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Validating iCorsi: An immersive virtual reality adaptation of the Corsi Block Tapping Test

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ABSTRACT

Immersive virtual reality (iVR) is increasingly used for cognitive assessment, yet its validity relative to established neuropsychological tools remains insufficiently characterized. The present study evaluates a novel iVR adaptation of the Corsi Block Tapping Test (iCorsi) as a measure of visuospatial working memory. Seventy participants completed both the traditional physical CBTT and the iCorsi, in forward and backward conditions, along with additional cognitive tasks assessing verbal working memory, attentional control, and executive functioning.

Performance across modalities was strongly correlated, indicating that iCorsi and the traditional CBTT capture consistent individual differences and rely on a shared underlying visuospatial working memory construct. Frequentist repeated-measures analyses suggested broad comparability between the two task formats, with no reliable main effect of modality. Bayesian paired comparisons provided some evidence of higher performance in the immersive version in the forward condition; however, this difference was modest and did not alter the overall pattern of results.

Taken together, these findings support the validity of iCorsi as a measure of visuospatial working memory, while suggesting that minor performance differences across formats may reflect task-related factors—such as attentional engagement—rather than differences in the underlying construct. Additionally, Stroop performance was associated with visuospatial working memory, highlighting the contribution of attentional control to task performance.

These results indicate that iVR can provide a valid and scalable platform for cognitive assessment, while underscoring the importance of considering how features of task presentation may subtly influence performance.

1. Introduction

The Corsi Block Tapping Test (CBTT; Corsi, 1972) is a widely used measure of visuospatial working memory in both research and clinical neuropsychology (Arce & McMullen, 2021). It is commonly included in diagnostic batteries for the assessment of neuropsychological conditions, including Alzheimer's disease and other neurological disorders (Carlesimo et al., 1994; Guariglia, 2007).

In its standard form, the CBTT consists of nine blocks arranged on a board. The examiner taps a sequence of blocks, and the participant reproduces it either in the same order (forward) or in reverse order (backward). Sequence length increases progressively until performance fails. Forward span is typically interpreted as a measure of visuospatial memory capacity, whereas backward span is associated with the manipulation of visuospatial information (Corsi, 1972). Previous research has shown that performance on the CBTT is associated with a broader set of cognitive functions, including attention and executive control processes (see Cavallini et al., 2003). Accordingly, standard measures such as Digit Span, the Stroop Test, and the Trail Making Test are often included alongside the Corsi to assess related cognitive processes.

Over the years, several adaptations of the Corsi Block Tapping Test (CBTT) have introduced modifications to the number and arrangement of blocks, administration methods (e.g., variations in sequence length and number), and scoring criteria (see, for example, Kessels et al., 2000; Monaco et al., 2013). Some versions have diverged further from the

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original test to assess additional cognitive components beyond visuospatial working memory span—for instance, the walkable Corsi test, which enables the analysis of spatial memory processes involved in wayfinding and topographical working memory (Piccardi et al., 2008).

Advancements in information technology have led to computerized versions of the CBTT, improving control over administration and scoring (Brunetti et al., 2014; Mueller & Piper, 2014). However, these implementations are typically limited to two-dimensional interfaces and may alter the spatial characteristics of the task (Arce & McMullen, 2021). Virtual reality (VR) provides a potential solution by enabling three-dimensional interaction while preserving the spatial structure of the original test.

Immersive virtual reality (iVR) has been increasingly used in the assessment of cognitive functions, often through complex and ecologically rich environments (Kim et al., 2021; Neguț et al., 2016). While these approaches enhance ecological validity, they may also introduce additional task demands and contextual variables that may influence performance (Neguț et al., 2016; Bell et al., 2020). As a result, it becomes difficult to disentangle the effects of the testing medium from the cognitive processes being measured, limiting direct comparability with traditional neuropsychological tests.

At the same time, iVR offers several advantages for cognitive assessment, including controlled stimulus presentation, standardized administration, and the possibility of remote testing. Importantly, iVR enables three-dimensional interaction and more realistic spatial representations of stimuli, which may better preserve the spatial characteristics of tasks such as the CBTT. However, whether cognitive tests administered in immersive environments are truly comparable to their traditional counterparts remains an open question. Existing VR adaptations of standardized tasks often vary in design and methodological rigor, further complicating direct comparisons (Neguț et al., 2016). In addition, factors such as technological familiarity, cybersickness, and the presence of environmental distractors may influence performance independently of the cognitive processes being measured (Bell et al., 2020; Neguț et al., 2016).

Recently, Szabó and colleagues developed a VR adaptation of the CBTT and compared it with the traditional version (Szabó et al., 2024). Their findings provide important initial evidence on the feasibility of implementing the Corsi task in immersive virtual environments, highlighting potential applications such as increased accessibility and customizable testing contexts. At the same time, differences in interaction modality and environmental configuration across implementations can make direct comparisons with the traditional task more complex. For this reason, further work is needed to examine VR-based implementations that more closely align with standardized task parameters, allowing a more direct assessment of comparability across modalities.

To address these limitations, the present study introduces Immersive Corsi (iCorsi), a virtual reality implementation of the standardized Corsi Block Tapping Test (Kessels et al., 2000; Mammarella et al., 2008). The iCorsi was designed to closely replicate the structure, spatial configuration, and administration parameters of the traditional task, while enabling precise control over stimulus presentation, an aspect known to influence performance in computerized versions of the Corsi test (Berch et al., 1998; Fischer, 2001). In particular, the virtual environment preserves the three-dimensional spatial characteristics of the original setup (Arce & McMullen, 2021) and allows direct hand interaction with the stimuli, minimizing differences in motor and perceptual demands across modalities (Argelaguet et al., 2016; Dewez et al., 2021; Tran et al., 2017). Both forward and backward conditions are implemented to match standard CBTT procedures (Corsi, 1972; Kessels et al., 2000). This design enables a direct comparison between modalities while minimizing task-related differences, thereby isolating the effect of the testing medium itself.

In addition to cognitive performance, individual differences related to VR experience were assessed through pre- and post-session questionnaires. These measures capture prior familiarity with immersive environments and subjective responses to the task, allowing us to examine whether such factors may influence performance independently of the cognitive processes under investigation.

The primary aim of this study is to compare participants' performance across the two versions of the Corsi Block Tapping Test—traditional and immersive VR-based—in both forward and backward conditions. Given that the iCorsi was designed to closely replicate the structure, stimuli, and administration parameters of the standardized CBTT, we do not expect systematic performance differences between the two modalities. Rather than testing for superiority of one format over the other, the present study adopts a validation framework, in which the critical question is whether the two versions yield comparable outcomes. Accordingly, we expect strong positive correlations between performance on the iCorsi and the traditional CBTT, reflecting their shared underlying cognitive construct of visuospatial working memory. In addition, we examine whether the two modalities show similar patterns of association with related cognitive measures (Digit Span, TMT-B, Stroop), as a further indication of construct validity. Together, these analyses are intended to evaluate the extent to which iCorsi can be considered a functionally equivalent and psychometrically comparable tool to the traditional Corsi test.

2. Methods

2.1. Participants

Seventy participants (49 females) took part in the study. They were recruited on a voluntary basis from among students at the University of Cagliari, Italy. All participants were adults (M = 23.8 years, SD = 3.84, range = 19–33 years) who self-reported typical development and had no history of cognitive or perceptual disorders. All participants had normal or corrected-to-normal vision and provided written informed consent prior to participation. Prior to participation, individuals completed a screening questionnaire addressing susceptibility to motion sickness, dizziness, balance problems, or discomfort during immersive experiences. No participant reported any of these issues; therefore, no one was excluded on this basis. Furthermore, no participant reported discomfort during or after the VR experience.

2.2. Materials

The tests used in this study included the iCorsi, the traditional Corsi Block-Tapping Test (CBTT), the Trail Making Test Part B (Italian version by Mondini et al., 2011), the Digit Span Forward and Backward subtests, and the Digit Reordering test from the WAIS-IV (Wechsler, 2008) as well as the Stroop Test (Stroop, 1935; Italian adaptation by Di Nuovo (2013)). Descriptions of all tests, apparatuses, and administration procedures are provided below.

2.2.1. iCorsi

iCorsi is a virtual reality adaptation of the Corsi Block-Tapping Test standardized version proposed by Kessels and colleagues (2000) and Mammarella et al. (2008), the sequences of items used in this study are derived from Mammarella et al. (2008) as in the traditional Corsi (see description below). In addition to the iCorsi environment, another virtual environment, the Device Familiarization Environment (DFE) was developed to enable participants to learn how to interact with objects in immersive virtual reality (iVR). Both the iCorsi and DFE environments were developed specifically for this study by the software house INFORA Soc. Coop., in collaboration with the University of Cagliari. Both applications were created using the Unity game engine development platform. According to Petridis et al. (2012), Unity provides all the essential components necessary for the creation of serious applications, such as serious games or simulations.

We aimed to keep the physical and virtual testing environments as similar as possible, in order to minimize additional factors such as contextual richness or environmental distractions that might have influenced task performance. The traditional Corsi test was administered in a laboratory setting characterized by white walls and minimal furnishings, and the VR environment was designed to closely replicate this same spatial context. The virtual environment in both applications (iCorsi and DFE) is simple, featuring a few pieces of furniture and a table on which the various materials appear. Additionally, a monitor provides written instructions, accompanied by audio, and a button allows users to navigate through the instructions. The virtual objects included in the DFE consist of 3D objects of different geometric shapes in different colors (see Fig. 1), in this environment, participants complete five simple object-manipulation tasks in sequence, which allow them to familiarize themselves with the device, the virtual environment, its objects, and the manipulation of the iCorsi environment.

The iCorsi materials consist of nine small, neutral-colored virtual cubes, each with an apparent size of 3 cm on each side (see Fig. 2). The cubes are analogous in both dimension and spatial layout to those used in the standardized Corsi Block-Tapping Test (CBTT) proposed by Kessels et al. (2000) and Mammarella et al. (2008). The avatar embodied by the participants in the environment is represented solely by a pair of transparent hands, which are precisely tracked up to the height of the wrists by the internal hand-tracking system of the headset. In accordance with the literature, avatars of this type optimize performance without disrupting the illusion of presence and possession (Herrera & Bailenson, 2021). Additionally, they help prevent unpleasant visual occlusion effects that could interfere with the manipulation of virtual objects (Argelaguet et al., 2016; Dewez et al., 2021; Tran et al., 2017).

The software runs on the head-mounted device (HMD) Meta Quest 2, developed by Facebook Reality Labs (formerly Oculus), which is capable of recreating highly immersive and engaging experiences (Sanchez-Vives & Slater, 2005). The lightweight and easily portable device offers excellent video quality, with a refresh rate of 90 Hz and a resolution of 1832 x 1920, providing a 90° field of view. The Meta Quest 2 has 50% more pixels than its predecessor, delivering sharper and more readable images without the so-called “screen door effect.” The goggles are equipped with two integrated speakers in the side arms and a microphone, as well as four infrared cameras for positional tracking of the head and hands (allowing use even without a controller).

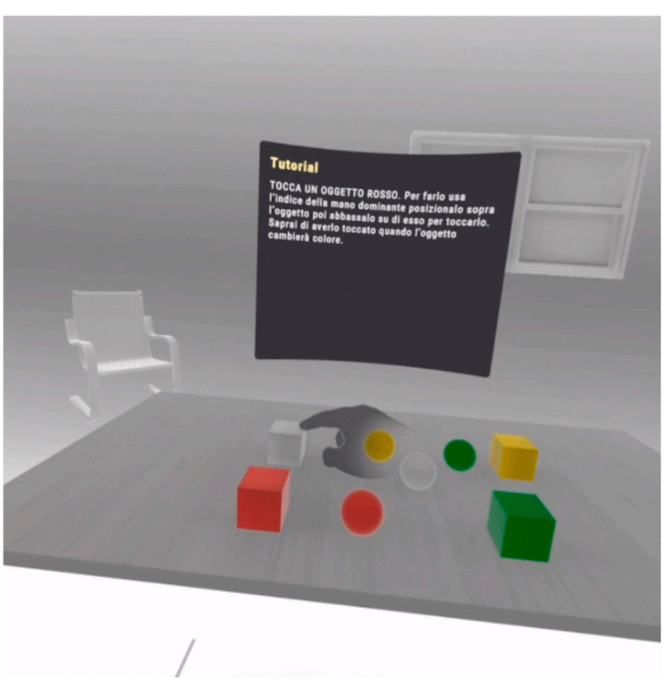

Fig. 1. Device Familiarization Environment: The virtual hand simulates the position of the real hand in the virtual environment.

Additionally, the device features a gyroscope and accelerometer, enabling its use in standalone mode and within a room-scale action space (2 × 2 meters), thereby enhancing the user's movement experience.

During the iCorsi administration, once the test parameters have been configured and the participant's code entered into the iCorsi software, the experimenter assists the participant in placing and adjusting the headset before seating them on a chair. The participant subsequently accesses the virtual Device Familiarization Environment (DFE, see Fig. 1), where they are embodied as an avatar represented solely by a pair of hands.

Once the familiarization tasks have been completed, nine cubes appear on the table in pseudo-random order (as in the traditional version) and after a brief training session, the participant performs the forward version of the iCorsi test according to the sequences taken from the BVS-Corsi manual (Mammarella et al., 2008).

The test consisted of sequences of blocks that increased progressively in length. During each trial, a series of cubes lit up sequentially with a blue light for 500 ms (tap rate), at a pace of one cube every 1000 ms (inter-tap rate). Participants were instructed to reproduce each sequence by touching the cubes in the same order in which they had just illuminated (see Fig. 2). At the end of each sequence, a short sound signal prompted the participant to start reproducing the sequence. The task began with sequences of three cubes, each sequence length being presented three times. For every sequence length, the three trials differed in the specific order of cube illumination. After completing the three trials of a given length, the sequence length increased by one cube, and a new set of three sequences was presented. The test was automatically terminated when the participant failed to correctly reproduce two out of the three sequences at the same length level.

After completing the forward test, participants remove the HMD and take a short break while the experimenter adjusts the parameters. The participants then perform the iCorsi backward test, preceded by a new brief training session for the backward mode. The backward version of the ICorsi test followed the same procedure as the forward version, except for the response phase. After observing each sequence, participants were instructed to reproduce it by touching the cubes in the reverse order of presentation, that is, starting from the last cube that had been illuminated and proceeding backward to the first.

Performance was measured as *visuospatial span,* which is defined as the longest sequence correctly reproduced with no more than one error out of three trials at a given sequence length (Mammarella et al., 2008). Both forward and backward visuospatial working memory spans were recorded for each participant.

2.2.2. Traditional CBTT

We employed the forward and backward versions of the Corsi Block-Tapping Test developed by Mammarella and collaborators (Mammarella et al., 2008). This version replicates the procedural parameters described by Kessels et al. (2000) but uses a different order of stimulus presentation.

The apparatus consists of a wooden board with nine cubes arranged in a pseudo-random pattern. The cubes are numbered on the examiner's side only, to facilitate test administration. During each trial, the examiner points to the cubes using a stick (about 1 s of inter-tap rate), and at the end of the sequence the participant is required to reproduce the same sequence (Corsi Forward) or the reverse sequence (Corsi Backward) by touching the cubes in the appropriate order.

The test is organized into increasing Levels of Complexity (LOCs), defined by the length of the sequences. Each LOC includes three different sequences of the same length. Correct reproduction of at least two out of the three sequences within a given LOC allows the participant to proceed to the next level. The test is discontinued after two consecutive errors within the same LOC.

As in the *iCorsi*, performance was measured as *visuospatial span*, defined as the longest sequence correctly reproduced with no more than

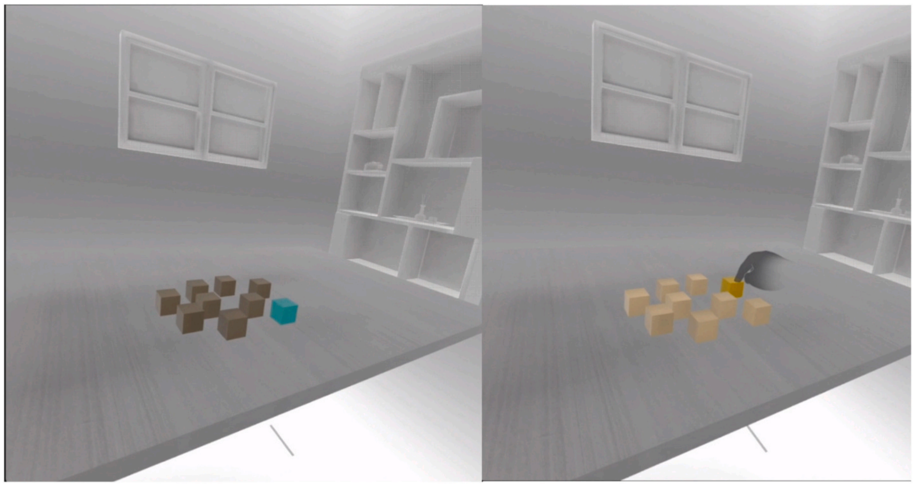

Fig. 2. iCorsi environment. On the left, a cube is highlighted by the system. On the right, the participant is reproducing the sequence tapping the cubes with the virtual hand.

one error out of three trials at a given sequence length (Mammarella et al., 2008). Both forward and backward visuospatial working memory spans were recorded for each participant.

2.2.3. The Trail Making Test B

The Trail Making Test B (Armitage, 1946; Italian adaptation by Mondini et al., 2011) assesses visuo-spatial search and executive functions. It is commonly used to evaluate cognitive flexibility by measuring the ability to manipulate multiple stimuli belonging to different codes simultaneously. Specifically, participants are instructed to draw a continuous line on a sheet of paper, using a pencil, to alternately connect numbers and letters in ascending order. Numbers and letters are arranged randomly, and the pencil must not be lifted from the paper. Typically, completion time and the number of errors are recorded as outcome variables. Due to the extremely low error rate, the analysis focused solely on completion time, measured in seconds. The TMT-A, a simpler version that includes only numbers and does not require code switching, was administered during the training phase.

2.2.4. Digit Span Test (WAIS-IV)

The WAIS IV Digit Span Test (Wechsler, 2008) is composed of three verbal memory tests, the forward digit span, the backward digit span, and the digit reordering. This test is designed to investigate the storage and processing capacity in phonological working memory. The sequences are of increasing length, starting from 2 digits up to 9. In the Reverse Digit Span, the procedure is similar except that the participant is asked to repeat the sequences of digits in a reverse order. The sequences have increasing lengths, starting from 2 digits up to 8. In the Digit Reordering task, the subject is asked to reorder the sequences of digits pronounced by the examiner in ascending order. For example, if the examiner says “6, 3, 8″, the correct response would be “3, 6, 8”. For all three-digit memory tests, each span level consists of two sequences of equal length. If the participant fails to correctly repeat both sequences, the test is terminated. According to the normative data of the WAIS-IV, task performance is calculated as a weighted score based on the total number of items correctly answered across all tests.

2.2.5. Stroop test

The Stroop test is one of the most widely used measures in neuropsychology (Ben-David et al., 2011). In its classic form, the test presents color names (e.g., “RED”, “BLUE”, “GREEN”) printed in an ink color that differs from the word itself (e.g., the word “RED” printed in blue ink). Participants are instructed to name the ink color rather than read the word. This incongruence induces cognitive interference, making it more difficult to ignore the word's meaning and focus on the ink color. The test is commonly used to assess inhibitory control, evaluating the ability to classify environmental information and respond appropriately while inhibiting responses to irrelevant stimuli (Golden et al., 2022). In the present study, Stroop performance was considered primarily as an index of visuospatial attention and was operationalized using response times. Interference scores were not analyzed due to minimal variability in the sample. Within the Stroop paradigm, attentional control processes act to counter and attenuate the interference arising from the automatization of the response (Logan, 1980). We employed a computerized version of the Stroop task included in the *Attention and Concentration Battery* (Di Nuovo, 2013). In this version, color names (e.g., RED, GREEN) are presented individually in uppercase letters at the center of the screen. As in the classic version, the ink color may match or mismatch the written word. Participants are required to identify the ink color, ignoring the word meaning, by pressing the keyboard key covered with the corresponding color cap. Response speed and accuracy are recorded. Given that accuracy was nearly 100%, median response time (in seconds) (see Fällman et al., 2020; Scarpina & Tagini, 2017 for reviews) was used as the primary performance measure.

2.2.6. Pre- and post-experience questionnaires

Two questionnaires were designed to measure the iVR experience of participants, a preliminary questionnaire (PreQ, 17 questions) and a post-experience questionnaire (PostQ, 29 questions).

PreQ questionnaire was used to register demographic data such as age, gender, and handedness. It also investigated the possible presence of physical issues (e.g., motion sickness, visual problems, balance issues or learning disabilities) and previous experiences sport related to the use of immersive and non-immersive VR devices, as well as practice with video games (e.g., video game type, platform used, average weekly hours played) and sport activities. Specifically, participants who self-identified as gamers and reported playing for at least 1 h per week were categorized as videogame players and assigned a code of 1, whereas those who did not identify as gamers were assigned a code of 0 (table 4 summarizing the main demographic and background variables is provided in Appendix A).

The PostQ questionnaire was used to investigate the experience of the so-called Presence, which refers to the psychological state in which a user feels fully immersed in and connected to the virtual environment, as if they are physically present within it (Witmer et al., 2005). The 29 questions have been translated into Italian from the Presence Questionnaire (PQ) by Witmer et al. (2005). The questionnaire allows us to evaluate Presence as a whole and through 4 dimensions: 1. Involvement, which measures the extent to which the design of the experience (visual and sound aspects, modality and response to interaction) allows subjects to feel completely immersed in the experience; 2. Sensory fidelity, which measures how realistic the experience is perceived through the different senses involved; 3. Adaptation/Immersion, which measures the subject's ability to adapt to the environment through their interactions and the involvement of their senses; 4) Interface quality, which measures how much hardware devices interfere during the experience and the user's interactions within the virtual environment. For data analysis, the total Presence score was used, calculated by adding the individual scores of the response scales (Witmer & Singer, 1994). The reliability in our sample for the overall Presence scale was Cronbach's alpha = 0.94.

Both questionnaires have been administered using Google forms and filled out by participants using a personal computer in the laboratory under the supervision of the experimenter, who intervened only in the event of technical problems or requests for clarification regarding the proposed questions.

2.3. Procedure

The research project received approval from the IRB (Institutional Review Board) of the University of Cagliari with Protocol n. 0152185 of 28/06/2023.

Data collection was conducted across two experimental sessions, during which all participants completed the following tasks: PreQ, Physical CBTT, iCorsi, Digit Span, Stroop Test, Trail Making Test Part B (TMT-B), and PostQ.

At the beginning of the first session, participants were informed about the aims and procedures of the study and provided written informed consent. To reduce potential learning and order effects—and because both the traditional Corsi Block-Tapping Test (CBTT) and the iCorsi were administered using identical tapping sequences—a counterbalanced design was implemented. Participants were randomly assigned to one of two groups (Group A or Group B), with gender distribution balanced across groups. The two versions of the Corsi task were administered 15 days apart (Deyo et al., 1991).

Group A completed the PreQ, the Physical CBTT, and two of the following tasks during the first session: Digit Span, Stroop Test, and TMT-B. In the second session, they completed the iCorsi, the PostQ, and the remaining task from the same set.

Group B completed the PreQ, the iCorsi, the PostQ, and one task among Digit Span, Stroop Test, and TMT-B during the first session. In the second session, they completed the Physical CBTT and the two remaining tasks.

The PreQ was always administered at the beginning of the first session, whereas the PostQ was administered immediately after the iCorsi. The order of administration of the additional cognitive tasks (Digit Span, Stroop Test, and TMT-B) followed a pseudorandom sequence to ensure a balanced distribution across participants.

2.4. Data analysis

Data were analyzed using the open-source statistical software Jamovi (version 2.3.21). First, descriptive statistics were computed for all variables included in the study, including forward and backward spans in the traditional Corsi Block-Tapping Test (CBTT) and in the immersive iCorsi, Digit Span scores, Trail Making Test Part B (TMT-B) completion time, Stroop task response time, and the total Presence score obtained from the post-experience questionnaire.

Second, Pearson's correlation analyses were conducted to examine associations among the continuous variables measured in the study (CBTT forward span, CBTT backward span, iCorsi forward span, iCorsi backward span, Digit Span score, TMT-B completion time, Stroop response time, and Presence score).

To examine relationships between continuous variables and categorical participant characteristics, point-biserial correlations were computed between the continuous variables and two dichotomous variables: Gender (coded as 0 = male, 1 = female) and Video game player status (coded as 0 = non-player, 1 = player).

Subsequently, a repeated-measures Analysis of Variance (ANOVA) was conducted to evaluate the effects of modality (traditional CBTT vs immersive iCorsi) and condition (Forward vs Backward) on visuospatial span performance. The independent variable was modality (traditional CBTT vs. iCorsi), while the dependent variable was visuospatial span, computed using identical sequences and scoring criteria across both conditions. Variables that showed significant correlations with any of the span measures in the preliminary correlation analysis were also included as covariates in the model.

In addition to frequentist analyses, Bayesian paired-samples t-tests were conducted to provide a complementary evaluation of performance differences between the traditional CBTT and the immersive iCorsi. Separate comparisons were performed for the Forward and Backward span scores. Bayesian analyses were conducted using the default Cauchy prior distribution (r = 0.707). Evidence for the alternative hypothesis relative to the null hypothesis was quantified using Bayes Factors (BF_{10}).

The present analyses are intended to assess comparability between modalities rather than to formally establish statistical equivalence; therefore, results are interpreted in terms of similarity of outcomes and strength of association rather than formal equivalence testing.

3. Results

3.1. Descriptive statistics

Descriptive statistics for all study variables are reported in Table 1, including forward and backward spans in the traditional CBTT and iCorsi, Digit Span scores, TMT-B completion time, Stroop response time, and the total Presence score.

3.2. Correlational analysis

Pearson's correlations (Table 2) revealed significant positive associations between corresponding measures of the traditional CBTT and the iCorsi. In particular, forward spans were moderately correlated across modalities ($r = 0.449$, $p < .001$), as were backward spans ($r = 0.394$, $p < .01$), supporting convergence between the two modalities in measuring visuospatial working memory.

Correlations between forward and backward conditions within each modality were comparatively weaker (CBTT: $r = 0.192$, $p > .05$; iCorsi: $r = 0.260$, $p < .05$), suggesting partial independence between the two components of the task.

Among the additional cognitive measures, Stroop performance was negatively associated with CBTT forward span ($r = -0.393$, $p < .001$), indicating that faster responses were associated with higher visuospatial span. No significant associations emerged between Corsi performance and TMT-B, Digit Span, videogame experience, or Presence (all ps > 0.05). A small but significant association was observed between gender and iCorsi forward performance ($r = -0.270$, $p < .05$).

3.3. Repeated-measures ANOVA

A repeated-measures ANOVA was conducted with Modality (CBTT vs. iCorsi) and Condition (Forward vs. Backward) as within-subject factors, with Stroop performance and Gender included as covariates. Normality was formally assessed using the Shapiro–Wilk test (see Table 1), which indicated significant deviations from normality for several variables. This outcome was expected given the bounded and discrete nature of span measures and the sample size. Inspection of standardized residuals via Q–Q plots (see Fig. 3) suggested approximate normality, and Levene's tests (See Table 3) indicated that the assumption of homogeneity of variance was largely met, with only a limited violation in one condition. Given that repeated-measures ANOVA is robust to

Table 1
Descriptive statistics of the variables considered in the study (n = 70).

Variable	Mean	SD	Range	Asymmetry		Kurtosis		Shapiro-Wilk	
				Asymmetry	SE	Kurtosis	SE	W	p
iCorsi-F span	5.82	1.12	3 - 8	−0.230	0.28	−0.464	0.5	0.92	<0.001
iCorsi-B span	5.10	1.1	3 – 7	−0.004	0.28	−0.634	0.5	0.91	<0.001
CBTT-F span	5.17	1.21	3 - 8	0.408	0.28	−1.105	0.5	0.85	<0.001
CBTT-B span	4.73	1.13	3 - 8	0.224	0.28	−0.150	0.5	0.91	<0.001
Verbal WM (WAIS)	7.32	2.39	3 – 12	0.146	0.28	−0.712	0.5	0.96	0.036
TMT-B (Time)	78.49	26.32	31.4 – 177.48	1.284	0.28	2.519	0.5	0.91	<0.001
Stroop (Time)	0.82	0.09	0.67 – 1.07	0.793	0.29	0.066	0.5	0.93	0.002
Presence	158.9	22.9	87 – 199	−0.584	0.28	0.576	0.5	0.97	0.143

Note. iCorsi-F span = iVR version of the Forward Corsi Block Tapping Task; iCorsi-B span = iVR version of the Backward Corsi Block Tapping Task; CBTT-F span = Forward Corsi Block Tapping Task classical version; CBTT-B span = Backward Corsi Block Tapping Task classical version; Verbal WM (WAIS) = weighted score of the WAIS three verbal subtest: Forward Digit span, Backward digit span and Number sequencing; TMT-B (Time) = execution time of Trial Making Test B; Stroop (Time) = the median time of execution of Stroop test; Presence = the total score of the Presence questionnaire.

Table 2
Correlations between the variables measured (n = 70).

Measure	1	2	3	4	5	6	7	8	9	10
1. CBTT-F span	-									
2. CBTT-B span	0.192	-								
3. iCorsi-F span	0.449***	0.310**	-							
4. iCorsi-B span	0.461**	0.394***	0.260*	-						
5. TMT-B (Time)	−0.159	−0.009	−0.116	−0.222	-					
6. Stroop (Time)	−0.393***	−0.169	−0.1182	−0.208	0.227	-				
7. Digit span (WAIS)	0.194	0.055	0.232	0.036	0.343**	−0.062	-			
8. Presence	−0.035	−0.061	0.144	−0.054	−0.114	0.076	0.085	-		
9. Gender	−0.062	−0.091	−0.270*	−0.025	−0.0323	0.086	−0.171	0.005	-	
10. Videogame_p	−0.013	0.138	0.147	−0.091	0.032	−0.023	0.156	−0.005	−0.309	-

Note. CBTT-F span = Forward Corsi Block Tapping Task classical version; CBTT-B span = Backward Corsi Block Tapping Task classical version; iCorsi-F span = iVR version of the Forward Corsi Block Tapping Task; iCorsi-B span = iVR version of the Backward Corsi Block Tapping Task; Digit span (WAIS) = weighted score of the WAIS three verbal subtest; TMT-B (Time) = execution time of Trial Making Test B; Stroop (Time) = the median time of execution of Stroop test; Presence = the total score of the Presence questionnaire; Gender: male (0); female (1); videogame player: yes (1); no (0). *p < .05. **p < .01. ***p < .001.

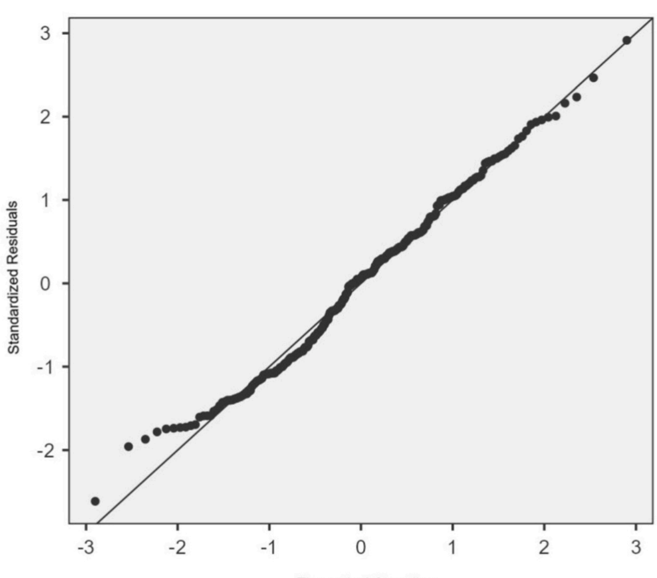

Fig. 3. Q–Q plot of standardized residuals.
Note: The distribution closely follows the theoretical normal line, with minor deviations at the tails.

moderate violations of normality and homoscedasticity under these conditions, the use of parametric analyses was considered appropriate.

No significant main effect of Modality was observed, $F(1, 66) = 0.554$, $p = .459$, indicating comparable performance between the traditional CBTT and iCorsi. The main effect of Condition was not significant, $F(1, 66) = 2.854$, $p = .096$. The Modality × Condition interaction was also not significant, $F(1, 66) = 0.002$, $p = .967$. Fig. 4 displays the mean Corsi spans across the four test conditions: iCorsi Forward, iCorsi Backward, CBTT Forward, and CBTT Backward. Neither Gender nor Stroop performance significantly interacted with the within-subject factors (all ps > 0.05), indicating that these variables did not differentially influence performance across modalities or conditions. However, a significant between-subjects effect of Stroop performance emerged, $F(1, 66) = 14.098$, $p < .001$, indicating that individual differences in Stroop performance were associated with overall visuospatial span. In contrast, the between-subjects effect of Gender was not significant, $F(1, 66) = 1.467$, $p = .230$.

Table 3
Levene statistic (n = 70).

Variable	F	df	p
CBTT-F span	0.03	1,65	0.86
CBTT-B span	0.12	1,65	0.72
iCorsi-F span	0.09	1,65	0.75
iCorsi-B span	9.08	1,65	0.004

Note. CBTT-F span = Forward Corsi Block Tapping Task classical version; CBTT-B span = Backward Corsi Block Tapping Task classical version; iCorsi-F span = iVR version of the Forward Corsi Block Tapping Task; iCorsi-B span = iVR version of the Backward Corsi Block Tapping Task. Significant p values (<0.05) indicate violation of the homogeneity of variance assumption.

In addition to the repeated-measures ANOVA, Bayesian paired-samples t-tests were conducted to directly compare performance between the traditional CBTT and the immersive iCorsi. Bayesian paired-samples t-tests revealed evidence for a difference between CBTT and iCorsi in the Forward condition ($BF_{10} = 662.44$), and only anecdotal evidence in the Backward condition ($BF_{10} = 2.05$).

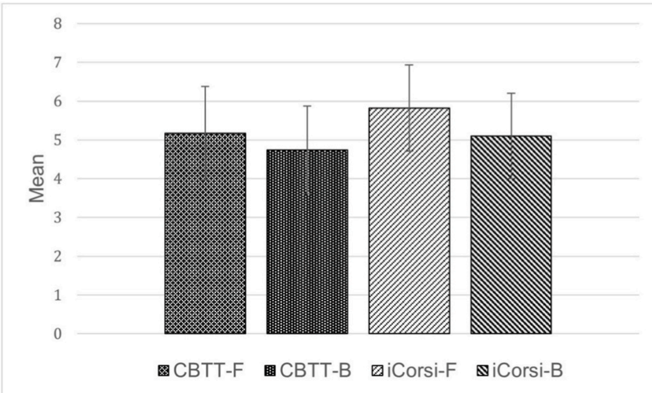

Fig. 4. *Forward and Backward iCorsi and Forward and Backward* CBTT Mean and sd (n = 70).
Note: the error bars represent standard deviation. CBTT-F span = Forward Corsi Block Tapping Task classical version; CBTT-B span = Backward Corsi Block Tapping Task classical version; iCorsi-F span = iVR version of the Forward Corsi Block Tapping Task; iCorsi-B span = iVR version of the Backward Corsi Block Tapping Task.

4. Discussion

The present study investigated the potential of immersive virtual reality (iVR) as a tool for cognitive assessment by examining visuospatial working memory through a virtual adaptation of the Corsi Block Tapping Test (iCorsi). The primary objective was to determine whether iCorsi provides a valid alternative to the traditional physical CBTT, while also examining the contribution of attentional and individual-difference factors to task performance.

Overall, the findings support the validity of iCorsi as a measure of visuospatial working memory. Performance in the virtual and physical versions of the task was strongly correlated, indicating that the two versions capture consistent individual differences across participants. This convergence provides evidence that iCorsi and the traditional CBTT tap into the same underlying cognitive construct, preserving the core demands of visuospatial working memory despite differences in task format.

At the same time, the results do not support a strict interpretation of equivalence between formats. While the frequentist repeated-measures analyses suggested broad comparability between the virtual and physical versions, the Bayesian paired comparisons indicated a difference between modalities, with participants tending to perform better in the immersive version. Crucially, this pattern must be interpreted in light of the strong cross-modality correlations, which demonstrate that both tasks are tightly coupled at the level of underlying ability. Accordingly, the observed modality effect is best understood as a performance modulation within a shared construct, rather than as evidence of a qualitative difference between tasks. The immersive format may confer a modest advantage through enhanced attentional engagement, increased perceptual saliency of spatial information, or more controlled and standardized stimulus presentation (Kourtesis et al., 2025; Makransky & Petersen, 2019; Parsons, 2015; Slater, 2009; Thorp et al., 2024). In this sense, the present findings support construct convergence alongside a modality-related facilitation effect, rather than strict interchangeability.

Importantly, the Bayesian and frequentist analyses should be interpreted as complementary rather than interchangeable. The Bayesian paired comparisons provide a direct quantification of evidence for differences between modalities and task conditions, whereas the repeated-measures analyses allow evaluation of covariates and broader model structure. When considered together with the cross-modality correlations, these approaches converge on a coherent interpretation: the immersive and traditional tasks rely on the same underlying cognitive mechanisms, while differences in task format may influence the efficiency with which these mechanisms are expressed in observable performance.

A further key finding concerns the role of attentional control. Within the frequentist framework, Stroop performance was significantly associated with Corsi performance, indicating that selective attention and interference control contribute meaningfully to visuospatial working memory. The observed association between Stroop performance and visuospatial span is consistent with the partial overlap between working memory and executive control processes, particularly inhibitory control and selective attention. Previous literature suggests that such relationships emerge primarily under conditions requiring increased cognitive control (Engle, 2002; Kane & Engle, 2003; Unsworth et al., 2004). In the present study, the association was modest and more evident in the traditional CBTT than in the iCorsi. This pattern may reflect differences in attentional demands or task engagement across modalities rather than differences in the underlying cognitive construct being measured. Importantly, the association with Stroop performance supports the interpretation that both CBTT and iCorsi primarily assess visuospatial working memory, with only a secondary contribution of executive control processes. This aligns with prior research demonstrating that working memory performance depends not only on storage capacity but also on the ability to maintain task-relevant information in the face of distraction (de Fockert et al., 2001; Stins et al., 2004). In contrast, Trail Making Test B performance did not show a meaningful relationship with task performance, suggesting that the Corsi task primarily engages attentional control processes rather than broader executive flexibility (Pearson, 2007; Vandierendonck et al., 2004).

The results also reinforce the dissociation between visuospatial and verbal working memory systems. As expected, performance on the Corsi tasks was not meaningfully associated with Digit Span performance, supporting the view that these tasks rely on partially distinct cognitive mechanisms. In addition, performance did not differ reliably between forward and backward conditions, replicating previous findings that backward recall does not necessarily impose additional difficulty in visuospatial tasks, in contrast to what is typically observed in the verbal domain. Overall, our findings align with previous evidence showing that, unlike in verbal span tasks, backward visuospatial recall does not systematically increase cognitive load, likely because it can be supported by holistic spatial representations rather than serial reordering processes (Mammarella & Cornoldi, 2005; Cornoldi & Mammarella, 2008; Donolato et al., 2017).

With respect to participant characteristics, no reliable effects emerged in the repeated-measures analyses. This pattern indicates that the observed modality-related differences are unlikely to be driven by these individual factors, and instead more plausibly reflect task-related properties of the immersive environment. In particular, gender, video game experience, and sense of presence did not significantly contribute to performance. Although gender did not emerge as a significant covariate overall, the observed association with iCorsi Forward performance—indicating higher scores in males—suggests an effect that warrants further investigation, in line with previous evidence of gender differences in visuospatial working memory (Piccardi et al., 2019). Contrary to some prior findings, video game experience did not correlate with Corsi performance in this sample. This discrepancy may reflect limited variability in gaming habits among our university participants. Importantly, participants reported high levels of presence in the virtual environment, confirming that iVR offers engaging and realistic experiences. However, sense of presence did not significantly correlate with iCorsi performance, suggesting that in the context of short and highly structured visuospatial working memory tasks, performance appears to be primarily determined by task-related cognitive load and attentional demands rather than by the subjective sense of presence, whose influence has been shown to be limited or indirect in similar paradigms (Kim et al., 2021; Kourtesis et al., 2025; Ma & Kaber, 2006; Pallamin & Bossard, 2016; Palombi et al., 2023; Sas et al., 2004; Slater, 2009). The absence of a relationship between presence and task performance may reflect ceiling effects in presence ratings and reduced inter-individual variability, particularly given the young and technologically experienced sample. Additionally, the highly structured and time-limited nature of the task likely emphasized cognitive and attentional demands over subjective experiential factors, limiting the behavioral impact of presence.

Beyond its theoretical implications, the present study highlights several practical advantages of iVR for cognitive assessment. The iCorsi allows for standardized administration, reduces experimenter-related variability, and enables the automated collection of detailed behavioral data, including timing and error patterns. Moreover, immersive environments may enhance engagement and ecological validity, while also supporting remote or telehealth applications. These features position iVR as a promising platform for both research and clinical contexts.

Nevertheless, several limitations should be acknowledged. First, the relatively small and homogeneous sample limits the generalizability of the findings. Accordingly, future research should aim to replicate these results in more diverse populations, including clinical groups, broader age ranges, and individuals with different educational backgrounds. These factors may plausibly influence iCorsi performance (e.g., through age-related changes in visuospatial working memory or task familiarity); therefore, caution is warranted when applying the tool beyond healthy young adults.

Another limitation, partly related to the previous one, concerns the limited ability to evaluate the potential influence of participants' familiarity with and frequency of use of VR devices and videogames. In the present study, participants were classified using a broad nominal distinction (gamers vs. non-gamers). Within this framework, gamer status did not show clear associations with the other variables of interest. However, this observation should be interpreted with caution, as the adopted categorization may have lacked sufficient sensitivity to capture more subtle or graded effects of gaming or VR experience. In particular, grouping individuals with heterogeneous levels of exposure within the same category may have reduced the ability to detect meaningful relationships. Future studies should therefore employ more refined, quantitative measures of gaming and VR use in order to more adequately examine their potential role in shaping task performance.

Finally, because the Bayesian analyses were limited to paired comparisons, they do not account for the potential contribution of covariates or more complex model structures. Future work should integrate these approaches within a unified analytical framework to more comprehensively characterize the determinants of iCorsi performance.

In conclusion, the present findings provide converging evidence that iCorsi is a valid tool for assessing visuospatial working memory and shows strong construct convergence with the traditional CBTT. At the same time, the results suggest that immersive VR may confer a modest performance advantage, indicating that the two formats are closely comparable but not entirely interchangeable in their behavioral outcomes. Together, these findings support the integration of immersive technologies into cognitive assessment and highlight their potential to enhance both the precision and ecological validity of neuropsychological testing.

5. Conclusions

This study provides evidence that iCorsi, an immersive virtual reality adaptation of the Corsi Block Tapping Test, is a valid tool for assessing visuospatial working memory. Performance in the virtual and physical versions of the task was strongly correlated, supporting the conclusion that both formats capture the same underlying cognitive construct.

While small differences in performance were observed, particularly in the forward condition, these did not substantially alter the overall pattern of results. Rather than indicating a divergence in the cognitive processes being measured, such differences are more plausibly attributable to task-related factors, such as variations in attentional engagement or stimulus presentation in the immersive environment. In addition, the observed association between Stroop performance and visuospatial working memory highlights the contribution of attentional control to task performance. At the same time, no reliable effects of participant characteristics such as gender, video game experience, or sense of presence were identified. Taken together, these findings support the use of iVR as a viable and scalable platform for cognitive assessment. More broadly, they suggest that immersive implementations can preserve the core properties of established neuropsychological tasks, while also introducing subtle variations in performance that should be interpreted with caution. Future research should aim to replicate these findings in larger and more diverse samples and to further examine how specific features of immersive environments may influence cognitive performance.

CRediT authorship contribution statement

Carla Meloni: Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing. **Giada Corrias:** Conceptualization, Data curation, Software, Writing – original draft. **Stefano Curatti:** Conceptualization, Funding acquisition, Project administration, Software, Supervision. **Franco Delogu:** Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Rachele Fanari:** Conceptualization, Data curation, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.chbr.2026.101192.

Appendix A

Table 4
Demographic and Background Characteristics of Participants (n = 70)

Variable	Description	Percentage
Gender	participants reported gender corresponding to sex assigned at birth	100%
	females	70%
	males.	30%
Age	From 19 to 33 years (M = 23.80, SD = 3.84).	
Video gaming experience	Participants who dedicate at least 1 h per week to video gaming	63%
Previous iVR experiences	Participants reporting prior iVR experiences	24.28%
Handedness	Right-handed participants	88.57%.
Visual problems	Participants with visual problems adequately corrected with lense	61.43%
Balance issue.	Participants reporting no balance problems	97.14%
Sport activities	Participants engaging in sport activities	37%
Educational Background	University educational background	100%

Note. All demographic information was self-reported.

Data availability

Data will be made available on request.

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