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Aging effects on extrapersonal (far-space) attention: cancellation and line bisection performance from 179 healthy adults

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ABSTRACT

Assessment of cognitive impairments is a vital part of clinical practice. Cancellation (visual search) and line bisection are commonly used tasks to assess visuospatial attention. Despite the fact visuospatial attention is engaged in both near (within reach) and far-space (out of reach), most studies have been conducted in near-space alone. Moreover, despite their use in clinical practice, it is unclear whether cancellation and bisection tasks are related. Here, we investigated the impact of aging on cancellation and line bisection performance in far-space in a large healthy sample. We provide preliminary age-graded norms for assessing visuospatial attention in far-space calculated from a sample of 179 healthy adults, between the ages of 18–94 (*mean age* = 49.29). Cancellation and line bisection were presented on a large screen in far-space and completed using a wireless remote. Aging was accompanied by longer task duration for both tasks, slower search speed and poorer quality of search. However, there was no significant effect of aging on line bisection error. There was a significant correlation between the two tasks in that longer task duration in line bisection was associated with slower search speed and poorer quality of search. Overall, participants presented a leftward bias during cancellation and line bisection akin to pseudoneglect. Moreover, we found that irrespective of age, search speed was faster in males than females. We offer novel evidence that performance on cancellation and line bisection tasks are related to one another in far-space, but are also sensitive to age-related decline, and even sex differences.

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aging; cancellation; line bisection; visuospatial attention; far-space

Introduction

Visual search is used in everyday life, from searching for people in a crowd to items in a supermarket. Several cognitive processes are thought to be essential to carry out efficient and successful visual search, including orienting attention toward an object or

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area in space (visuospatial attention), alertness, executive control, and perceptual grouping (Müller-Oehring et al., 2013). These processes are important for conducting organized and efficient (i.e., finding targets successfully in less time) searches in cluttered everyday environments. Organized searches can be measured according to their consistency (maintaining the same search pattern), number of intersections (search path crossing over itself), and distances between targets (finding the next target close to the previous one; Ten Brink et al., 2016). Moreover, our visuospatial attention operates to find stimuli in peripersonal (within reach/near-space) and extra-personal space (out of reach/far-space) and locate them using egocentric (location of objects relative to the body) and allocentric (relative to other objects) reference frames (Lane et al., 2015). The central role visual search plays in everyday life becomes apparent when observing deficits in visuospatial attention after brain injury or changes with healthy aging.

Cancellation tests (i.e., visual search tasks to find targets amongst distractors) are commonly used in clinical and research settings (Checketts et al., 2021; Moore et al., 2022) to detect deficits in visuospatial attention in neurological populations. Currently, they are thought of as the most sensitive measure of spatial inattention (or spatial neglect; Ferber & Karnath, 2001; Moore et al., 2022), a syndrome affecting a person's ability to attend to stimuli on the side of space opposite to the side of brain lesion. Given that spatial inattention can be observed both in egocentric and allocentric reference frames (Demeyere & Gillebert, 2019), some cancellation tests are able to measure both ego- and allocentric biases (e.g., Bickerton et al., 2011; Demeyere et al., 2015; Ota et al., 2001).

In practice, stroke survivors have been shown to perform less efficient or disorganized searches compared to healthy controls (Ten Brink et al., 2016). Using a computerized cancellation task, Ten Brink and colleagues reported that stroke survivors with spatial inattention after a right hemisphere lesion had an increased number of intersections compared to healthy controls, and stroke survivors with spatial inattention after left hemisphere lesions. Deficits in spatial working memory impact the individual's ability to "update" their internal representation of the scene (i.e., targets already found), meaning they may revisit previously search areas (perseverate), consequently increasing the number of intersections, resulting in a disorganized search (Ten Brink et al., 2016).

Similarly, performance in aspects of visuospatial attention declines in healthy aging. For example, older people tend to display slower processing speeds (i.e., search duration) in visual search and cancellation tasks compared to younger people (Benjamins et al., 2019; Brucki & Nitrini, 2008; Hommel et al., 2004; Müller-Oehring et al., 2013; Potter et al., 2012; Tamura & Sato, 2020; Warren et al., 2008). A large study consisting of 523 healthy participants reported that search duration increased by 59 milliseconds with each year of age (Benjamins et al., 2019). This decline began at around 50–60 years old (Tamura & Sato, 2020; Warren et al., 2008).

In everyday life, most of our visual searches occur in far-space and processing of this space seems different than attentional mechanisms within near-space. In fact, attentional deficits in far-space have been shown to dissociate from deficits in near-space in neurological patients (Aimola et al., 2012; Committeri et al., 2007; Halligan & Marshall, 1991). Surprisingly, however, most research on attention has been conducted in near-space (i.e., on a computer screen within reach of the participant), so it remains unknown how different tasks are performed in this section of space and how this is impacted by aging. One study using an everyday-based supermarket task presented in far-space, found that search duration was faster for those in their 20s and 30s compared to older adults, particularly those in their 70s and 80s (Potter et al., 2012). This suggests that healthy aging affects visual search duration in far-space.

However, aging effects in visual search seem highly dependent on the task used (Hommel et al., 2004), suggesting that different mechanisms may be involved. For example, older adults take longer than younger participants to complete conjunction than feature searches (Hommel et al., 2004; Müller-Oehring et al., 2013; Potter et al., 2012; Tamura & Sato, 2020). Feature searches utilize a pre-attentive stage (information not yet selectively attended to) of processing to find a target using basic visual features, such as color and orientation (Treisman, 1982; Wolfe, 2021). Targets in feature searches often "pop-out" from distractors since they are unique in their basic visual features and visually different from distractors (Wolfe, 2021). In contrast, conjunction searches are thought to use both stimulus-driven (bottom-up) and known (top-down) features of a target in the pre-attentive stage to create a priority map that guides where we allocate our attention (Wolfe, 2021). In other words, the priority map acts as an "*attention-directing landscape*", whereby our attention is allocated to "spikes" until the target is found (Wolfe, 2021, p. 6). It has been proposed that older adults are slower at conjunction searches as it relies on later, serial processing stages and requires executive control to shift, inhibit, and select attention between targets and distractors (Müller-Oehring et al., 2013; Tamura & Sato, 2020).

Whether aging affects line bisection performance has been more debatable. Like cancellation tasks, line bisection assesses visuospatial attention by measuring the deviation error when individuals mark the center of lines. To quantify spatial inattention, line bisection tasks are recommended alongside other tests (e.g., cancellation), since biases presented can be affected by motor, visual, and visuomotor impairments (Moore et al., 2022). Generally, healthy individuals bisect lines leftward from the true center (a phenomenon known as pseudoneglect; Bowers & Heilman, 1980). Right hemisphere dominance in spatial processing is widely used to explain pseudoneglect (i.e., an increased orientation to the left; Brooks et al., 2016). Some studies report rightward biases in participants over 50 years old (Benwell et al., 2014; Fujii et al., 1995; Jewell & McCourt, 2000) while others report leftward biases (Varnava & Halligan, 2007). The variance in findings could be due to a high variance between individuals (Manning et al., 1990), and task and stimuli used (e.g., line length and placement, hand used, starting position; Brooks et al., 2016; Benwell et al., 2014; for review see; Jewell & McCourt, 2000). However, a recent meta-analysis of 63 studies found a leftward bias in studies where all participants were over the age of 50 (Learmonth & Papadatou-Pastou, 2021). The authors propose that preserved right hemisphere dominance could explain why pseudoneglect is observed in older age and that spatial attention may not be as affected by age-related changes compared to other cognitive functions, such as memory (Brooks et al., 2016; Learmonth & Papadatou-Pastou, 2021). Much like visual search research, most studies of line bisection are conducted in near-space, with the exception of one study, which found a reduction in pseudoneglect in healthy adults aged between 17 and 41 years old in far versus near-space (Varnava et al., 2002). To date, it's unclear how (or if) age affects line bisection in far-space and how this relates to visual search performance.

Studying the effects of age on line bisection and visual search is particularly important as these tasks make up a large proportion of neuropsychological assessments of attention impairments (Checketts et al., 2021). For tests where cognitive processes are known to be affected by age (such as visual search duration), age-graded norms can be useful for detecting subtle cognitive changes in older people indicative of early brain disease (Lezak et al., 2004). However, many paper-and-pencil cancellation tasks used to detect attentional deficits after brain injury do not provide age-specific cutoffs and are limited in the types of performance metrics they can provide (e.g., overall accuracy, spatial bias scores, overall search duration, e.g., Broken Hearts Cancellation test; Demeyere et al., 2015).

Computerized tasks record rich performance metrics, such as search organization (i.e., search paths, intersections; Dalmaijer et al., 2015), which have been shown to be a sensitive measure of attentional deficits after stroke (Ten Brink et al., 2016). Computerized tests also facilitate the manipulation of attentional demands (thus increasing sensitivity in detecting even mild attentional deficits; Peskine et al., 2011) and the area of space stimuli are presented (e.g., in far-space; Ogourtsova et al., 2018; Yasuda et al., 2017). Attentional deficits (such as spatial inattention) or age-related declines in search efficiency (success and speed) in far-space could impact the efficiency of activities in daily life (e.g., navigation, finding objects; Potter et al., 2012; Ten Brink et al., 2016). Yet, visuospatial attention tasks (e.g., cancellation, line bisection) are not routinely carried out in far-space in clinical environments.

To address these knowledge gaps, here we investigated cancellation and line bisection performance in far-space across different ages (and other demographic variables, e.g., sex, education, handedness) in a large sample of healthy individuals (Objective 1). This included producing the initial age-graded norms for the tasks for use with clinical populations (Objective 2). To do this, we used our novel Computerized Extrapersonal Neglect Test (CENT) consisting of a cancellation and line bisection task presented in far-space. Based on the literature, we expected to see an increase in processing speed as age increased and evidence of pseudoneglect across the sample. Based on findings from Benjamins et al. (2019), we did not expect education or sex to influence performance.

Methods

Participants

Adult (+18 years of age) members of the public were recruited using convenience sampling in a city center venue in Norwich, United Kingdom in February 2019. In total, 246 adults took part in the study with 67 participants excluded. Of the 67 excluded, 45 participants (67.16%) did not meet the inclusion criteria: 37.31% had a previous brain injury or disease, 28.36% had uncorrected vision or a visual impairment, and 1.49% had a history of severe psychiatric condition. The remaining 15 participants (22.39%) were excluded since they deviated from task instructions (e.g., used both hands, moved closer to the screen during the task). Of these, just under half ($n = 7$) were over 65 years old. Finally, 7 (10.45%) were excluded due to missing data (e.g., did not finish the study). Thus, the final sample included in the analysis was 179 participants (50% female, 48% male, 2% unspecified). Age ranged between 18 and 94 years ($M = 49.29$, $SD = 18.36$). Years of education ranged between 8 and 35 ($M = 16.34$, $SD = 3.84$; see Table 1 for full descriptive

Table 1. Descriptive statistics of sample ($n = 179$).

Age group	Mean age (*SD*)	n Female	n Male	n Total	Handedness: Left	Right	Ambidextrous	Mean year's education
18–29	23.11 (3.21)	20	16	36	3	29	3	16.77 (1.99)
30–39	35.23 (3.11)	11	15	26	5	20	0	17.21 (5.28)
40–49	43.50 (2.93)	13	7	20	2	17	0	17.19 (4.18)
50–59	55.03 (2.68)	19	18	38	2	32	1	16.44 (3.78)
60–69	63.73 (2.99)	13	17	32	4	27	1	15.70 (3.72)
70–79	72.93 (2.32)	8	10	19	3	14	2	14.97 (4.21)
80–94	84.75 (4.50)	5	3	8	2	6	0	15.75 (4.00)
Overall	49.29 (18.36)	89	86	179	21	145	7	16.34 (3.84)

Note: Year's education = from UK primary school (11 years old) to end of last education level obtained (e.g., degree or college).

statistics by age group). Ethical approval was obtained from the Research Ethics Committee at the University of East Anglia (2018–0026–001469). All participants provided informed consent in accordance with the Declaration of Helsinki.

Apparatus and stimuli

Our novel Computerized Extrapersonal Neglect Test (CENT) was projected onto a 60-inch television screen (full HD 1080p/50 Hz, pixel size 1920 × 1080) mounted on a 1.8-m stand. CENT was developed working with end-users and in collaboration with Evolv Rehabilitation Technologies (https://evolvrehab.com/). CENT was programmed on Unity (Unity Technologies) and run on a laptop (OMEN by HP 15-dc0003) connected to the television. Participants used a wireless HTC Vive controller to complete CENT and responses were recorded via an HTC Vive base station placed on a tripod underneath the television and in line with the middle of participants' bodies. Both the HTC Vive base station and controller were connected to the laptop using a Steam wireless dongle.

CENT featured both a cancellation and line bisection task designed to be presented on a large screen (minimum 40 inch). The cancellation task consisted of 50 small (220 mm height x 220 mm width) and large (280 mm height x 280 mm width) targets (complete mugs; Figure 1(a)) amongst 100 small and large distractors (50 mugs with a left-side gap; 50 with a right-side gap; Figure 1(b)) presented across the screen (Figure 1(c)). The stimuli were static, positioned within a grid of 10 cells (373.4 mm height x 265.6 mm width; Figure 1(d)) for each cell containing 5 targets, 5 left-gap, and 5 right-gap distractors.

The line bisection task consisted of 10 short (604 mm length x 50 mm thickness) black horizontal lines presented one at a time (Figure 2). Two lines were presented in the middle of the screen (i.e., the midline of the line aligned with the midline of the participant and screen), four on the left and four on the right.

Procedure

Participants were seated approximately 170 cm away from the television, with their midsagittal plane in line with the center of the television. Participants were given a wireless HTC Vive controller to click on stimuli. For the cancellation task, participants

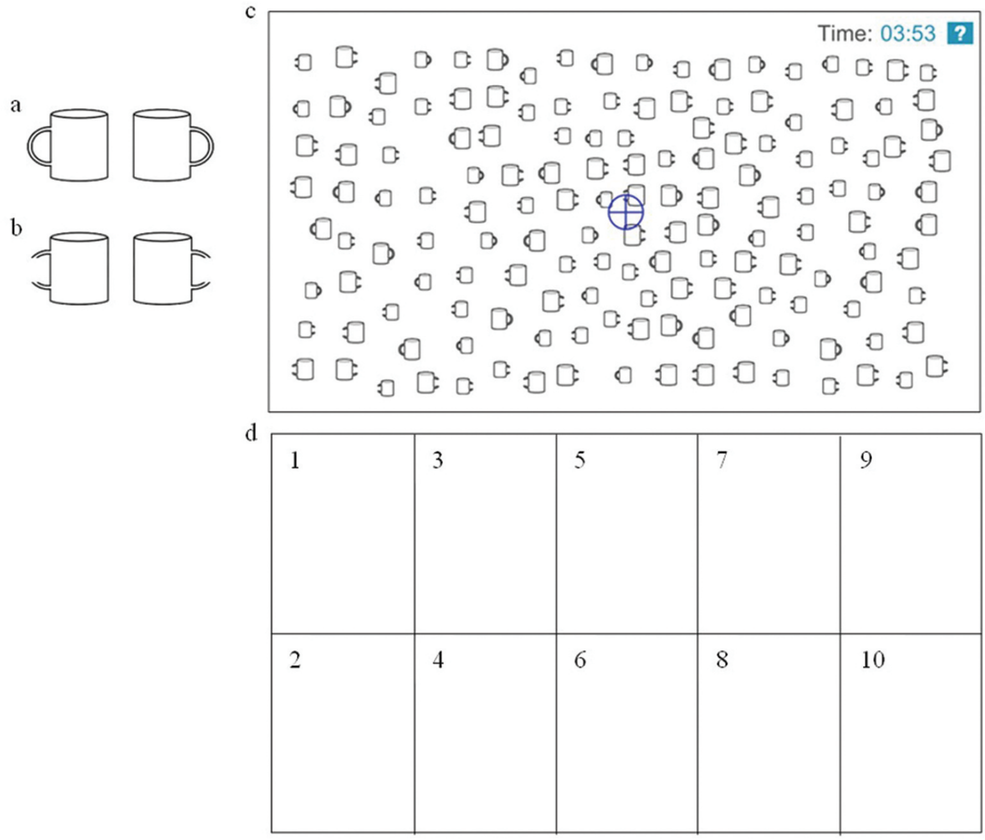

Figure 1. a) Cancellation task target stimuli; b) distractor stimuli; c) task display; d) grid used to position stimuli (boxes 1–4 indicate left; 5–6 middle; 7–10 right side of the screen).

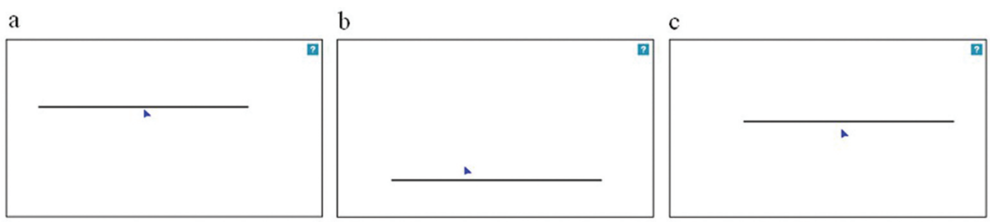

Figure 2. Line bisection task. Lines presented on a) left; b) middle; c) right.

were instructed to "Please click on all the complete mugs (those with no gaps)" using the Trackpad button. A blue "bulls-eye" symbol was used as a cursor for participants to guide their selection of stimuli on the screen. Upon clicking, a short diagonal line and "popping" noise indicated a registered response.

For the line bisection, a blue arrow was used as a cursor and participants were instructed to "Please click using the controller where you consider the center of the line to be." Note that participants were not explicitly encouraged to work quickly since we wanted to collect naturalistic processing speeds across ages.

Participants completed one practice trial with 12 targets and 12 distractors before completing the full cancellation task. Participants received the same instructions for both the practice and the full task. No feedback was given on the cancellation practice trial, but was repeated once if participants did not follow the instructions. No practice was completed for the line bisection task since it is not common practice in neuropsychological testing (e.g., Ferber & Karnath, 2001; Lezak et al., 2004; Wilson et al., 1987). There was no time limit for either task and participants notified the experimenter when they finished the cancellation task. The line bisection task ended automatically after responding to the final line. Task order was counterbalanced across participants.

Outcome variables

Based on CancellationTools (Dalmaijer et al., 2015) and a previous study using computerized visual search (cancellation; Benjamins et al., 2019), we extracted the following variables of visuospatial attentional bias used in standard paper-and-pencil assessments (Table 2): accuracy (total number of targets canceled), line bisection error (% left/right deviation from true center), egocentric score (asymmetry score between the number of targets found on left versus right side of the screen) and allocentric score (asymmetry score between left-gap and right-gap distractors canceled). To test search organization (e.g., consistency, intersections, inter-cancellation distance; Ten Brink et al., 2016), we measured search speed (time and distance between consecutive cancellations), quality of search (speed and accuracy of search), and intersections (number of times search path crosses over itself; Dalmaijer et al., 2015). Since previous evidence has shown processing speed

Table 2. Description of each variable from the CENT tasks. Formulas for the quality of search and search speed are available in CancellationTools (Dalmaijer et al., 2015.).

Variable	Description
Accuracy	Total number of targets canceled. Max score 50.
Errors	Total number of distractors canceled. Max score 100.
Intersections	Number of times cancellation path crosses over itself.
Re-cancellations	Cancellation of a target already canceled (perseverations).
Search duration	Total time (secs) taken in cancellation task.
Quality of search	Shows speed and accuracy of search using a single score (Q score) using number of targets canceled, total number of targets and total task duration. High score indicated high number of targets detected and high cancellation speed. Formula available in CancellationTools (Dalmaijer et al., 2015).
Search speed	Inter-cancellation distance (Euclidean) in pixels divided by inter-cancellation time (secs). Formula available in CancellationTools (Dalmaijer et al., 2015).
Egocentric score	Measure of bias in finding targets across the screen (space neglect). Calculated by subtracting number of targets canceled on left of the screen from number of targets canceled on right. Positive value represents more targets canceled on left side, indicating right egocentric neglect. Negative value represents more targets canceled on right side, indicating left egocentric neglect.
Allocentric score	Bias in canceling distractors with a gap on left or right side (object neglect). Calculated by subtracting number of left-gap distractors by number of right-gap distractors. Positive value represents more right-gap distractors canceled, indicating right object centered neglect. Negative value represents more left-gap distractors canceled, indicating left object centered neglect.
Line bisection error	Deviation (%) from true center when judging the middle of ten lines on screen.
Total line bisection duration	Total response time (secs) taken in line bisection task (10 lines).

declines with age (Benjamins et al., 2019; Brucki & Nitrini, 2008; Hommel et al., 2004; Müller-Oehring et al., 2013; Potter et al., 2012; Tamura & Sato, 2020; Warren et al., 2008), we recorded search duration (total time taken in cancellation task) and total line bisection duration (total response time taken to judge middle of 10 lines). Finally, to measure inhibitory control and short-term memory at different ages we included variables of errors (distractors canceled) and re-cancellations (cancellation of a target already canceled; also known as perseverations; Benjamins et al., 2019; Dalmaijer et al., 2015). Further details on each variable of interest and how they were computer are presented in Table 2.

Statistical analysis

Spearman's rank correlation was first used to test for a relationship between age, education, and all cancellation and line bisection variables (Objective 1). Spearman's rank correlation was used since several the variables were not normally distributed (accuracy, errors, intersections, re-cancellations, ego- and allocentric score). We used Analysis of Variance (ANOVA) to estimate the effect of age on normally distributed task variables, and Kruskal-Wallis by ranks on all non-normally distributed variables. Distribution of the data was checked graphically using Q-Q and histogram plots and Levene's test was used to test equality of variances within the variables. For these analyses, age was categorized by decade (e.g., 18–29; 30–39; 40–49; 50–59; 60–69; 70–79; 80–94). The oldest age group (80–94) extended to 94 to include our oldest participant rather than having an additional age category with just one participant.

Means, medians (non-normally distributed variables), minimum, and maximum are reported for each variable. Additionally, 5th and 95th percentiles were calculated to provide cutoff values to determine impairments compared to this sample of neurologically healthy people (Objective 2). Cutoff values were calculated for each age group for those variables that were significantly associated with age.

To test our hypothesis, predicting a small bias to one side of space (i.e., pseudoneglect), paired t-tests were used to test for the effect of side of space within each task. Additionally, analysis of Covariance (ANCOVA) and separate rank analysis of covariance (Quade's; Quade, 1967 for non-normally distributed variables) was used to investigate the effect of categorical variables (sex, handedness) on line bisection and cancellation performance whilst controlling for age.

To investigate performance across different ages, K-means clustering analysis was used to explore sub-groups within the sample with shared or similar performance on outcome variables. Variables were transformed into z-scores to standardize variables before running the analysis. Optimal number of clusters was determined using the Elbow method to visually determine when cluster values decline or plateau as the number of clusters increase (Kodinariya & Makwana, 2013).

Chi-squared tests were carried out post-clustering to investigate differences between categorical demographic variables (sex, handedness) and cluster membership. Independent samples t-tests were used post-clustering to test differences in age and education between clusters. ANOVAs were also used to determine which outcome variables had a significant effect on cluster groupings. Accidental re-cancellations (or re-clicks) were defined as clicks performed less than 1 s apart and removed from the analysis. The alpha level was set at 0.05 for all analyses. Bonferroni correction was used to correct for multiple comparisons ($n = 78$) and reduce the chance of Type 1 errors, giving an adjusted p-value of $p = 0.0006$.

Results

Correlations between age and cancellation and line bisection variables

As can be seen in Figure 3, search duration, search speed, quality of search and line bisection duration were all significantly correlated with age. More specifically, age was significantly associated with slower timings on the cancellation task: longer search duration [$r_s(179) = 0.379$, $p < 0.001$, 95% C.I. = 0.24, 0.50], slower search speed [$r_s(179) = -0.408$, $p < 0.001$, 95% C.I. = −0.53, −.027], longer line bisection task duration [$r_s(179) = 0.264$, $p < 0.001$, 95% C.I. = 0.12, 0.40], and poorer quality of search [$r_s(179) = -0.398$, $p < 0.001$, 95% C.I. = −0.52, −0.26]. Moreover, some cancellation and

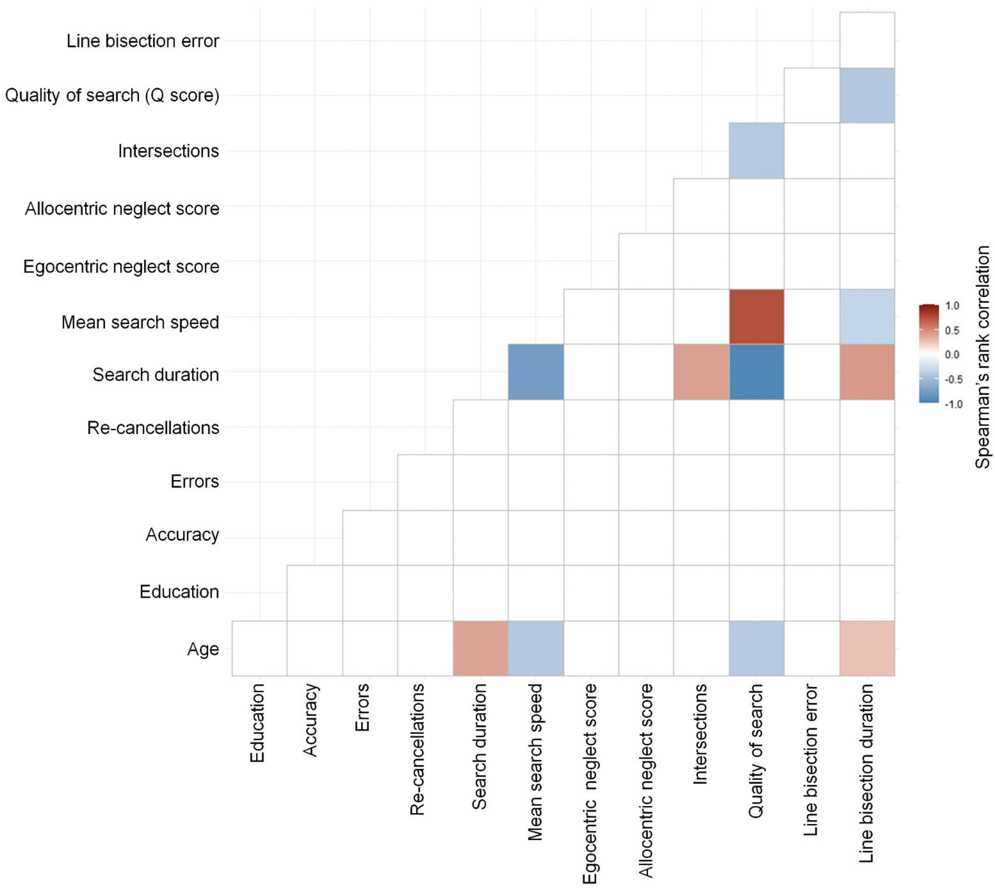

Figure 3. Correlation (Spearman's rank) matrix of cancellation and line bisection task variables. Only correlations significant after Bonferroni correction are presented. See Table 2 for variable details.

line bisection variables were significantly correlated: line bisection duration was positively correlated with search duration [$r_s(179) = 0.434$, $p < 0.001$, 95% C.I. = 0.30, 0.55] but, negatively correlated with search speed [$r_s(179) = -0.331$, $p < 0.001$, 95% C.I. = −0.46, −0.19] and quality of search [$r_s(179) = -0.422$, $p < 0.001$, 95% C.I. = −0.54, −0.29].

In addition, several cancellation variables were significantly correlated with each other: search duration was negatively correlated with search speed [$r_s(179) = -0.760$, $p < 0.001$, 95% C.I. = −0.82, −0.68] and quality of search [$r_s(179) = -0.953$, $p < 0.001$, 95% C.I. = −0.97, −0.93], but positively correlated with number of intersections [$r_s(179) = 0.397$, $p < 0.001$, 95% C.I. = 0.26, 0.52]. Finally, quality of search was significantly correlated with search speed [$r_s(179) = 0.738$, $p < 0.001$, 95% C.I. = 0.65, 0.81] and intersections [$r_s(179) = -0.400$, $p < 0.001$, 95% C.I. = −0.52, −0.26]. There was no significant correlation between any of our variables and years of education ($p > 0.05$).

Age grouping effects on task performance

Search duration

There was a significant effect of age on search duration [$F(6, 172) = 5.24$, $p < 0.001$, $\eta^2 = 0.16$]. Search duration was significantly slower in age group 80–94 compared to age groups: 18–29 [62.28, $p < 0.001$, 95% C.I. = 20.73, 103.83]; 30–39 [65.10, $p < 0.001$, 95% C.I. = 22.12, 108.07], 40–49 [57.00, $p = 0.002$, 95% C.I. = 12.53, 101.47], and 50–59 [45.70, $p = 0.017$, 95% C.I. = 4.35, 87.05; Figure 4(a)). No other significant differences were found.

Quality of search

A significant interaction was found between the age groups and the quality of search [$F(6, 172) = 6.64$, $p < 0.001$, $\eta^2 = 0.19$]. The quality of search was significantly better in the younger age group, 18–29 compared to older age groups; 60–69 [0.088, $p = 0.019$, 95% C.I. = 0.01, 0.17], 70–79 [0.11, $p = 0.008$, 95% C.I. = 0.02, 0.20] and 80–94 [0.19, $p < 0.001$, 95% C.I. = 0.06, 0.32]. Additionally, the quality of search was better in age group 30–39 compared to older age groups; 60–69 [0.10, $p = 0.013$, 95% C.I. = 0.01, 0.19], 70–79 [0.12, $p = 0.006$, 95% C.I. = 0.02, 0.22] and 80–94 [0.20, $p < 0.001$, 95% C.I. = 0.06, 0.33; Figure 4b]. No other significant differences were found. There were no statistically significant differences between age group 18–29 and age groups 30–59.

Search speed

There was a statistically significant difference in search speed between at least seven age groups [$F(6, 172) = 6.573$, $p < 0.001$, $\eta^2 = 0.19$]. Search speed was significantly slower in age group 80–94 compared to younger age groups: 18–29 [−46.40, $p < 0.001$, 95% C.I. = −77.13, −15.67], 30–39 [−45.76, $p < 0.001$, 95% C.I. = −77.54, −13.97], 40–49 [−42.93, $p = 0.002$, 95% C.I. = −75.82, −10.04], and 50–59 [−34.80, $p = 0.012$, 95% C.I. = −65.38, −4.22; Figure 4(c)]. Search speed was also significantly slower in age group 60–69 compared to: 18–29 [−25.04, $p = 0.002$, 95% C.I. = −44.14, −5.94) and 30–39 (−24.40, $p = 0.008$, 95% C.I. = −45.15, −3.64). No other significant differences were found.

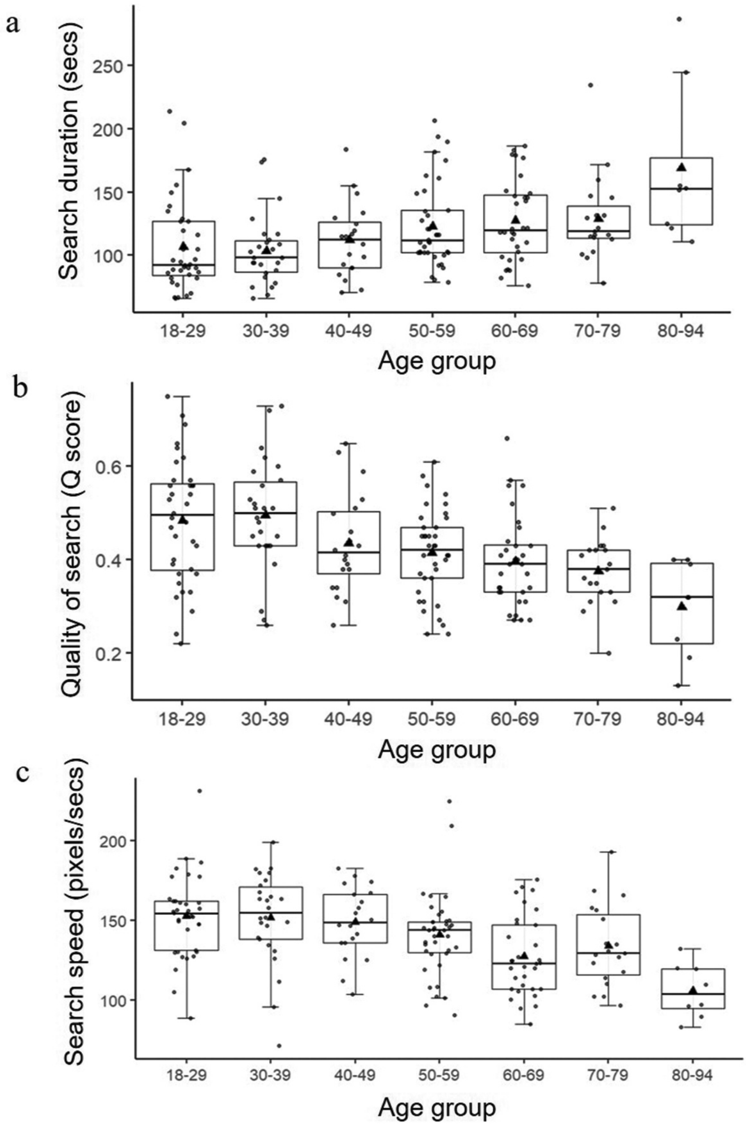

Figure 4. Boxplots with error bars showing mean (triangle) and median values of (a) search duration (seconds), (b) quality of search (Q score) and (c) search speed (inter-cancellation distance (Euclidean) in pixels divided by inter-cancellation time (secs) per age group). See Table 2 for variable details.

Egocentric bias

There was an overall statistically significant interaction between egocentric neglect score and age [H(6) = 13.82, $p = 0.032$, $\eta^2_H = 0.05$]. However, differences between groups (i.e., increased rightward bias in age group 80–94 compared to all other age groups) were not significant after Bonferroni correction.

Line bisection duration

There was an overall significant effect of age on line bisection duration [$F(6, 172) = 2.47$, $p = 0.026$, $\eta^2 = 0.08$], however, post-hoc tests found no statistically significant difference between the seven age groups.

No effect of age on remaining variables

There was no statistically significant difference in line bisection error, accuracy, errors, intersections, re-cancellations, and allocentric neglect score between the seven groups.

Normative data for cancellation and line bisection tasks

Data for all variables produced by the cancellation and line bisection tasks are presented in Table 3. The 5th and 95th percentiles can be used as normal cutoffs for performance. Cutoff scores for each age group by a decade (Table 4) are provided only for variables that significantly correlated with age (see Figure 3). Note that some variables with higher values indicate worse performance (i.e., search duration, line bisection duration, errors, intersections, re-cancellations), and others with lower values indicate worse performance (i.e., search speed, quality of search). A value close to 0 for line bisection error represents no bias in bisection judgments.

Table 3. Tables showing overall normative data for normally distributed (3a) and non-normally distributed (3b) variables from cancellation and line bisection tasks. 5th and 95th percentiles are shown here to be used as preliminary cutoffs to determine impairment.

A	Variable	Mean score (SD)	Min score	Max score	5th	95th
	Total line bisection duration (secs)	35.47 (13.14)	17	109	21	59
	Search duration (secs)	119.07 (36.85)	66	287	73	187
	Left side (% of search duration)	54.12 (6.05)	35.31	71.28	43.71	63.46
	Right side (% of search duration)	45.88 (6.05)	28.72	64.69	36.54	56.29
	Time asymmetry time score (% time of right – % time on left)	−8.24 (12.11)	−42.57	29.37	−26.92	12.58
	Quality of search	.43 (.12)	.13	.75	.26	.64
	Search speed	140.86 (27.79)	71.19	231.20	96.29	182.68
	Left side	135.49 (29.33)	65.28	209.24	86.12	180.23
	Right side	126.54 (27.95)	64.98	182.69	78.97	171.02
	Line bisection error (%)	−.83 (4.61)	−11.5	29.70	−6.40	5
B	**Variable**	**Median score**	**Min score**	**Max score**	**5th**	**95th**
	Accuracy	49	39	50	46	50
	Errors	0	0	4	0	1
	Intersections	3.00	0	43	.00	20.00
	Re-cancellations	0	0	1	0	0
	Egocentric score	0	−3	5	−2	2
	Allocentric score	0	−2	1	0	1

Time asymmetry time score = negative value shows more time spent searching on the left side of the screen. Quality of search = shows speed and accuracy of search as a single measure. High Q score = high number of targets detected and high cancellation speed. Search speed = pixels per second. Left/right side = side of the screen when completing tasks. Scores lower than 5th centile and higher than 95th centile indicate an impairment.

Table 4. Normative data by age groups (by decade). 5th and 95th percentiles are reported to determine impairment on each variable.

		18–29 ($n = 36$)	30–39 ($n = 26$)	40–49 ($n = 20$)	50–59 ($n = 38$)	60–69 ($n = 32$)	70–79 ($n = 19$)	80–94 ($n = 8$)
Total line bisection duration (secs)	Mean (SD)	32.67 (13.12)	33.19 (7.83)	30.80 (7.58)	36.82 (17.25)	36.06 (9.77)	40.26 (11.20)	47.00 (22.19)
	Min	17	17	20	22	19	23	29
	Max	72	49	46	109	56	65	96
	5^{th}	18.70	17.35	20.05	22.00	20.30	23.00	29.00
	95^{th}	64.35	47.95	45.95	81.45	56.00	-	-
Search time (secs)	Mean (SD)	106.47 (36.53)	103.65 (27.86)	111.75 (29.08)	123.05 (33.32)	127.38 (32.29)	128.89 (34.05)	168.75 (63.19)
	Min	66	66	71	79	76	78	111
	Max	214	176	184	207	187	235	287
	5^{th}	66.85	67.05	71.10	80.90	79.90	78.00	111.00
	95^{th}	206.35	175.30	182.55	194.65	184.40	-	-
Quality of search	Mean (SD)	.48 (.13)	.50 (.12)	.43 (.11)	.41 (.09)	.40 (.10)	.37 (.07)	.30 (.10)
	Min	.22	.26	.26	.24	.27	.20	.12
	Max	.75	.73	.65	.61	.66	.51	.40
	5^{th}	.24	.26	.26	.24	.27	.20	.13
	95^{th}	.72	.72	.65	.58	.60	-	-
Search speed	Mean (SD)	152.31 (25.93)	151.66 (28.65)	148.84 (21.93)	140.71 (26.39)	127.27 (24.71)	133.90 (25.67)	105.91 (17.05)
	Min	88.82	71.19	103.78	90.47	84.94	96.77	82.93
	Max	231.20	198.97	182.68	224.58	175.57	192.72	132.13
	5^{th}	102.75	79.69	104.19	96.49	91.29	96.77	82.93
	95th	194.93	193.20	182.45	209.77	172.52	-	-

Effect of side on cancellation and line bisection tasks

Overall, participants displayed a small, but significant leftward error ($M = -0.83\%$, SD $= 4.61$) in the line bisection task [$t(178) = -2.40$, $p = 0.018$, 95% C.I. $= -1.51$, -0.15, d $=$ 0.18], replicating previous findings of pseudoneglect in neurologically intact adults (Jewell & McCourt, 2000). This leftward error was not significantly larger when lines were presented on the left side compared to the right side of the screen [$t(179) = -1.63$, $p = 0.106$, 95% C.I. $= -6.53$, 0.63], nor was there a significant difference in response times for lines presented on the left or right ($M = 3.48$, $SD = 1.31$), [$t(179) = 0.25$, $p = 0.800$, 95% C.I. $= -0.53$, 0.69].

During the cancellation task, the participants spent significantly more time searching on the left side ($M = 54.12\%$, $SD = 6.05$) compared to the right of the screen ($M = 45.88\%$, $SD = 6.05$), [$t(178) = 9.11$, $p < 0.001$, 95% C.I. $= 6.45$, 10.03, d $=$ 0.68]. Mean search speed was also faster on the left side ($M = 135.49$, $SD = 29.33$) compared to the right of the screen ($M = 126.54$, $SD = 27.95$), [$t(178) = 6.55$, $p <$ 0.001, 95% C.I. $= 6.25$, 11.64, d $= 0.49$]. Finally, 89% of the sample started their search on the left side of the screen, compared to 11% who started on the right side. There was no significant difference in finding targets on the left versus right side of the screen (egocentric score), nor was there a bias in selecting distractors with left versus right gaps (allocentric score).

Sex effects on cancellation and line bisection variables

There was a significant effect of sex on search speed [F(1, 172) $= 4.15$, $p = 0.043$, $\eta^2 =$ 0.24], whereby males had a faster search speed ($m = 144.15$) compared to females ($m = 137.71$). We also found a statistically significant difference in allocentric neglect score (non-normally distributed variable; [F(1, 173) $= 6.01$, $p = 0.015$, $\eta^2 = 0.03$] between males (unstandardized residuals; $m = 5.09$) and females ($m = -4.89$), when controlling for age. No other significant effects of sex were found on remaining variables.

Handedness effects on cancellation and line bisection variables

There were no effects of handedness on cancellation and line bisection variables.

K-Means clustering analysis

A k-means cluster analysis revealed two clusters (Figure 5(a)) of participants based on cancellation and line bisection variables. Cluster 1 ($n = 103$; mean age $= 43.87$) is characterized by participants with shorter search and line bisection durations, faster search speed, fewer intersections in search path, higher quality of search score (indicating a more efficient search) and increased rightward error in line bisection task. In contrast, Cluster 2 ($n = 76$; mean age $= 56.53$) included participants with longer search and line bisection durations, slower search speed, more intersections, lower quality of search, and more leftward error in line bisection judgments. Moreover, participants in Cluster 1 were significantly younger ($m = 43.87$, $SD =$

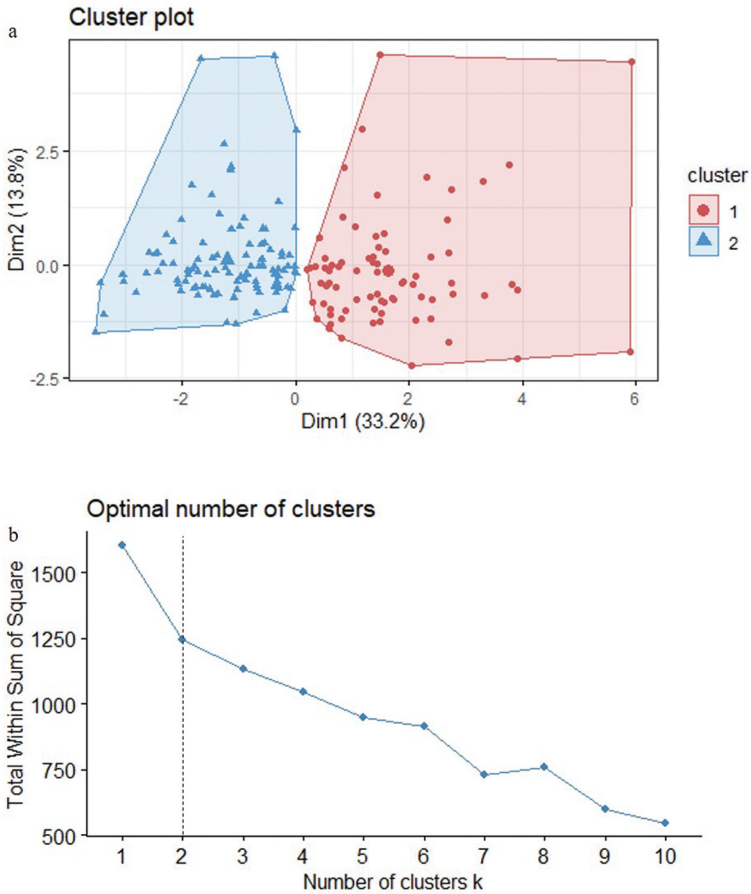

Figure 5. (a) Cluster plot representing Cluster 1 ($n = 103$) and Cluster 2 ($n = 76$) in cancellation and line bisection task performance. Dim = Dimensions. (b) Elbow method for determining the optimal number of clusters.

16.86) than those in Cluster 2 ($m = 56.63$, $SD = 17.85$), [$t(177) = -4.88$, $p < 0.001$, d = .738]. These variables all had a significant impact on cluster groups: search speed [$F(1, 177) = 163.76$, $p < 0.001$, $\eta^2 = 0.48$]; search duration [$F(1, 177) = 219.65$, $p < 0.001$, $\eta^2 = 0.55$]; intersections [$F(1, 177) = 24.69$, $p < 0.001$, $\eta^2 = 0.12$]; quality of search [$F(1, 177) = 222.68$, $p < 0.001$, $\eta^2 = 0.58$]; line bisection error [$F(1, 177) = 4.49$, $p = 0.035$, $\eta^2 = 0.03$]; line bisection duration [$F(1, 177) = 51.95$, $p < 0.001$, $\eta^2 = 0.23$]. The remaining performance variables (accuracy, errors, re-cancellations), education, sex, and handedness did not have a significant impact on cluster groupings.

Discussion

We aimed to investigate the effect of aging on the performance of computerized cancellation and line bisection tasks in far-space. We found that older age was associated with slower task processing speed, slower search speed, and poorer quality of search. Males were faster on the cancellation task compared to females. In addition, we found a leftward bias on the line bisection task akin to pseudoneglect, and increased search duration and speeds on the left side of space in the cancellation task. Finally, our cluster analysis found two age-related groups: the younger cluster had more efficient (faster, organized) searches compared to the older cluster.

Age was the primary demographic factor affecting performance on our cancellation task. This pattern of results is consistent with previous literature showing that processing speed in visual search and cancellation declines with aging (Benjamins et al., 2019; Hommel et al., 2004; Müller-Oehring et al., 2013; Potter et al., 2012; Tamura & Sato, 2020; Warren et al., 2008). Exhaustive search behavior (e.g., increased caution) could contribute to this increased processing speed in older adults (Hommel et al., 2004; Potter et al., 2012).

Older age was also associated with longer processing times in the line bisection task. There was good convergent validity between tasks: line bisection duration was positively correlated with cancellation duration, and negatively correlated with search speed and quality of search. This suggests that the time taken to complete line bisection is a predictor of performance in cancellation. This is surprising given the controversy around whether the two tasks do (Ferber & Karnath, 2001; Keller et al., 2005), or do not (Molenberghs et al., 2011) measure different aspects of attention. In future studies, it would be interesting to compare the performance of CENT in near versus far-space to see if our findings replicate in near-space.

We observed a decrease in search organization, or efficiency (i.e., slower search speed, poorer quality of search) in older adults. More specifically, quality of search began to decline significantly in those older than 60 years old. These changes could reflect a decline in processing speed, difficulties with inhibitory control when navigating around distractors to find targets (Müller-Oehring et al., 2013; Potter et al., 2012; Tamura & Sato, 2020), or fine motor skills (e.g., movement time, speed variability; Hoogendam et al., 2014; Rossit & Harvey, 2008).

More generally, omissions and re-cancellations were rare, and accuracy was high among the sample (e.g., Benjamins et al., 2019; Uttl & Pilkenton-Taylor, 2001). The sample also displayed a methodical and efficient search pattern (i.e., few intersections, quality of search score as high as 0.75), such as searching for the next nearest target following a vertical (i.e., top to bottom, moving rightward) or horizontal (i.e., left to right, moving downward) "snake pattern" search path (Ten Brink et al., 2016). Like Benjamins et al. (2019), some participants showed a relatively inefficient search (i.e., many intersections), with a mean quality of search score just 0.43. On this basis, poor search organization alone may not be sensitive to attentional changes (Benjamins et al., 2019).

Pseudoneglect was evident across the sample, irrespective of age, replicating previous studies in near (e.g., Learmonth & Papadatou-Pastou, 2021) and far-space (Stancey & Turner, 2010). However, contrary to previous studies (Fujii et al., 1995; Jewell & McCourt, 2000), we did not find an effect of age on line bisection error. It seems the role of age and pseudoneglect is still unclear and highly dependent on task factors (e.g., hand use, starting position, line placement; Brooks et al., 2016; for review see; Jewell & McCourt, 2000), none of which were manipulated here.

In a similar vein, we found novel findings of an "over-attendance" (English et al., 2021), or pseudoneglect in both line bisection and cancellation in far-space. More specifically, participants showed a leftward bias when bisecting lines and were faster finding targets on the left side of space (like English et al., 2021). One interpretation of this may be due to the dominance of the right hemisphere in visuospatial attention (e.g., inferior parietal lobe; Cona & Scarpazza, 2019; Çiçek et al., 2009). Alternatively, this leftward bias could reflect learned processes, such as Western reading systems (i.e., reading from left to right) which may impact our search organization (e.g., "reading-experience" hypothesis; Brucki & Nitrini, 2008; English et al., 2021; Ransley et al., 2018). For example, participants in a rural, illiterate Amazonian community exhibit random search patterns compared to those who had been exposed to reading and writing (Brucki & Nitrini, 2008). On the other hand, Arabic speakers show faster reaction times detecting Arabic letters presented on the right side, compared to on the left and when using English letters (Ransley et al., 2018). We found no relationship between education level and task performance. Based on this finding, our novel CENT test has potential for use across individuals with varying levels of formal education and cultures.

Contrary to previous evidence (Benjamins et al., 2019; Brucki & Nitrini, 2008; Saykin et al., 1995; Uttl & Pilkenton-Taylor, 2001), we found that males had a significantly (albeit small effect size) faster search speed compared to females (irrespective of age). Two previous studies have found similar sex differences in younger samples, whereby males were faster than females in near-space conjunctive visual search paradigms (English et al., 2021; Stoet, 2011). The authors propose this as evidence for increased hemispheric asymmetry in males (English et al., 2021), or the evolutionary hunter-gatherer theory (i.e., men's "innate" hunting behaviors predict them to be better at visual search; Eals & Silverman, 1994; Stancey & Turner, 2010; Stoet, 2011). Alternatively, a large ($n = 21{,}781$) study using a sustained attention task found faster reaction times and more commission errors (erroneous response in quick succession) in males, compared to females (Riley et al., 2016). The authors suggest that increased speed and commission errors could reflect increased impulsivity in males (though these gender effects varied between cultures). Although we did not include commission errors within our analysis and no measure of impulsivity (or indeed any personality traits), these previous findings may be helpful in explaining our sex effects in our visuospatial attention task. Nevertheless, previous studies were conducted in near-space, and so our findings could provide evidence of sex differences in search speed in far-space.

Limitations

Although we did not take a measure of experience with technology; however, we do not believe this contributed to the age-related decline in CENT performance. Age-related decline in processing speed in visual search tasks are well documented (see Introduction). We also argue that the technology used in the study (the controller) was not overly complex in that it was very similar to a television remote. Importantly, there is no evidence to suggest that poorer performance on tasks in those older than 65 years old is due to the use of novel technologies (augmented reality; Peleg-Adler et al., 2018). The assumption that less experience with technology would exclusively affect older people contributes to ageist beliefs surrounding technology use in older people and widens the digital health divide (Mace et al., 2022). Moreover, we provide the first set of age-graded normative data for our new task, though some age-groups are small (e.g., $n = 8$) and underpowered, the sample sizes are not unlike other studies (Webb et al., 2022). Finally, our study was carried out in a public setting with an unselected sample, but the average years of education was still 16 years, and all English speakers. Future studies could explore CENT performance across different education levels and cultures

Despite these limitations, we believe that the preliminary cutoffs provided here could be useful in evaluating attentional deficits (e.g., ADHD), motor or impulse control impairments (particularly re-cancellations; Benjamins et al., 2019), or potentially early onset of cognitive impairment and brain disease. Going forward, normative data for age-groups could continue to grow since CENT is open access and free to use to researchers and clinicians.

Conclusion

To the best of our knowledge, we offer novel findings that computerized visuospatial attention tasks in far-space are sensitive to aging with changes in performance beginning at 60 years of age. Our testing methods of a far-space measure of visuospatial attention could be considered to have more ecological validity compared to the ones previously tested (conducted in a laboratory environment; e.g., Brucki & Nitrini, 2008; Hommel et al., 2004; Müller-Oehring et al., 2013; Tamura & Sato, 2020; Uttl & Pilkenton-Taylor, 2001; Warren et al., 2008), since most everyday visuospatial attention tasks are indeed performed in our busy and noisy day-to-day lives just like in the current experiment. We are currently investigating if these tasks have the potential to be used with clinical populations (i.e., stroke survivors). If so, they could be useful in detecting subtle cognitive changes in older people, which could be indicative of early brain disease.

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Data availability statement

The data and analyses scripts conducted in R (version 2022.07.0 Build 548; R Core Team, 2022) are available at https://osf.io/uzdwk/. The CENT task is available at https://github.com/UEANeuroLab.

CRediT author statement

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