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Age-Related Navigation Impairment in Virtual Reality Path Integration Task: A Feasibility and Effectiveness Study.

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Abstract

Background: The senescence of brain neural mechanisms caused by aging has effects on the decline of human spatial navigation ability. Although a large number of studies have demonstrated that aging can cause impairment of old adults' spatial navigation performance when using allocentric navigation strategies, and also the impairment of older adults ' performance in choosing and switching between navigation strategies, however, there is little research on the basic mechanism of old adults when using egocentric navigation strategy. In this study, we aimed to test the effectiveness of path integration tasks in the study of older adults' spatial navigation performance when using egocentric navigation strategies under an immersive virtual reality paradigm. Methods: Facing the current situation of global Alzheimer's disease, combined with virtual reality technology, 42 volunteers with an average age of 74.5 years old were tested in four different situations. The experimental results have a certain reference nature. Results: The subjects are separated by age and gender. To explore the factors that influence the result of Path integration experiment, one-way ANOVA and General liner Model of Univariate Anova is used to assess the Demographic differences between age and gender. The conclusion of this research is that age would influence people's result of task. Among the aged, older people have worse navigation ability than the younger people. Besides, gender would not influence the result of path integration task. Conclusions: This study demonstrated that path integration task under virtual reality environment has optional value in evaluating spatial navigation ability when old adults are using egocentric navigation strategies.

Keywords

Brain Neural Mechanisms; Virtual Reality Path; Age-Related Navigation Impairment.

1. Introduction

Most nerve cells in the human brain do not have the ability of growth, brain cells will die and cause atrophy of brain as aging. Studies have shown that the gradual decline of the brain with aging can lead to the degradation of memory, learning, motor coordination, attention, decision-making other skills (Denise Park et al., 2001; Alexander et al., 2012; Levin et al., 2014). And the risk of cognitive impairment and dementia may be related to the development of brain atrophy in aging (Jack et al.,

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2005). As an advanced cognitive ability, spatial navigation relies on the integration of a number of different basic cognitive processes, such as spatial orientation, vision and proprioception, and the updating of environmental representations (Wolbers et al. , 2010). At the same time spatial memory and path integration also play important parts in it. (; Gazova I et al. , 2013). Complexity can also be reflected in the fact that space navigation involves a wide range of brain activities. In terms of the whole brain, the navigation network involves the occipital, parietal, temporal and frontal lobes; and in terms of the specific brain structure, the precuneus, parietal cortex, post-pressor cortex, hippocampus and par hippocampal gyrus function in different ways. (Latini-corazzini L et al., 2010) . Decline in these brain mechanisms and basic cognitive abilities as aging also affects older adults' ability to navigate spatially (Klencklen, G. , 2012).

The two most commonly used spatial navigation strategies include allocentric and egocentric (Rodgers, et al., 2012). The allocentric strategy requires the navigator to extract the allocentric representation, encode the spatial scene, and build a flexible cognitive map in mind according to the relative position of landmarks in the environment, and utilize path integration to achieve goal (Byrne, et al., 2007; Colombo et al., 2017; Lester et al. , 2017; Gramnn, Muller, Eick, & Schonebeck, 2005). The egocentric strategy requires Navigator to update the position and direction of the environmental object relative to himself in order to form a egocentric spatial representation, and also to memorize body turns, angles, and distances when encountering a particular environmental landmark, to judge navigation routes (Colombo et al. , 2017; Ruggiero, d'Errico, & Iachini, 2016) . In the actual navigation process, Navigator need to switch or co-ordinate these two navigation strategies according to different environmental tasks (Bohbot et al. , 2007; Colombo et al. , 2017) . Performance of spatial navigation can be affected if the appropriate navigation strategy is not chosen, or if are not able to integrate spatial and sensory information from both strategies due to impairment of corresponding brain neural mechanisms (Lithfous s et al. , 2013).

Many studies have shown that aging can cause deficits of old adults' brain neural mechanism related to using allocentric navigation strategies. In current developed cognitive model of spatial navigation, hippocampus is regarded as a very important central hub, and has a great impact on allocentric spatial navigation ability. Signals from areas such as the primary sensory cortex and the entorhinal cortex are projected to hippocampus, then outputted to other areas of the brain associated with spatial navigation after primary processing. (Chersi & Burgess, 2015; Coutureau & Di Scala, 2009; Dahmani & Bohbot, 2015). Allocentric navigation strategies can only be used when cognitive maps are developed successfully (Lithfous s et al., 2013) . The anterior hippocampus is responsible for forming cognitive maps, while the posterior hippocampus is responsible for forming spatial memories and storing cognitive maps (Lithfous s et al., 2013) . In 1971, John o'Keefe discovered the Place Cell, the first component of the brain's location system, in the Hippocampus of rats (O'Keefe & Dostrovsky, 1971). Place cells encode a sense of space and form cognitive maps by collaborating with other neurons in and around the hippocampus (O'Keefe & Nadel, 1978). The hippocampus is susceptible to aging, and studies have shown that it shrinks in size and functions during normal aging (Igloi et al., 2015; Lovden et al. , 2012) , affect the generation and retrieval of non-cognitive maps, resulting in impaired allocentric navigation strategies (Konishi et al., 2016).

In addition to the impairment of the navigation strategies themselves, there are also studies showing that older adults had the impairment of strategy selection and strategy switching (Bellassen et al., 2012; Dahmani et al., 2015;) . This may be related to the aging of the hippocampus and prefrontal cortex. One study suggests that the hippocampus is responsible for the calculation of spatial vectors, and that it outputs preliminary processed information to the prefrontal cortex (Harris et al., 2012) . Finally, the prefrontal cortex is engaged in strategy selection and path planning (Boccia, Nemmi, & Guariglia, 2014; Chersi & Burgess, 2015; Dahmani & Bohbot, 2015; Spiers & Gilbert, 2015). It has been reported that the ability of older adults to shift from egocentric to allocentric strategies is significantly impaired, and in the process, frontal lobe damage affects older adults'strategic judgment, making bad strategic choices (Harris et al., 2012; Mathew & Thomas, 2014).

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Current research suggests that older adults have impairment in the use of allocentric strategies and strategy switching, but egocentric strategies are relatively intact (Gazova et al., 2013; Sanders et al., 2008) . However, from a functional point of view, the damage of related brain regions also affects the application of egocentric strategies. When using the egocentric strategy for spatial navigation, participants were asked to remember their body turns when they encountered a series of environmental landmarks, which included both temporal and spatial information, similar to episodic memory (Bullens et al., 2010). The hippocampus is often thought to be responsible for encoding and storing episodic memories. It has also been shown that the hippocampus contains "Time cells" that are activated to indicate a continuous time, rather than a continuous location in space. Their emission characteristics are similar to those of Place cells (Eichenbaum, 2014; Nicholas et al., 2016; Gray U et al. , 2020) . More recently, the neural mechanisms behind egocentric navigation strategies have been discovered, and a new study by neuroscientists at Columbia University of engineering shows that there are large numbers of Egocentric bearing cells (EBCs) in the parahippocampal cortex, these cells are activated during spatial navigation, support vector representation and encode their distance to the reference, and are particularly involved in processing spatial information. At the same time, the researchers found that the activity of these EBCs increased when patients successfully recalled their position in an object, suggesting that the cells were not only involved in navigation but also played a role in spatial memory (Lukas K. et al., 2021).

Path integration is a mechanism that one uses to track one's spatial position by integrating information about one's movements during a cruise task (Moser et al. , 2005) . Path integration does not rely on beacons, landmarks or the use of external cues to determine the direction and location of a target, but rather on proprioceptive perception or visual flow to accomplish navigation tasks (Benjamin C, 2009), therefore, the use of allocentric strategies and the selection and switching of navigation strategies are not involved, which is of great significance to the study of the underlying mechanism of egocentric strategies in the elderly. Indeed, studies have also shown that the aging of neural mechanisms affects the path integration. In 2005, Swedish scientists Edvard Moser and May-Britt Moser discovered Grid cells in the entorhinal cortex of mice. Compared to location cells, this grid network or trellis coding provides a way to navigate without external cues and thus is responsible for path integration (Moser, 2005) . Studies have shown that the activation of Grid cells declines in healthy older adults when performing object orientation tasks, and this decline is associated with path integration performance (Stangl et al., 2018) . Studies also have shown that aging, atrophy, and damage to the entorhinal cortex typically affect navigation and are associated with cognitive impairment and Alzheimer's disease in humans (Coutureau & Di Scala, 2009; Howett D, et al., 2019) . In the human path integration task, there was a high positive correlation between the activation of the right hippocampus and the accuracy of pointing to the starting point after completing the task (Wolbers et al., 2007). Linear path integration is associated with Pyramidal cells (Hodgson, E., & Waller, d. 2006) in the CA1 region of the hippocampus. Studies have also shown that the Dentate gyrus of the hippocampus is susceptible to age-related atrophy (Leal & Yassa, 2015; Yassa et al., 2011). The aging of this region prevents older people from correctly distinguishing between similar input scenarios and stimuli and thus encoding different representations (Knierim & Neunuebel, 2016; Stark & Stark, 2017). The judgment of spatial representation affects the realization of spatial updating and path integration.

The development of virtual reality technology brings more possibilities to the research of human space navigation. A large number of traditional animal experimental paradigms have been well applied to human subjects. Research has shown that young people, the elderly, people with mild cognitive impairment, and people with early Alzheimer's disease are strongly correlated with the overall spatial navigation performance in both virtual and real environments, this also demonstrates the effectiveness of virtual reality in the study of aging in space navigation (Cushman, Stein, & Duffy, 2008) . In this study we aimed to use the virtual environment technique to examine the path integration performance of old adults using egocentric strategies, and believe that this methodology can be very effective because it can, provide old adults a realistic sense of noumenon when providing a safe experimental environment, and we can also control the experimental environment to reduce the influence of irrelevant variables.

2. Methods

2.1 About the Current Situation of Alzheimer's Disease

According to the 2012 report of the World Health Organization on Alzheimer's disease, dementia has become a global crisis, with a new case of dementia every four seconds. In 2013, it is estimated that 44 million people worldwide will suffer from dementia, which will increase to 76 million by 2030 and 135 million by 2050. Alzheimer's disease (AD) accounts for more than half of the dementia population. The cost of ad in the world reaches 604 billion US dollars every year. The cost of AD has exceeded the cost of heart disease, cancer and stroke, which has brought a heavy economic burden to the world1.

In addition, data show that China has the largest number of patients with Alzheimer's disease in the world, and the number of patients is expected to exceed 40 million by 2050.

In order to better understand Chinese AD patients and their living conditions and provide objective basis for the opinions of the State Council on the implementation of healthy China action, the 2019 survey on the survival status of Chinese Alzheimer's disease patients and families jointly launched by ADC and the people's daily health times was officially launched on November 5, 2019.

Alzheimer's disease (AD) is one of the most common dementia. Around the world, there is an AD patient every 3 seconds. As of 2019, China has more than 10 million AD patients, which is the country with the largest number of patients in the world. It is estimated that there will be 28 million AD patients in China in 2050. However, at present, the treatment rate of dementia, including ad, is only 26.9%, and the standardized treatment rate is only 21.3%.

The prevalence of Alzheimer's disease among the elderly over 65 years old in China is 5.9%. At present, there are about 7 million patients, and an average of 300000 Chinese elderly join this ranks every year.

The ad survey conducted in 40 cities and 60 hospitals in China in 2009 showed that the average time from the onset of clinical symptoms to the first diagnosis was > 1 year (3 ~ 21 months); Most of the patients were moderate to severe (67%), needed to be taken care of by others, and were often accompanied by abnormal mental behavior, which increased the burden of care, and missed the best treatment stage.

2.2 Experimental Introduction

In order to help the early discrimination of Alzheimer's disease, the following experiments were carried out according to the relevant research on impurities in brain in 2019.

For explore the relationship between impaired navigation function of entorhinal cortex and Alzheimer's disease, subjects were tested as follows:

The memory test under virtual reality is carried out in a 5.5 * 3.5m space for trial walking.

In the experimental design, when the subject is out of bounds (i.e. there is a collision risk when touching the field outside), the interface will prompt "you are out of bounds" and prompt the subject to return;

In addition, there are no road signs to indicate the boundary in the venue environment.

There are three kinds of situations in the experiment, including road signs (barricade cone) indication, no prompt, and other coordinate positioning prompts (distant mountains, clouds or fences, etc.). In each case, the subjects need to walk 12 times, and a total of 48 path data are collected. The order of these three cases is random.

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2.3 Experimental Steps

At the beginning of the test, the subjects will enter a simulated real environment, including virtual reality scenes such as wind, cloud, mountain range and grassland. The simulation of plants can control the influence of optical flow and strive to simulate the real environment when people walk. When the start button is pressed, the subject can see the first point prompted by the road sign. At this time, the system will prompt the subject to go over. When the subject arrives, the first road sign disappears; The second road sign appeared, and the subjects disappeared after arriving here; When the subjects walked to the third point, they were asked to return to the original point indicated by the first road sign.

2.4 Key Points for Experiment

It is worth noting that here, the subjects cannot restore the path in the form of triangle according to any way irrelevant to the path integration, such as recall de memory angle and reduction steps, but should reach the original first point in a straight line based on the memory of position and orientation. This will give some hints to the subjects before the test.

In addition, it should be added that since most of them are elderly subjects, a certain test will be conducted on whether they produce vertigo on virtual reality before the test, that is, there will be about five minutes before the formal start, which can be used for subjects to adapt to and adjust the relevant environment. Once the subject has dizziness and nausea during the test, the test shall be ended immediately.

2.5 Experimental Information

The test was conducted in the Institute of psychology, Chinese Academy of Sciences from November 8, 2019 to January 9, 2020. A total of 42 subjects' test information was obtained before and after the test (of course, except for the analysis and research of scientific research data, the names and other relevant information of the subjects were kept confidential).

3. Subject Introduction

3.1 Overview of Subjects

The average age of 42 volunteers was 74.5 years old, the oldest was 90 years old and the youngest was 62 years old (deviation value 28), including 11 male subjects and 31 female subjects. All subjects did not pass the cerebrospinal fluid test of Alzheimer's disease biomarkers that can point to patients with mild cognitive impairment, that is, there may be patients with mild cognitive impairment with positive or negative cerebrospinal fluid biological data in the 42 volunteers (the information provided by the subjects themselves may be inaccurate). It was confirmed that there were healthy control participants.

3.2 Test Time

The test time of each subject is 1 hour, and the partition is:

9:00-10:00.

11:00-12:00.

14:00-15:00.

15:00-16:00.

16:00-17:00.

This time is relatively abundant for the subjects. They have enough time to recall the path, integrate the path through the cognitive and positioning functions of the entorhinal cortex, and make angle judgment.

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4. Relevant Experimental Results are Presented

4.1 Data Presentation Direction

It can be divided into angle deviation and path deviation (azimuth deviation and distance deviation). The output results include the subject's walking and positioning roadmap. The residence path of the subjects can be observed. Since the virtual reality device can only detect the movement of the subject's head, the probe's observation of the surrounding environment during the experiment will be shown in the final figure. This is also a good direction for research.

4.2 Previous Research Findings

In terms of experimental results, according to the original research, it can be found that:

① There was no significant difference in age, gender and years of education;

② The absolute distance error detected by brain section experiment was positively correlated with the total tau protein in cerebrospinal fluid and the amyloid layer of CSF β Negative correlation;

③ The relationship between MCI + and ad can help judge.

4.3 Relevant Instructions

Path integration does not depend on external references, but the accumulation of their own motion. External references only help to correct. Although the subjects completed significantly better and more accurately with road signs and references, this is also the process of the subjects' own accumulation.

4.4 Insufficient Experiment and Supplement

① Due to the limited site and equipment, the site is too small, and there are few three landmarks, so the data obtained is relatively one-sided;

② Due to the limitations of the equipment, the scene setting may not be so close to life, such as the lack of wind and cloud flow, which will have a large deviation from the real-life environment;

③ Due to the limited time conditions, there are only 42 subjects, so the information obtained is difficult to generalize; And the group type of subjects is not clear enough.

5. Results

5.1 Statistical Analysis

Demographic differences between age and gender are assessed using one-way ANOVA and General liner Model of Univariate Anova. The relevance between age and return error including distance error and angle error is investigated by Pearson's correlation coefficient. 42 Subjects are separated into 3 group according to age and number of people. Group 1 ranges from 56 years old to 67 years old, containing 14 subjects, which stand for middle- aged people. Group 2 ranges from 68 to 79 years old, containing 13 people, which stand for aged people. Group 3 ranges from 80 to 90 years old containing 15 people, which stand for advanced aged people.

Between-group performance in the task compared all different group against each other. It was investigated by one-way Anova, The dependent variable is return error while the independent variable is age. Then, brivariate correlation analysis is used to test the relevance of the return error and age.

The subjects are also separated into Group A comprised by male and Group B comprised by female. There are 11 males and 31 females. To explore the relation between gender and return error, one-way Anova is used to check the differences of them.

Then, this research also explore the differences among age, gender and their interaction with return error. General liner Model of Univariate Anova is applied to discuss their relation.

Besides, the data of return error was divided into four group according to different scene. There are four different scenes during the path integration task including only mountain, mountain and wall,

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mountain and landmark and nothing. This research also explore the association between the set of some mark and the average return error.

5.2 Result

In Figure 1, it can be concluded that advanced aged group exhibited more distance errors than aged group and middle aged group. Figure 2 also demonstrates that the average distance error of middle aged group 0.97 meters, aged group is 1.17 meters and advanced aged group is 1.31 meters. Besides, there is significant difference between age group and distance return errors ($F(2,39)=4.244$, $P<0.05$). In addition, positive association can be observed between age group and distance error ($P<0.005$).

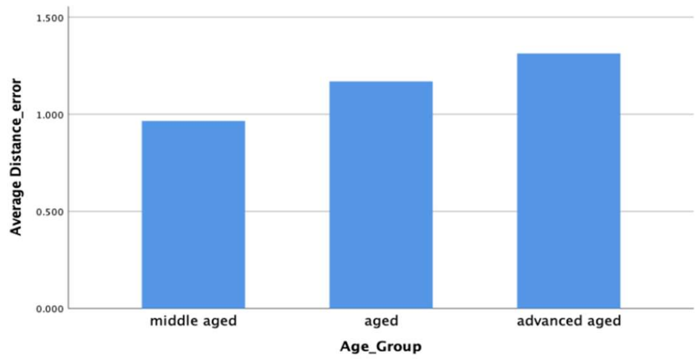

Figure 1. The group performance in distance error

Figure 2 demonstrates the group performance between different age group and angular error. No significant differences can be observed between age group and angular error ($F=0.857$, $P>0.05$).

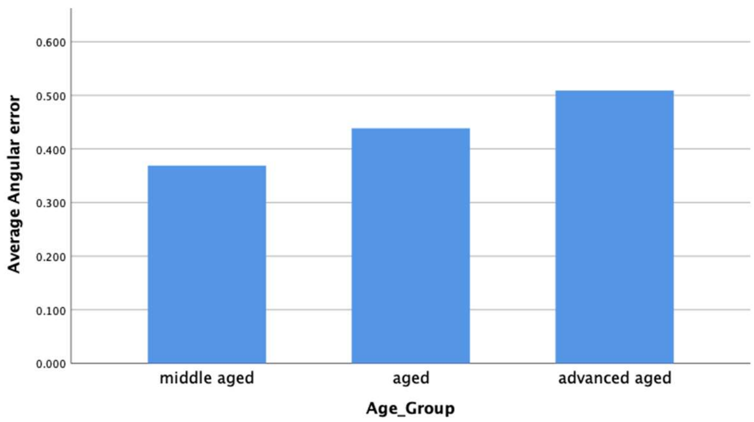

Figure 2. Group performance in the angular error

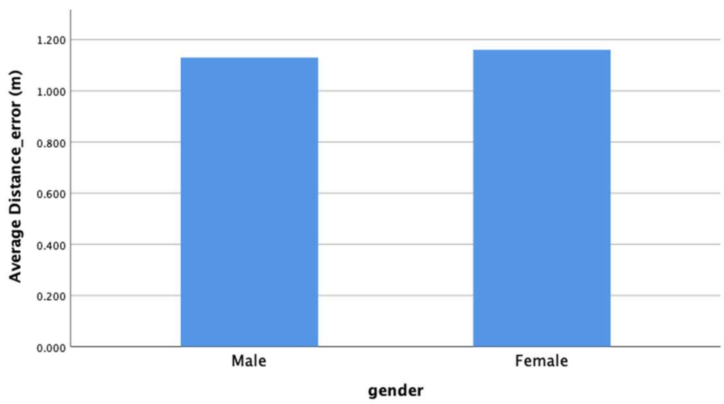

Figure 3. Gender performance in distance error

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Figure 3 indicates that male and female perform similarly in return error of path integration task. The average distance error of male is 1.13 meters while female is 1.16 meters. No significant differences is found between gender and distance error (F(1,0.007)=0.060, P>0.05).

Figure 4 indicates the performance of male and female on angular error. It can be observed from the graph that males and females exhibit similarly. The average angular error of male is 0.418 while female is 0.449. In addition, no significant difference can be found between gender and angular error (F= 0.253, P>0.05).

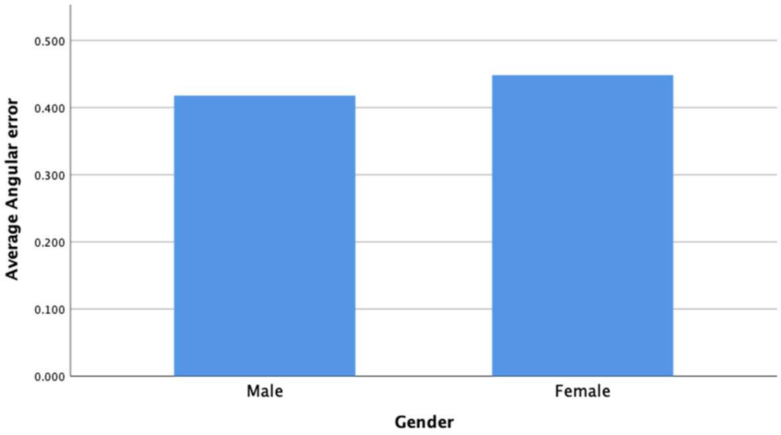

Figure 4. Gender performance on angular error

Anova analysis is also applied to discuss the differences between return error with gender and age. The dependent variable is the return error, while the independent variable is age and gender. As a result, no significant differences is observed between gender with age and distance error (F(4,37)=2.191, P>0.05). For in-group effect, significant differences can be observed between middle aged group and advanced aged group (P<0.01). There is no significant differences neither between middle aged group and aged group nor advanced aged group and aged group (P>0.05). In male group, there is no significant effect between any two of age groups (P>0.05). While in female group, significant effect can be observed between middle aged group and advanced aged group (P<0.05). In addition, no significant differences can be found neither between female middle aged group and female aged group nor female advanced aged group and female aged group (P>0.05). Figure 5 introduces interaction among gender, age and distance error. It can be observed from figure that younger male subjects exhibited significantly less distance errors compared elder female subjects.

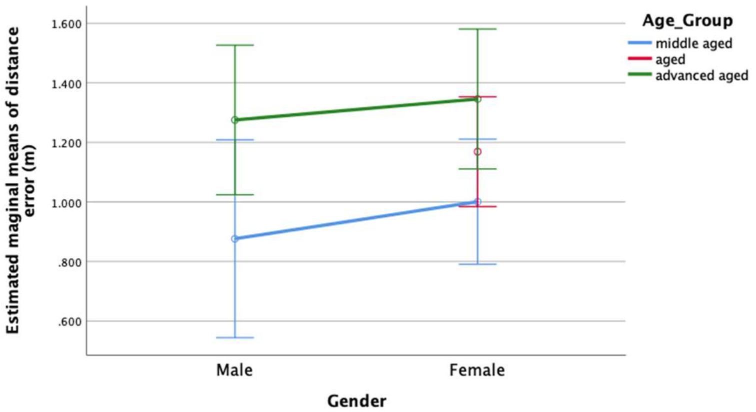

Figure 5. Interaction among gender, age and distance error

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For age, gender and angular error, no significant difference can be observed between the interaction of gender and age between angular error (F(1,37)=0.136, P>0.05). As for in-group effect of age, significant difference can be observed between middle aged group and advanced aged group (P<0.05). In addition, there is no significant difference between male and female (P>0.05). Figure 6 demonstrates the interaction among gender, age and angular error. It can be observed from the Figure that advanced aged group exhibit significant more angular error than advanced group. And for male aged group, there is no male subjects in this group.

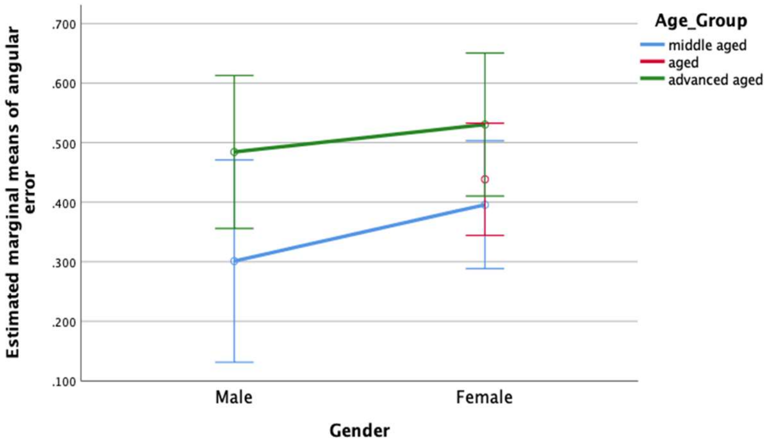

Figure 6. Interaction among gender, age and distance error

For the set of different scenes, it can be seen from Figure 7 that the average distance error in these four scenes are 1.25meters, 1.19 meters, 1.09 meters and 1.07 meters. In addition, there is no significant effect can be observed between different scenes and distance error (F(3,164)=0.497, P>0.05). For in-group effect, significant difference can only be observed between the scene of only mountain and nothing. From Figure 7, the average distance error in these four scenes are 1.25meters, 1.19 meters, 1.09 meters and 1.07 meters.

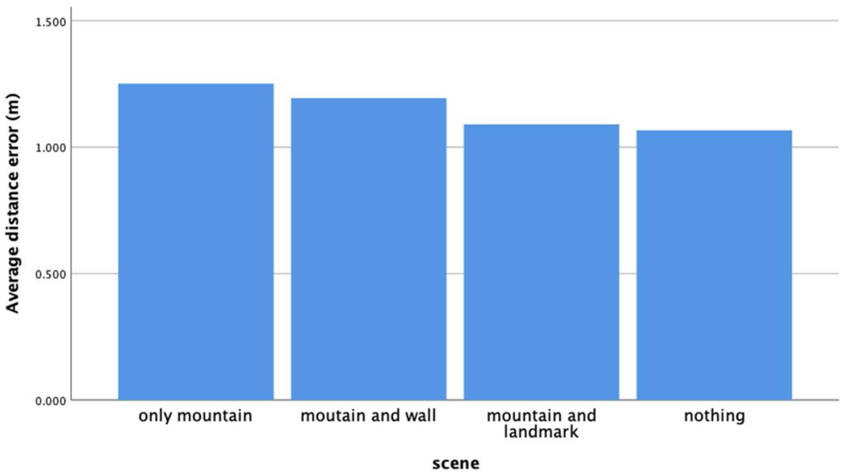

Figure 7. Performance of different scene

6. Discussion

Based on the demographic data, gender will influence the result of path integration task. Younger aged people exhibits better than advanced aged people. In previous studies (David, Andrew, Krzywicka, et al, 2019), significant effect can be observed between Mild Cognitive Impair and the performance of path integration task. It can be inferred that for the aged, elder people has worse cognitive ability in navigation comparing with younger people.

This study also indicates that gender has few influence in path integration task. It can be inferred that gender would not influence people's navigation ability. This result is also in accordance with previous study (Guo jichengsi,; Wan xiaoang, 2015).

For the set of the scene, this result is incompatible with previous research. One possible reason to explain this is the order of the scene and subjects' age. Almost all the subjects are the aged, they are limited in the use of technological equipment, thus they need to adjust themselves to this experiment. As a result, they exhibit better in the last trails which is the scene of nothing.

7. Conclusion

This study explore the factor which would influence the result of path integration task. From the analysis, it can be concluded that age would influence people's result of task. Among the aged, older people have worse navigation ability than the younger people. Besides, gender would not influence the result of path integration task.

Some limitations can be found in this research. At first, the sample size of subjects would influence the accuracy of the result. This study does not collect the data of different age layer, thus, there is a lack of control group of youth. Besides, gender side is imbalanced, there is no male subjects in aged group. This would have negative influence for the result. Thirdly, there is no data of subjects' cognitive situation, thus, this research can not build connection between the experiment and cognitive ability.

For future study, cognitive situation and their association with navigation ability can be explored via path integration task. And the result can be applied in the clinical treatment.

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