Contents lists available at http://qu.edu.iq

Al-Qadisiyah Journal for Engineering Sciences

Journal homepage: https://qjes.qu.edu.iq

The Impact of Studio Width on Students' Cognition and Preference: A Neuroarchitectural Study of Learning Spaces in Erbil Universities

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ARTICLE INFO

Article history:
Received
Received in revised form
Accepted

Keywords:
Neuroarchitecture
Spatial width
Virtual Reality (VR)
Cognitive performance
Design studios

ABSTRACT

Neuroarchitecture provides valuable insights into how built environments influence students' cognitive performance and academic success. However, spatial characteristics related to architectural studios are still inadequately examined, particularly within non-Western academic settings. This study aims to investigate the impact of studio width on students' cognitive performance and environmental preferences in architectural learning spaces using virtual reality (VR). A quantitative research method was employed using VR-based environments to measure attention, memory and preferences across varying studio widths. A within-subjects experiment was conducted with 90 undergraduate architecture students from three universities in Erbil. Participants performed standardized auditory attention and memory tasks in narrow and spacious virtual studios. The results indicated that narrow studios significantly improved cognitive performance, resulting in faster reaction times, fewer attentional errors, and improved memory recall. However, students preferred wider studios, and female students consistently outperformed male students on all cognitive tests. These findings highlight the difference between objective cognitive outcomes and subjective preferences. This study demonstrates the value of spatial width as a neuroarchitectural feature that influences cognition in university students. It provides context-specific evidence to support the alignment of evidence-based design with user-centered outcomes in higher education, particularly in underrepresented regions such as Erbil.

1. Introduction

The way learning spaces are designed has an impact on students' cognition, emotions, and academic success. Research suggests that environments designed with sensory richness and intentionality can enhance cognitive processing and learning by improving attention, increasing memory retention, and facilitating stress management [1, 2]. Neuroarchitecture, a collaborative discipline that combines neuroscience, psychology, and architecture, offers a theoretical and practical framework for designing spaces that enhance cognition and regulate emotions [3-5].

Architectural design has a significant impact on cognitive processes, particularly memory and attention. Earlier studies have revealed that the physical elements of a classroom, such as color and light, affect memory and attention [6, 7]. Architectural features such as ceiling height, spaciousness, lighting, and material texture can be unconsciously processed through the human senses. Ultimately, these features will affect emotional and physiological states [8, 9]. These effects may be instantaneous, such as changes in mood or comfort, or they may build over time, affecting attention, memory, and long-term learning.

Virtual Reality (VR) has been identified as a viable technique in educational architectural research, possessing a high degree of ecological validity and the capacity for spatial manipulation. Previous studies [10-12]

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https://doi.org/10.30772/qjes.00000.0000
2411-7773/

suggested that VR was effective at measuring attention and that this was preferable to other standard instruments. Moreover, virtual reality (VR) was also used by researchers to isolate factors such as room width and ceiling height to analyze their impacts on emotions and cognition [7, 13].

One of the most important yet often overlooked spatial elements in educational settings is the width of the space. It has a notable effect on cognition, well-being and perception. While the effect of classroom design on cognitive processes has been studied, most research utilizes simplified layouts with little spatial variation; architectural studios have not been studied yet. These studios differ from conventional classrooms in their configurations and pedagogical use, and require further investigation.

In addition, prior research is mainly derived from Western academic settings and does not adequately indicate how spatial arrangements affect cognition in Erbil, Iraq. Architecture education is expanding globally, but it should be grounded in local contexts and evidence-based. Further research is needed to investigate the effect of spatial width differences on cognition in culturally appropriate learning environments.

This research seeks to address this gap through a quantitative within-subject experimental design that utilizes VR. It aims to investigate how studio width affects architecture students' attention, memory, and preference. The integration of virtual reality simulations with validated cognitive assessments enhances methodological rigor and contextual relevance within neuroarchitecture and evidence-based design. This approach has significant implications for developing environments in higher education that are both cognitively supportive and culturally responsive.

This study focuses on the following research questions:

1. How do students perceive their sense of presence within VR-simulated studio environments of varying widths?
2. How does studio width in Erbil universities affect students' attention, memory and spatial preferences?
3. To what extent do gender differences influence attention, memory, and spatial preferences across varying studio width?

2. Theoretical Framework

Neuroarchitecture refers to an emerging interdisciplinary field that studies how the built environment interacts with the brain, influencing how we feel, think and behave [1]. In learning environments, where the use of the mind plays a crucial role, it helps to understand how design affects brain attention, memory, and stress [3]. Neuroarchitecture combines neuroscience, environmental psychology, and embodied cognition to create design strategies that actively support cognitive performance and emotional well-being [1, 14]

Environmental psychology is at the core of neuroarchitecture. It studies the relationship between individuals and their environments, as well as the effects of this interaction on experience, behaviour, and well-being. Research has revealed the impact of environmental design on the value of life. Moreover, the perception of space significantly influences the formation of experiences [15]. This applies in particular to the development of educational settings ideal for students' cognition, emotion, and behaviour.

Embodied cognition, which draws upon various fields like cognitive science, psychology, and philosophy of mind, posits that the mind, body, and environment are interdependent [16]. The theory suggests that humans are constantly engaging with their physical and social environment at cognitive, affective, and sensory levels [17, 18]. This perception encourages the creation of learning environments that stimulate the senses and the body, fostering a more natural cognitive experience. Educational spaces need to be structured to enhance the core cognitive processes required for learning, particularly attention and memory [13, 19]. The features of the classroom, including lighting, spatial configuration, and acoustics, have a significant impact on cognitive functions, particularly attention and memory [6]. Attention is the capacity to select and regulate the processing of information. This is a simple yet complex function. Moreover, attention is essential for academic and emotional outcomes [20-23]. Complementing this, memory acts as a dynamic system in which information is stored and retrieved over time. Memory is always shaped by experience [24].

Aspects of spatial design, such as ceiling height and width, light colours, materials, texture of materials, and sound, significantly affect focus, memory, and feeling. Studies have highlighted that high ceilings also enhance creative thinking and visual exploration, whereas enclosed spaces improve attention and memory retention [25]. Similarly, higher ceilings may boost creativity and brain activity associated with spatial manipulation [26]. Enclosed and narrow spaces lead to boosting attention control and memory retention [7], whereas more expansive spaces may encourage relaxation [27]. The impacts are particularly beneficial in design studios, which require visual focus and spatial reasoning over sustained periods of engagement.

Aside from width, numerous neuroarchitectural features influence cognition, well-being, and behaviour. Form and geometry have a notable impact on learning spaces, as they affect emotional and cognitive responses in learning environments [1, 26, 28-31]. Color and materiality also moderate people's emotions and cognitive functions [18, 32]. Lighting conditions influence stress regulation and cognitive engagement [2, 14, 33]. The incorporation of natural elements in the indoor environments of educational institutions is favourably correlated with students' attention and productivity. The presence of indoor nature in classrooms can effectively alleviate associated stressors and enhance students' psychophysiological well-being [34-36]. Biophilic elements, including natural light, greenery, and natural materials, when integrated into a space, will lead to boosting attention, memory, creativity, and emotional well-being [27, 37, 38]. Furthermore, furnished spaces impact emotional and neurophysiological states, increasing heart rate and theta brain activity [26, 39-41].

Environmental conditions, including acoustics and temperature, affect learning. Quiet conditions, with noise levels around 50 dB(A), facilitate attention and memory processes and reduce cognitive fatigue. Temperature is also crucial. Places with low temperatures (~17°C) aid attention, neutral temperatures (~22°C) support perception, and warmer environments (~27°C), with good light and low noise, aid memory [1, 42].

Although the cognitive effects of conventional classrooms have been extensively researched, architectural design studios present unique spatial and mental challenges that have not been well-explored. Classrooms generally support passive, teacher-oriented learning with stationary seating, while studios promote project-based learning, extended visual focus, and collaborative innovation—requiring flexible, adaptable, and cognitively enriching settings [43].

In architectural studio settings, the quality of learning space is crucial factor and affects students significantly [44]. While design studios present distinct cognitive challenges, empirical research on spatial factors such as width is insufficient. Most studies draw their conclusions from general classroom environments in Western contexts, neglecting the educational and cultural subtleties of architectural training in areas such as the Middle East [15]. Recent research suggests that virtual reality (VR) is a legitimate and practical approach to evaluating spatial perception and cognitive responses within educational design environments. VR enables researchers to replicate various spatial scenarios without physical limitations, providing more authentic and quantifiable insights into how the dimensions of a studio influence cognition, particularly attention and memory [45-47].

To fill these gaps, the current study aims to investigate how varying studio widths affect attention, memory, and preference of architecture students in Erbil universities. The research provides contextual findings related to a relatively less-explored spatial variable in architectural studios, utilising immersive VR contexts that reflect actual studio dimensions. This contributes to the broader discourse on neuroarchitecture and evidence-based design in higher education, demonstrating that spatial attributes can be employed to enhance learning in design disciplines.

3. Methodology

3.1. Research Design

This research used a quantitative, within-subjects experiment to investigate the effects of spatial width in architectural design studios on students' attention, memory and preference. The comprehensive Research Design and Methodological Workflow for the study is illustrated in Figure 1. Each participant experienced two studio scenes of different widths (narrow and wide) generated using VR. To prevent any order effects due to learning or fatigue, the research design included a counterbalancing method in which participants were randomly assigned to either start with the narrow studio and then the wide one, or vice versa. This counterbalancing reduced sequence-related biases and improved the internal validity.

Participants underwent standard auditory attention and memory tasks in both conditions. The width of the studio (narrow vs. wide) was the independent variable, while reaction time, attention errors, memory recall and preference were dependent variables. VR technology ensured the exact spatial dimensions and environmental control for all sessions. Thus, enabling replicability and ecological validity. This research obtained ethical approval from Salahaddin University of Erbil (SUE). The design enabled an objective assessment of how spatial width influences cognition and preference outcomes, thereby providing empirical validation for neuroarchitecture in education.

3.2. Case Study Selection and Participants

Three universities in Erbil, Iraq, were selected as case studies, including Salahaddin University-Erbil (SUE), Tishk International University (TIU), and the University of Kurdistan Hewler (UKH). These institutions were purposefully selected due to their architectural diversity and institutional representation of the public and private sectors. Two architectural design studios of varying widths (narrow and wide) were chosen from each university, and they were digitally recreated in VR with precise accuracy to ensure experimental consistency under realistic conditions. A total of 90 undergraduate architecture students (45 males, 45 females), aged 18–24, were recruited equally across the three universities (n = 30). Inclusion criteria included normal or corrected-to-normal vision, no color blindness, and no known medical contraindications to VR exposure. All subjects provided informed consent prior to data collection. The demographic distribution of this study is illustrated in Table 1.

Table 1. Participant demographic distribution (N = 90)

Characteristic	Category	N	Percentage (%)
Gender	Male	45	50.0%
	Female	45	50.0%
Age group	18–20 years	28	31.1%
	21–23 years	62	68.9%
Academic stage	3rd Stage	35	38.9%
	4th Stage	31	34.4%
	5th Stage	24	26.7%
Vision characteristics	Normal vision	65	71.1%
	Corrected vision	25	28.9%
VR experience	prior experience	21	23.3%
	No prior experience	69	76.7%

3.3. Virtual Environment Design

Six immersive virtual environments were developed, one narrow and one wide studio from each of the three universities: Salahaddin University-Erbil (SUE), Tishk International University (TIU), and the University of Kurdistan Hewler (UKH). These studios were digitally modelled using verified architectural drawings, field measurements, and on-site photographic documentation. Accurate dimensions were ensured using laser-based field measurements. Studio lengths of each university were averaged to control for depth, isolating width as the only variable. Table 2 illustrates all the dimensions for (narrow, wide) studios across the three universities.

Table 2. Studio dimensions used in VR environments across the three universities.

University	Narrow width	Wide width	Ceiling height	Average length
SUE	7.5m	11.3m	3.2m	14.35m
TIU	7.2m	8.4m	2.8m	17.2m
UKH	6.2m	7.8m	3.1m	9.8m

The floor plans were created in AutoCAD 2024, modelled with 3ds Max 2024, and rendered with V-Ray 7. The outputs were refined in Adobe Photoshop 2020. Final 360° panoramic scenes were exported and deployed to Meta Quest 3 headsets for immersive presentation. Table 3 illustrates the Simulated studio environments for (narrow and wide) conditions across the three universities. In order to isolate the effect of studio width, all other environmental features were held constant across simulations, including: ceiling height, lighting (neutral LED, 4000K), wall color (N5 neutral white), and furniture. The participant's viewpoint was standardized at the geometric center of the scene at each time. The visual consistency of the narrow and wide scenes has been improved by making slight adjustments to certain physical features, including furniture types and door locations. A pilot walkthrough of the scenes by an architecture staff verified the ecological validity of the environments.

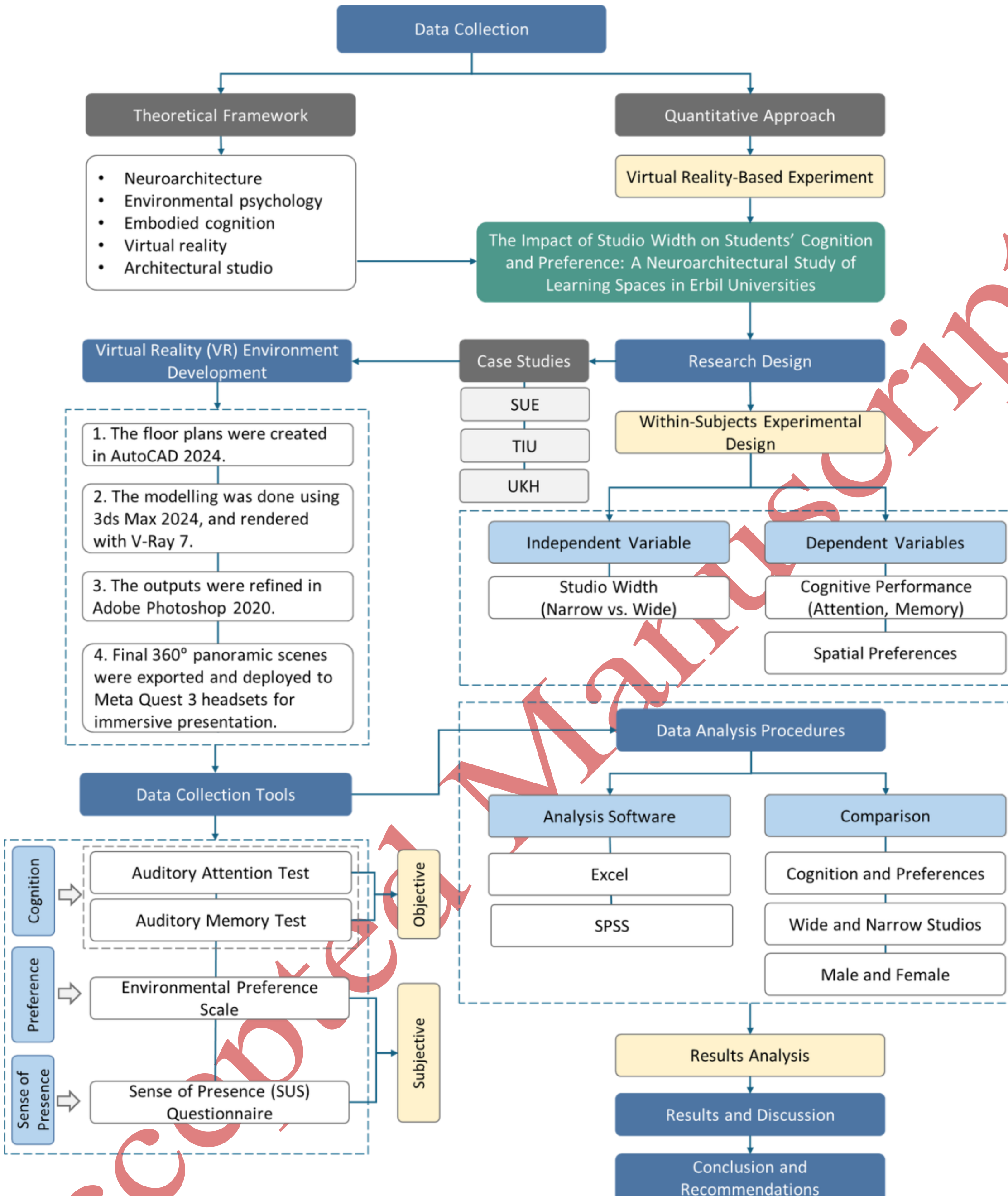
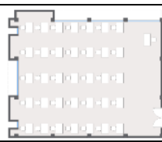
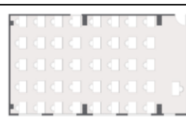
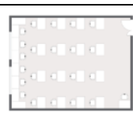


Figure 1. Research Design and Methodological Workflow

Table 3. Simulated studio environments with floor plans for (narrow and wide) conditions across the three universities.

Univ.	Studio width	Floor plan	Virtual scene
SUE	Narrow (7.5m)		
	Wide (11.3 m)		
TIU	Narrow (7.2 m)		
	Wide (8.4 m)		
UKH	Narrow (6.2m)		
	Wide (7.8 m)		

3.4. Experimental Design and Procedure

Participants underwent a within-subjects experimental design where each participant was exposed to both narrow and wide studio environments conditions. To prevent order effects, learning bias, and fatigue, the order of exposure was counterbalanced within participants by gender, leading to four balanced groups (Male NW/WN, Female NW/WN) as illustrated in Figure 2. Each experimental session took place in a quiet, temperature-controlled laboratory setting between 9:00 AM and 12:00 PM to reduce the circadian rhythm's influence on performance. Figure 3 illustrates the setup for each session, which includes a participant putting on the VR headset and completing cognitive tasks at the workstation. The standardized six-stage session lasted approximately 20–25 minutes:

- Preparation (2 min) – Headset calibration and task briefing
- Demographic Survey and Consent (2 min)
- VR Habituation (2 min) – Exploration of both environments to reduce novelty effects
- Cognitive Testing (10 min) – VR-based attention task followed by the memory task
- Self-report (4 min) – Sense of Presence (SUS questionnaire) and Environmental Preference ratings
- Finalization (2 min) – Task debrief and exit protocol

To reduce fatigue and carryover effects, a short rest (1–2 minutes) was provided between the VR sessions.

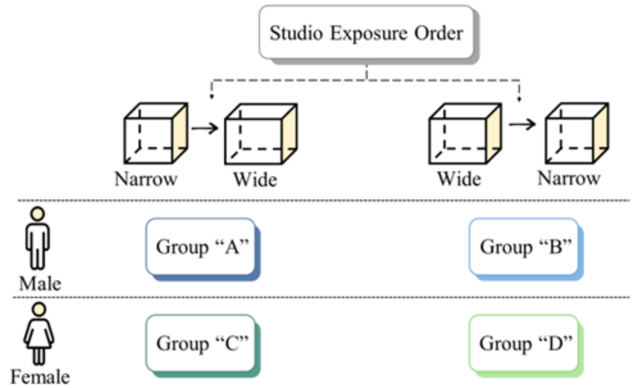


Figure 2. Counterbalancing diagram (adapted by the authors)

Figure 3. Participants during the VR-based experiment

3.5. Cognitive Task Design and Measures

Two standardized auditory tasks were developed for the assessment of attention and memory under each spatial condition. After the participants were given the liberty to explore the studio environment, all tasks were presented in immersive VR, such that the preceding spatial experience influenced participants' cognitive and preference responses. The cognitive psychology paradigms on which the two tasks were adapted to verbal content and VR administration.

3.6. Auditory Attention Task

A customized auditory continuous performance task (CPT) was used to assess sustained attention based on recognized neuropsychological approaches. The task employed architecture-related vocabulary to align with participants' academic context and maintain engagement. Before each session, participants listened to four words: one target and three distractor words for familiarity. Following that, they were exposed to a randomized list of 40 stimuli. These included 8 targets and 32 distractors. The interval was set at 800–1600 millisecond (ms). The participants clicked the mouse when the target was detected. Each of the target stimuli had a window of 750 millisecond (ms). All the stimuli were generated using LuvoVoice, an online text-to-speech platform, and then edited in Adobe Premiere Pro 2023. They were played via Windows Media Player to ensure consistency. Both conditions were presented with the same word set, but the order of presentation was randomized to counteract any learning effect and to maintain task validity.

Attention performance was measured using three indicators:

- Reaction time (attention time), measured in milliseconds, for correct target responses
- Missed targets (omissions)
- False positives (incorrect responses)

3.7. Verbal Memory Recall Task

Memory was assessed by a free-recall task under both spatial conditions. In every trial, participants listened to 15 words related to architecture, and they had to recall them in any order within 30 seconds. Responses were digitally recorded for transcription and scoring. The task was performed twice, following each studio condition, using different word lists in a counterbalanced order to mitigate sequencing and familiarity effects.

Similar to attention tests, the audio stimuli were generated using LuvoVoice, edited in Adobe Premiere Pro 2023, and played through Windows Media Player to ensure consistent delivery. The duration of each complete list was around 15 seconds, with no breaks in between words, mimicking the timing guidelines utilized in analogous verbal memory paradigms [13]. Two carefully matched word lists were used for the experimental task, in which the length and phonological complexity were very similar, as was their familiarity, ensuring that differences in performance could be ascribed to the spatial condition used rather than to any differences in the stimuli used.

Recall performance was measured through:

- Number of correct recalls
- Number of incorrect or unrelated items

3.8. Sense of Presence

The Slater-Usoh-Steed (SUS) Presence Questionnaire was utilized to assess the sense of presence, described as the mental notion of being physically present in a virtual setting [48]. The SUS contains seven items that assess spatial realism, immersion and perceived engagement. Respondents rate each item on a seven-point Likert scale, where 1 represents Strongly Disagree and 7 indicates Strongly Agree. All participants filled in the questionnaires immediately after each of the VR conditions. Participants were able to rate the presence in the narrow studio and the wide studio.

Low scores, which are nearer to 0, indicate that the subjects perceive the environments as artificial. Conversely, higher scores, approaching the maximum of 49 (which is calculated as 7 points multiplied by 7 items), reflect a significant sense of presence within the virtual reality environment. Results of the earlier studies suggest that scores of 24 or higher indicate an optimum sense of presence when the study involved six items [13]. This measure provided insight into participants' affective engagement with the virtual environments and complemented the cognitive performance data.

3.9. Environmental Preference

A single-item Likert scale, administered after the experiment, measured the participants' spatial preference for the two VR studio environments. The question (Which of the two studio environments did you prefer?) was assessed using a 5-point Likert scale ranging from 1 (Strongly Prefer Narrow) to 5 (Strongly Prefer Wide), and 3 indicating no preference. The measure was conducted post-completion of both the VR sessions by the participant for a fully informed comparison. The preference score was viewed as a subjective measure of the students' environmental comfort.

4. Results

4.1. Validation of the VR environment (Sense of Presence)

The Slater-Usoh-Steed (SUS) questionnaire was employed to validate the VR environment following each exposure to narrow and wide studio conditions in TIU, SUE, and UKH. The benchmark of 28 was exceeded by all mean scores, which confirms that the immersion was sufficient. As illustrated in Figure 4, the narrow studios had a slightly higher presence (M = 45.09) than the wide ones (M = 44.68). The greatest scores were reported by SUE in both conditions (46.17 narrow; 45.67 wide). UKH reported lower scores overall, with a modest preference for narrow (44.50 vs. 43.67), while TIU showed minimal difference (44.60 vs. 44.70). These findings indicate that perceived immersion may be marginally influenced by institutional context and spatial width.

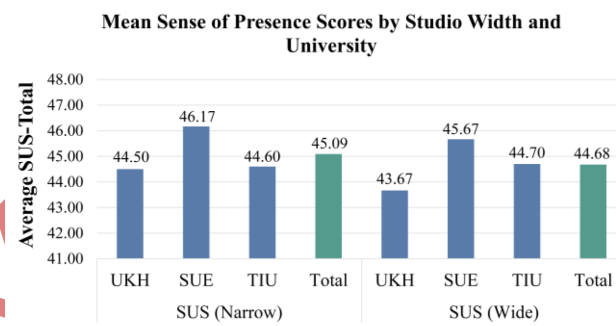


Figure 4. Mean sense of presence scores by studio width and university

4.2. Psychological Metrics

4.2.1 Attention-Time

In the VR attention task, Attention-Time (reaction time) measured how quickly participants reacted to an auditory target, with longer times indicating reduced attentional performance. The mean reaction times for narrow and wide studio settings at each university were recorded as shown in Figure 5. The Mann–Whitney U test was used for analysis because the Kolmogorov–Smirnov (K–S) test indicated a non-normal distribution ($p < 0.05$). At TIU, reaction time increased from 0.90s (narrow) to 1.10s (wide), a significant difference ($p = 0.030$) that indicates greater attention in narrow studios. An increase in SUE from 0.70s (narrow) to 1.14s (wide) was observed, which was nearly statistically significant ($p = 0.056$). At UKH, the increase from 0.79s (narrow) to 1.02s (wide) was not significant ($p = 0.636$). These results showed that narrower studios support faster attentional responses, but the effects varied by institution.

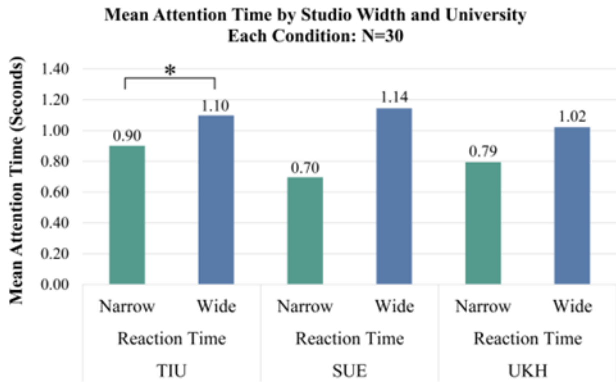


Figure 5. Mean attention time for (narrow and wide) conditions across TIU, SUE, and UKH. The asterisk the significance level (*p < 0.05, **p < 0.01)

4.2.2 Attention Errors

The Attention Errors metric captured the total number of omissions and incorrect responses committed during the VR-based auditory attention task, where higher values indicated diminished attentional control. Figure 6 illustrates the average number of attention errors recorded in narrow and wide studio conditions across the three universities. The Kolmogorov–Smirnov (K–S) test confirmed the non-normality of the error data ($p < 0.05$), leading to the use of the Mann–Whitney U test for comparisons.
At TIU, errors increased from 1.70 (narrow) to 2.30 (wide), indicating a significant difference (p = 0.000). SUE showed a rise from 1.20 (narrow) to 1.70 (wide), also reaching statistical significance (p = 0.001). Similarly, in UKH, the average number of errors increased from 1.60 (narrow) to 2.00 (wide), with the difference again proving statistically significant (p = 0.015). According to the results, the attentional accuracy was reduced in the widest spatial conditions, as all differences were statistically significant.

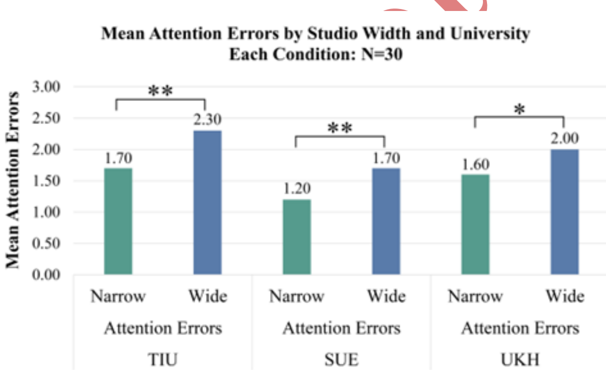


Figure 6. Mean attention errors for (narrow and wide) conditions across TIU, SUE, and UKH. The asterisk the significance level (*p < 0.05, **p < 0.01)

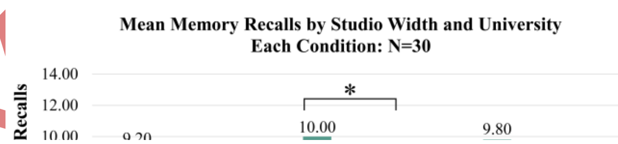
4.2.3 Memory Recalls

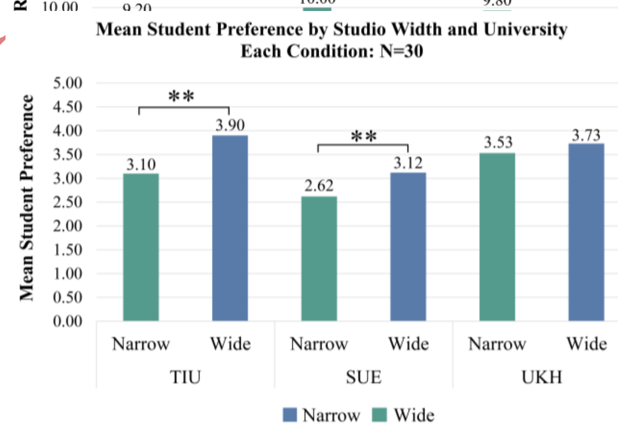
The Memory recall metric assessed the short-term memory performance of participants by evaluating their capacity to recall words presented during the auditory task in the VR environment. Better cognitive retention was indicated by higher recall values. Figure 7 presents the mean recall scores under narrow and wide studio conditions across universities. Due to non-normal data distribution (K–S, $p < 0.05$), non-parametric Mann–Whitney U test was applied. At SUE, recall decreased from 10.00 (narrow) to 8.50 (wide), showing a significant difference (p = 0.026). At TIU, scores declined from 9.20 (narrow) to 8.00 (wide), and not reaching significance (p = 0.064). At UKH, recall dropped from 9.80 (narrow) to 8.10 (wide), also non-significant (p = 0.081). These results indicated a trend of diminished memory performance in wider spaces, with significance only observed at SUE.

Figure 7. Mean memory recalls for (narrow and wide) conditions across TIU, SUE, and UKH. The asterisk the significance level (*p < 0.05, **p < 0.01)

4.2.4 Environmental Preference

In order to assess participants' preferences, a 5-point Likert scale was administered post-experiment, where 1 showed "Strongly Prefer Narrow" and 5 showed "Strongly Prefer Wide." Figure 8 illustrates the mean preference scores for both studio widths across the three universities.
A consistent trend was observed across all three universities: wider studio environments were rated more favorably than narrow ones. At TIU, the





wide studio scored 3.90 (wide) vs. 3.10 (narrow), a highly significant difference is observed between the conditions ($p < 0.01$). Similarly, at SUE, the wide studio scored 3.12 versus 2.62 for the narrow condition, also a significant difference ($p < 0.01$). At UKH, scores were 3.73 (wide) vs. 3.53 (narrow), the difference was not statistically significant.

Figure 8. Mean student preference for (narrow and wide) conditions across TIU, SUE, and UKH. The asterisk the significance level (*p < 0.05, **p < 0.01)

These results indicated that, while students generally performed better in narrower studios in terms of attention and memory, with statistically significant differences in each condition. However, their subjective preferences favored wider rooms, particularly at SUE and TIU. This discrepancy underlines an important design insight: surroundings that promote cognitive function may not necessarily be viewed as comfortable or desirable.

4.3. Gender-Based Analysis Based on University

To investigate gender-based differences in spatial preference and cognitive performance based on university, four variables were compared between male and female participants at TIU, SUE, and UKH: reaction time, memory recall, attention errors, and preference, as indicated in Figure 9.

Tishk International University (TIU)

- Reaction Time: Females responded faster than males (0.85s vs. 0.96s), with a significant difference ($p = 0.030$).
- Attention Errors: Females made fewer errors (1.17 vs. 2.43), a significant difference ($p = 0.000$).
- Memory Recall: Females recalled more words (9.47 vs. 8.43), but with no significant difference ($p = 0.064$).
- Preference: Female preference was slightly higher (3.80 vs. 3.47), with no significant difference ($p = 0.437$).

Salahaddin University-Erbil (SUE)

- Reaction Time: Faster in females (0.83s vs. 1.00s), but not statistically significant ($p = 0.056$).
- Attention Errors: Females had fewer errors (1.03 vs. 1.87), showing a significant difference ($p = 0.001$).
- Memory Recall: Females scored higher (9.83 vs. 8.67), a significant difference ($p = 0.026$).
- Preference: Higher preference in females (3.27 vs. 2.47), but not significant ($p = 0.111$).

University of Kurdistan Hewler (UKH)

- Reaction Time: Almost similar between genders (0.99s vs. 1.00s), with no significant difference ($p = 0.636$).
- Attention Errors: Fewer in females (1.60 vs. 2.40), a significant difference ($p = 0.015$).
- Memory Recall: Higher in females (9.10 vs. 8.10), but not significant ($p = 0.081$).
- Preference: Female preference was higher (3.73 vs. 3.27), with no significant difference ($p = 0.521$).

Across the three universities (TIU, SUE, and UKH), female participants generally outperformed males in cognitive and perceptual metrics, particularly in attention errors, which showed statistically significant differences at all institutions. Females also had faster reaction times and higher memory recall, with significant results observed at TIU for the reaction time and SUE for memory recall. Nevertheless, there were no statistically significant gender disparities in studio preference at any of the universities.

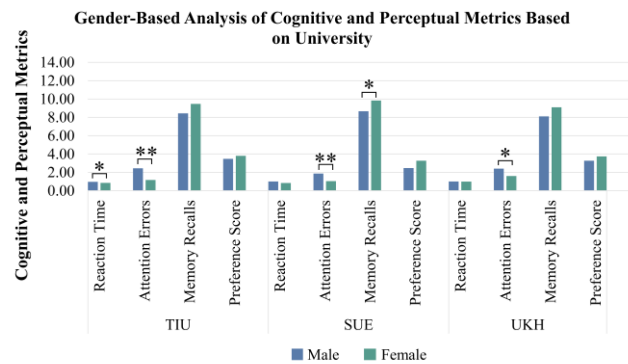


Figure 9. Gender-Based Analysis of Cognitive and Perceptual Metrics across TIU, SUE, and UKH. The asterisk the significance level (*$p < 0.05$, **$p < 0.01$)

4.4. Gender-Based Analysis Based on Spatial Width Condition

This study analyzed gender differences in cognitive and perceptual responses across varying spatial widths (narrow and wide) by comparing four metrics between male and female participants: attention time, attention errors, memory recalls, and spatial preference, illustrated in Figure 10.

Narrow Studio Condition

- Reaction Time: Female participants exhibited faster responses than males (0.75s vs 0.84s), with a statistically significant difference ($p < 0.05$).
- Attention Errors: Females made fewer errors than males (1.02 vs 1.98), a highly significant difference between them ($p < 0.01$)
- Memory Recall: Females demonstrated higher memory recall scores than males (10.31 vs 9.02), showing a highly significant difference between them ($p < 0.01$).
- Preference: Although both genders preferred narrow studios, females rated them slightly higher than males (10.31 vs 9.02); however, the difference was not statistically significant.

Wide Studio Condition

- Reaction Time: Female participants continued to respond faster than males (1.03s vs 1.14s), with a highly significant difference ($p < 0.01$).
- Attention Errors: Females again showed fewer attention errors compared to males (1.51 vs 2.49), with a highly significant difference ($p < 0.01$).
- Memory Recall: Memory performance was higher in females than in males under wide conditions (8.62 vs 7.78), a significant difference ($p < 0.05$).
- Preference: Both genders reported lower preference ratings for wide studios compared to narrow ones, with females maintaining a slightly higher rating than males (8.62 vs 7.78), a non-significant preference was observed.

Across both spatial width conditions, female participants consistently outperformed males in all cognitive metrics. For the reaction time, statistically significant gender differences were observed in narrow conditions, and a highly significant difference was observed for wide conditions. In terms of attention errors, there was a highly significant difference between genders in both narrow and wide condition. Whereas for memory recall, a highly significant difference was observed in narrow conditions, while a significant difference was observed for wide conditions. However, gender-based differences in spatial preference ratings were not statistically significant under either condition.

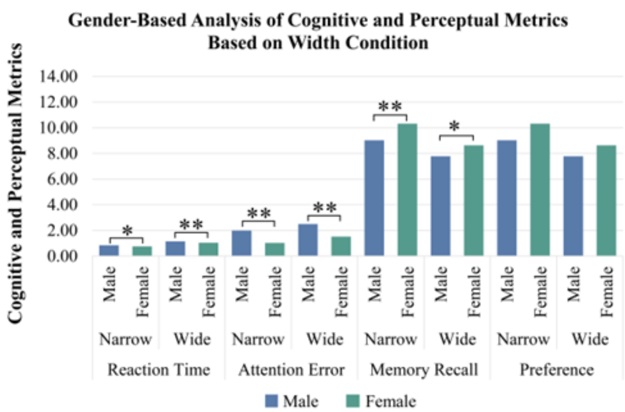


Figure 10. Gender-based analysis of Cognitive and Perceptual Metrics based on width condition (Narrow and Wide). The asterisk the significance level (*p < 0.05, **p < 0.01)

In general, the results based on both university settings and width conditions showed that gender must be taken into account in this type of analysis, given that the differences between most groups were significant.

4.5. Order Effects Analysis

This analysis aimed to investigate whether the sequence in which participants experienced the narrow and wide studio conditions influenced their cognitive performance and preference outcomes. To assess for potential order-related bias, a Mann–Whitney U test was conducted, comparing participants who completed the task in the Narrow-Wide (NW) order with those who did so in the Wide-Narrow (WN) order. As shown in table 4, the results obtained included reaction time ($p = 0.871$), attention errors ($p = 0.909$), memory recalls ($p = 0.934$), and preference ($p = 0.480$), suggesting that the exposure order of Narrow-Wide (NW) and Wide-Narrow (WN) did not significantly impact participant performance or preference. These outcomes confirm that the effects of studio width are attributable to the spatial conditions rather than any sequence-related bias.

Table 4. Order effects analysis for cognitive performance across studio exposure sequences (NW vs. WN)

Metric	Studio sequence	Mean	Std. deviation	Test value	p-value
Reaction Time	NW	0.94	0.23	439.00	0.871
	WN	0.94	0.21		
Attention Error	NW	1.72	1.26	442.50	0.909
	WN	1.78	1.17		
Memory Recall	NW	8.97	2.06	444.50	0.934
	WN	8.90	2.06		
Preference	NW	3.38	1.81	406.00	0.480
	WN	3.29	1.86		

5. Discussion

The present study aimed to explore the influence of spatial width in architectural design studios on students' attention, memory, and preference through immersive virtual reality (VR) environments. It also examined the students' sense of presence in the VR-simulated studios. The core contribution of this research lies in its empirical evaluation of how variations in studio width affect cognitive performance and subjective experience, thereby bridging architectural simulation with psychological measurement. Furthermore, the study offers comparative insights based on gender-balanced counterbalancing, allowing for the controlled observation of potential gender-related cognitive and perceptual responses.

The use of immersive Virtual Reality (VR) in this study provided a controlled yet ecologically valid method to examine the cognitive impact of spatial width in architectural studio environments. VR generates simulation environments that allow for precise control of 3D space presentations, helping end users evaluate different design alternatives. Thus, these presentations can be altered in a dynamic way in response to user interactions, behavioral monitoring, and recording of functional and cognitive performance [10, 12]

The high presence scores reported across both conditions further support the effectiveness of the VR environments in eliciting authentic cognitive and affective responses. These findings echo previous research suggesting environments accessed through VR have similar effects on people as environments in the physical world [49-51]. VR has been considered a viable tool to create environments that can be used to study or enhance psychological well-being, including mood and stress [52-54]. It can also be employed to train individuals in situations that might be dangerous, impossible, counterproductive, or expensive to create in the physical world [55, 56].

The results of the research are also in line with recent studies that have used VR to study the cognitive impacts of a building design, such as attention, memory, and learning [13, 25, 45]. This study utilized VR to connect architectural design with cognitive science and offer a simple experimental framework for spatial cognition in education.

Regarding cognitive functioning, the participants in the narrow studio space showed significantly faster reaction times, lower error rates, and higher accuracy rates in the memory recall task, consistent with previous studies

[7, 12]. These environments may strengthen attention and memory by filtering out distracting stimuli and minimizing the field of perception. Confined spaces may enhance on-task behavior by minimizing visual complexity, which aids in processing learning-relevant stimuli.

Research from environmental psychology supports this perspective, demonstrating that smaller, less visually complex spaces enhance focus and information encoding by reducing the cognitive load resulting from unnecessary sensory input [57, 58]. This phenomenon can be understood through the lens of cognitive load theory, which suggests that minimizing visual distractions reduces cognitive demands; therefore, more resources will be available for working memory and attentional regulation [59, 60]. Perceptual load theory supports these findings by reinforcing the notion that minimizing irrelevant stimuli enhances attentional selectivity, even if it generally focuses on the task features [61].

In conclusion, this suggests that the physical characteristics of space, particularly spatial width, may influence cognitive performance. Architectural elements should not only be aesthetically pleasing but also provide evidence-based solutions to enhance attention and memory.

Participants' self-reported preferences were in favor of the wide studio, contrasting with the objective performance results. A majority expressed a stronger subjective liking for the wider conditions, as indicated by Likert scale responses favoring openness and visual spaciousness. This affective preference aligns with prior research suggesting that students of both genders prefer wide spaces over narrow ones, as they mention feeling suffocated in narrow spaces, which could negatively affect their learning experience [14]. Another research suggested that Open rooms were more likely to be judged as beautiful, and activated structures underlying perceived visual motion, while enclosed spaces elicit greater avoidance decisions [62].

The observed discrepancy between participants' cognitive performance and their spatial preferences reveals a notable divergence between objective and subjective evaluations of learning environments. While the narrow studio environment yielded significantly better outcomes in both attention and memory tasks, participants predominantly favored the wide studio in self-reported preference measures. This contradiction may be attributed to the affective and perceptual appeal of spatial openness, which is often associated with feelings of freedom, reduced confinement, and improved mood. Nonetheless, such preferences may not correspond to environments that optimize cognitive load control and attentional efficiency.

These results underscore the importance of assessing educational learning environments through both subjective user experiences and objective cognitive performance metrics. Designing learning spaces based solely on preference or cognition may undermine overall effectiveness. Therefore, evidence-based neuroarchitectural design should aim to integrate both user preferences and empirically validated cognitive performance.

The study's findings highlight significant implications for evidence-based architectural practice in educational design. The discrepancy between participants' cognitive performance and spatial preferences raises a critical question: Should design prioritize environments that enhance cognitive outcomes or the ones users prefer? Though participants performed better in narrow spaces, they preferred wider ones, suggesting the need to balance both cognitive functions and psychological comfort. Evidence-based design should merge both performance and preference, producing settings that are both cognitively efficient and emotionally fulfilling. This necessitates a multidisciplinary comprehension of the interplay between spatial form, sensory experience, and psychological response in order to influence learning outcomes. Ultimately, more holistic and inclusive learning spaces can be achieved by prioritizing both empirical evidence and user feedback.

Gender-based differences were also identified based on university and spatial width conditions. The university-based analysis revealed that female participants exhibited improved attention performance, characterized by faster reaction times and a lower number of attention errors. Females exhibited superior performance in memory recall, aligning with existing literature that associates female cognition with improved verbal encoding and sustained attention [63, 64]. Thus, female participants performed better and preferred wider studios across all universities. Additionally, a secondary gender-based analysis, which took into account spatial width conditions, further demonstrated that these trends remained consistent in both narrow and wide studio environments. Although both genders performed better in narrow studios, females exhibited more significant cognitive improvements, particularly in memory recall. These results underscore the need to account for gender-based disparities when creating enriching learning spaces.

This study makes several significant contributions to the emerging field of neuroarchitecture and its application in educational design. By employing immersive Virtual Reality (VR) and a fully counterbalanced within-subjects experimental design, the research provides robust evidence that spatial width has a significant impact on cognitive outcomes, particularly attention and memory. Unlike previous studies, this research integrates both objective behavioral data and subjective user preferences, revealing a notable discrepancy between cognitive performance and environmental satisfaction. Furthermore, the inclusion of gender-based analysis provides novel insights into gender-related cognitive variability in response to spatial configurations.

6. Conclusion

This study presents strong evidence suggesting that studio width affects cognitive performance in architectural education spaces. This study implemented a fully counterbalanced within-subjects design using virtual reality (VR) simulations scaled to actual studio dimensions. The results showed that narrower studios resulted in significantly faster reaction times, fewer attention errors and better memory recall of undergraduate architecture students in Erbil.

Despite enhanced cognitive results in narrow spaces, individuals consistently favored wider studio settings. This perceptual-cognitive disparity illustrates the intricate connection between environmental comfort and task performance, indicating that students could prefer emotional comfort and visual expansiveness over cognitive functioning. The findings highlight the need for educational design in balancing both psychological well-being and performance optimization.

The results were further clarified by gender-based analysis. In almost every cognitive measure, but especially in sustained attention and memory recall, female individuals performed better than their male counterparts. This aligns with research that links female cognition to enhanced language processing and improved attentional stability. Interestingly, females also showed more positive affective responses to wider spaces. A supplementary gender-based study using the spatial width condition confirmed similar results. In both narrow and wide conditions, female students consistently scored better than male students on all cognitive measures, with memory recall showing the most significant disparities. Although the narrower spaces were advantageous to both genders, women showed a higher level of sensitivity to spatial arrangement. These results underscore the significance of integrating gender-inclusive design strategies into the development of cognitive-optimized learning environments.

In conclusion, the study reveals that spatial width is a critical neuroarchitectural factor that directly influences students' attention and memory. It underscores the need for educational environments, particularly in Erbil, to incorporate empirical studies connecting spatial design to cognitive outcomes. The implications of this research are significant for architects, educators, and university planners, emphasizing the importance of adopting evidence-based spatial design strategies. Such strategies can enhance student well-being and academic success by fostering environments that promote optimal cognitive functioning. Future higher education design must adopt a multidisciplinary, inclusive, and evidence-based approach to foster students' cognitive development and academic achievement.

7. Limitations and Future Directions

This study presents three primary limitations. First, although Virtual Reality (VR) offered precise spatial control, it lacked multisensory fidelity, excluding factors such as temperature, acoustics, and tactile engagement that characterize real-world environments and may influence cognitive performance. Second, the experimental design isolated studio width as the sole independent variable while controlling for all others, limiting the ecological complexity of architectural settings where multiple design features interact to shape user experience. Third, the participant sample was confined to architecture students from three universities in Erbil, which restricts the generalizability of the findings to broader academic disciplines, cultural settings, and learning populations.

In future research, the focus should not be solely on the effect of studio width, but rather on numerous combinations of spatial elements, such as ceiling height, light quality, color, acoustics, enclosure, and biophilia, as they collectively shape thinking and feeling. Since this study focused on architecture students from three universities in Erbil, further studies should be more geographically and discipline-wise diverse to ensure more generalizable results across diverse learning environments.

Additionally, incorporating neurophysiological tools, such as electroencephalography (EEG), would reveal the underlying neural mechanisms of attention and memory in response to different spatial configurations. Furthermore, incorporating neurophysiological tools such as electroencephalography (EEG) would provide deeper insights into the underlying neural mechanisms of attention and memory in response to spatial configurations, thereby enhancing our understanding of how learning space design influences students' cognitive functions.

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

The authors declare no conflicts of interest.

Funding source

This study didn't receive any specific funds.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgments

The authors would like to acknowledge that this study was conducted with the support of Salahaddin University of Erbil (SUE).

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