

Virtual Reality Study on Cortisol Interaction with Preschool Classroom Size and Window View on Cognitive Outcomes: Implications for Early Childhood Educators

Kijoo Cha¹⁾

Ewha Womans University

Abstract

This study explored the interaction between baseline cortisol (BC) levels and spatial elements—specifically classroom size and window view—within a virtual reality (VR) early childhood classroom setting, to assess their impact on the cognitive functions of young adults (aged 19-28 years). The research involved 160 university students (80 male, 80 female) in South Korea. Participants' BC levels were determined through saliva assays, while additional data on demographics, fatigue, and sleep quality were gathered via questionnaires. They undertook computerized tests assessing memory, attention, and cognitive flexibility both before and after exposure to one of four VR scenarios, which differed in classroom size (large vs. small) and window view (natural vs. built). Regression analysis, adjusted for initial test scores, showed no main effects of VR conditions on cognitive outcomes. However, a significant moderating effect of BC was observed: participants with higher BC levels performed better on the card sorting task in large classroom settings compared to those with average or lower BC levels. No differences were noted in the small classroom condition. These findings highlight the potential interplay between the physical aspects of preschool environments and the differential susceptibility of adults, suggesting implications for optimizing educational practices through enhancing cognitive flexibility.

Keywords: *differential susceptibility, preschool, classroom size, window view*

Corresponding author, ¹⁾ kijoocha@ewha.ac.kr

Introduction

Prior studies have underscored the significant role that school buildings and classrooms play in shaping cognition and emotional responses, where individuals spend considerable amounts of time (e.g., Benfield et al., 2015; Cruz-Garza et al., 2022). However, these investigations primarily focus on students, often overlooking teachers who also extensively utilize these environments. This oversight presents a significant gap in research, particularly concerning *the effects of classroom spatial elements* on teachers. Early childhood educators spend more time in classroom settings compared to their counterparts in higher education levels. Since the well-being of these educators influences their ability to interact effectively with children (Ansari et al., 2020), it becomes essential to explore how these educators are affected by the physical conditions of their workspaces. To address this gap, this study utilizes VR technology to assess how environmental factors such as classroom size and window views impact young adults' cognitive functions to these spatial elements, shedding light on how specific environmental conditions interact with individual sensitivity to influence cognitive performance.

Literature Review

Nature View and Classroom size and Individuals' Cognitions

Previous research on the impact of environmental factors on cognitive function draws extensively from two foundational theories, highlighting the therapeutic benefits of natural settings: the Stress Reduction Theory (SRT) by Ulrich (1984) and the Attention Restoration Theory (ART) by Kaplan (1995; Kaplan & Kaplan, 1989). SRT maintains that nature alleviates stress and enhances emotional recovery by providing a tranquil environment that reduces stress responses. In contrast, ART emphasizes the cognitive benefits of nature, particularly in terms of attentional recovery. It suggests that natural environments promote effortless engagement and curiosity and that this interaction with natural elements helps relieve mental fatigue, thereby refreshing attention spans and enhancing cognitive abilities.

Drawing on these theories, extensive research has evaluated the positive effects of nature exposure in educational environments on students' cognitive functions such as attention and memory (Benfield et al., 2015; Cruz-Garza et al., 2022; Li & Sullivan, 2016). For example, Li & Sullivan (2016) demonstrated that high school students with classroom views of natural landscapes performed better on working memory tasks compared to their peers with views of urban settings. Further support comes from a VR study, where large windows that allow natural light and views have been linked to enhanced cognitive performance in tasks requiring attention and memory among graduate students (Zou & Ergan, 2019). Additionally, virtual environments enriched with natural elements have been shown to improve working memory performance and relaxation responses among participants aged 23–42 years (Yin et al., 2018). However, some studies have noted exceptions. For instance, despite exposure to natural views in their classrooms, fourth-grade students did not exhibit significant improvements in attention and concentration compared to those in urban-view classrooms (Lindemann-Matthies et al., 2021). Similarly, no noticeable differences were found in executive function test scores between kindergarteners in natural- versus built-view VR classrooms (Cha, 2023).

While considerable research has examined the effects of natural elements within educational environments, studies specifically addressing classroom size and its impact on cognitive functions are notably scarce. For example, Cruz-Garza et al. (2022) used VR technology to investigate how window presence and room size affect cognitive functioning in college students. Their findings indicated no substantial differences in cognitive performance across the different VR classrooms, although changes in brainwave activity depending on the VR conditions were observed. Another VR study by Cha (2023) found that children in larger ECE classrooms performed significantly better on a cognitive flexibility task, while those in smaller classrooms showed marginally lower performance on working memory tasks.

Although not specifically focused on classroom size and cognitive functions, there is evidence to suggest that larger spaces may enhance cognitive, emotional, and social responses. For instance, Vartanian et al. (2015) indicates that environments with higher ceilings can encourage more focused and explorative behaviors among 18 healthy adults. Similarly, Han et al. (2024) found that such spaces not only promote feelings of

restorativeness and awe but also enhance affective well-being and attention towards others within these environments among adults aged 18-59 years. Furthermore, Li et al. (2020) reported that 30 university students associated enhanced concentration with more spacious and less restricted environments. However, Han et al. (2024) also proposed that larger spaces with high ceilings might inhibit social interactions by increasing the physical distance between individuals. This body of research suggests that the physical dimensions of a space size can significantly impact cognitive performance.

It is clear from a review that while numerous studies have confirmed the impact of natural elements and room sizes on cognitive functions, there has been scant research specifically targeting ECE classrooms, particularly regarding their effects on the cognitive functions of adults. Furthermore, existing research highlighting individuals' differential susceptibility to external stimuli—which result in varying adaptation outcomes—underscores the necessity to explore the gap in research.

Differential Susceptibility and Cortisol

The Differential Susceptibility Theory (DST) posits that individuals vary in their sensitivity to environmental influences, which profoundly impacts their developmental and health outcomes. According to Belsky et al. (2007) and Boyce (2016), DST argues that those who are particularly susceptible to negative influences may also benefit more from positive changes, leading to a wider range of developmental outcomes based on their environment. This redefines susceptibility not just as a vulnerability but as a capacity for significant response to beneficial environments.

Research examining the role of differential susceptibility as a moderator between environmental influences and adjustment outcomes often focuses on physiological responses, such as heart rate, hormone levels, and other biological markers—like respiratory sinus arrhythmia, salivary cortisol reactivity, and heart rate variability (Ellis et al., 2011; Kalomiris et al., 2019). Notably, within this framework, cortisol has been extensively studied. Studies suggest that cortisol reactivity—defined as changes in cortisol levels in response to stress or challenges—is a critical marker of susceptibility. Individuals with heightened cortisol reactivity were found to be more responsive to both positive and negative environmental

conditions (Ellis et al., 2011; Kalomiris et al., 2019; Obradović et al., 2010). For instance, Obradović and colleagues (2016) have shown that children with increased cortisol reactivity tend to fare better in supportive environments, exhibiting improved cognitive and behavioral regulation, and greater academic competence, while encountering worse outcomes in less favorable environments. These findings underscore how individuals with specific physiological profiles may benefit more from positive environments and be more adversely affected by negative ones, highlighting the importance of considering physiological reactivity when assessing the impact of environmental factors on personal adjustment.

Research on the DST has focused more on childhood and adolescence due to the greater malleability of stress response systems during these periods. In adulthood, however, these susceptibility traits tend to stabilize, reducing the potential for changes in physiological reactivity and developmental outcomes by environmental influences (Boyce, 2016). Studies on adults often shift to examining the differential impact of environmental influences through genetic and epigenetic moderators, viewing cortisol levels as outcomes of adaptation to environmental factors rather than as a moderator (Alexander et al., 2014; Taylor et al., 2022). For example, Alexander et al. (2014) noted that epigenetic modifications, such as the methylation of the serotonin transporter gene (SLC6A4), moderate the effects of the 5-HTTLPR genetic polymorphism on the cortisol stress response. Nonetheless, research specifically examining how cortisol as a moderator interacts with environmental factors at the behavioral level to influence adult adjustment outcomes remains limited.

In research focusing on cortisol as an indicator of physiological reactivity, a relatively fewer studies have examined basal cortisol in individuals (e.g., Cha, 2024; Pascual-Sagastizabal et al., 2021; Vaillancourt et al., 2018), compared to those focusing on cortisol reactivity. The investigations on basal cortisol have yielded inconsistent results concerning its role in moderating responses to environmental stimuli, with both high and low cortisol levels being reported as associated with higher susceptibility to environmental impacts. For example, Cha (2024) demonstrated that preschool-aged children with *higher* basal cortisol levels performed better on working memory tasks in environments with natural views compared to built views. Similarly, research by Pascual-Sagastizabal et al. (2021) indicated that boys with *higher* baseline cortisol levels responded more variably to their fathers' authoritarian parenting style, exhibiting a range of aggressive behaviors. In contrast,

Vaillancourt et al. (2018) observed that children with *lower* basal cortisol levels showed more aggressive behaviors in situations of increased peer victimization than those with higher levels.

Despite the extensive research on the DST, much of the focus has been on how social environments, like parenting, educational practices, and interpersonal relationships, influence individuals' development and well-being. Notably, there is a gap in studies exploring the interaction between physical environment and physiological markers such as cortisol within the DST framework. This study aims to fill this gap by examining whether initial cortisol levels as indicators of differential susceptibility interact with classroom conditions to affect cognitive performance in young adults. To examine the variations in participants' cognitive performance in relation to their basal cortisol levels and different VR conditions, this study poses the following research questions (RQs):

RQ 1: Does participants' performance on cognitive tests differ depending on VR conditions: (a) classroom size condition: large vs. small classrooms; (b) window view condition: nature-view vs. built-view classrooms?

RQ 2: Does participants' baseline cortisol moderate the relationship between their cognitive performance and VR conditions: (a) classroom size condition: large vs. small classrooms; (b) window view condition: nature-view vs. built-view classrooms?

Methods

Participants

Due to the COVID-19 restrictions during the data collection period, in-service ECE teachers were not permitted to participate in research involving in-person contact. Therefore, university students—falling with the typical age range for ECE teaching positions (20s to 40s; OECD, 2019)—were recruited as a proxy sample. From October 2022 to April 2023, one hundred sixty college students from a university in the capital area of South Korea participated (IRB Approval No.1044396-202007-HR-138-05). The inclusion criteria required participants to: 1) have no history of neurological or mental health disorders such as

schizophrenia, ADHD, or epilepsy, nor have any family members with these conditions; 2) not be taking medication for any unrelated illnesses; and 3) not have color blindness and possess corrected vision of 0.8 or above. Recruitment was conducted through posters placed on school buildings within the campus where the lab was located. Participants' ages ranged from 19 to 28 years (average age = 22.41, SD = 2.09), and represented approximately 40 different academic departments. About 28.8% (N = 46) were ECE majors, and the remaining participants came from a diverse range of disciplines. The sample (N=80) comprised 50% males. Participants were equally assigned to four different experimental conditions (N=40 per condition) while ensuring gender balance. Each participant received approximately \$35 as compensation.

Procedures

Design of VR Classrooms

This study involved the construction of four distinct virtual classrooms to systematically assess the impact of two environmental variables: room size and window view. Each variable was manipulated to create two contrasting conditions, culminating in four unique virtual environments. First, as for the classroom size condition, the large classroom was configured with dimensions of 2.6 meters in height, 8.9 meters in width, and 7 meters in depth, allocating 3.1 square meters per child, based on an assumed class size of 20. This configuration is illustrated in Figure 1(a). In contrast, the small classroom measured 2.6 meters in height, 5.0 meters in width, and 4.0 meters in depth, providing only 1 square meter per child, approximately one-third the space per child compared to the larger classroom (Figure 1(b)). Next, as for the window view condition, the nature view classroom showcased a virtual environment with windows displaying a natural landscape, including grass fields and trees (Figure 1(c)). The built view classroom featured windows overlooking urban structures such as concrete buildings and streets (Figure 1(d)).

To ensure uniformity across the various virtual classrooms, all elements aside from the treatment variables of room size and window view were kept consistent. However, the smaller classroom had limitations in accommodating as many furniture pieces and play materials as the larger one. To prevent any bias in the participants' reactions, each classroom

was equipped with identical types and amounts of essential materials and designated activity zones. The only reductions were made in non-essential furnishings, such as tables and chairs.

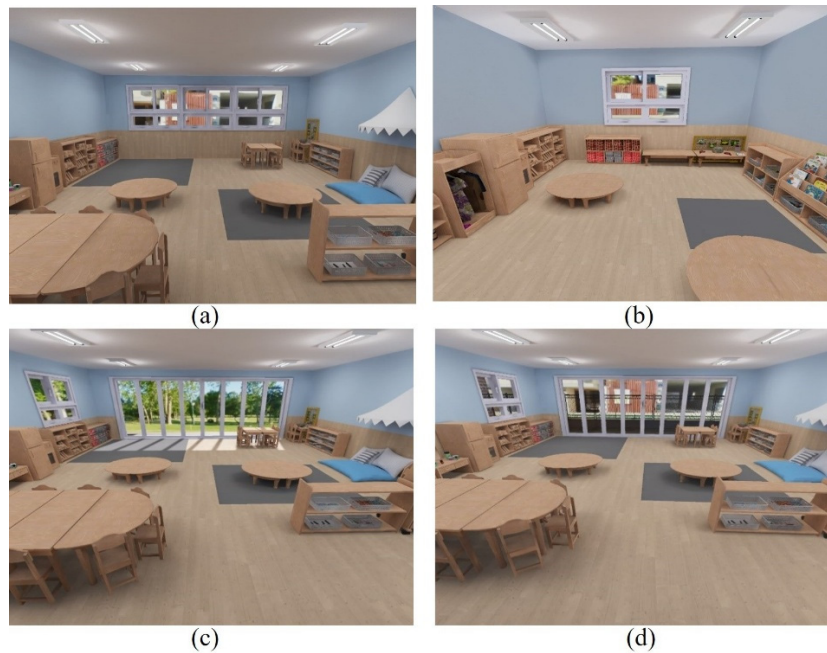


Figure 1. The four virtual reality ECE classrooms:
(a): large classroom; (b): small classroom; (c): nature view; (d): built view

Experimental Procedures

Participants registered online and were categorized by sex before being randomly assigned to one of four VR classroom conditions. Study details, including purpose, procedures, and compensation, were explained by phone, and lab visits were scheduled accordingly. A reminder sent the day before instructed participants to avoid gum, food, or lip balm within an hour prior, to prevent interference with cortisol analysis. To control for diurnal fluctuations, experiments were conducted at fixed times (10 AM for classroom size, 1 PM for window view). All participants wore masks throughout the procedure due to COVID-19 precautions, and the laboratory environment was kept consistent in temperature and humidity.

Upon arrival, participants received a briefing, completed consent forms, and filled in demographic and physical condition questionnaires. Baseline saliva samples were collected, followed by computer-based cognitive tests (~20 minutes). Participants then engaged in a 5-

minute VR classroom experience with a headset, consistent with prior VR research durations (Mark et al., 2021; Mistry et al., 2020; Palanica et al., 2019; Zhou & Ergan, 2019). After VR exposure, they completed post-tests and provided a second saliva sample. The entire procedure was completed within approximately one hour.

Measures

Socio-demographics and physical condition. Data were collected on participants' age, sex, and academic department. Additionally, participants were asked about their fatigue levels and the quality of sleep from the previous night. These were assessed using five-point Likert scales, where '1' indicated 'not tired' ('very bad' sleep), and '5' indicated 'very tired' ('very good' sleep) for fatigue and sleep quality, respectively. Thus, higher average scores indicate higher levels of tiredness and better sleep quality, respectively.

Cognitive Functions. The study employed four computerized tests, which have been shown to be influenced by spatial factors (e.g., Cha, 2023; Li & Sullivan, ; Zou & Ergan, 2019): 1) Digit Span tests (working memory), where participants repeated sequences of numbers forward and backward as dictated by the computer; 2) Visual Span tests (working memory), requiring participants to recall and replicate sequences of flashing circles on the screen in both forward and backward order; 3) the Word-Color (WC) Test (attentional and inhibitory control), where participants identified the color of words or read words displayed in either congruent or incongruent colors as quickly as possible; and 4) the Card-Sorting (CS) Test (cognitive flexibility), which involved identifying sorting criteria (color, shape, or number) and adapting to changes based on feedback. Practice sessions were conducted for all tests. For the WC and CS tests, the response time (WCRT) and the number of total and perseverative errors (CSE and CSPE, respectively) were used in the analyses, as is widely adopted. CSE indicate deficits not only in cognitive flexibility but also in working memory and attentional and inhibitory control, as they encompass all types of errors, including switching to an incorrect new criterion or randomly shifting sorting rules without a signal, as well as perseverative errors. CSPE specifically represent issues in set-shifting (inhibitory control), highlighting difficulties in changing cognitive strategies. Despite preliminary

testing before the experiment with five adults, scores concerning working memory (the digit and visual span tests) were excluded from the final analysis due to ceiling effects noted among most participants.

Cortisol. While basal cortisol levels are typically measured multiple times to ensure measurement reliability, this study utilized a single measurement taken before the administration of VR stimuli. Post-VR exposure cortisol measurement was not included in the analysis due to the expected divergent physiological responses from each VR condition (i.e., reducing and inducing stress and relaxation). Despite these methodological limitations, the study identified a strong correlation between pre- and post-cortisol levels ($r = .78, p < .001$), reinforcing the reliability of the initial measurement, even as a singular data point.

Analyses

Prior to addressing the main research questions, descriptive statistics and correlational analysis were conducted. It was noted that the distributions of all primary variables exhibited rightward skewness. To meet the fundamental prerequisites for regression analysis, these variables underwent logarithmic transformation (Hammouri et al., 2020).

To investigate the impact of the VR conditions, regression analyses were conducted using the post-test scores as the dependent variable and the VR condition as the independent predictor. The variables were mean-centered (Aiken & West, 1991), and robust standard errors were utilized to correct for potential heteroscedasticity, which could skew the standard errors and lead to inaccurate conclusions (Wooldridge, 2010). The analyses controlled for pre-test scores to account for any initial differences. Socio-demographic factors like age and gender, along with fatigue and sleep quality, were not included as controls since they showed no correlation with the cognitive test scores (Table 1). Additionally, to explore how baseline cortisol levels might moderate the effects of VR conditions on cognitive outcomes, an interaction term between pre-cortisol levels and VR conditions was introduced into the model. When significant interaction effects were identified, follow-up analyses were performed to ascertain at which levels of the moderator variable—1SD above the mean, at the mean, and 1 SD below the mean—these effects were significant (Aiken & West, 1991).

Results

Correlations among Main Study Variables

Correlational analyses are presented in Table 1. Baseline cortisol was not correlated with any of the cognitive tests, which fulfills the conditions as a moderator in testing the DST (Belsky et al., 2007). Sleep quality and fatigue were negatively correlated ($r = -0.55$, $p < .001$), indicating that good sleep was associated with better physical condition the following day. However, neither the sleep and fatigue variables nor age were correlated with cognitive test scores. Participants' pre- and post-test scores showed moderate correlations within the respective measures: CSE ($r = .31$, $p < .001$), CSPE ($r = .29$, $p < .001$), and WCRT ($r = .32$, $p < .001$). WCRT was not significantly correlated with the other two tasks. Regarding the CS task, CSE and CSPE were analyzed separately in the main analyses, as each measure appearing to assess different aspects of cognitive functions. This was evidenced by approximately 50% to 60% independent variances of each variable (pre: $r = .76$, $p < .001$; post: $r = .80$, $p < .001$).

Table 1. *Correlations among the Variables*

	1	2	3	4	5	6	7	8	9	10	11
1. Pre-Corti	—	—	—	—	—	—	—	—	—	—	—
2. Post-Corti	.78***	—	—	—	—	—	—	—	—	—	—
3. Fatigue	.18*	.07	—	—	—	—	—	—	—	—	—
4. SQ	-.15+	-.02	-.55***	—	—	—	—	—	—	—	—
5. Gender	.03	.06	-.01	-.17*	—	—	—	—	—	—	—
6. Age	.09	-.00	.03	-.06	.32***	—	—	—	—	—	—
7. Pre-CSE	.08	.11	.02	-.04	-.00	-.03	—	—	—	—	—
8. Post-CSE	-.15+	.02	-.10	.04	-.06	.06	.31***	—	—	—	—
9. Pre-CSPE	.09	.16*	-.02	-.01	-.06	-.01	.76***	.29***	—	—	—
10. Post-CSPE	-.08	.04	-.11	-.02	-.08	-.02	.32***	.80***	.32***	—	—
11. Pre-WCRT	-.05	-.01	-.07	.06	.02	.08	.14+	-.02	.13	-.03	—
12. Post-WCRT	-.08	-.02	.00	.04	.00	.16*	.13	.03	.14+	.06	.75***

Note.: Corti = cortisol; SQ = Sleep quality; Gender: 0=female, 1=male; CSE= Errors on the card sorting task, CSPE = Perseverative errors on the card sorting task; WCRT = Response time on the word-color task; + $p \leq .10$, * $p \leq .05$, *** $p \leq .001$

Descriptive Statistics of the Main Study Variables

Tables 2 and 3 present the descriptive statistics for the entire group and by experimental conditions. Overall, participants reported slight to normal levels of fatigue. Independent *t*-tests confirmed that there were no significant between-group differences, with the exception of WCRT in the classroom condition. The large classroom group exhibited significantly higher scores on WCRT at the post-VR testing, with marginal differences noted at the pre-measurement point. However, these differences were controlled for by including the pre-WCRT scores as a control variable.

Table 2. Descriptive Statistics as an Entire Group

	N	M	SD	Min	Max
Age	160	22.41	2.09	19	28
Sleep quality	160	3.69	0.90	1	5
Fatigue	160	2.58	0.84	1	4
CSE (pre)	160	11.23	4.06	5	26
CSE (post)	160	9.78	3.29	4	29
CSPE (pre)	160	7.61	2.34	4	18
CSPE (post)	160	6.74	1.98	2	19
WCRT (pre)	160	65.51	7.83	48.13	94.00
WCRT (post)	160	60.80	8.04	41.38	89.06

Note. CSE= Errors on the card sorting task, CSPE = Perseverative errors on the card sorting task; WCRT = Response time on the word-color task (in seconds)

Effects of Classroom Size and Window View

Regression analyses (Models A, C, and E in Tables 4 and 5) revealed no main effects of classroom size or window view on cognitive functions. This indicates that participants' overall performance on cognitive tests was comparable between groups regardless of the VR conditions.

Table 3. Descriptive Statistics by Experimental Conditions

		Room Size		<i>t</i> -value	Window View		<i>t</i> -value
		Large (n = 40)	Small (n = 40)		Nature (n = 40)	Built (n = 40)	
		M (SD)	M (SD)		M (SD)	M (SD)	
CSE	Pre	11.10 (3.94)	10.97 (3.46)	- 0.15	11.57 (4.33)	11.27 (4.54)	- 0.30
	Post	9.97 (2.82)	9.62 (3.25)	- 0.51	9.55 (2.90)	9.95 (4.12)	0.50
CSPE	Pre	7.62 (2.30)	7.57 (2.21)	- 0.09	7.62 (2.34)	7.6 (2.56)	- 0.04
	Post	6.70 (1.96)	6.47 (1.61)	- 0.55	6.77 (1.52)	7.00 (2.64)	0.46
WCRT	Pre	64.00 (8.20)	66.37 (7.53)	1.34 [†] (<i>p</i> = 0.09)	65.01 (6.63)	66.65 (8.83)	0.93
	Post	58.83 (8.00)	61.92 (7.23)	1.81* (<i>p</i> = 0.03)	60.93 (7.33)	61.50 (9.36)	0.30
Cortisol	Pre	21.10 (10.32)	21.64 (11.82)	0.21	14.93 (8.12)	14.43 (7.25)	- 0.28
	Post	19.77 (8.38)	19.65 (10.73)	- 0.05	15.03 (7.89)	13.73 (5.81)	- 0.81

Note. CSE= Errors on the card sorting task, CSPE = Perseverative errors on the card sorting task; WCRT = Response time on the word-color task.

Table 4. Regression Models regarding the Classroom Size Condition

Outcome variable	ECS (post)	ECS (post)	PECS (post)	PECS (post)	RTWC (post)	RTWC (post)
	Model A β (SE)	Model B β (SE)	Model C β (SE)	Model D β (SE)	Model E β (SE)	Model F β (SE)
Test score (Pre)	0.32** (0.10)	0.37*** (0.08)	0.41** (0.10)	0.41** (0.13)	0.77*** (0.08)	0.76*** (0.08)
Pre-cortisol		-0.01 (0.08)		-0.01 (0.05)		-0.01 (0.03)
Room size	0.04 (0.06)	0.085 (0.06)	0.01 (0.06)	0.02 (0.39)	-0.02 (0.02)	-0.03 (0.12)
(Pre-cortisol) × (Room size)		-0.24* (0.12)		-0.002 (0.12)		0.002 (0.04)
R ²	0.13	.21	0.15	0.17	0.53	0.55
F	5.75	7.77	8.24	3.63	46.48	24.94
P	<.01	<.001	<.001	<.01	<.001	<.001

Note. SE: standard error; Room size (large classroom = 1; small classroom = 0); **p*<.05, ** *p*<.01, *** *p*<.001

Table 5. Regression Models regarding the Window View Condition

Outcome variable	ECS (post)	ECS (post)	PECS (post)	PECS (post)	RTWC (post)	RTWC (post)
	Model A β (SE)	Model B β (SE)	Model C β (SE)	Model D β (SE)	Model E β (SE)	Model F β (SE)
Test score (Pre)	0.25** (0.08)	0.27** (0.09)	0.23* (0.10)	0.23* (0.11)	0.85*** (0.09)	0.85*** (0.09)
Pre-cortisol		-0.15 (0.11)		-0.05 (0.09)		-0.00 (0.04)
Window view	-0.03 (0.06)	-0.25 (0.38)	-0.01 (0.05)	0.07 (0.29)	0.01 (0.02)	0.04 (0.13)
(Pre-cortisol) $\times$ (Window view)		0.09 (0.14)		-0.03 (0.10)		-0.01 (0.05)
R ²	0.07	0.13	0.04	0.07	0.49	0.51
F	4.19	2.60	2.68	1.58	40.08	27.70
P	<.05	<.05	0.07	0.18	<.001	<.001

Note. SE: standard error; Window view (nature view = 1; built view = 0); * $p < .05$, ** $p < .01$, *** $p < .001$

Moderating Effects of Baseline Cortisol

Regression analyses revealed significant interaction effects in the model examining the relationship between classroom size and CSE, while controlling for the pre-CSE score (Model B in Table 4).

When visually illustrating Model B in Table 4 (Figure 2), contrastive patterns were observed between groups with different levels of baseline cortisol. No significant differences in performance on the CS task were found in the small classroom condition across varying levels of baseline cortisol. However, discrepancies were noted in the large classroom condition. Participants with +1SD cortisol levels demonstrated better performance (fewer errors) compared to those with -1SD cortisol levels in the large room condition. Conversely, the -1SD group exhibited lower performance (more errors) in the large room condition. Follow-up analyses were conducted to identify where the slopes significantly differed from each other.

Follow-up analyses revealed that the interaction effect slope for the +1SD group significantly differed from those of the average group ($t = -2.04$, $p = 0.045$) and the -1SD group ($t = -2.76$, $p = 0.007$), while the slopes of the -1SD and average groups did not significantly differ ($t = 0.80$, $p = 0.43$). The slope for the +1SD group was significantly

different from zero ($t = -2.16, p = 0.034$), indicating that classroom size had a significant effect on cognitive performance for individuals with higher baseline cortisol levels. The slopes for the mean and lower cortisol groups respectively did not significantly differ from zero ($t = 0.41, p = 0.680$; $t = 1.84, p = 0.069$), suggesting that for participants with average and below-average cortisol levels, performance on the CSE did not significantly differ between the large and small classroom conditions (Figure 2). Significant differences between the large and small classroom conditions were observed only among participants with +1SD baseline cortisol levels. This finding suggests that individuals with higher cortisol levels may be more responsive to the beneficial effects of a larger classroom size.

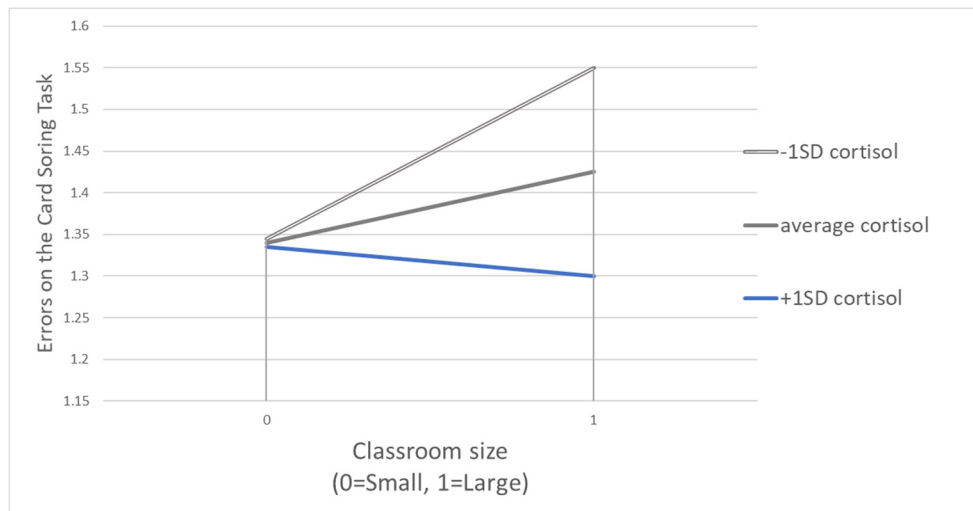


Figure 2. Moderating effects of baseline cortisol: The number of errors on the card sorting task by classroom size. Regarding the window view condition, no interaction effects between baseline cortisol and the VR condition were detected across the tasks (Table 5).

Discussion

While many studies have consistently demonstrated the positive effects of natural views and spacious indoor environments on human cognition, there has been limited research on how individual sensitivity to the environment affects this relationship. Additionally, prior research on spatial factors in educational settings has primarily focused on children,

neglecting adults in their 20s to 40s, who primarily comprise the ECE teaching workforce (OECD, 2019). To address these gaps, this pioneering study examined whether the physical aspects of ECE classroom environments influence cognitive flexibility and attention in young adults in their 20s, and how baseline cortisol as a marker of differential susceptibility plays a role. The results indicated that there were no significant main effects of classroom size and natural view on cognitive functions. This finding is in line with previous work reporting inconsistent effects of classroom spatial factors on cognition (e.g., Cruz-Garza et al., 2022; Lindemann-Matthies et al., 2021). However, baseline cortisol levels moderated the effect of classroom size on cognitive flexibility. Specifically, while participants' performance on the card sorting task did not vary with cortisol levels in the small classroom condition, higher cortisol levels were associated with significantly better performance in the large classroom condition.

The moderating effects of baseline cortisol in this study support the DST over the contrastive model, as outlined by Belsky et al. (2007). Specifically, individuals with +1SD and above cortisol levels exhibited better cognitive performance in the large classroom condition. In contrast, those with -1SD and below cortisol levels showed no significant differences between the large and small classroom conditions. These findings suggest that participants with higher baseline cortisol were more responsive to the beneficial effects of the large classroom, such as the relaxation induced by the spacious environment. Conversely, those with lower cortisol levels showed no responses, probably due to lower susceptibility to environmental influence. In this study, the morning basal cortisol levels of participants in the classroom size condition ($M = 21.37$ nmol/L) were slightly above the typical adult morning range (10-20 nmol/L). However, considering that university students typically exhibit higher basal cortisol levels due to academic stress (average 18-23 nmol/L) (Castillo-Navarrete et al., 2023; Nijakowski et al., 2023), the levels observed in this study fall within the expected range. Notably, cortisol levels from which significant differences in moderation effects exist seem to emerge between the average cortisol group (approximately 20.08 nmol/L), which falls within the typical adult range, and the above-average group, whose levels exceed the typical adult range. This suggests that the observed variability in the impact of spatial elements may be relevant not only to university students but also to the broader population with higher baseline cortisol levels.

In this study, a difference from previous research was noted (Dravigne et al., 2008; Li & Sullivan, 2016; Palanica et al., 2019), as no significant main effects were observed for natural scenery on cognitive performance. This may be attributed to the participants' lack of focused attention on the natural scenery, compounded by the study design where participants were allowed to look around the VR classroom freely. If participants had focused more on other parts of the classroom indeed, it is plausible that different results might have emerged between ECE majors, who are accustomed to ECE settings, and other majors. Post-hoc analyses suggest a trend where, unlike in the built-view condition, which showed no major-dependent differences, ECE majors ($N = 24$) performed marginally better in the card sorting task in the nature-view condition compared to their peers from other disciplines ($N = 56$) ($t = -1.92, p = 0.059$). However, a discrepancy by majors was observed only in a single task and only one experimental condition. Also, the interpretive value of the finding is limited by the small and unbalanced sample sizes. Contrary to the window view condition, which demands explicit attention to derive benefits, the classroom size condition might trigger automatic subconscious responses, potentially explaining the observed moderating effect of cortisol. This aligns with earlier findings in preschool-aged children, where the positive effect was observed only in the classroom size condition, while no significant effect of natural scenery was noted (Cha, 2023).

This study identifies several key differences from previous findings regarding the impact of physical space on cognitive functions. Initially, whereas an earlier investigation established that classroom size positively affects cognitive flexibility in young children (Cha, 2023), the present study observed that these effects were primarily moderating rather than direct. This variation might stem from the general differences in neuroplasticity to environmental stimuli. Another possible explanation is that the total time of exposure to the VR environment may have been insufficient. While many studies have demonstrated valid effects of VR on adults with only a few minutes of exposure (Mark et al., 2021; Zhou & Ergun, 2019), a longer duration might have produced more pronounced effects.

Next, while a past study noted cortisol's moderating role in *working memory* among kindergarteners (Cha, 2024), the current research identified this influence within a *cognitive flexibility* task. This discrepancy might be attributed to a ceiling effect observed in the working memory performances, leading to its exclusion from the analysis and potentially

obscuring significant findings. Additionally, the card sorting task, a representative measure of cognitive flexibility, likely taps into two distinct sub-skills related to the three primary components of executive functions (i.e., working memory, attention shifting, and inhibitory control): 1) learning new rules and exploring strategies and 2) switching tasks or rules, requiring attention and inhibitory control (Miyake et al., 2000). This may explain why the moderating effect was detected in total errors on the card sorting task—a more comprehensive measure—rather than in perseverative errors, which assess cognitive rigidity exclusively. Finally, previous studies showing a negative association between performance on the card sorting task and response inhibition suggest a trade-off between these capacities or their independence (Mittal et al., 2015). These findings imply that inhibitory control, as measured through the word-color task in this study, might be less directly or interactively susceptible to environmental influences (Mittal et al., 2015), whereas cognitive flexibility and working memory appear to be more affected (Cha, 2023; 2024), which warrants further investigation.

Limitations and Future Research

The current study brings several strengths, such as being the first to explore the moderating effects of physiological reactivity alongside spatial factors, focusing on ECE levels and adult participants. However, given the exploratory and pioneer nature of this study, it is acknowledged that there are several limitations that future research should address.

One key limitation is the study's reliance on a sample consisting solely of university students in their twenties, with no in-service ECE teachers included due to COVID-19 restrictions. Although participants were within the typical ECE teacher age range (OECD, 2019), including in-service teachers in future research would strengthen the applicability of the results to the target professional population.

Another consideration is familiarity with ECE classroom settings. Although no significant differences were found between ECE majors and non-majors across the main study variables, except the slight marginally significant discrepancy only in one measure as mentioned earlier. However, since this difference emerged at the pre-measurement stage—before any

experimental manipulation—it is unlikely to be attributable to familiarity with ECE classrooms. Furthermore, existing evidence suggests no fundamental differences in biological mechanisms of differential susceptibility within this adult age group based on academic majors (Boyce, 2016; Ellis et al., 2011). Nevertheless, future research could further investigate this factor by comparing teachers versus non-teachers or ECE majors versus non-majors.

Next, this study did not initially aim to investigate cortisol's moderating effects, and as such, cortisol was collected only once per session. Multiple cortisol measurements across three to four time points would improve reliability. Furthermore, although the laboratory environment was consistently maintained in terms of temperature and humidity, the original records were lost over time, making it impossible to report the exact ranges. Acknowledging this as a limitation, future research should document and report these values to better control for their potential influence.

Additionally, given that the study involved university students, whose cognitive abilities are generally high, employing tasks with varying difficulty levels and complexity to mitigate potential ceiling effects could improve power to detect differences in cognitive responses.

Finally, all participants completed the study while wearing face masks due to COVID-19 safety protocols. Although mask use is unlikely to have substantially influenced the results, future replication without mask requirements will be important to confirm the robustness of the findings.

Conclusion

Early childhood educators spend extensive time in the classroom directly engaging with young children, whose cognitive and emotional development relies heavily on adult guidance. Therefore, this study's examination of the interaction between spatial factors and physiological sensitivity in influencing teachers' cognitive functions, which can affect teacher-child interactions, is critically important. Given the novelty of this research area and the exploratory nature of this study, it is prudent to approach any conclusions with caution. Nevertheless, the preliminary findings suggest a potential interaction between classroom size and variations in individual susceptibility, which could differentially affect cognitive

flexibility. Enhanced cognitive flexibility in ECE teachers leads to numerous benefits in their interactions with young children. Educators with elevated cognitive flexibility are better equipped to adapt their teaching methods and behavioral management strategies to accommodate the diverse learning styles and needs of children in real-time (Esen-Aygün, 2018; Kaçay et al., 2021). Although the observed effect in this study was limited to a single significant interaction (baseline cortisol×classroom size) on cognitive flexibility, the pattern of findings suggests that, for educators with higher physiological stress sensitivity, more spacious classroom layouts may offer cognitive benefits. In practice, when designing or renovating ECE classrooms, ensuring adequate space for educator could be explored as one possible strategy to support their cognitive adaptability. Future research is essential to elucidate the underlying biological mechanisms of these observed relationships, replicate these findings with professional ECE teachers, and develop a robust knowledge base.

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