing shared individual differences across tasks in the respective domains. For the feature attention tasks, separate factors for the centroid and the enumeration tasks were required for achieving an acceptable fit for both age groups.[2] Reliabilities for all factors were mostly acceptable (>.70; Nunnally & Bernstein, 1994) for younger and older adults (see Table 4), except for the spatial attention factors and the feature enumeration factor for older adults, for which reliabilities were around .60. The correlations between the four extracted factors indicated considerable shared variance (all $\rho > .50$) in the baseline performance of the 11 tasks (see Table 5 for correlations estimates including their 95% CI). In sum, this result indicates that there is substantial overlap in baseline performance in tasks tapping the same domain, as well as across the different domains.

Shared Variance in the Ability to Focus Attention

Figure 4B shows the CFA model for focus effects. For younger adults, model fit was acceptable when considering absolute indices, BRMSEA = .063, 95% HDI [.052, .072], but the comparative fit to a null model assuming no correlations among the different indicators was bad, BCFI = .758, 95% HDI [.670, .840]. This is likely due to the generally low correlations among the focus effects in the different tasks (see Table S6 in the additional online material for the correlation matrix at https://osf.io/nf4dp/). For older adults, model fit was acceptable in all indicators, BRMSEA = .038, 95% HDI [.020, .056] and BCFI = .921, 95% HDI [.848, .986].

Akin to the baseline model, we formed a single factor for focus effects in the spatial domain and the attention to working memory domain. Like in the CFA for baseline performance, we had to estimate separate factors for the feature enumeration and the feature centroid tasks.[3] Generally, reliability for these factors was below the threshold of .70 to be considered acceptable (Nunnally & Bernstein, 1994). This is a known issue for individual differences in experimental effects (Hedge et al., 2018) but also sometimes observed for personality traits such as openness and agreeableness (Viswesvaran & Ones, 2000). Reliability was especially poor for the younger adults, for which only the factor for attention to working memory was close to the threshold of .70. Note that for younger adults, there were very little systematic individual differences in spatial attention (values closer to 0). For the older adults, all but the feature enumeration factor had reliabilities close to .70. Note, however, that there were little systematic individual differences in feature-based attention measured with enumeration tasks for older adults.

Overall, factor reliabilities were lower in the CFA for focus effects than for baseline performance, indicating that there is generally less shared variance between the focus effects within tasks of the same domain. A second observation was that correlations between factors for focus effects (see Figure 4B and Table 5) were generally low, often not credible, and of varying directions across age groups. Due to the low factor reliabilities, there was also considerable uncertainty in correlation estimates. Nonetheless, these results indicate that there are more commonalities in the ability to focus attention within a single domain (spatial, feature, and memory) than across domains. In other words, the ability to focus attention on space, features, and memory representations seems relatively independent. In sum, although there seems to be some overlap in the individual abilities to focus attention within a domain, there is little evidence for a domain-general ability to focus attention.

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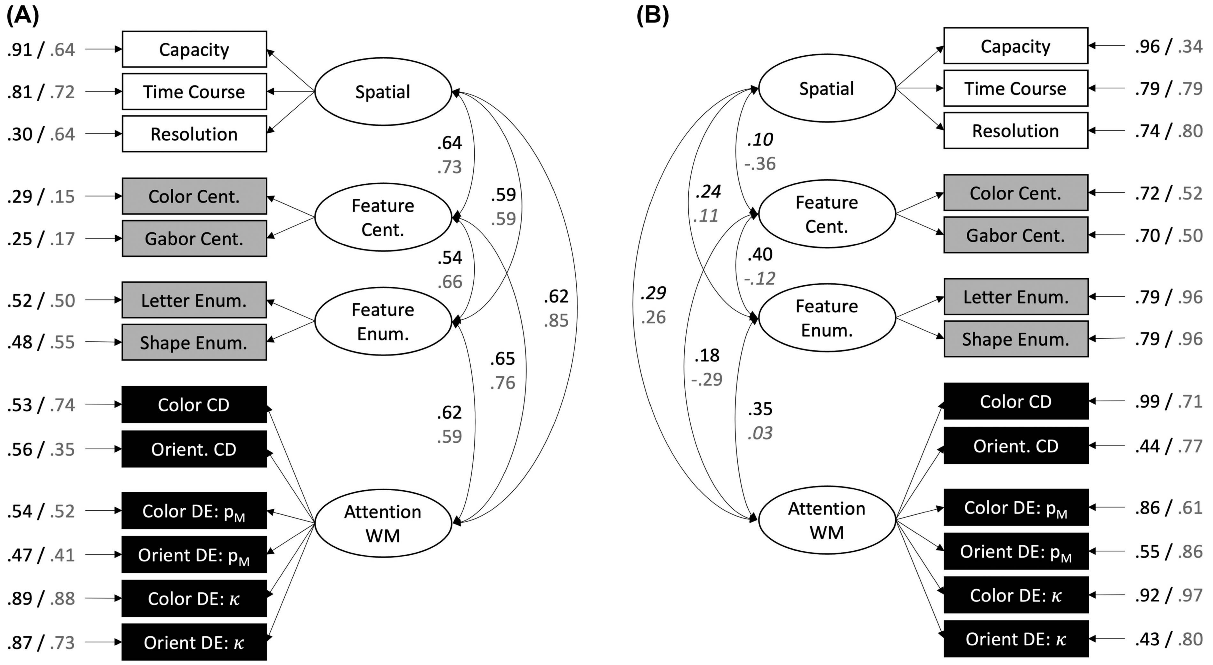
[2] A three-factor model fit had a bad fit for younger adults, BRMSEA = .084, 95% HDI = [.076, .097] and BCFI = .888, 95% HDI = [.863, 910], but it was acceptable for older adults, BRMSEA = .044, 95% HDI = [.030, .059] and BCFI = .971, 95% HDI = [.952, 989]. We aimed, however, for replicability across both age groups.

[3] Unlike the baseline performance CFA, the need for two feature attention factors was primarily due to factor loadings not converging for a model with a single feature attention factor for the centroid and enumeration tasks.

Figure 4

Simplified Illustrations of the CFA for Baseline Performance (Panel A) and of the Focus Effects (Panel B) in the Performance Indicators of the 11 Attention Tasks for Younger (Parameters Printed in Black) and Older Adults (Parameters Printed in Gray)



Note. Parameters on the links between latent factors are correlations; parameters next to the indicators are error variances. Parameter values refer to the posterior mean of the standardized posterior estimates. For parameters printed in italics, the 95% credibility intervals include zero. CFA = confirmatory factor analysis. Cent. = Centroid; Enum. = Enumeration; WM = working memory; CD = change detection; DE = delayed estimation.

Discussion

The present study assessed age differences in the ability to focus attention using a battery of 11 behavioral tasks. Exposing participants to different tasks measuring the same underlying ability allowed us to distinguish age effects on the ability level from task-specific variation. Generally, our results indicate that both older and younger adults were able to focus attention on spatial locations, features, and representations maintained in working memory. In all three domains, there were some tasks in which older adults were equally able or even better at focusing attention than younger adults and tasks in which younger adults were better able to focus attention. In total, age differences favored older adults on at least one performance indicator in five tasks; they favored younger adults in three tasks, and there were no credible age differences in four tasks. Tasks showing age-related advantages and disadvantages occurred for all three attention domains assessed. On balance, the evidence is as strong for improvements as for declines of attention with aging. This varied pattern precludes a general conclusion about age-related decrements in focused attention. Our findings are inconsistent with the claim that there is an age-related decline in any of the three attentional selection domains we investigated or generally across domains.

A varied pattern of age-related changes in attention functions has previously been observed in the attention network task (Veríssimo et al., 2022), which is typically used to measure attentional functions related to the alerting, orienting, and executive networks (Petersen & Posner, 2012; Posner & Petersen, 1990). Whereas a decline was observed in alerting, improvements accrued in the orienting and executive attention networks across age, for at least up to the age of 70 (see also Rey-Mermet et al., 2018; Rey-Mermet & Gade, 2018). Our attention selection tasks are more related to the orienting function in this classification (Petersen & Posner, 2012; Posner & Petersen, 1990), and our older adult sample is in a similar age range (mean of 71 years) to the one reported in that study. Hence, our results are broadly in line with the claim that orienting functions are preserved in aging. The novelty of our study is that we evaluated performance in multiple tasks that measured several ways to orient attention. We will discuss our pattern of findings in each attention domain in turn.

Spatial Attention

With regards to spatial attention, our findings are generally in line with prior work indicating preserved ability in aging (Folk & Hoyer, 1992; Gottlob & Madden, 1998; Greenwood et al., 1993; Hartley et al., 1990; Madden, 2007; Madden & Gottlob, 1997; Zanto & Gazzaley, 2014). Our spatial tasks assessed the ability to focus attention on a subset of locations to better detect a target stimulus, to quickly direct attention in response to a cue, and to improve visual resolution in an attended location. From our set of three tasks, there was only one in which younger adults showed more effective attentional focusing than older adults, namely the time-course task. Although this could be interpreted as suggesting that older adults have difficulty in quickly moving attention in response to a cue—which was the ability targeted in this task—previous studies have generally found similar time courses

Table 4

Reliability of CFA Factor of Baseline Performance and Focus Effects for Younger and Older Adults

Factor reliability (ω^2)	Age group	Spatial	Feature cent.	Feature enum.	Attention WM
Baseline performance	Younger	.57	.84	.69	.73
	Older	.60	.91	.64	.79
Focus effects	Younger	.01	.45	.35	.67
	Older	.60	.66	.07	.56

Note. Factor reliabilities were estimated based on the posterior means of the estimated factor loadings as well as posterior means of the model-implied variance–covariance matrix using the method proposed by McDonald (1999). WM = working memory; Cent = centroid; Enum = enumeration; CFA = confirmatory factor analysis.

in the orientation of spatial attention in young and old adults (Folk & Hoyer, 1992; Gottlob & Madden, 1998; Lincourt et al., 1997). Thus, our results seem generally consistent with the claim that orienting of spatial attention is preserved in aging (Zanto & Gazzaley, 2014).

Feature-Based Attention

For feature-based attention, we relied on tasks that measure the ability to form a filter to selectively weight a cued feature higher than other, irrelevant features. Here, again, we observed a mixed pattern: Age differences favored older adults in two tasks, younger adults in one task, and were not credible in one task. These findings suggest that older adults do not have a difficulty in weighting one feature more than others. Some studies have reported that older adults perform worse in visual search tasks (Hommel et al., 2004; Zanto & Gazzaley, 2014). However, it has been challenging to control for age-related changes in sensory processing and general slowing in this paradigm. In the present study, we controlled for these age differences through a control condition measuring performance in the absence of the need to create an attentional filter. With this approach, we were able to show that age-specific decrements in feature-based attentional selection are not consistently observed.

Attention to Memory

With regards to attention to mental representations, this was the domain in which we obtained most evidence for equal attentional effects across age groups. Of the six parameters evaluated, only two showed credible age differences, equally split between favoring one or the other age group. The only task showing an age-related decrement was the orientation change detection task, in which younger adults obtained a larger cueing benefit than older adults. For the subsequent tasks, older adults showed similar or larger benefits compared to their younger counterparts. Overall, our results show that older adults can use attention to efficiently select among representations in working memory and indicate that earlier studies that failed to observe efficient attentional selection in old age could be an exception (Duarte et al., 2013; Newsome et al., 2015), or they did not provide the ideal conditions for older adults to learn how to use the retrocues. It is also worth noting that older adults learned to use cues in both types of paradigms, namely change detection and continuous reproduction, and hence, the type of memory test was not predictive of whether retro-cue benefits were observed or not. These results dovetails with prior reports that older adults are not impaired in modulating their access to memory representations via attention (Loaiza & Souza, 2018; Mok et al., 2016; Souza, 2016; Strunk et al., 2019).

Recently, we performed a model-based analysis of performance in the attention to memory tasks reported here using the diffusion model (Souza & Frischkorn, 2023). This modeling framework combines accuracy and reaction time measures to estimate psychologically meaningful parameters assumed to affect decision making. In this framework, we observed a small, but credible, age-related

Table 5

Correlations Among the Factors of the CFA Models for Baseline Performance and the Focus Effects Including Their 95% Credibility Intervals for Younger Adults (Values in Bold Font Below the Diagonal) and Older Adults (Values in Regular Font Above the Diagonal)

Domain	Spatial	Feature centroid	Feature enum.	Attention WM
Baseline				
Spatial		.74 [.59, .86]	.60 [.39, .78]	.87 [.73, .97]
Feature centroid	**.67 [.49, .84]**		.66 [.51, .79]	.77 [.67, .84]
Feature enum.	**.62 [.40, .83]**	**.55 [.37, .69]**		.60 [.43, .75]
Attention WM	**.65 [.45, .83]**	**.66 [.52, .77]**	**.62 [.45, .77]**	
Focus				
Spatial		−.36 [−.60, −.16]	.11 [−.64, .80]	.26 [.04, .52]
Feature centroid	**.10 [−.49, .63]**		−.12 [−.81, −.65]	−.29 [−.52, −.05]
Feature enum.	**.24 [−.43, .77]**	**.40 [.05, .80]**		.03 [−.71, .76]
Attention WM	**.29 [−.70, .89]**	**.18 [−.07, .52]**	**.35 [.11, .76]**	

Note. Correlation estimates are posterior means, and the credibility interval represents 95% equally tailed interval of the full posterior. The left-bottom values (in bold font)represents the correlation estimates for younger adults, and the right-top values (in regular font)represents the correlation estimates for older adults. WM = working memory; Enum = enumeration; CFA = confirmatory factor analysis.

reduction in focusing efficiency on the drift-rate parameter but not on the remaining model parameters, namely nondecision time and boundary separation. The drift is the rate with which evidence is accumulated in memory in favor of or against a response. These findings, together with the ones reported here, show that when considering only accuracy measures, older adults can extract the same benefits from focusing attention as young adults do. However, the model-based analysis shows that the rate of evidence accumulation for retrieval from working memory is reduced with older age. Accordingly, this allows us to predict that in situations that require heightened speed, older adults will underperform compared to younger adults. However, this does not reflect reduced focusing ability but rather slowed information processing in older age.

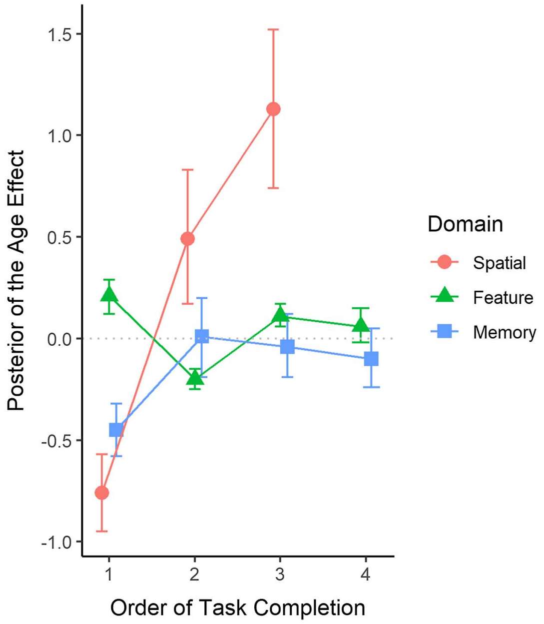
Task-Specific Variance

Overall, our results suggest that the mixed pattern of findings in the literature regarding age-related decrements in attention could reflect task-specific variance. For all domains, there were some tasks in which age differences disfavored and others in which they favored older adults. We have no definitive answer as to why some tasks showed detrimental age effects and others did not, but one apparent pattern from our data relates to experience with the type of task. Figure 5 shows age differences in the focusing effect as a function of the order of exposition to tasks within the same domain (Table 2 indicates the names of the specific tasks). Notably, age differences tended to disfavor older adults at the first exposition to a task type (i.e., spatial task, attention to memory task). The only exception is for the feature attention domain, for which age differences were larger in the second task instead of the first. However, given that the enumeration and centroid tasks were completed in alternate fashion in each session and that they formed separate attention factors, the second task reflects the first exposition to the centroid task. These results suggest that older adults may be slower to catch up with the younger adults, but after they learned how to cope with a task's attentional demands, they were no longer impaired, even when the task specificities changed (e.g., stimuli were different; recall requirements changed). This shows general learning effects rather than task-specific learning.

Overall, our findings suggest that basing claims of age-related demise or preservation of cognitive abilities on single tasks is dangerous. Two factors should be carefully considered in future studies: (a) the number of tasks assessed and (b) experience with the task's demands. If we had obtained evidence from only one task and this happened to be a task in which older adults underperformed, we would conclude that older adults had difficulties in focusing attention. Conversely, if it happened to be a task with no credible differences or in which older adults outperformed younger adults, we would conclude in favor of preserved abilities. Additionally, we should consider that a cross-sectional comparison always implies comparing people of different cohorts, and older adults may be less used to computers and to the artificial demands imposed by our tasks. As such, task length might make a large difference for allowing them to adapt and develop an appropriate strategy to deal with the task requirements. The present results therefore underscore the importance of assessing age differences in multiple task paradigms and potentially with longer exposition or multiple sessions to assess a cognitive function of interest before one can conclude for or against a demise of that cognitive function in older age.

Figure 5

Age Differences in the Focusing Effect as a Function of the Order of Exposition to Tasks Within a Domain



Note. Error bars depict 95% credible intervals. Negative values reflect age differences favoring younger adults. Positive values reflect age differences favoring older adults. See the online article for the color version of this figure.

Domain-Specificity of Attentional Selection

Studies assessing individual differences have mainly examined selective attention as a facet of executive function; in that context it is commonly termed "inhibition." This function has been mainly studied through tasks that measure interference effects, such as the Stroop or flanker task (Braver et al., 2010; Friedman et al., 2006, 2016; Friedman & Miyake, 2004; Kane et al., 2001; McVay et al., 2013; Miyake et al., 2000; Miyake & Friedman, 2012; Rey-Mermet et al., 2018, 2019; Unsworth, 2015; Unsworth & McMillan, 2014; von Bastian et al., 2020). Results of these studies are also converging to a lack of evidence for selective decline of inhibition in aging (Rey-Mermet et al., 2018, 2019).

In contrast to this more established literature, individual differences in attentional selection—as defined here—have been much less investigated. To the best of our knowledge, only three studies have assessed the pattern of correlations between performance in attention paradigms, mostly following an exploratory approach. Huang et al. (2012) evaluated correlations across tasks measuring visual search, intuitive counting, tracking of multiple objects, speed of recognition of briefly presented colors and of spatial patterns, response selection, change blindness, and visual working memory. An exploratory factor analysis extracted a single common latent factor—which they termed visual attention ability—explaining 35% of variance in these indicators. Skogsberg et al. (2015) explored the pattern of correlations across 11 paradigms: for example, flanker, multiobject tracking, shifting of spatial attention, attentional blink, motion discrimination, object selection, and working memory. Hierarchical cluster analysis and multidimensional scaling were used to identify two potential axes along which attentional abilities differentiated: a focused-global axis and a transient-sustained attention axis. Treviño et al. (2021) examined the intercorrelations of a set of five attentional paradigms (multiple object tracking, visual search, approximate number sense, flanker, and visual working memory), one sustained attention task (gradual onset continuous performance test), and eight neuropsychological tests (trail making test versions A and B, digit symbol, forward and backward digit span, letter cancellation, spatial span, and arithmetic). Across iterations of exploratory and confirmatory factor analyses, they obtained a five-factor solution: an *attentional capacity factor* with multiple object tracking, visual working memory, and spatial span, and to a lesser degree, digit symbol; a *search factor* consisting of visual search, trail making, digit symbol, and letter cancellation; whereas the three remaining factors were paradigm-specific: *digit span* with loading of the forward and backward digit span; *arithmetic* with its single task and the *sustained attention* factor with the sustained attention task. Flanker interference did not load on any factor and had low and negative correlations to all tasks assessed. It is worth noting that in all studies, task selection was not theory-guided; they came rather from the assumption that attention is a unitary factor, and they were additionally driven by the popularity of the paradigms. Their batteries also included tasks that are known to measure working memory or complex abilities (arithmetic), for which it is problematic to assume that they specifically measure attentional selection.

In contrast to these previous studies, here we included multiple paradigms assumed to measure distinct but interrelated attentional functions as defined in a taxonomy of attention (Chun et al., 2011). We also separated general task performance contributions (baseline performance) from benefits of attentional modulation (focus effect). The latter specifically reflects a person's ability to focus attention. Additionally, we used CFAs to evaluate the structure of attention selection to space, features, and memory representations. We could reasonably fit models for both age groups with domain-specific factors for these three attention domains. Correlations across these factors were, however, generally low and inconsistent. This suggests that attentional focusing abilities across these domains are relatively independent. This finding supports the assumption that attention is a multidimensional construct and that generalizations across domains should be made with caution. Yet, despite the relative independence of individual differences across domains, our findings speak against the possibility that the three domains we investigated follow diverging trajectories with aging. Across the board, older adults mostly showed preserved focusing abilities, with a few exceptions that might be explained by lower familiarity with the task demands (see Figure 5).

Revisiting Assumptions of Attentional Decrement in Healthy Aging

Many assume that cognitive decline is the norm with healthy aging. Yet, aging is associated with multifaceted processes in which decline, stability, and growth coexist (Loaiza, 2024). The assumption of an attentional decrement in aging has been highly influential (Hasher & Zacks, 1988; Zanto & Gazzaley, 2014). However, mounting evidence provides little support to claims of specific aging-related decline in several attentional functions: inhibition (Rey-Mermet et al., 2018; Rey-Mermet & Gade, 2018, 2020; Verhaeghen, 2011; Veríssimo et al., 2022), sustained attention (Robison et al., 2022), orienting (Veríssimo et al., 2022), guiding of attention by prior knowledge (Smith et al., 2021), and selective attention (Vallesi et al., 2021). Our findings add to this literature by showing that the domain of selection (i.e., space, features, memory) does not provide an explanation for mixed patterns of decline and preservation in focused attention in the aging literature. Reports of decrements in focused attention might be related to artifacts of sampling, motivation, practice, or task difficulty that have long plagued the aging research (Craik & Byrd, 1982). Considered together, the time is ripe for abandoning the assumption of attention decline in aging.

Constraints on Generality

Age is associated with changes in several cognitive functions. Our sample of older adults, although highly functional, also showed signs of age-related decline in most of our measures of baseline task performance. Specifically, they were slower to encode a target stimulus, compute a centroid of a pattern of dots, or enumerate elements in a cloud of dots, and they could store fewer items in working memory. These results are consistent with a wealth of prior work (Bopp & Verhaeghen, 2005, 2007; Brockmole & Logie, 2013; Cerella, 1985; Cerella & Hale, 1994; Hartshorne & Germine, 2015; Ratcliff et al., 2006, 2010b; Verhaeghen, 2011; Verhaeghen & Cerella, 2002). Therefore, the absence of evidence for age-related decline in focused attention cannot be explained by our sample being particularly fitter cognitively than in previous studies (Veríssimo et al., 2022). The fact that—despite our adjustments to baseline difficulty—older adults found most tasks more difficult than young adults could have put them at a disadvantage for the measurement of attentional selection. Take, as an example, the case of attending to working memory representations. If a person can store a smaller proportion of items of the memory array in working memory, there is a larger chance that a cue directing attention to one item will point to information that is not accessible. This could reduce the chance to gain anything from the cue and the incentive to heed the cues in future trials. Yet, our results suggest that despite the remaining differences in task difficulty, attentional selection in aging was generally not deficient.

One limitation of our study is that the calibration of task difficulty did not fully equate difficulty in the control condition between age groups for every task. Calibrating task difficulty to the same approximate level across age groups is necessary to dissociate age-related changes in attentional functioning from other variables that may also covary with age, namely, slowing of processing, differences in working memory capacity, and general differences related to experience with computers and task demands. To that end, we measured age differences in attentional focusing through the interaction of the focus effect with age. That interaction is difficult to interpret in the presence of large age differences in overall performance. This is because we would measure the focus effect of young and old adults in different sections of the measurement scale (i.e., the scale for measuring performance). Because the latent variable of interest—the ability to focus one's attention—cannot be assumed to translate into the measurement scale by a linear function, the same size of a focusing effect on different sections of the performance scale can reflect different latent abilities to focus attention, and vice versa (Loftus, 1978). For those tasks for which the calibration did not equate performance well between age groups, it is possible that a replication with better calibration yields different results concerning age differences in the focus effect. Therefore, it is risky to generalize our findings from individual tasks to future efforts to measure selective attention with these tasks. That said, the imperfect calibration did not lead to a biased measurement of age differences in focusing ability across tasks because the remaining age differences in baseline performance were unrelated across tasks to the age differences in focusing ability (Table 3).

Another potential limitation refers to the use of an extensive task battery, which could introduce fatigue effects. We have taken several precautions to minimize fatigue: We included breaks, varied task material, and did not impose time pressure. Overall, the data presented in Table 2 show relatively stable performance across tasks. If anything, we tended to observe that the second exposition to a similar task was associated with better performance even when the second task occurred at the very end of the session and should suffer from substantial fatigue effects. For example, the letter enumeration (second task) and orientation change detection (forth task) occurred at the beginning of the first session—when participants were less tired—whereas the shape enumeration and the color change detection tasks were the last two of the second session—hence when fatigue was maximal. Yet, we observed better performance in these later two tasks. All in all, we contend that fatigue is unlikely to pose a substantial challenge to the interpretation of our data.

An additional limitation was the use of an extreme age-group design—contrasting a younger to a much older sample—which does not permit conclusions regarding the function relating age to focused attention ability. Recently, it has become increasingly more common to collect data of massive samples (including thousands of people), thereby allowing for the characterization of life-span changes in diverse cognitive domains (Brockmole & Logie, 2013; Erb et al., 2023; Fortenbaugh et al., 2015; Hartshorne & Germine, 2015; LaPlume et al., 2022; Reimers & Maylor, 2005; Salthouse, 2019). These massive samples allow for the estimation of the age at which peak cognitive performance is observed and the rate of cognitive decline with aging. Our study cannot provide an estimation of either, given our modest sample size and the aggregation over a 15-year period in each age group. Overall, our findings suggest that there might be very small changes in the efficiency of focused attention across these broad age ranges. One may wonder, however, if we may have missed the age range in which focused attention ability peaks and therefore might be underestimating cognitive decline in this function. We find this possibility unlikely given that the massive data sets mentioned above observed peak performance before the age of 30 on domains that rely on fluid abilities such as sustained attention, executive attention, short-term memory, and working memory. Later age of performance peaks were observed in domains that rely more on crystalized knowledge such as vocabulary, arithmetic, and emotional identification (Hartshorne & Germine, 2015). We find it unlikely that focused attention would peak later in life, diverging from other attentional functions such as sustained attention and executive attention. Yet, future studies sampling the full age range should assess focused attention to precisely estimate life-span changes in this ability.

One final limitation regarding the generality of our findings is that our sample comes from a high-income country (Switzerland) with above-average levels of education, which may provide a buffer against cognitive decline (Steptoe & Zaninotto, 2020; Wagg et al., 2021). Additionally, we target older participants with no signs of dementia and without any reported psychological/neurological illness. As these health issues may become more common for older adults, our findings do not generalize to the entire population of older adults. Further studies should evaluate the role of these variables as protective factors against age-related decline in attention functions.

Conclusion

Aging is associated with performance changes in several cognitive tasks. Yet, it is unclear to what degree these changes are produced by decrements in specific cognitive functions. It is often assumed that attentional abilities decline during the natural aging process. The evidence for this claim in the literature has remained mixed. Our study provides data from a battery of 11 attention tasks measuring the ability to focus attention on space, features, and memory. Although our sample of older adults showed reduced overall performance in all tasks, they did not have a specific decrement in focusing attention. In virtually all tasks, they followed cues to focus attention, thereby improving performance, and focusing benefits were sometimes larger, sometimes similar, and sometimes smaller than the ones observed for younger adults. These results reject the claim of a general age-related decline in attention. The focus of attention seems to remain sharp as people age.

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