

Visual attention allocation induced by landmarks can advance the spatial navigation performance of older adults

Rui Bao

China Medical University

Ruibai Wang

China Medical University

Shijie Chang

China Medical University

Yunning Wang

China Medical University

Zhehui Mu

China Medical University

Jiaoyue Fang

China Medical University

Xintong Yang

China Medical University

Xuan Ouyang

China Medical University

Shuo Li

China Medical University

Yifu Guan

yfguan@cmu.edu.cn

China Medical University

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Abstract

Background: Spatial navigation ability is a crucial component of daily functioning for adults aged 55 and above. In the context of a rapidly aging society, the issue of older adults getting lost due to age-related cognitive decline has become an increasingly prominent public health concern. Maps posted in public places play a vital role in helping older adults find pathways and reach destinations with less effort. However, the effects of information presented in maps on spatial navigation remain less explored. From a public-health perspective of supporting older adults' safe mobility, this study used eye-tracking to examine whether text-labeled landmarks on public-style maps help adults aged 55 years and older allocate visual attention during route learning and make more accurate navigation decisions.

Method: The control group was presented with an ordinary map, while the experimental group viewed the same map with conspicuously labeled landmarks. Participants first completed a route-learning task to memorize a designated route and then performed a spatial navigation task in a computer-generated virtual environment. Their route-learning behavior and navigation performance were evaluated.

Result: Text-labeled landmarks attracted visual attention during map reading, strengthened route memory, and served as environmental cues to enhance navigation accuracy and mitigate the negative effects associated with aging and cognitive decline. The improved performance was attributed to visual attention allocation during decision-making at each crossroad.

Conclusion: Text-labeled landmarks on public maps may improve navigational decision accuracy among adults aged 55 years and older. As a simple, scalable information-design approach, this strategy could be applied in nursing homes, transport hubs, and other public settings to support wayfinding, reduce travel inconvenience, and promote safer everyday mobility.

1. Contributions to the Literature

- Frames wayfinding as a population-health issue: difficulty finding one's way can restrict independent mobility and community participation in later life.
- Identifies public-map design as a modifiable environmental factor, rather than placing the full burden of navigation difficulties on older individuals.
- Brings visual-attention evidence into public-health planning for age-friendly, cognitively accessible environments.
- Points to a potentially low-cost and scalable approach for nursing homes, transport systems, and community spaces, where clearer wayfinding may support safer everyday mobility.

2. Introduction

Visuospatial functioning constitutes one of the cognitive competencies essential for human survival and independent living (Garg et al., 2024). Daily activities such as visiting friends, shopping at markets, locating the places of interest (museums, libraries, bookstores, ...), and traffic exchanges (subways, airports, train stations, ...) rely strongly on visuospatial capabilities. Previous research revealed that visuospatial capabilities decline with aging and cognitive dysfunction such as MCI and AD (Coutrot et al., 2022; Mendez-Lopez et al., 2020; Van Gerven et al., 2012). When navigating in reality, these adults could encounter multiple challenges caused by poor memories, ineffective attention allocation to navigation-relevant information, slow response to environmental visual cues, and impaired capability of route recognition (Meng et al., 2019). These difficulties can lead directly to the increased risks of getting lost, becoming anxiety and tumbling incidents even in familiar environments, and ultimately to the decreased quality of their life.

In the context of rapidly aging worldwide, the proportion of adults aged 55 and over is rising significantly (Gianfredi et al., 2025), bringing with it an increased prevalence of cognitive decline and impairment (Pais et al., 2020). This trend places a substantial economic burden on families, healthcare systems, and societies at large. Among these age-related cognitive challenges, visuospatial impairment—characterized by declines in spatial perception and navigation (Bao et al., 2025)—is particularly common yet frequently overlooked in the aged population. It severely compromises independence, safety, and quality of their life (Klencklen et al., 2012; Muffato et al., 2022), making it a pressing public health concern that demands greater societal and research attention. Low-cost modifications to widely used public maps may therefore represent a population-level environmental strategy to support older adults' independent mobility.

Two-dimensional maps posted in public places serve as one of the most common and fundamental means for helping people to locate their positions, find destinations and plan their routes of convenience. In general, these maps are planar geometric drawings of many lines representing streets, buildings, landscapes and other types of environmental objects. These highly abstract lines fail usually to represent the true external features of the original objects. Such maps, thus, could create attention dispersing and confusing, resulting in poor navigation behavior for map-readers, in particular for those who are experiencing visual attention deficits and visuospatial capability impairment (Richter & Winter, 2014; Yu & Chattopadhyay, 2020). In order to assist the older adults to focus their attention more effectively on the information in maps and to utilize the information as environmental cues during spatial navigation, it has been proposed to incorporate prominently text-labeled landmarks in maps.

In this study, we examined whether intentionally text-labeled landmarks on maps can attract older adults' visual attention during route learning and serve as useful environmental cues to support subsequent navigation. Eye-tracking metrics were used to quantify attention allocation during route-learning and navigation. Results showed that text-labeled landmarks attracted visual attention and supported landmark use as navigational cues for correct decisions, thereby improving navigation performance in older adults. These findings highlight the public-health relevance of improving text labeling and map design to assist wayfinding in aging populations, including individuals with lower cognitive scores.

3. Methods

3.1 Participants

All participants were voluntarily recruited via advertisements and given informed consent. They were assessed with the Chinese version of the Montreal Cognitive Assessment (MoCA) prior to recruitment (Hobson, 2015). The final participants included 78 adults aged 55 and above living in community-dwelling and retirement homes. All participants reported no color blindness, no history of neurological or psychiatric problems, and no consumption of alcohol or recreational drugs in 24 hours prior to experiments. All participants were fully capable of communicating, walking, and managing their daily activities without assistance. Participants were grouped based on the frequency matching results of minimized differences in gender, age and MoCA scores.

The study adhered to the principles of the Declaration of Helsinki and has been evaluated and accepted by The Research Ethics Committee of China Medical University (No. 202373). All participants have read the information letter, and signed the informed consent prior. All participants were verbally informed about the overall purpose of this experiment and agreed to participate.

3.2 Experimental Procedure

This study used a custom-developed virtual space navigation program. The application was built in Unity Editor 2022.3.17f1c1, integrated with Tobii Pro SDK 5.0.0.3 (for eye tracking), and program running script was written in C# language. Data processing was implemented via Python scripts written in PyCharm Community Edition 2025. The experiment was run on computers equipped with Tobii Spectrum 4C eye trackers. The interface featured large fonts and high contrast ratios, with interaction simplified with mouse operations or four keyboard keys to accommodate older adults' needs.

Participants were required to seat in front of the apparatus with a 600 mm distance between participants' eyes and the monitor. They were asked to put their chin on the chin-rest and to remain their heads stable during the entire experiment. Prior to test, the eye-tracker was calibrated for each participant with the program provided by Tobii 4C manufacture.

This experiment consists of two tasks: route-learning task and spatial navigation task. During the route-learning phase, participants were presented with a cartographic map showing the layout of streets and buildings (Figs. 1(a1) and (a2)). A red line with labeled "start" and "end" at two ends is the stipulated route that participants need to follow during their navigation in virtual space. For convenience of data analysis, street intersections (also referred to as decision-making points) on the red line are marked with capitals A – F (Fig. 1(a1)). These capitals are invisible to participants during route-learning and spatial navigation. Three distinct landmarks were set near three intersections: a fountain (Fig. 1(c1)) at the upper-right corner of point A, an advertising board (Fig. 1(c2)) at the upper-right corner of point C, and a school bus station (Fig. 1(c3)) at the upper-right corner of point F. The control group was given an ordinary map (Fig. 1(a1)) and the experimental group was given the same map but with prominently

labeled texts (red color) on landmarks (Fig. 1(a2)). After route-learning, participants were required to “walk” in a computer-generated virtual space following the route encoded in their memories. Their navigation trails were recorded.

3.3 Eye-Tracking and Behavioral Data

Parameters used for evaluating the route-learning task include the total route-learning time, total number of gaze points on landmarks, total fixation duration on landmarks, total gaze points on decision-making points, and total fixation duration on decision-making points. Parameters for characterizing the navigation performance include the navigation completion time, navigation decision accuracy rate, the first error decision point (the position at which participants made their first incorrect decision), total decision-making time.

3.4 Data Processing

The D'Agostino and Pearson test (D'Agostino and Pearson, 1973) and Shapiro-Wilk test (Royston, 1992) were employed to assess data normality. For non-Gaussian distributed datasets, the Mann-Whitney U test (McKnight and Najab, 2010) was applied to examine intergroup differences, reporting medians with 25th–75th percentiles. Spearman correlation coefficients were computed to calculate correlation matrices within the two groups (Ali Abd, 2022). Participant group matching effectiveness was verified using the chi-square test (McHugh, 2013) and the Mann-Whitney U test. All statistical analyses were performed using GraphPad Prism software (version 10.1.2) and $p < 0.05$ was deemed statistically significant differences.

4. Results

4.1 Demographic Data and Cognitive Assessment Score

Table 1 summarizes the demographic data, MoCA scores, and navigation performance parameters of all participants. MoCA scores were used to evaluate participants' general cognitive status. The frequency matching was utilized during grouping to ensure that differences between the control and experimental groups were minimized in gender ($\chi^2=0.0051$, $df = 1$, $p = 0.943$), age ($U = 751$, $p = 0.931$, $r = 0.0118$), and MoCA scores ($U = 753.5$, $p = 0.950$, $r=-0.0074$).

Table 1
Demographic data, MoCA scores and navigation performance of participants

Characteristics	Ctrl. (n = 40)	Exp. (n = 38)	U/ χ^2	p-Value
	Median (Q1, Q3) or n (%)	Median (Q1, Q3) or n (%)		
Gender			0.0051	0.943
Male	14	13		
Female	26	25		
Age (years)	77.5 (62.3, 84.8)	75.5 (61.8, 85.0)	751	0.931
55–65	13	12		
66–75	6	7		
76–85	13	10		
> 85	8	9		
MoCA score	24 (22, 27)	24 (22, 27)	753.5	0.950
RLT (s)	59.1 (46.0, 122.1)	75.6 (50.4, 142.2.0)	623	0.173
NDAR (%)	75 (33, 100)	100 (75, 100)	569.5	0.020*
TDT (s)	10.42 (4.08, 33.41)	14.48 (3.60, 38.15)	739	0.839
NCT (s)	77.32 (56.44, 136.6)	85.58 (59.63, 122.8)	755	0.817
U=Mann-Whitney U Test; χ^2 =Chi-square test. RLT: route-learning time; NDAR: navigation decision-making accuracy rate; TDT: total decision-making time; NCT: navigation complete time. *p < 0.05				

4.2 Performance of Route-learning Task

As shown in Fig. 2a, the experimental group made more gaze points on landmarks (Median = 166.5, IQR = 257) than the control group (Median = 78.5, IQR = 144.5) with statistically significant difference (U = 581.5, p = 0.037, r=-0.2020). Similarly, the experimental group showed a longer total fixation duration on landmarks (Median = 2.94 s, IQR = 4.45) than the control group (Median = 1.46 s, IQR = 4.26); this difference approached but did not reach statistical significance (U = 623, p = 0.086, r=-0.1551) (Fig. 2b). Consequently, the experimental group used a longer time (Median = 75.6 s, IQR = 91.8) to complete the route-learning process than the control group (Median = 59.1 s, IQR = 76.1) (U = 623, p = 0.173, r=-0.1551) (Fig. 2e). These results strongly suggest that the text-labeled landmarks in the map indeed attracted more visual attention as visual stimuli of older adults. However, neither the total number of gaze points nor the total fixation duration on decision-making points showed a slight difference without significant difference (Figs. 2c and 2d).

4.3 Performance of Spatial Navigation

Table 1 shows that the experimental group completed the spatial navigation task (Median = 85.58 s, IQR = 63.17) slightly slower than the control group (Median = 77.32 s, IQR = 80.16) ($U = 755$, $p = 0.817$, $r = -0.0057$). The experimental group also took a longer time (Median = 14.48 s, IQR = 34.55) than the control group (Median = 10.42 s, IQR = 29.33) ($U = 739$, $p = 0.839$, $r = -0.0238$) to make decisions.

These two groups demonstrated differences in navigation decision accuracy rate: experimental group (Median = 100, IQR = 25) versus the control group (Median = 75, IQR = 67) ($U = 569.5$, $p = 0.020$, $r = -0.2156$) (Fig. 3c). This comparison indicates that the control group had a lower capability of making correct decisions at crossroads, being more prone to errors. Figure 3d shows that more participants in the control group made their first wrong decision than the experimental group at crossroads except D and F. These results provide primary evidence to support our hypothesis that landmarks with conspicuously labeled texts can enhance the spatial navigation performance of the older population.

4.4 Fixations on Landmarks and Decision-making Points

To understand how these landmarks influence decision-makings, we further analyzed their fixation distribution patterns. Their fixation durations were classified into five specific types based on the duration lengths. Unconscious Fixation (UF, $0 < t \leq 150$ ms): it is an unconscious state resembling the transient pauses between saccades or aimless observation that does not yield a concrete impression conducive to learning; Ambient Fixation (AF, $150 \text{ ms} < t \leq 300$ ms): it establishes initial visual impressions of environmental information, initiating discrimination of multiple elements in the surroundings; Focal Fixation (FF, $300 \text{ ms} < t \leq 500$ ms): following the ambient fixation, participants concentrate their visual attention to acquire detailed information of the objects of interest; Decision-making Fixation (DF, $500 \text{ ms} < t \leq 1000$ ms): participants make their decisions when gazing the objects, demonstrating strong positive responses; Confused Fixation (CF, $1000 \text{ ms} < t$): it involves excessively prolonged eye-catching period, which might indicate confusion and diverted attention.

When exposed to visual stimuli, participants transitioned from unconscious observation to purposeful responses, progressively escalating attention allocation patterns. The left two columns of Figure S1 illustrate the fixation behaviors of participants on landmarks in virtual space. The experimental group exhibited more total fixations on landmarks (Median = 12, IQR = 11) than the control group (Median = 10.5, IQR = 10.5). Similarly, the experimental group also spent longer time on landmarks (Median = 4.13 s, IQR = 6.10) than the control group (Median = 3.61 s, IQR = 3.90) (Figure S1a).

The experimental group demonstrated a significantly higher ambient fixations (Median = 4, IQR = 4.25) on 3D landmarks compared to the control group (Median = 3, IQR = 2.75), with statistical significance ($U = 539.7$, $p = 0.026$, $r = -0.2494$). Additionally, the experimental group showed more decision-making fixations (Median = 2, IQR = 2.5) on landmarks than the control group (Median = 1, IQR = 1.75), and demonstrating a statistical significance ($U = 514.5$, $p = 0.0173$, $r = -0.2779$). However, the observed differences between the two groups in unconscious fixations, focus fixations, and confused fixations did not reach statistical significance.

The right two columns of Figure S1 show the fixation behaviors of participants on decision-making points in 3D virtual space. The total number of fixations at decision-making points of the experimental group (Median = 13, IQR = 9.25) showed a smaller margin from the control group (Median = 11, IQR = 9) ($U = 594.5$, $p = 0.3565$, $r = -0.1873$) (Figure S1a, third column). Similarly, the total fixation duration at decision-making points also varied slightly ($U = 600.5$, $p = 0.1901$, $r = -0.1169$) between of the experimental group (Median = 4.08 s, IQR = 6.17) and the control group (Median = 3.80 s, IQR = 3.79) (Figure S1a, fourth column).

The number of ambient fixations at decision-making points of the experimental group (Median = 5, IQR = 5.25) was higher than in the control group (Median = 3, IQR = 3) ($U = 444.5$, $p = 0.0096$, $r = -0.3571$). Similarly, the number of focus fixations at decision-making points in the experimental group (Median = 3, IQR = 3.25) was also higher than that in the control group (Median = 2, IQR = 2) ($U = 494$, $p = 0.0404$, $r = -0.3011$). The difference in decision-making fixations at decision-making points between the control group (Median = 1, IQR = 3.75) and experiment group (Median = 2, IQR = 4) closely approached, yet ultimately did not reach, the conventional threshold for statistical significance ($U = 583.5$, $p = 0.1058$, $r = -0.1998$). No significant differences were observed in unconscious or confused fixations.

The fixation distribution on the landmarks (Fig. 4a) reveals how these two groups allocate their visual attention. Without conspicuous text-labels, the control group spend larger portion of attention (36.36%) on landmarks with the unconscious fixation in comparison with the experimental group (25.00%) (Fig. 4a), whereas the experimental group showed significantly higher proportions of environmental (33.33% vs. 27.27%) and decisional fixations (16.67% vs. 9.09%) on landmarks than the control group.

The proportions of focal fixation (16.67% vs. 18.18%) and confused fixation showed little difference (8.33% vs. 9.09%). The fixation distribution of participants on the decision-making points exhibits a similar pattern (Fig. 4b). The most significant differences were the increased proportions of the environmental fixation (39.06% vs. 33.33%) and decisional fixations (15.63% vs. 11.11%) of the experimental group. All these data indicate clearly that the conspicuous text-labels has effectively captured participants' attention, making them focus more efficiently on information from the surrounding environment when making decisions.

4.5 Correlation-Matrice Analysis within Groups

As shown, the navigation decision-making accuracy rate (NDAR) of the control group has a positive correlation with MoCA scores (Fig. 5a) and a negative correlation with age (Fig. 5b), which are consistent with the known facts that the higher the MoCA scores, the better the visuospatial function, as well as that the younger the age, the better the visuospatial function. In contrast, such correlations are virtually absent in the experimental group. These results suggested that the older adults and cognitive-dysfunctional participants can use the landmarks in virtual space as experimental cues to navigate accurately, becoming independence of the age and cognitive status. Moreover, the number of fixations on landmarks during route-learning of the experimental group is positively correlated with total decision-making time during spatial navigation (Fig. 5c), suggesting that when making decisions at crossroads,

the experimental group seemed to recall their memories for confirming the correctness. To gain a comprehensive overview of the association patterns among all parameters, we constructed correlation matrices using Spearman correlation analysis including demographic data, eye movements, route-learning and navigation behavioral data (Figure S2). For example, the negative correlation ($r = -0.492$) between NDAR and age just mentioned above is the red element at the intersection of first column and third row with an asterisk (*) symbolizing the statistical significance (Figure S2a).

Comparison between these two matrices revealed the effects of the text-labeled landmarks. For example, in the control group (Figure S2a), elements in the first column indicate that the total number of fixations on landmarks (Figure S2a, line 13), the total number of fixations at decision-making points (Figure S2a, line 19), and several other fixation behaviors showed significant negative correlations with age. However, in the experimental group (Figure S2b), these negative correlations with age became less significant and even disappeared. Furthermore, while a significant positive correlation was observed between route-learning time and MoCA score in the control group, this association did not reach statistical significance in the experimental group. By comparing these differences of intra-group correlations between two groups, the role of landmarks can be further elucidated.

5. Discussion

Spatial navigation is a relatively complex process involving multiple sub-phases: recalling the route information from their memory, correlating the observed tangible entities in a 3D space with the information on the map, determining constantly their own relative positions in space, searching environmental cues at each decision-making point to ensure the decision correctness, and so on (Bao et al., 2025). In the case of being lost, navigators have to re-calibrate their locations and replan their alternative routes to the destination. The older and MCI individuals encounter inevitably navigation-relevant difficulties in daily activities (Gazova et al., 2012; Plácido et al., 2022). To reduce their cognitive burden, labeling landmarks prominently on maps had been proposed to be a helpful means since the text-labeled landmarks on the maps could stimulate their visual attention for deeper memories, and consequently, be used as environmental cues to improve their position determination and decision making during spatial navigation. This issue is particularly important in any emergence events such as fire safety evacuation at public places.

5.1 Landmarks improve the navigation performance

As shown in Fig. 5, the navigation decision accuracy rate of control group exhibited a negative correlation with age and a positive correlation with MoCA scores. These results are in a good agreement with the well-known fact that spatial navigation performance is affected adversely by aging (Alexander et al., 2012; Muffato et al., 2020; Schulz et al., 2022; Zhang et al., 2023) as well as by the declined visuospatial capabilities (Coughlan et al., 2018; Gonzales et al., 2022; Schulz et al., 2022). However, these correlations disappeared in the experimental group: the navigation decision accuracy rate is no longer sensitive to MoCA score and age (Figures 6a and 6b). The number of the first-error decisions

has also been reduced (Fig. 3d). Furthermore, the results showed that the more they directed attention to the text-labeled landmarks in the map during the route-learning task, the more they allocated attention to these landmarks in space during navigation (Fig. 2). These results indicate that the text-labeled landmarks indeed attracted visual attention of aged participants when memorizing the stipulated route and have been used as the guiding cues to make correct decisions during spatial navigation.

In a previous study, distinctive landmarks in 2D map have been identified to aid younger individuals' spatial navigation (Kapaj et al., 2024). In comparison, Kaneko et al. found that older adults exhibited longer reaction times when processing 2D visual information (Kaneko et al., 2021). Muffato et al. further demonstrated that map-learning ability declined with age, and older adults experienced greater difficulty on recalling landmarks in memories (Muffato et al., 2022). Head and Isom confirmed that older adults have difficulty on determining landmark locations and directional information during path learning, and struggle to recall landmarks and fail to recognize environmental cues during navigation (Head & Isom, 2010). Collectively, these findings suggested that older adults did not use the landmark information effectively and might need additional visual aids. Scialfa et al. proposed that adding text-labels to landmarks could enhance their comprehensibility for older adults (Scialfa et al., 2008).

The layouts of streets and buildings drawn in simple lines on maps do not exhibit distinctive features of landmarks, and are probably not attractive enough to draw attention of map-readers and to leave deep impressions in their memories. The data showed that reading such maps are more challenging for older adults since there was no direct correlation between total decision-making time and total 2D map landmark fixations in this study (Figure S1a). In contrast, the experimental group showed that text-labeled landmarks successfully attracted their attention to landmarks which were utilized as guiding cues for their navigations. These two groups in this study were matched on age, gender and cognitive ability (Table 1), hence, the conclusions could be most likely generalized to the majority of aged population.

5.2 Landmarks optimize the visual attentional allocation

In previous studies, Staub and Benatar employed fixation duration as a metric to study the reading process and found that the distribution of fixation durations may reflect functionally distinct processes (Staub & Benatar, 2013). Škvareková et al. and Tsitsi et al. also utilized the fixation duration to evaluate the workload of pilots and to diagnose Parkinson's disease (Škvareková et al., 2020; Tsitsi et al., 2021). Further experiments, however, showed that fixation duration as a sole indicator was not sufficient enough to describe the visual attention changes adequately during the navigation process. Velichkovsky et al. categorized fixations into two distinct phases based on duration length. The first phase (150 ms-250 ms) is primarily influenced by spatial density and layout, and the second phase (> 500ms) is governed by decision complexity (Velichkovsky et al., 2002). Negi and Mitra provided a summary of the literature on fixation duration classification in their study, referring them to as ambient and focal fixations, and further revealed that fixations exceeding 1000 ms impacted learning negatively (Negi & Mitra, 2020).

Considering that fixation is a continuous process, we classified fixations into five distinct categories based on the duration length, each representing a different underlying cognitive mechanism. When comparing results, we observed an apparently different visual attention distribution between these two groups. The control group had 27.27% of ambient fixation and 9.09% of decision-making fixation on the landmarks. In contrast, the experimental group demonstrated a higher proportion of ambient fixation (33.33%) and decision-making fixation (16.67%) during their spatial navigation (Fig. 4a). The visual attention allocation suggests that the experimental group concentrates more attention during ambient fixation, most likely looking for the memorized landmarks from surroundings and assessing the correctness before making decisions.

At decision points, the experimental group had significantly higher proportions of both ambient fixation and focus fixation, indicating a greater attention to environmental cues. Correlation analyses revealed that older adults paid more attention to text-labeled landmarks on maps and took longer time to make navigation decision, reflecting the cognitive process of linking 2D information to spatial navigation choices. During spatial navigation, these environmental cues triggered actively the retrieval of the route in their memories (Newman & McNamara, 2022). Overall, enhanced navigation performance stemmed primarily from more efficient attentional deployment (Fig. 4).

Contemporary spatial cognition theory proposes two principal navigation frameworks: egocentric (using the navigators themselves as the reference frame and relying on route-based sequential information) and allocentric (using one designated environmental location as a reference point to calculate the navigator's relative position to this point) (Vijayabaskaran & Cheng, 2022). Previous studies have shown that older adults prefer the egocentric strategy over the allocentric strategy (Bao et al., 2025; Fricke & Bock, 2018; Rodgers et al., 2012) since the allocentric navigation function becomes usually deteriorated earlier than the egocentric one. It is worth noting that the proportional distribution of fixation types changed notably (Fig. 4b). The experimental group showed a higher proportion of ambient fixations (39.06% vs 33.33%), seeming that they allocated more attention to the surroundings for environmental cues during the decision-making process. Since allocentric navigation poses greater challenges for older adults (Bécu et al., 2023), it is difficult to alter established strategies even after attending to landmark indications.

The distinct fixation patterns at decision-making points (Figures S1 and 4) also provided evidence that the experimental group utilized landmarks as effective environmental cues to support their decisions during navigation, without altering their fundamental navigation strategy. Indeed, Xia et al. have indicated that environmental cues can serve as navigational aids (Xia et al., 2008), and Qiu et al. specifically designed a landmark-based assisted navigation system (Qiu et al., 2024). Their work lends support to the reliability of our perspective. Analogous to how they attended to the landmarks themselves, text-labeled landmark on 2D map altered participants' attentional allocation when making decisions during navigation. This enabled them to more efficiently sense critical environmental information, allowing them to maintain their route-following strategy while simultaneously using landmarks to verify navigational choices. Our findings demonstrate that this approach offers a more intuitive and precise assessment of participants' attention allocation.

5.3 The limitations of the research and future prospects

Our results indicate that prominently text-labeled landmarks optimized visual attentional allocation in older adults, and enabled them to more effectively utilize the spatial information during spatial navigation. When applying such approaches to the maps posted in nursing homes, supermarkets, public libraries, et al., it could be very helpful for older adults to find their ways and destinations with a minimal effort.

The further study should be improved in two aspects. First, expanding the number of eligible participants would help to achieve greater statistical power and more reliable results. Secondly, our conclusions were drawn solely from eye-tracking metrics. Therefore, incorporating direct behavioral measures of landmark recognition and utilizing neuroimaging or EEG techniques to uncover the underlying neural mechanisms of the visuospatial capability is highly expected (Luo et al., 2025). Such multi-modal approaches would allow us to analyze changes in cognitive states at the brain level induced by landmarks, thereby further elucidating the underlying mechanism role of landmarks in 2D planar maps and 3D steric space.

6. Conclusions

This study used eye-tracking to examine how text-labeled landmarks on planar maps affect spatial navigation in adults aged 55 years and older. Text labels helped participants allocate attention to landmarks, which may strengthen environmental memory and improve decision-making accuracy during navigation. The findings also suggest that such map cues can weaken the negative association of older age and lower MoCA scores with navigational decision accuracy. From a public-health perspective, improving landmark text labeling on maps used in nursing homes, transport hubs, and other public places offers a simple, scalable approach to support wayfinding and safer everyday mobility in aging populations.

Declarations

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Conflict of Interest Statement:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethics approval and consent to participate:

This study adhered to the principles of the Declaration of Helsinki and was reviewed and approved by the Research Ethics Committee of China Medical University (Approval No. 202373). All participants were

provided with written information about the study, including its content and objectives, prior to participation. After reading the information sheet, all individuals voluntarily signed an informed consent form before being enrolled in the study.

Consent for publication:

Not applicable.

Availability of data and materials:

The datasets and accompanying documentation generated and analysed during the current study are publicly available on the Open Science Framework (OSF) repository at https://osf.io/fa4d5/overview?view_only=0b67330d55c748838c646612ac7e73df.

Author Contributions:

Rui Bao: Manuscript drafting, experimental design, software preparation, data collection and data analysis

Ruibai Wang: Experimental design, data collection and data analysis

Shijie Chang: Reviewing & editing manuscript

Yunning Wang: Data collection and data analysis

Zhehui Mu: Data collection and data analysis

Jiaoyue Fang: Data collection and data analysis

Xintong Yang: Data collection and data analysis

Xuan Ouyang: Data collection and data analysis

Shuo Li: Reviewing & editing manuscript

Yifu Guan: Project initiation and project supervision, manuscript drafting

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Figures

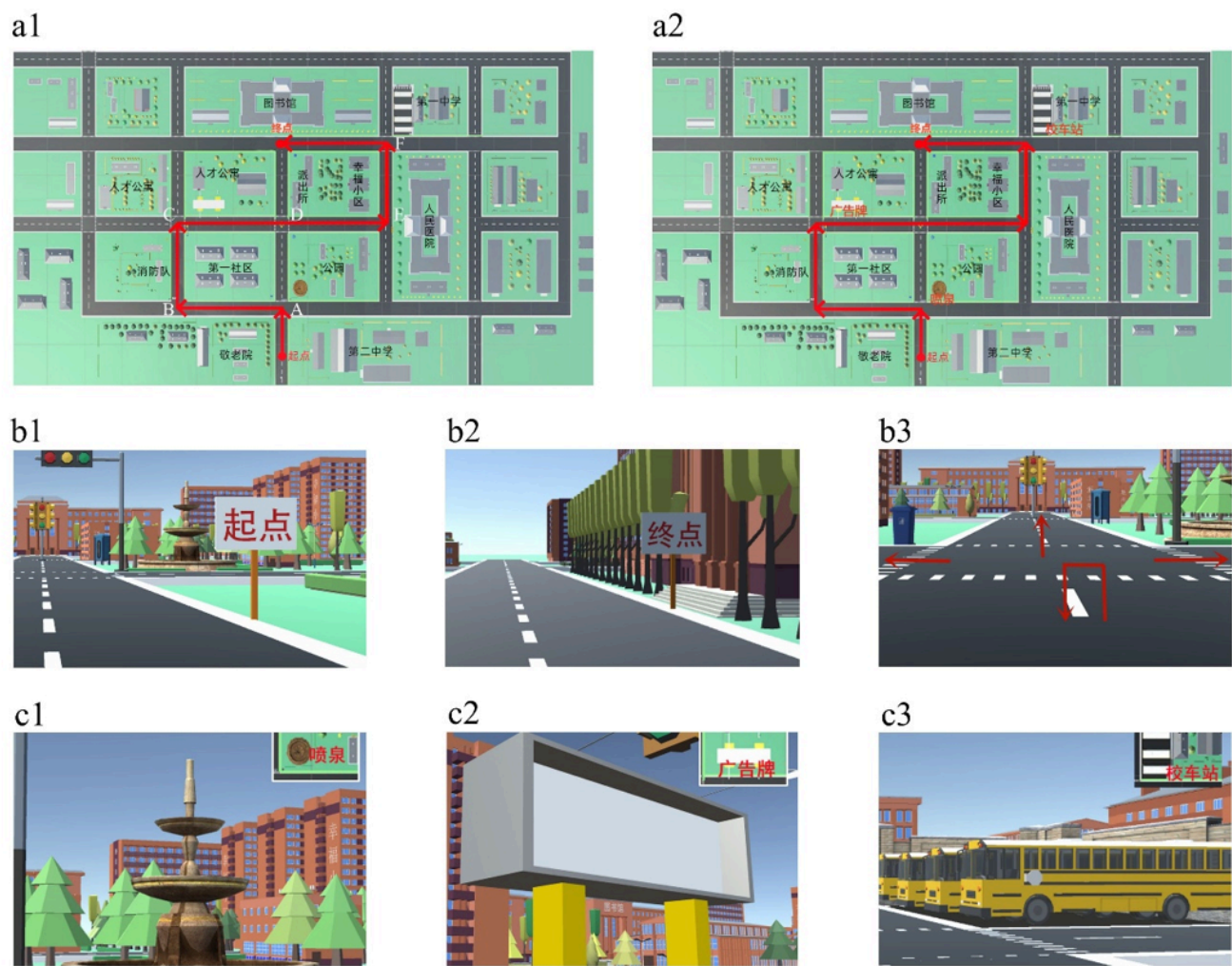


Figure 1

Route learning two-dimensional map for control group (a1) and for experimental group (a2). The red line marked with “start” and “end” at two ends is the stipulated route to be memorized and should be followed during spatial navigation.

b1-b3. Screenshots of “start” point, “end” point and intersection in virtual space.

c1-c3. Three landmarks of fountain, billboard and school bus station.

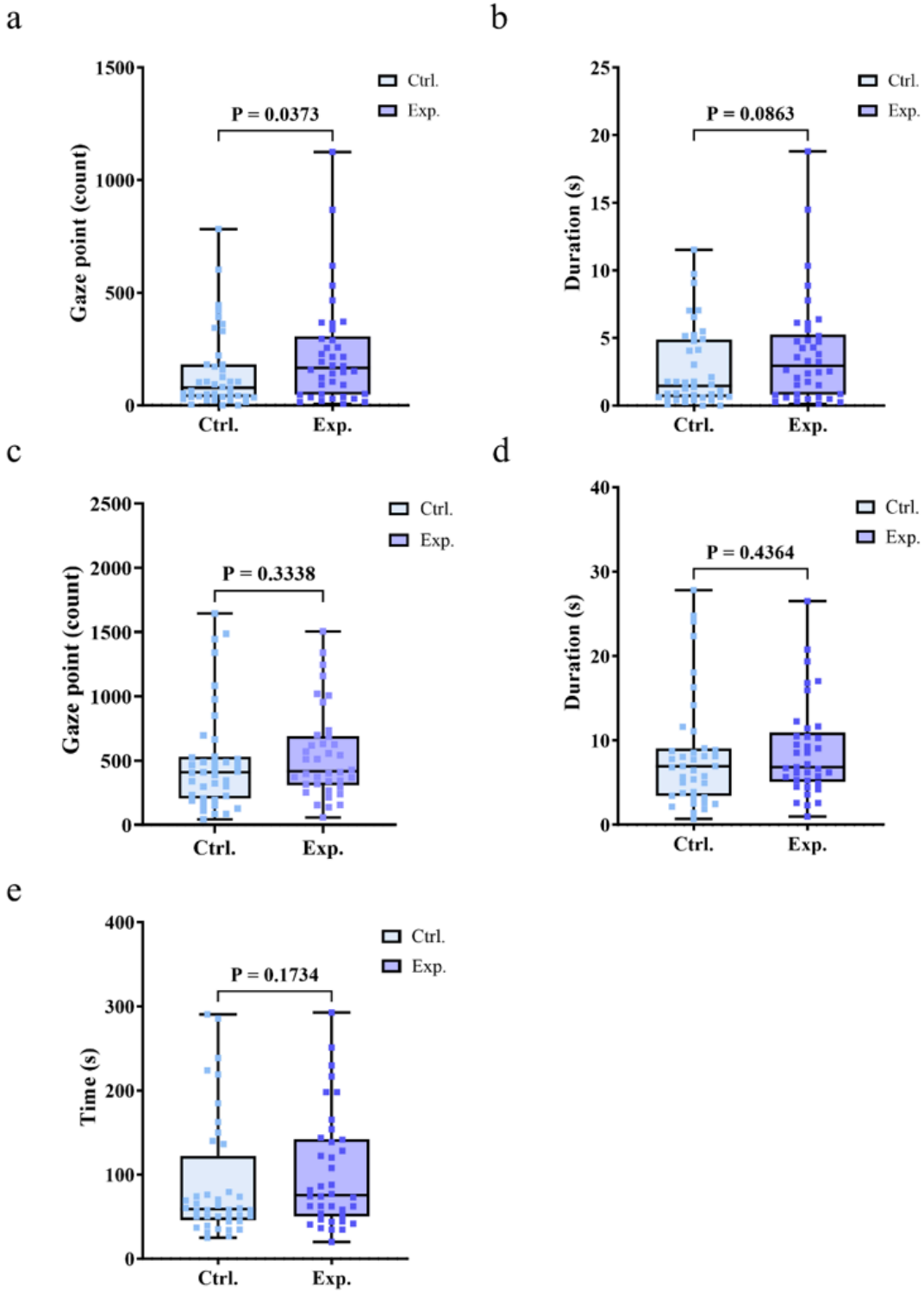


Figure 2

Route-learning performance. a: Map gaze points on landmarks (MGPL); b: Map gaze duration on landmarks (MGDL); c: Map gaze points on decision-making points (MGPP); d: Map gaze duration on decision-making points (MGDP). e: Route-learning time (RLT).

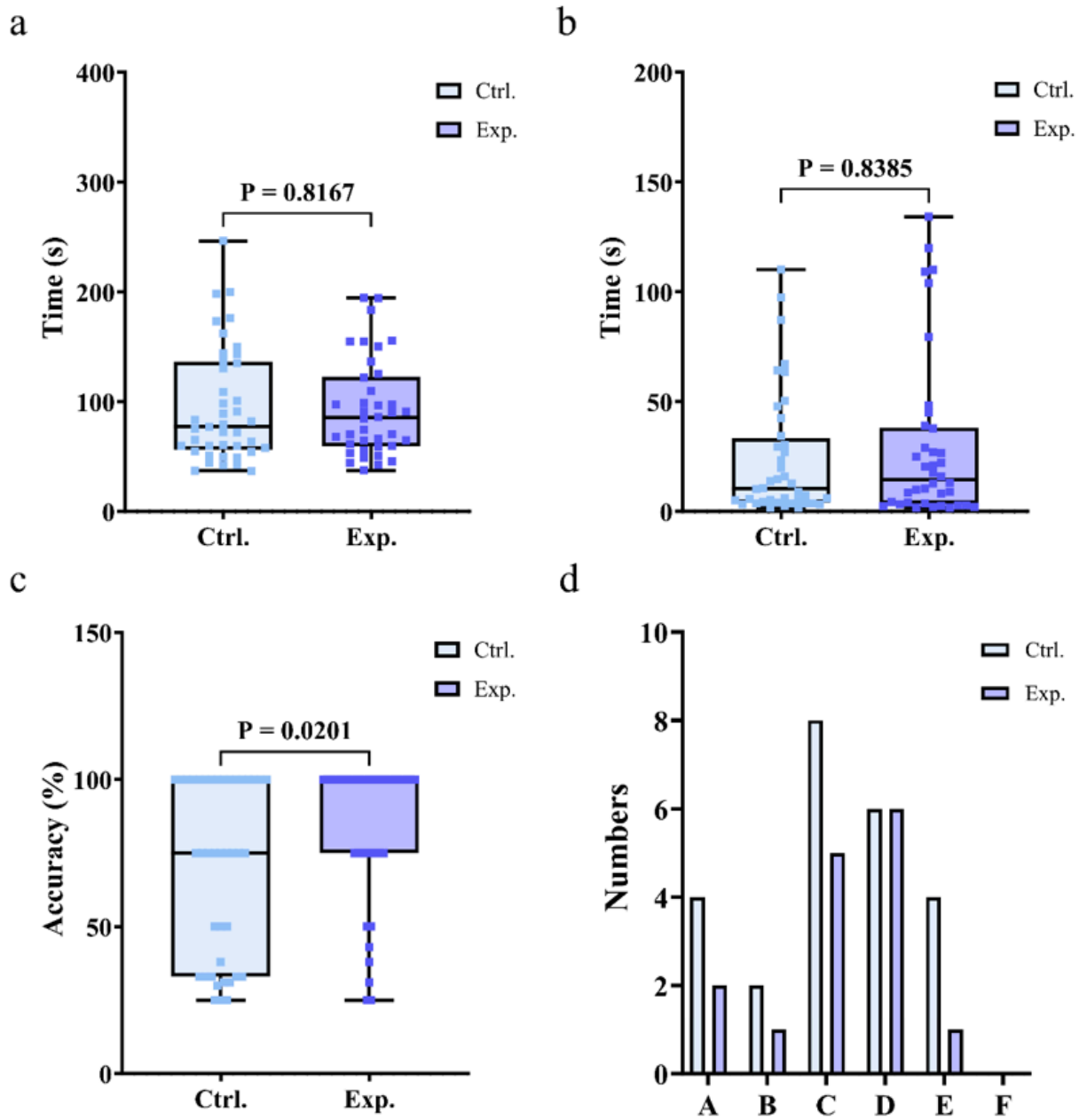


Figure 3

Navigation performance in 3D virtual space. a: navigation completion time (NCT); b: total decision-making time (TDT); c: navigation decision accuracy rate (NDAR); d: Numbers of participants making their first incorrect decisions at each intersection.

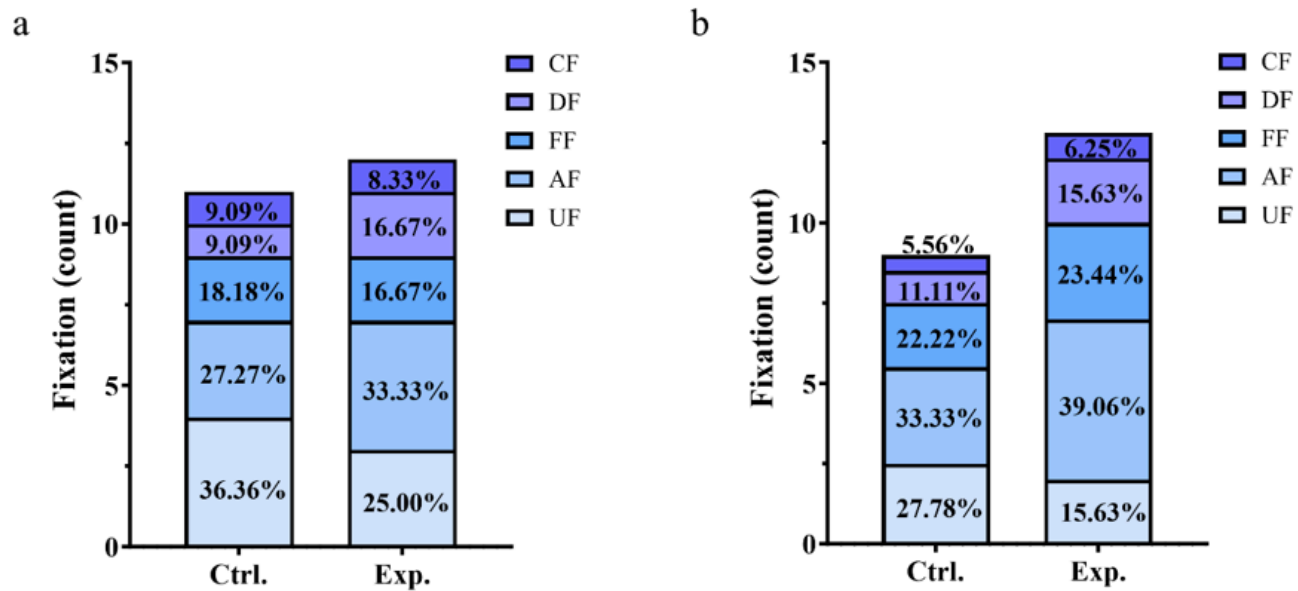


Figure 4

Fixation point distribution of participants on landmarks (a) and on decision-making points (b) during spatial navigation.

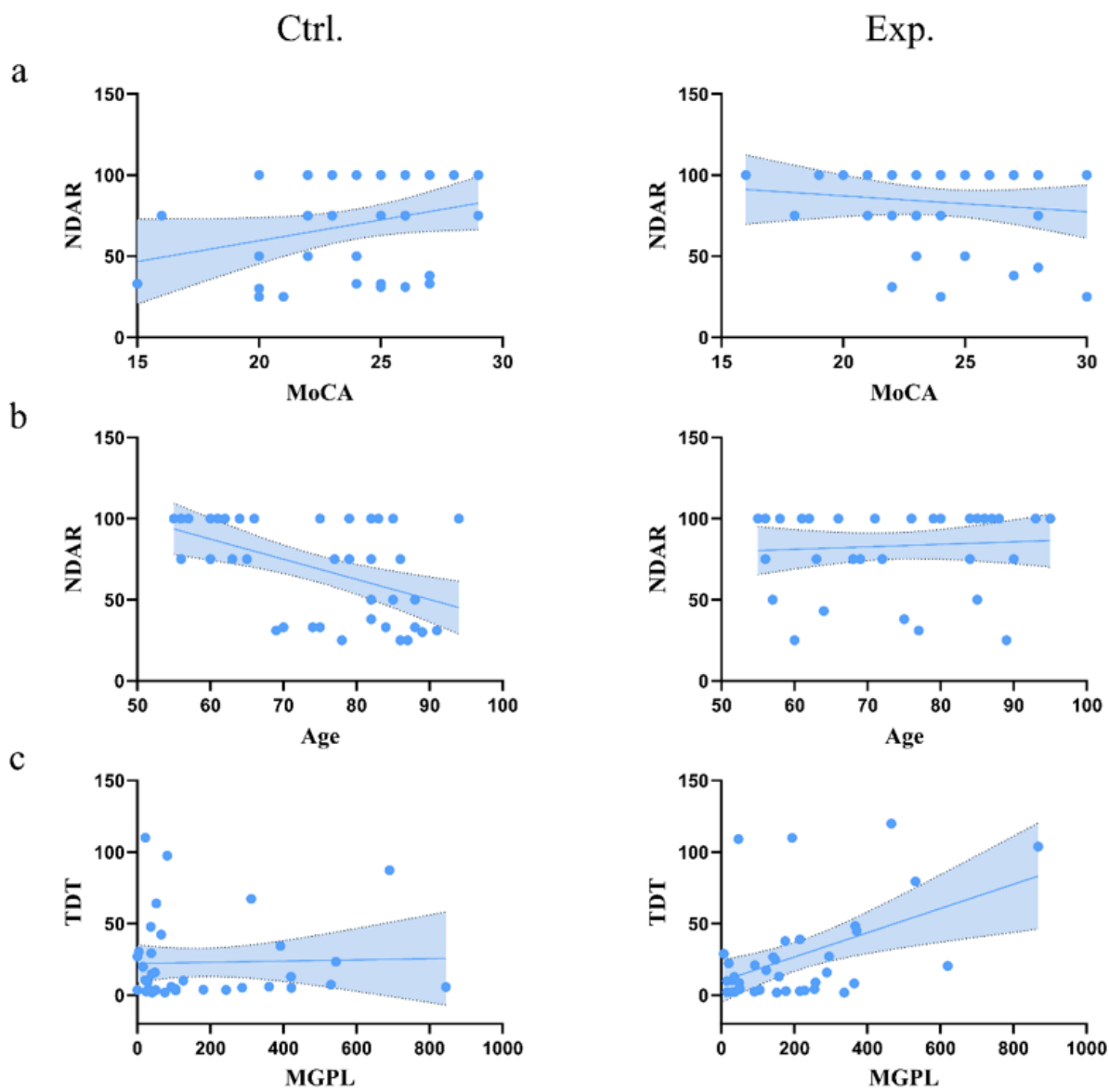


Figure 5

Correlations between spatial navigation behaviors and MoCA scores, age, and attentional measures.

a: Navigation decision-making accuracy rate versus MoCA score;

b: Navigation decision-making accuracy rate versus age;

c: Total decision-making time during spatial navigation task versus map gaze points on landmarks during route-learning task.

Supplementary Files

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- [SupplementaryMaterials.docx](#)