

Assessment of visuospatial working memory using virtual reality: Design of the Corsi Cubes video game

Evaluación de la memoria de trabajo visoespacial mediante realidad virtual: diseño del videojuego Cubos Corsi

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SUMMARY

Background: *Visuospatial memory is fundamental to understanding and learning, as it allows individuals to remember and manipulate information about the space around them and the objects within it, enabling the orientation, attention, and memory required for daily activities. Traditional assessments of visuospatial memory, such as the Corsi block-tapping task, can be highly motivating in their standard application, especially in infant populations, given the wide range of available technological options, which can undermine the accuracy of their results. In this sense, the research aimed to design and preliminarily validate an educational virtual reality video game to assess short-term visuospatial memory in an immersive, automated manner.*

Material and methods: *Design Thinking methodology was used for software development.*

Results: *A responsive web application, using the Three.js library for Meta Quest 2 viewers via WebXR, which is an accessible tool that automates the patient's cognitive record.*

Conclusions: *A video game is a viable and innovative alternative for neuroeducation.*

Keywords: *Virtual reality, visuospatial memory, Corsi test, gamification, WebXR, cognitive assessment.*

RESUMEN

Introducción: *La memoria visoespacial es fundamental para la comprensión y el aprendizaje, ya que permite a un individuo recordar y manipular información sobre*

DOI: <https://doi.org/10.47307/GMC.2026.134.S2.3>

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Recibido: 20 de diciembre 2025

Aceptado: 22 de febrero 2026

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el espacio que le rodea y los objetos que hay dentro de él, lo que favorece la orientación, la atención y la memoria necesarias para el desarrollo de las actividades diarias. Las evaluaciones tradicionales de la memoria visoespacial, como la prueba de Cubos Corsi, pueden resultar menos motivadoras en su aplicación tradicional, especialmente en población infantil, por lo que conviene considerar las diferentes opciones tecnológicas ampliamente disponibles, lo cual puede debilitar la precisión de sus resultados. En este sentido, el estudio tuvo como objetivo el diseño y la validación preliminar de un videojuego educativo en realidad virtual para evaluar de manera inmersiva y automatizada la memoria visoespacial a corto plazo.

Materiales y métodos: *Se utilizó la metodología Design Thinking para el desarrollo del software.*

Resultados: *Se obtuvo una aplicación web responsive que utiliza la librería Three.js para los visores Meta Quest 2 mediante WebXR, lo que constituye una herramienta accesible que automatiza el registro cognitivo del paciente.*

Conclusiones: *El videojuego se propone como una alternativa viable e innovadora para la neuroeducación.*

Palabras clave: *Realidad virtual, memoria visoespacial, test de Corsi, gamificación, WebXR, evaluación cognitiva.*

INTRODUCTION

Working memory is considered a highly relevant cognitive ability inasmuch as it allows us to retain information about what happened before in mind and relate it to what comes next. It is considered an important skill in various learning processes, including reading, writing, and mathematics (1), and is also taken into account when calculating IQ (2). This skill can be defined as the ability to temporarily retain information for mental manipulation, considering two modalities: auditory and visuospatial (3). The auditory modality of working memory has been extensively studied in clinical and school settings, being evaluated mainly with mental tasks such as the retention of digits in direct and reverse order (4-6) among other digitized tasks (7) that allow its exploration and training, while in the visuospatial plane it is conceived as a system that allows one to temporarily keep in mind visual information required to carry out tasks that involve complex demands in their execution. The most common way to evaluate this construct is the Corsi Block-Tapping Task,

for which robust normative data on spatial storage capacity across different population groups have been obtained (8). However, less emphasis has been placed on digital versions. With the advent of new technologies, various digital adaptations of the test have emerged, including the eCorsi test, which enables standardization and greater precision in the collection of response times (9) while preserving the degree of abstraction and the two dimensions of the original test. Despite the advent of new technologies, the current approach to the problem focuses on ecological or motivational issues with the tool. In fact, these traditional tests, which are conducted on paper or on a screen, often do not fully capture the dynamic complexity of cognitive processing in real life, particularly in children, as the project must capture participants' attention. The literature review indicates that learning and cognitive performance depend on emotion and engagement (10) and that traditional practices provide little stimulus for children, which reduces the validity of the results due to their lack of interest. However, virtual reality (VR) has been conceived as a technology-based solution capable of creating immersive experiences that exponentially increase engagement and the possibility of situated learning (11). Research on VR-based instruction suggests that this technology improves learning outcomes compared to conventional methods (12) and provides a context for more sustainable and sensitive neuropsychological assessments (13).

Despite evidence of VR's effectiveness and its growing clinical acceptance (14), there are very few standardized technological applications that provide the psychometric rigor of the Corsi test and incorporate gamification elements specifically designed for the school context. The validation of new immersive tools poses a challenge for professional practice, as metrics can be compared with desktop tests when these are designed with usability and user experience in mind across different environments (15).

The purpose of this study was to construct an educational virtual reality video game, "Cubos Corsi VR," to assess short-term visuospatial memory and address this need. This tool aims to assess short-term visuospatial memory in children aged 8 to 12 by integrating Corsi-type sequences into an immersive three-dimensional

environment that seeks to enhance motivation, concentration, and data recording accuracy, thereby overcoming the limitations of traditional two-dimensional assessments.

METHOD

Design

An exploratory design with a *Design and Development Research (DDR)* approach was proposed to design and preliminarily validate technology-supported neuropsychological assessment instruments. Design Thinking, a user-centered methodology with iterative improvement cycles, was used to develop the “Cubos Corsi VR” video game. This methodology has been reported to be useful for the development of serious educational games and digital health solutions (16). This approach organizes the process into five stages, repeated according to the findings: empathize, define, ideate, prototype, and test. The aim is to achieve a technically feasible implementation and an attractive experience for children (17).

The study was divided into two main phases: (I) Design of the virtual environment according to the principles of the standard Corsi test, and (II) Development of an educational video game for assessing short-term visuospatial memory in children aged 8 to 12 years.

Instruments and Materials

Hardware and Virtual Reality Configuration: The Meta Quest 2 headset was used for the virtual reality configuration. This is a standalone device that allows physical movement and manipulation of objects within the virtual environment. This is achieved by its six degrees of freedom (6DoF) tracking, which records the user’s movement on six axes. This device was selected for its high resolution and because it does not require external sensors for hand tracking, making it easy to use in school and professional environments (18).

Software Development and WebXR Architecture

The VR Corsi Cubes were developed with Three.js, a lightweight JavaScript-based

library for rendering 3D graphics in web browsers. The WebXR Device API standard was implemented, which guarantees accessibility and interoperability, allowing the application to run directly in a browser without complex installation, thereby democratizing access to cognitive assessment tools (19). The virtual environment was optimized to maintain a stable refresh rate (72-90 Hz) to minimize visual-motor latency, a critical factor for the validity of reaction time measurements.

The central stimulus of the VR Corsi Cubes consists of an immersive adaptation of the Corsi Block-Tapping Task (20). This test, in its traditional form as a cognitive assessment of visuospatial working memory, involves a board with nine identical cubes arranged in an irregular pattern. During the task, the evaluator taps a sequence of cubes at a constant rate (approximately one per second), and the participant must reproduce the sequence in the same order immediately after its presentation. The sequence begins with two cubes and increases progressively, thereby increasing the memory demands. A minimalist, distraction-free setting (dark neutral background) was designed for the video game, where three-dimensional cubes float at an ergonomic height adjustable to the user. The dynamics of the test follow the standard protocol validated by Kessels et al. (8, 21), adapted to virtual interaction: where the user (children aged 8 to 12) receives a stimulus when interacting with the cubes, which light up sequentially in a distinctive color, accompanied by an auditory stimulus to reinforce multisensory coding; in response, the user must replicate the sequence by touching the virtual cubes with the hand controllers or by hand tracking, imitating the natural spatial response. To measure progress, the test begins with a sequence of two cubes. After two consecutive correct attempts, the sequence length increases by 1 item (level +1) and ends automatically when the participant makes 2 mistakes at the same level of difficulty.

Procedure

The development of the video game followed the phases of the Design Thinking methodology, detailed below:

- Empathize phase: A comprehensive review of the literature (2020-2025) and interviews were conducted with three neuropsychology experts to understand the scope and limitations of current tests. These interviews revealed a trend toward cognitive assessment primarily using traditional paper-and-pencil tests, involving block manipulation, manual time recording, and counting of correct and incorrect responses. While this assessment methodology has been widely used and validated, it may be less appealing to children and adolescents due to competition from the wide range of available technology, potentially underestimating their actual working memory capacity (22). An “Actor Map” (Figure 1) was constructed to visualize the interaction between the population of children between 8 and 12 years of age (end users), health professionals (psychologists), health entities that can be linked to strengthen the results, and universities that participate in research processes and manage the knowledge and technology that facilitates product development.
- Definition phase: To test this phase, a summary of the findings from the literature review was prepared and compared with an interview aimed at identifying technical and pedagogical requirements. It was established that the system should automatically record (a) correct and errors, (b) memory level or maximum level achieved, (c) reaction time for each movement, and (d) total duration of the session. Design criteria based on cognitive accessibility were also established, with a clean interface and no unnecessary elements that could distract the child or consume attentional resources.
- Ideation phase: Brainstorming sessions were used to construct a Priority Diagram to choose the key features of the Minimum Viable Product (MVP). Gamification mechanics such as Simon Says were included, with color and sound cues to sustain attention during the task. An extensive story was ruled out, as it could introduce distractions and affect the direct measurement of spatial memory in children. In this phase, the presentation of the block-based cognitive assessment tasks was defined, including the ordering of the levels to be presented to the participant, the frequency of the stimuli, the time, and the recording indicators.
- Prototyping phase: A functional prototype with iteration capability was developed. First, low-fidelity sketches were made to establish the spatial arrangement of the cubes (Figure 2). Then, the environment was implemented in Three.js, and algorithms were programmed to generate random sequences, avoiding identical patterns across consecutive attempts, which helps preserve the internal validity of the test. A diegetic user interface (UI) was designed that shows the score and current level within the virtual world without breaking immersion.
- Testing Phase (preliminary validation): The participants in the pilot sample performed the entire task in individual sessions lasting approximately 10 to 15 minutes. The Department of Research and Innovation endorsed the testing protocol. It included participation by five students from the Multimedia Engineering program at Universidad Simón Bolívar, who signed informed consent before the study. For testing, the viewer and the safe play area were

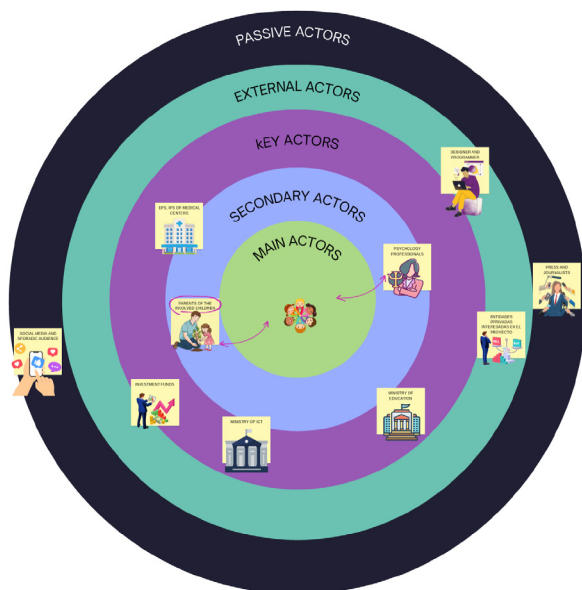


Figure 1. Map of actors. Source: Own elaboration.

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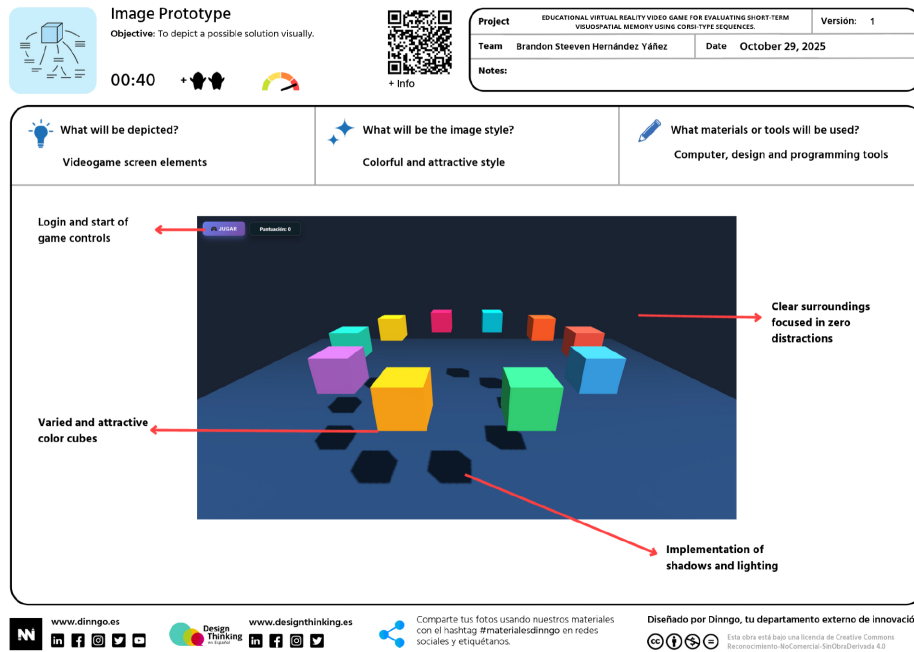


Figure 2. Base prototype of the video game. Source: Own work, using tools from designthinking.es.

adjusted, and the video game’s instructions were presented as visual text before the test began. The memory task was performed until the stop criterion was met, generating an Excel file containing the performance data, which is automatically exported for analysis. Qualitative feedback was also collected on the comfort of the viewer, the clarity of the instructions, and the sense of presence.

Data Analysis

The “VRCorsiCubes” system was programmed to perform automatic telemetric recording, eliminating the error of manual recording by the evaluator. The dependent variables stored by the algorithm include: the maximum length of the correctly reproduced sequence, the percentage of incorrect sequences among the total number of attempts, the time, in milliseconds, elapsed from the end of the stimulus presentation to the user’s first touch, and the cumulative score based on gamified performance.

For the pilot validation analysis, descriptive statistics (mean and standard deviation) were used to characterize the performance of the technical sample serving as a quality control for the software (23). Usability was evaluated qualitatively through content analysis of participants’ verbal reports during the debriefing.

RESULTS

Implementation and Technical Performance of the Virtual Environment

The development of the “VR Corsi Cubes” prototype culminated in a functional, responsive web application built on the WebXR architecture, enabling native deployment in the Meta Quest 2 viewer browser without external software installations. Technical performance tests revealed that using the Three.js library in a single optimized HTML file kept computational load low, maintaining a stable refresh rate between 72 and 90 Hz. Maintaining these refresh rates is key

because several studies indicate that frequencies below 60 Hz in virtual reality can induce vestibular dissonance and discomfort associated with cybersickness. These effects compromise the validity of any cognitive measurement (24).

The rendering of the 3D environment showed stable performance under moderate graphics load. Figure 3 shows a minimalist scene with dynamic

lighting, in which floating cubes cast consistent shadows on a neutral plane. This approach, verified in technical terms, reduces the likelihood of visual artifacts or frame drops that could divert attention or alter the perception of the stimulus sequence. In the pilot test, no perceptible delay was reported between controller movement and visual response, supporting the viability of WebXR in tasks requiring psychomotor precision.



Figure 3. View of the final immersive environment. Source: Own elaboration.

A circular arrangement of ten interactive cubes is visible on a neutral plane. They were designed with high-contrast colors and numbering to aid visual discrimination and sustain attention during the test.

The “Play” button and score counter are placed as diegetic elements within the 3D space. The evaluator and user can track the session’s progress without leaving the immersive environment.

Validation of interaction and user experience (UX)

The user experience evaluation of a pilot sample of Multimedia Engineering students (n=5) yielded relevant qualitative findings regarding ergonomics and immersion. Participants described the interaction with virtual reality controllers (6DoF) as natural and intuitive. Multimodal feedback worked adequately:

when selecting a cube, the system responded immediately with a visual change in lighting and an auditory signal using an assigned tone. Post-test comments indicated that multisensory feedback strengthened the sense of presence and allowed for confirmation of the selection, with less uncertainty during the task.

During testing, key aspects for refining the design were identified. Initially, it was observed that the sequence presentation was too fast for some users, with a short interval between the lighting up of one cube and the next. This pace increased anxiety and led to unforced errors. The stimulus interval was modified from 500 ms to 1 000 ms, with a cognitive processing margin more appropriate for the target child population (25). The diegetic scoring interface, visible as a floating element within the virtual environment (Figure 4), received a favorable assessment; it does not break immersion and maintains attention on task execution.

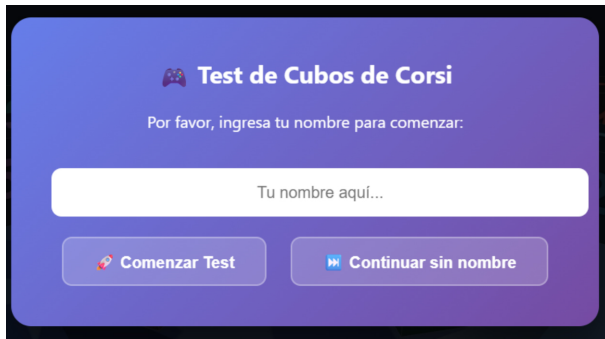


Figure 4. Diegetic user interface and login. Source: Own elaboration.

Automated recording system and cognitive metrics

One of the key contributions was verifying the telemetry and recording system. In the conventional Corsi test, the evaluator takes notes manually; in “VR Corsi Cubes,” the capture of performance variables was automated with millisecond resolution. The algorithm recorded four metrics per session and produced consistent outputs: an Excel report was generated with the level achieved and the breakpoint identified when the user failed two consecutive attempts; at that point, the test was stopped, and the maximum level was saved. Accumulated hits and errors were counted to calculate effectiveness percentages, the total session duration, and the average response latency. A “Session History” panel was also enabled to save previous attempts (Figure 5).

The implemented functionality for exporting data to Excel (Figure 6) worked stably and generated structured files ready for statistical analysis. The result places the tool as a measurement instrument with objective and comparable data, not as an isolated game.

For each attempt, the interface displays specific metrics such as duration, score, errors, and level achieved. This visibility makes longitudinal monitoring of user performance easier.

The system presents performance by level and by sequence. This gives us a breakdown that provides an immediate reading of the evaluated person’s visuospatial working memory performance.



Figure 5. Session history panel. Source: Own elaboration.

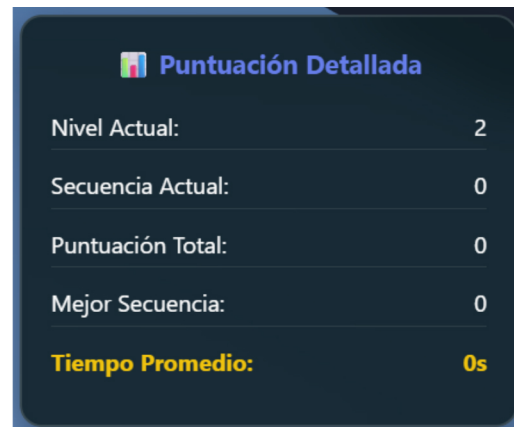


Figure 6. Detailed score display. Source: Own elaboration.

Preliminary comparison with parameters

The purpose of this phase was to check technical and usability aspects. Initial data from the pilot sample showed that the mechanics distinguish levels of difficulty. Participants progressed from sequences of 2 items to higher ranges of 5–6 items. This behavior coincides with the expected progression in the standard Corsi test. The result suggests that the transition to a 3D environment does not add an extraneous cognitive load that alters the measurement of basic memory capacity. From the records generated by the game,

it is possible to obtain direct scores expressed in hits, errors, and response times, which in later phases of the study can be applied to samples of a normal population to obtain normative data and preserve the psychometric validity of the existing task within the neuropsychological evaluation.

DISCUSSION

The main purpose of the study was to design and preliminarily validate the video game “VR Corsi Cubes” as a tool that combines psychometric accuracy with gamification-based motivation. The results obtained show that the implementation using the WebXR architecture remained stable at the technical level and enabled the standard Corsi protocol to be reproduced. This supports the feasibility of bringing classic neuropsychological tasks to easily accessible immersive environments, demonstrating their technological and conceptual viability and enabling further studies of their use in other populations.

The literature reports that gamification in virtual reality increases the ecological validity of assessments (26). In the pilot sample, a favorable response to multisensory feedback and the 3D environment was recorded. The “liveness” of the system was linked to greater sustained attention. The format mitigates motivational barriers described in traditional pencil-and-paper tests (4). Mystakidis points to the sense of presence as a decisive variable in the effectiveness of immersive educational interventions (27).

Comparison with previous methods: when comparing the results with previous digital adaptations, such as eCorsi (1). The video game “VR Corsi Cubes” provides a significant advantage in terms of interaction. While eCorsi maintains a two-dimensional response (click), the tool that integrates virtual reality requires natural visomotor interaction (3D reach and touch). This is consistent with recent systematic reviews indicating that immersion activates more complex cognitive networks without compromising measurement accuracy (28). The latency and level data obtained remain within the expected ranges, suggesting that the additional cognitive load of the virtual environment does not distort

memory measurement, a common concern in the literature that our results help to dispel.

Technical and safety implications

From a technical perspective, the reported stable performance of 72-90 Hz validates the choice of lightweight libraries (Three.js) over heavy graphics engines. This result meets the safety standards for minimizing cybersickness described by Somrak et al. (29). It validates the use of WebXR technologies to democratize access to clinical tools, as proposed by Li et al. (19).

CONCLUSION

This study concludes that implementing the video game “VR Corsi Cubes” using WebXR technology is a viable solution for modernizing the assessment of visuospatial memory in children. The tool achieved the objective of combining the rigor of the standard Corsi task’s methodology with the principles of neuropsychology in an immersive gamified environment. The recording of cognitive variables was automated without affecting usability or technical stability. The results of this initial validation indicate that accessible virtual environments can provide useful records for cognitive assessment and increase motivation compared to traditional tests. This approach shows promise as a valuable resource for neuroeducation and for supporting early detection of strengths and needs in school settings. Therefore, future phases of the study are expected to continue its implementation in neurotypical and clinical populations to further the validation and standardization process.

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