

The Effectiveness of Immersive Virtual Reality for Spatial Learning Tasks in Two Diverse Age Groups

Efectividad de la Realidad Virtual Inmersiva Para Tareas de Aprendizaje Espacial en Dos Grupos Diversos de Edad

Bernardo Burgos-Muñoz,^{1,2} Emilia Soto-Aguayo,³ Luz Gómez-Martínez,¹ Álvaro Navarro-Soto,¹
Diego Oyarzun-González,¹ Rodrigo Montefusco-Siegmund¹

Abstract

Spatial learning is a critical function for our effective functioning in the world. Despite the importance of this function, its study has been limited to unrealistic contexts, hindering a deep understanding of its underlying mechanisms. Today's technological advancements allow us to study this phenomenon in environments close to natural ones, with the potential to perform physiological measurements that help us understand its mechanisms in humans. In this work, we aimed to evaluate the box room task implemented in an Immersive Virtual Reality System (IVRS) for studying spatial learning in humans. The sample consisted of healthy children and older adults, without neurological or psychiatric alterations. All participants successfully completed the task without any problems associated with the use of IVRS. Although in different ways, both children and older adults showed improvements in the three established performance measures used to assess their performance over the course of the rounds: time, travel distance, and number of errors. Our results support the effectiveness of the box room task implemented in an IVRS for studying spatial learning and navigation in humans. The flexibility of the task positions it as a valuable tool for investigating spatial cognition in a variety of populations with diverse characteristics.

Keywords: Virtual Reality, Spatial Learning, Spatial Navigation, Spatial Cognition

Resumen

El aprendizaje espacial es una función crítica para nuestro funcionamiento efectivo en el mundo. A pesar de su importancia, su estudio ha estado limitado a contextos poco realistas, lo que dificulta una comprensión profunda de sus mecanismos subyacentes. Los avances tecnológicos actuales nos permiten estudiar este fenómeno en entornos similares a los naturales. En este trabajo, nuestro objetivo fue evaluar la tarea Sala de Cajas implementada en un Sistema de Realidad Virtual Inmersivo (SRVI) para estudiar el aprendizaje espacial en humanos. La muestra consistió en niños sanos y adultos mayores, sin alteraciones neurológicas o psiquiátricas. Todos los participantes completaron con éxito la tarea sin problemas asociados al uso del SRVI. Aunque de diferentes maneras, tanto los niños como los adultos mayores mostraron mejoras en las tres medidas de rendimiento establecidas para evaluar su desempeño a lo largo de las rondas: tiempo, distancia recorrida y número de errores. Nuestros resultados apoyan la efectividad de la tarea Sala de Cajas implementada en un SRVI para estudiar el aprendizaje espacial y la navegación en humanos. La flexibilidad de la tarea la posiciona como una herramienta valiosa para investigar la cognición espacial en una variedad de poblaciones con diversas características.

Palabras clave: Realidad Virtual, Aprendizaje Espacial, Navegación Espacial, Cognición Espacial

Rev. Ecuat. Neurol. Vol. 35, N° 1, 2026

Introduction

The ability to navigate in space is a fundamental cognitive function that enables individuals to orient themselves and move effectively within their environment, facilitating socialization, food searching, and interaction with their surroundings.^{1,2} This skill is not only crucial for proper

environmental interaction but has also been established as a valuable indicator of cognitive health throughout the life cycle.³ From childhood to old age, the capacity to learn and remember routes, identify landmarks, and orient oneself in new spaces can be influenced by various factors, including neural development, aging, and life experiences.⁴ The

¹Institute for Movement and Human Occupational Sciences, Faculty of Medicine, Universidad Austral de Chile, Valdivia, Chile.

²Audio Mining Laboratory (AuMiLab), Universidad Austral de Chile, Valdivia, Chile.

³SIG Center for Computer Graphics, Department of Computer & Information Science, University of Pennsylvania, Philadelphia, USA.

Correspondencia:

Rodrigo Montefusco-Siegmund

Institute for Movement and Human Occupational Sciences, Faculty of Medicine, Universidad Austral de Chile.

Address: #1650 Rudloff Street, Valdivia, Chile

Phone: +569 69055499

E-mail: rodrigo.montefusco@uach.cl

decline of these abilities may serve as a key indicator of the onset of various neurological conditions, including neurodegenerative disorders such as Alzheimer's Disease.⁵

Despite its relevance, the study of spatial navigation faces multiple challenges, with the recreation of environments that effectively and naturally simulate real-world conditions being one of the most prominent.⁶ This situation emphasizes the need for research tools that are not only realistic but also precise, reliable, and adaptable to the capabilities and needs of different populations.⁷ In this context, Immersive Virtual Reality Systems (IVRS) emerge as an innovative technology capable of overcoming these limitations. By providing controlled and highly realistic environments, these systems allow users to experience navigation under conditions that closely resemble real life.⁸ One of their most notable features is the ability to generate natural sensorimotor perception, facilitating free movement within the virtual environment and the execution of actions such as bending down and turning one's head, akin to movements in the real world. This experience of free mobility not only enhances immersion but also promotes the integration of proprioceptive, vestibular, and optical flow information, which are crucial factors in the study of spatial navigation.⁹

In this context, the present work aims to evaluate the validity of an innovative task that we have implemented using IVRS for use in individuals across a wide age spectrum. This task, called "the boxes room," was previously developed in a desktop version, where participants were required to remain stationary in front of a screen while recording their responses using a mouse or joystick.¹⁰ Adapting this task to an IVRS allows not only for a more dynamic assessment of learning and spatial memory but also provides valuable insight into the neurophysiology underlying these processes under conditions that mimic natural interaction with the environment.¹¹ Furthermore, the use of IVRS may potentially reveal performance differences based on age, thereby contributing to the understanding of how cognitive capabilities related to navigation evolve throughout the lifespan.¹²

Methods

Participants

We recruited 22 children (11 girls; mean age 10.57, SD 0.76) and 23 older adults (21 women; mean age 66.78, SD 5.88). Children were enrolled through social media campaigns directed at their parents and caregivers, while older adults were selected from two local senior associations. According to parental reports, the children had no intellectual difficulties, learning disorders, or attention deficits. Similarly, the older adults reported no neurological or psychiatric disorders at the time of the study. All participants had normal or corrected-to-normal vision and reported having no prior experience with IVRS.

Before beginning, older adults provided informed consent, and children gave their assent, with additional consent obtained from their parents or caregivers. The entire research was conducted at the Institute for Movement and Human Occupational Sciences of the Austral University of Chile. The Scientific Ethics Committee of the Valdivia Health Service approved all study procedures.

Equipment

To perform the 'The Boxes Room' task, we used an IVRS, Vive Pro Eye, along with the Unity 3D game engine (Unity Technologies, San Francisco, CA, USA). This system includes a virtual reality headset (head-mounted display) and a wireless hand controller, allowing participants to interact with the virtual environment. The headset displays images at 90 Hz with a resolution of 1140 x 1600 pixels per eye, covering a visual field of 110°. 'The Boxes Room' was run on an HP Omen laptop equipped with an Intel(R) Core(TM) i7 9750H processor, 16 GB of RAM plus 32 GB of Intel Optane, and a 512 GB NVIDIA GeForce 2070 graphics card.

Procedure

Each participant was introduced into a virtual room measuring 3.5 x 3.5 virtual meters/real meters, with identical yellow gift boxes on the floor and elements such as doors, windows, objects, and paintings on the walls serving as spatial references (Fig. 1A). Participants were instructed to locate a specified number of target boxes as efficiently as possible, meaning in the shortest time and with the fewest errors. When a participant touched a target box, it changed to green, and an agreeable sound was immediately emitted. In contrast, when interacting with a non-target box, it turned red and was accompanied by an unpleasant sound. Once all the target boxes were found, the room would rotate randomly by 90°, 180°, or 270°, and a new round would begin, with the boxes reset to their original color.

Before starting the experiment, since all participants lacked prior experience with IVRS both groups underwent a training session. This session included free exploration of the virtual room, two practice rounds, and the opportunity to ask questions, which facilitated understanding of the task. Additionally, they were provided with information about the number of reward boxes and were informed that their positions would remain constant throughout all rounds of the experiment. However, no information was given regarding effective navigation strategies, the location of the reward boxes, visual reference cues, or other experimental conditions. Children completed 10 rounds in which they had to locate 5 target boxes out of a total of 25 available in the room. Meanwhile, older adults also completed 10 rounds, but only with 3 target boxes out of 9

available. This difference was established after conducting a pilot test, during which it was observed that older adults, in the absence of conditions such as dementia, faced various difficulties in understanding the task. This resulted in erratic behavior during the search for the target boxes, accompanied by a high degree of frustration and discouragement. A unique pattern for the distribution of the target boxes was used for each group, avoiding random biases (Fig. 1B and 1C). At the end, the IVRS equipment was removed, and participants' impressions were collected.

For an objective evaluation, three performance variables were determined: time to complete each search round (in seconds), distance traveled during the search (in virtual meters), and the number of errors per round (defined as touching a non-target box).

Analyses

We used Matlab 2019b (Mathworks Inc.) to perform all analyses. To assess the performance of both groups, we calculated the average of the three variables of interest for each round across all participants, which subsequently allowed us to determine relationships. For the children, we applied a two-term exponential model ($f_2(x) = ae(bx) + ce(dx)$) and then compared the performance between the second and tenth rounds using the paired Student's t-test, in addition to calculating the effect size using Hedges' *g*. In contrast, for the older adults, we employed Spearman's correlation.

The decision to use a different analytical approach for both groups is based on the intention to apply a model that offers a high degree of fit to the obtained results. This allows for a more accurate description of the learning process, thereby optimizing the validity and relevance of the findings.

Results

All participants successfully completed the task, and no adverse events or symptoms associated with "cybersickness" were reported during or after the conduct of the experiment.¹³

Children

Children were presented with a more challenging task where they had to find 5 target boxes in a 25-box array (Fig 1B; 5 x 5 boxes). The first round was excluded from the analysis as the search was entirely random. However, from the second round onwards, a sustained decrease was observed following a two-term exponential model, for search time (Fig. 2A left; $R^2 = 0.994$), distance traveled (Fig. 2B left; $R^2 = 0.987$), and the number of errors (Fig. 2C left; $R^2 = 0.951$). Performance consistently improved from round 2 to round 10, in terms of search time (2nd round 62.6 seconds +/- 39.3 SD to 10th round 17.4 seconds +/- 9.6 SD; Fig. 2A right; $p = 1.73 \times 10^{-5}$, paired t-test, Hedges' *g* = 1.54), distance traveled (2nd round 27.3 virtual meters +/- 12.8 SD to 10th round 11.1 virtual meters +/- 5.7 SD ; Fig. 2B right; $p = 2.53 \times 10^{-6}$, paired t-test, Hedges' *g* = 1.59), and the number of

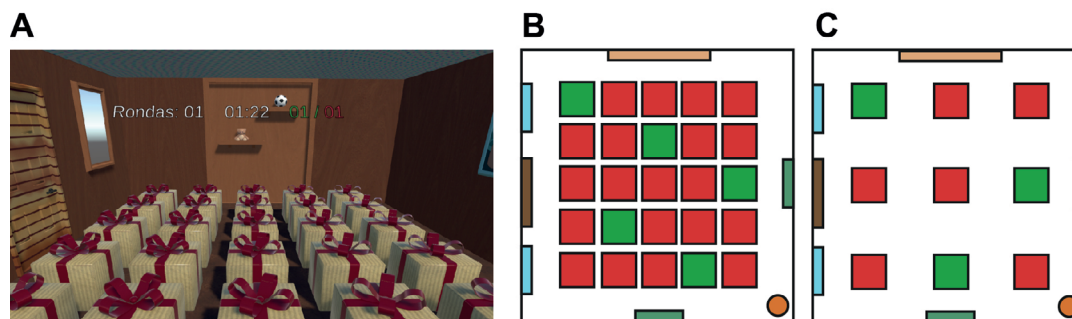


Figure 1. Box Room Task in a Immersive Virtual Reality System. **A.** Virtual room consisting of a 3.5 x 3.5 meter space. Visual cues are visible, and there is a 5 x 5 grid of boxes on the floor. **B.** Box distribution for children, where green squares represent target boxes and red boxes represent distractor boxes. Rectangles and squares of other colors show the distribution of other elements that serve as orientation cues. **C.** Same as B, but for older adults.

errors (2nd round 8.3 errors +/- 6.7 SD to 10th round 1.5 errors +/- 3.3 SD; Fig. 2C right; $p = 8.78 \times 10^{-5}$, paired t-test, Hedges' $g = 1.25$)

Older Adults

During the pilot phase of our task, older adults reported high levels of frustration and an inability to complete the task when set with 5 target boxes in a 25-box arrangement. For this reason, their task was adjusted to 3 target boxes in a 9-box arrangement (Fig 1C; 3 x 3 boxes).

The performance of older adults consistently improved across the rounds (Fig. 3, left panel). This performance follows an inverse linear relationship with the number of rounds for search time (Fig 3A right; $R = -0.78$, $p = 0.0086$,

Spearman correlation), distance traveled (Fig 3B right; $R = -0.78$, $p = 0.0086$, Spearman correlation), and the number of errors (Fig 3C right; $R = -0.63$, $p = 0.038$, Spearman correlation). Similar to the group of children, performance consistently improved from round 2 to round 10, in terms of search time (2nd round 34.4 seconds +/- 15.3 SD to 10th round 24.2 seconds +/- 13.1 SD; Fig. 3A right; $p = 5.63 \times 10^{-4}$, paired t-test, Hedges' $g = 0.7$), distance traveled (2nd round 10 virtual meters +/- 3.6 SD to 10th round 8 virtual meters +/- 4.1 SD ; Fig. 3B right; $p = 0.0108$, paired t-test, Hedges' $g = 0.51$), but not in the number of errors (2nd round 3.8 errors +/- 1.6 SD to 10th round 3.1 errors +/- 2 SD ; Fig. 3C right; $p = 0.15$, paired t-test, Hedges' $g = 0.37$)

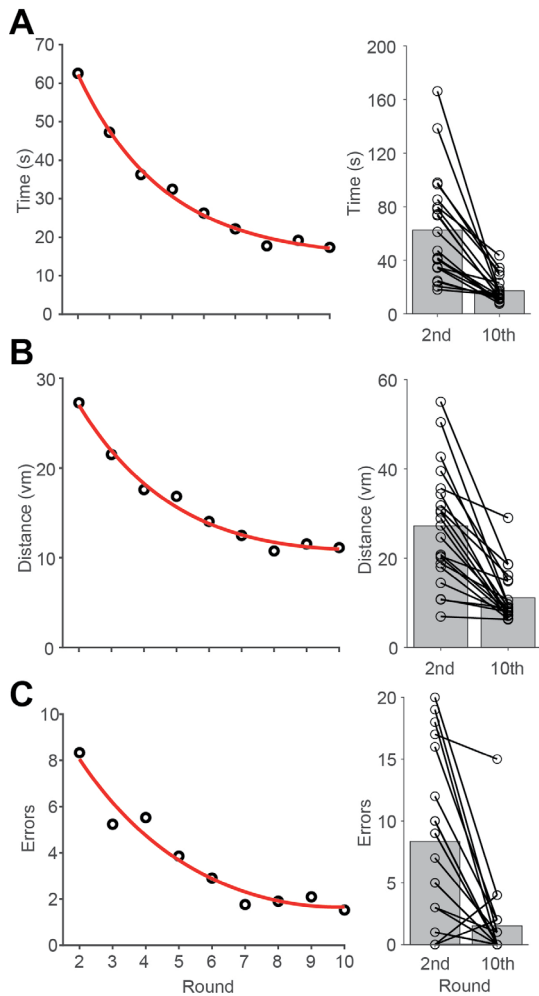


Figure 2. Performance in children. **A left.** Search time (s, seconds) across rounds. The circles represent the average value of all subjects. The red line represents the exponential fit. **A right.** Search time in the 2nd and 9th rounds. The bars show the average value of all volunteers. The circles represent the values of individual subjects. The lines connect the value of each individual in the 2nd and 9th round. **B and C,** the same as A, but for distance traveled (vm, virtual meters) and number of errors, respectively.

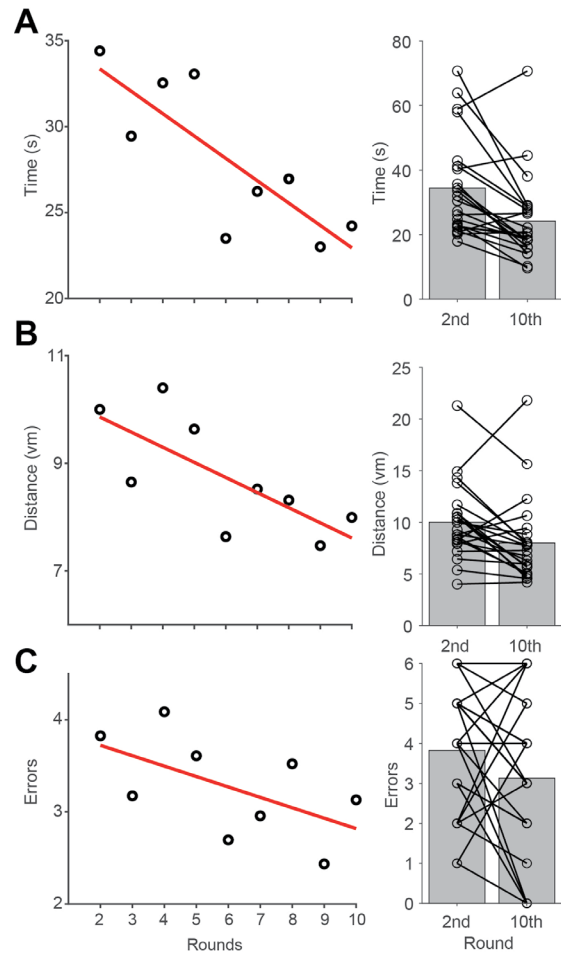


Figure 3. Performance in older adults. **A left.** Search time (s, seconds) across rounds. The circles represent the average value of all subjects. The red line represents the linear fit of the correlation. **A right.** Search time in the 2nd and 9th rounds. The bars show the average value of all volunteers. The circles represent the values of individual subjects. The lines connect each individual's value in the 2nd and 9th rounds. **B and C,** the same as A, but for distance traveled (vm, virtual meters) and number of errors, respectively.

Discussion

This study aimed to validate the use of an immersive virtual reality tool across two extremes of the life cycle. For this purpose, we implemented the "the boxes room" task, previously described in a non-immersive environment⁹ and widely used in various contexts.¹⁴⁻¹⁶ Standard measures of search time, distance traveled during the search, and number of errors were used to assess participants' performance during the spatial learning process.^{17,18}

As previously reported, individual performance improved consistently and significantly throughout the session, indicating the occurrence of spatial learning.¹⁹ Our results are in line with studies comparing the performance of older adults and young subjects in spatial learning tasks, including route learning²⁰ and recognition of critical and non-critical points after navigating a non-immersive virtual maze.⁷ Distinctly, the learning curves show different progressions for children and older adults. One possibility is that the course of learning indeed develops differentially, considering a range of other factors related to immersive spatial exploration that could either become more efficient with the maturation of the nervous system or deteriorate with age.²¹ Another, less exciting possibility could be an effect caused by the difference in the number of boxes or "targets" in the room. In studies conducted in non-immersive media, no change in the progression of spatial learning due to the total number of elements or targets in the room was observed, although this was not directly assessed.¹⁶ Instead, the reported progression is similar to that found in children (exponential type). Nevertheless, we should not dismiss the possibility of a ceiling effect, produced by a natural reduction in search times, travel distance, and errors, resulting from fewer options. Finally, a potential bias in our sample of older adults, which is predominantly female, could explain the discrepancy in the progression of spatial learning throughout the session between the group of children and older adults. Previous studies have shown significantly poorer progression in women aged 65-74 compared to men of the same age group.²² We believe this last option best explains the differences in spatial learning progression observed in our study. However, differences have been reported among age groups of men, so we cannot rule out the same effect in our work.²² Future studies should address this issue more thoroughly.

The use of an immersive system brings us closer to a more natural situation where the individual moves through space using their entire body, directing their gaze through head and eye movements to gather information from the environment that allows them to orient and position themselves in space and ultimately move towards the target. This opens up a series of opportunities for studying other variables related to spatial search that will be evaluated in future studies. Of particular interest are the use of eye movements to obtain information from spatial cues,²³ positioning strate-

gies to solve the task,²⁴ effects of experience on spatial learning,²⁵ and schema-based spatial learning,²⁶ among others. All this occurs in a more ecological context where the restriction of movement has been greatly overcome.

Search and positioning strategies help subjects efficiently solve the search task.²⁷ Although not evaluated, two search strategies were identified through observation of sessions and discussion with subjects at the end of their participation. The first strategy, more "egocentric" in nature, involves the participant, from the center of the room, turning their head to use reference points such as doors or paintings to locate nearby target boxes.²⁸ This was the most frequently adopted strategy. The second strategy, "allocentric", involves the participant positioning themselves at the edge of the room to obtain a panoramic view, facilitating the localization of boxes in relation to spatial references and other boxes.²⁸ This was the second most common strategy. Some participants employed a combination of both or less defined strategies. Future studies are necessary to understand how these strategies interact with aspects such as body movement,²⁹ eye fixation on spatial references,³⁰ familiarity with these references,³¹ and prior experience in egocentric and allocentric virtual environments, such as video games.³²

There has been a significant effort over the last decade to incorporate experimental paradigms that mimic real-life situations into research.³³ Traditionally, neuropsychological tests and questionnaires have been used to assess cognitive abilities, such as episodic memory, through tasks like recalling lists of words or recent events.³⁴ While these tests can identify certain abnormalities, they do not delve into understanding the underlying physiological mechanisms.³⁵ In response, more ecological tools have been developed that allow direct interaction in virtual environments, whether immersive or not.³⁶ A crucial aspect of spatial navigation in immersive virtual environments is the congruence between visual and motor movement, something not achievable with joysticks or keyboards, as the user remains stationary.³⁷ This congruence is essential for studying the physiology of cognitive processes, as our everyday experience involves free and coordinated movement, reflecting the natural functioning of our nervous system.³⁸ Breaking this coherence distorts our understanding of how these variables influence natural cognitive mechanisms. Ultimately, the use of ecological tasks allows us to get closer to understanding the actual actions of the brain, not just its capabilities.

As previously noted, it is crucial to adapt the difficulty of the task to the capabilities of each group studied.³⁹ Children require significant challenges to maintain their interest, while older adults benefit from less demanding tasks to avoid frustration.⁴⁰ Therefore, we adjusted the task to 25 total boxes and 5 target boxes for children, and 9 total boxes with 3 target boxes for older adults. A key focus

with older adults was to ensure they understood the task and comfortably adapted to the virtual environment. For this, we used explanatory diagrams and practical simulations. In addition, we implemented preliminary familiarization sessions with virtual reality to safely improve their mobility in the virtual environment. It was also important to exclude those at high risk of falls, dizziness, or vestibular problems, using questionnaires and specific tools to identify these conditions.⁴¹ Our task design allows for easy adjustment of the total number of boxes, target boxes, their placement, and the number of rounds via an interactive menu. This facilitates the investigation of both spatial learning within a session and spatial memory, i.e., how the locations of the "target" boxes are retained in a subsequent assessment session. We can examine various variables that might influence memory, either within the same group or among different groups of participants; such as time between sessions, drug use, sleep quality, stress, or the impact of the virtual experience.

As previously mentioned, there are multiple tools, tests, surveys, and questionnaires to evaluate various cognitive functions in general and hippocampal-dependent memory in particular.^{42,43} However, there are no modern tools that allow for an integrated and functional evaluation of the latter,⁴⁴⁻⁴⁶ i.e., that can determine the impairments and compensations a patient may have. We believe this is a promising path for developing a new line of cognitive function assessment in which the patient is evaluated in a realistic context.⁴⁷

The absence of an objective clinical assessment to characterize the subjects in our sample represents a limitation in the development of our study. Consequently, it is possible that unconsidered factors initially may have influenced the results obtained. Future research should incorporate a comprehensive sociodemographic and clinical characterization of the study participants.

Conclusions

The results obtained by participants, both children and older adults, in the three established performance measures support the validity and safety of the "Box Room" task implemented in an IVRS for studying spatial learning and navigation in humans. The absence of reported adverse events suggests that both groups adapted well to the IVRS and the cognitive challenges posed by the task, particularly highlighting the ability of older adults to face technological challenges without prior experience.

In conclusion, the implementation of this task represents an innovative and ecologically valid tool for studying spatial cognition in humans. This tool is applicable to individuals at various stages of the life cycle, and potentially to people diagnosed with different disorders. By providing a more natural and realistic context for assessing spatial memory and other cognitive functions, these tools have

the potential to uncover aspects of cognition that were previously difficult to evaluate, thus paving the way for more effective and personalized interventions.

References

1. Fernández-Velasco P, Spiers HJ. Wayfinding across ocean and tundra: what traditional cultures teach us about navigation. *Trends Cogn Sci.* 2024;28(1):56–71. <http://dx.doi.org/10.1016/j.tics.2023.09.004>
2. Gazova I, Vlcek K, Laczó J, Nedelska Z, Hyncicova E, Mokrisova I, et al. Spatial navigation—a unique window into physiological and pathological aging. *Front Aging Neurosci.* 2012;4:16. <http://dx.doi.org/10.3389/fnagi.2012.00016>
3. Lester AW, Moffat SD, Wiener JM, Barnes CA, Wolbers T. The aging navigational system. *Neuron.* 2017;95(5):1019–35. <http://dx.doi.org/10.1016/j.neuron.2017.06.037>
4. Allen GL, Kirasic KC, Rashotte MA, Haun DBM. Aging and path integration skill: kinesthetic and vestibular contributions to wayfinding. *Percept Psychophys.* 2004;66(1):170–9. <https://doi.org/10.3758/BF03194870>
5. Plácido J, de Almeida CAB, Ferreira JV, de Oliveira Silva F, Monteiro-Junior RS, Tangen GG, et al. Spatial navigation in older adults with mild cognitive impairment and dementia: a systematic review and meta-analysis. *Exp Gerontol.* 2022;165:111852. <https://doi.org/10.1016/j.exger.2022.111852>
6. Schöberl F, Zwergal A, Brandt T. Testing navigation in real space: contributions to understanding the physiology and pathology of human navigation control. *Front Neural Circuits.* 2020;14:6. <http://dx.doi.org/10.3389/fncir.2020.00006>
7. Zhong JY, Moffat SD. Age-related differences in associative learning of landmarks and heading directions in a virtual navigation task. *Front Aging Neurosci.* 2016;8:122. <http://dx.doi.org/10.3389/fnagi.2016.00122>
8. Kaiser AP, Villadsen KW, Samani A, Knoche H, Evald L. Virtual reality and eye-tracking assessment, and treatment of unilateral spatial neglect: systematic review and future prospects. *Front Psychol.* 2022;13:787382. <http://dx.doi.org/10.3389/fpsyg.2022.787382>
9. Kafri M, Weiss PL, Zeilig G, Bondi M, Baum-Cohen I, Kizony R. Performance in complex life situations: effects of age, cognition, and walking speed in virtual versus real life environments. *J Neuroeng Rehabil.* 2021;18(1):30. <https://doi.org/10.1186/s12984-021-00830-6>
10. Cánovas R, Espínola M, Iribarne L, Cimadevilla JM. A new virtual task to evaluate human place learning. *Behav Brain Res.* 2008;190(1):112–8. <http://dx.doi.org/10.1016/j.bbr.2008.02.024>
11. Jeung S, Hilton C, Berg T, Gehrke L, Gramann K. Virtual reality for spatial navigation. En: *Virtual Reality in Behavioral Neuroscience: New Insights and Methods.* Cham: Springer International Publishing. 2023;103–29.

- https://doi.org/10.1007/7854_2022_403
12. Díaz-Orueta U, Climent G, Cardas-Ibanez J, Alonso L, Olmo-Osa J, Tirapu-Ustarroz J. Memory assessment by means of virtual reality: its present and future. *Rev Neurol*. 2016;62(2):91–6. <https://doi.org/10.33588/rn.6202.2015453>
 13. Lorca M, Araya E, Monrroy M, Enríquez J, Moscoso P, Montefusco R, et al. Experience of the use and presence of cyber disease in immersive virtual reality exposure in urban community-dwelling older adults. *Rev Esp Geriatr Gerontol*. 2025;60(4):101634. <https://doi.org/10.1016/j.regg.2025.101634>
 14. Cánovas R, León I, Serrano P, Roldán MD, Cimadevilla JM. Spatial navigation impairment in patients with refractory temporal lobe epilepsy: evidence from a new virtual reality-based task. *Epilepsy Behav*. 2011;22(2):364–9. <http://dx.doi.org/10.1016/j.yebeh.2011.07.021>
 15. Rosas K, Parrón I, Serrano P, Cimadevilla JM. Spatial recognition memory in a virtual reality task is altered in refractory temporal lobe epilepsy. *Epilepsy Behav*. 2013;28(2):227–31. <http://dx.doi.org/10.1016/j.yebeh.2013.05.010>
 16. Tascón L, Di Cicco C, Piccardi L, Palmiero M, Bocchi A, Cimadevilla JM. Sex differences in spatial memory: comparison of three tasks using the same virtual context. *Brain Sci*. 2021;11(6):757. <http://dx.doi.org/10.3390/brainsci11060757>
 17. Barnes CA, Nadel L, Honig WK. Spatial memory deficit in senescent rats. *Can J Psychol*. 1980;34(1):29–39. <https://doi.org/10.1037/h0081022>
 18. Astur RS, Taylor LB, Mamelak AN, Philpott L, Sutherland RJ. Humans with hippocampus damage display severe spatial memory impairments in a virtual Morris water task. *Behav Brain Res*. 2002;132(1):77–84. [http://dx.doi.org/10.1016/s0166-4328\(01\)00399-0](http://dx.doi.org/10.1016/s0166-4328(01)00399-0)
 19. Moffat SD, Zonderman AB, Resnick SM. Age differences in spatial memory in a virtual environment navigation task. *Neurobiol Aging*. 2001;22(5):787–96. [http://dx.doi.org/10.1016/s0197-4580\(01\)00251-2](http://dx.doi.org/10.1016/s0197-4580(01)00251-2)
 20. Taillade M, N’Kaoua B, Sauzéron H. Age-related differences and cognitive correlates of self-reported and direct navigation performance: the effect of real and virtual test conditions manipulation. *Front Psychol*. 2016;6:1234. <http://dx.doi.org/10.3389/fpsyg.2015.02034>
 21. Zhang J-X, Wang L, Hou H-Y, Yue C-L, Wang L, Li H-J. Age-related impairment of navigation and strategy in virtual star maze. *BMC Geriatr*. 2021;21(1):1. <https://doi.org/10.1186/s12877-021-02034-y>
 22. Nazareth A, Huang X, Voyer D, Newcombe N. A meta-analysis of sex differences in human navigation skills. *Psychon Bull Rev* 2019; 26(5):1503–28. <https://doi.org/10.3758/s13423-019-01633-6>
 23. Harris T, Hagg J, Pletzer B. Eye movements during navigation in a virtual environment: sex differences and relationship to sex hormones. *Front Neurosci*. 2022;16:755393. <https://doi.org/10.3389/fnins.2022.755393>
 24. Qiu Y, Wu Y, Liu R, Wang J, Huang H, Huang R. Representation of human spatial navigation responding to input spatial information and output navigational strategies: an ALE meta-analysis. *Neurosci Biobehav Rev*. 2019;103:60–72. <http://dx.doi.org/10.1016/j.neubiorev.2019.06.012>
 25. Mohammadian J, Najafi M, Miladi-Gorji H. Effect of enriched environment during adolescence on spatial learning and memory, and voluntary consumption of morphine in maternally separated rats in adulthood. *Dev Psychobiol*. 2019;61(4):615–25. <https://doi.org/10.1002/dev.21808>
 26. Van Kesteren MTR, Brown TI, Wagner AD. Learned spatial schemas and prospective hippocampal activity support navigation after one-shot learning. *Front Hum Neurosci*. 2018;12:486. <https://doi.org/10.3389/fnhum.2018.00486>
 27. Rahman Q, Sharp J, McVeigh M, Ho M-L. Sexual orientation-related differences in virtual spatial navigation and spatial search strategies. *Arch Sex Behav*. 2017;46(5):1279–94. <http://dx.doi.org/10.1007/s10508-017-0986-5>
 28. Zaehle T, Jordan K, Wüstenberg T, Baudewig J, Dechent P, Mast FW. The neural basis of the egocentric and allocentric spatial frame of reference. *Brain Res*. 2007;1137:92–103. <http://dx.doi.org/10.1016/j.brainres.2006.12.044>
 29. Wexler M. Voluntary head movement and allocentric perception of space. *Psychol Sci*. 2003;14(4):340–6. <https://doi.org/10.1111/1467-9280.14491>
 30. Davis R, Sikorskii A. Eye tracking analysis of visual cues during wayfinding in early stage Alzheimer’s disease. *Dement Geriatr Cogn Disord*. 2020;49(1):91–7. <https://doi.org/10.1159/000506859>
 31. Maguire EA, Gadian DG, Johnsrude IS, Good CD, Ashburner J, Frackowiak RSJ, et al. Navigation-related structural change in the hippocampi of taxi drivers. *Proc Natl Acad Sci USA*. 2000;97(8):4398–403. <https://doi.org/10.1073/pnas.070039597>
 32. De Castell S, Larios H, Jenson J. Gender. Videogames and navigation in virtual space. *Acta Psychol*. 2019;199:102895. <http://dx.doi.org/10.1016/j.actpsy.2019.102895>
 33. Burns PC. Navigation and the mobility of older drivers. *J Gerontol B Psychol Sci Soc Sci*. 1999;54(1):S49–55. <http://dx.doi.org/10.1093/geronb/54b.1.s49>
 34. Bruno D, Slachevsky A, Fiorentino N, Rueda DS, Bruno G, Tagle AR, et al. Validación argentino-chilena de la versión en español del test Addenbrooke’s Cognitive Examination III para el diagnóstico de demencia. *Neurología*. 2020;35(2):82–8. <https://doi.org/10.1016/j.nrl.2017.06.004>
 35. Cogné M, Taillade M, N’Kaoua B, Tarruella A, Klinger E, Larrue F, et al. The contribution of virtual reality to

- the diagnosis of spatial navigation disorders and to the study of the role of navigational aids: a systematic literature review. *Ann Phys Rehabil Med.* 2017;60(3):164–76. <http://dx.doi.org/10.1016/j.rehab.2015.12.004>
36. Diersch N, Wolbers T. The potential of virtual reality for spatial navigation research across the adult lifespan. *J Exp Biol.* 2019;222(1). <http://dx.doi.org/10.1242/jeb.187252>
 37. Stramba-Badiale C, Tuena C, Goulene KM, Cipresso P, Morelli S, Rossi M, et al. Enhancing spatial navigation skills in mild cognitive impairment patients: a usability study of a new version of ANTaging software. *Front Hum Neurosci.* 2024;17:1–12. <http://dx.doi.org/10.3389/fnhum.2023.1310375>
 38. Hejtmanek L, Starrett M, Ferrer E, Ekstrom AD. How much of what we learn in virtual reality transfers to real-world navigation?. *Multisens Res.* 2020;33(4–5):479–503. <http://dx.doi.org/10.1163/22134808-20201445>
 39. Van der Staay FJ, Gieling ET, Pinzón NE, Nordquist RE, Ohl F. The appetitively motivated “cognitive” hole-board: A family of complex spatial discrimination tasks for assessing learning and memory. *Neurosci Biobehav Rev.* 2012;36(1):379–403. <http://dx.doi.org/10.1016/j.neubiorev.2011.07.008>
 40. Dodge NC, Thomas KGF, Meintjes EM, Molteno CD, Jacobson JL, Jacobson SW. Spatial navigation in children and young adults with fetal alcohol spectrum disorders. *Alcohol Clin Exp Res.* 2019;43(12):2536–46. <http://dx.doi.org/10.1111/acer.14210>
 41. Podsiadlo JD, Bscpt S, Richardson MDJ. The timed “Up & Go”: A Test of Basic Functional Mobility for frail Elderly Persons. *J Am Geriatr Soc.* 1991;39(2):142–8. <http://dx.doi.org/10.1111/j.1532-5415.1991.tb01616.x>
 42. Nasreddine ZS, Phillips NA, Bédirian V, Charbonneau S, Whitehead V, Collin I, et al. The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. *J Am Geriatr Soc.* 2005;53(4):695–9. <http://dx.doi.org/10.1111/j.1532-5415.2005.53221.x>
 43. Almaguer-Rodríguez AG, Riquelme-Heras H, Gómez-Gómez C, Méndez-Espinosa E, Gutiérrez-Herrera R, Ordoñez-Azua Y. Evaluation of the daily cognitive function of adults and elderly adults through the use of ECog (everyday cognition). *Revista Ecuatoriana de Neurología.* 2023;32(3):40–46. <https://doi.org/10.46997/revecuatneurol32300040>
 44. Opitz B. Memory function and the hippocampus. *Frontiers of Neurology and Neuroscience.* S. Karger AG; 2014.p. 51–9. <https://doi.org/10.1159/000356422>
 45. Marreros-Tananta J, Guerrero-Alcedo JM. Psychometric properties of the neuropsychological evaluation test – Neuropsi in peruvian population. *Revista Ecuatoriana de Neurología.* 2022;31(1): 40–48. <https://doi.org/10.46997/revecuatneurol31100040>
 46. Zegarra-Valdivia JA, Chino-Vilca BN, Paredes-Manrique CN. Cognitive impairment prevalence in peruvian middle-Age and elderly adults. *Revista Ecuatoriana de Neurología.* 2023;32(1):43–54. <https://doi.org/10.46997/revecuatneurol32100043>
 47. Bauer ACM, Andringa G. The potential of immersive virtual reality for cognitive training in elderly. *Gerontology.* 2020;66(6):614–23. <http://dx.doi.org/10.1159/000509830>

Funding: This work was supported by Instalación-VIDCA INS-INV-2020-31.

Declaration of interests: The authors declare that they have no conflicts of interest.