Exploring the Role of Virtual Reality in Physical Education for Stress Adaptation Among Adolescents in Socio-Political Crisis Settings

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Abstract

Physical education can serve as more than a motor domain. In unstable social environments, it can also function as a structured context for emotional regulation, controlled challenge, and resilience-oriented learning. The present quantitative experimental study examined cardiovascular stress reactivity during a single-session virtual reality protocol embedded in a secondary-school physical education setting. Fifty high school students aged 15-19 years participated (25 males, 25 females). After a resting baseline assessment, each participant completed a time-pressured virtual fire emergency task followed by a standardized 5-minute AimXr combat-survival challenge. Heart rate was monitored continuously with a Mi Band 6 wearable, and the primary physiological outcomes were resting heart rate, minimum heart rate, average heart rate, maximum heart rate. In addition, a composite performance score was derived from cardiovascular and task-performance indicators. The findings indicated clear cardiovascular activation during virtual exposure, with average heart rate increasing substantially from pre-exposure baseline to task performance. The primary physiological outcomes were resting heart rate, minimum heart rate, average heart rate, and maximum heart rate. Average heart rate showed a weak-to-moderate positive association with performance score. This finding suggests that greater cardiovascular engagement was modestly related to better task performance, but it should be interpreted cautiously because the study did not formally test a curvilinear model. The result may be discussed conceptually in relation to the Yerkes-Dodson framework, but it does not provide direct evidence of an inverted-U relationship. The results support the educational use of supervised virtual reality in physical education as a safe means of rehearsing decision-making, self-regulation, and stress adaptation in adolescents living under conditions of heightened uncertainty.

Keywords: virtual reality, physical education, cardiovascular response, adolescent resilience, socio-political crisis.

JEL Classification: I.

1. Introduction

Physical education is increasingly understood as a multidimensional school subject with physical, affective, social, and cognitive value rather than as a narrow vehicle for motor training alone. Reviews of school-based physical education and youth physical activity have linked participation to broad developmental benefits, while major policy documents continue to frame quality physical education as an important contributor to health, inclusion, and life-skills education (Biddle et al., 2019; UNESCO, 2015; World Health Organization, 2020).

This broader view becomes especially relevant in socio-political crisis settings. Adolescents exposed to prolonged uncertainty, emergency discourse, forced displacement in their communities, or conflict-related anxiety may not necessarily require direct trauma simulation in school. Rather, they may benefit from structured, developmentally appropriate opportunities to rehearse self-control, situational awareness, and adaptive coping under manageable pressure. Research on war-affected and crisis-affected youth has repeatedly emphasized ecological resilience, school functioning, social support, and protective processes over purely deficit-oriented framings of trauma (Betancourt & Khan, 2008; Betancourt et al., 2013; Masten, 2014; Panter-Brick & Leckman, 2013; Tol et al., 2011).

Within that perspective, virtual reality is pedagogically attractive because it allows controlled exposure to challenge without exposing learners to real danger. The sense of presence created by immersive environments can heighten emotional engagement and decision urgency, but the school retains control over scenario content, duration, intensity, and debriefing. This makes VR conceptually compatible with resilience-oriented physical education in settings where preparedness, uncertainty tolerance, and emotional composure are educationally salient objectives. At the same time, immersion alone does not guarantee better learning. The educational literature indicates that instructional design, usability, cognitive load, and sequencing strongly shape outcomes (Jensen & Konradsen, 2018; Makransky & Lilleholt, 2018; Makransky & Petersen, 2019, 2021; Merchant et al., 2014; Radianti et al., 2020).

Against this background, the present study investigated whether an acute VR protocol embedded in physical education would elicit measurable cardiovascular activation in adolescents and whether this activation would vary by sex and relate to performance. The study was guided by two The expectations: first, that VR exposure would increase cardiovascular activation relative to rest; and second, that performance would be associated with the magnitude of cardiovascular activation, without assuming that higher activation would always be beneficial.

2. Literature Review

A substantial body of work has established that immersive and semi-immersive virtual environments can increase attention, presence, engagement, and perceived relevance in educational tasks, although effects on knowledge outcomes are mixed and depend on the fit between media, task structure, and learner preparation (Jensen & Konradsen, 2018; Merchant et al., 2014; Parong & Mayer, 2018; Radianti et al., 2020). Studies by Makransky and colleagues further suggest that VR learning processes follow both affective and cognitive pathways, in which presence, positive emotion, usability, cognitive value, and self-efficacy jointly influence outcomes rather than immersion acting as a simple main effect (Makransky & Lilleholt, 2018; Makransky & Petersen, 2019, 2021).

Theoretical work on presence and experiential transformation helps explain why VR is particularly suitable for stress-adaptation pedagogy. Slater and Sanchez-Vives (2016) argued that immersive VR changes behavior primarily when users respond to virtual events as if they matter, while Riva et al. (2016) emphasized the capacity of immersive systems to reorganize emotionally meaningful experience and support adaptive change. In educational settings, these mechanisms suggest that VR can be used not only for content delivery but also for embodied rehearsal of coping, composure, and action sequencing under time pressure.

The safety-training literature is especially relevant to the present study. Virtual environments have been shown to support procedural learning in safety scenarios and to compare favorably with traditional materials in terms of engagement and, in many cases, retention. Fire and evacuation training has emerged as a prominent domain, and recent meta-analytic evidence indicates that VR safety training generally outperforms conventional approaches in knowledge acquisition and retention, although the literature still suffers from limited theoretical integration and relatively sparse long-term follow-up (Buttussi & Chittaro, 2018, 2021; Pallavicini et al., 2016; Scorgie et al., 2024).

From a psychophysiological standpoint, adolescence is a period of heightened sensitivity to stress-related biological and psychosocial demands. Reviews have documented developmental shifts in stress responsivity during adolescence, while meta-analytic work on heart rate variability has supported the use of cardiovascular indices as pragmatic markers of autonomic regulation under stress. (Kim et al., 2018; Laborde et al., 2017; Romeo, 2013; Shaffer & Ginsberg, 2017). Simulation research in education also indicates that heart rate can capture meaningful stress changes across task phases, although excessive activation may hinder performance rather than help it, in line with the classic Yerkes-Dodson formulation (Nakayama et al., 2018; Yerkes & Dodson, 1908).

Taken together, the literature supports the integration of immersive technologies into school contexts when the aim is not only content transmission but also the development of self-regulation, situational awareness, and adaptive coping. In unstable socio-political environments, this is particularly relevant because education systems require methods that are engaging, ethically acceptable, and capable of simulating challenge without reproducing trauma.

3. Methodology

The study used a quantitative experimental design with one standardized VR session per participant. The protocol was conducted at Laude-Reut Educational Complex, Bucharest, Romania, in a school gymnasium annex temporarily configured as a supervised VR assessment station. Data were collected between September 2025 and January 2026. Each participant completed the same experimental sequence, consisting of a resting baseline assessment, a fire-emergency VR simulation, and a standardized 5-minute AimXr challenge. The crisis frame was educational rather than traumatic: students were not exposed to graphic injury, victimization, or war scenes. Instead, the scenarios were designed to represent emergency preparedness, uncertainty management, rapid response, and cognitive pressure, which are constructs relevant to resilience education in socio-politically unstable environments. The pedagogical aim was to observe physiological adaptation to controlled stress, not to simulate trauma.

Immersive stimuli were delivered using a Meta Quest 2 headset, and the 5-minute combat-survival block was standardized through AimXr in an offline, bot-controlled condition. Cardiovascular data were recorded continuously with a Mi Band 6 wrist-worn monitor. The Quest 2 supports 1832 × 1920 resolution per eye and refresh rates up to 120 Hz, while AimXr provides a repeatable shooter-survival environment for timed decision-making tasks. Recent validation work suggests that smart-band devices can be used cautiously for field-based monitoring, although they should not be treated as equivalent to clinical-grade instruments (Ortiz-Gutiérrez et al., 2025).

3.1. Participants

The sample comprised 50 adolescents enrolled in high school, with equal sex distribution: 25 males and 25 females. Participants were between 15 and 19 years of age (M = 16.8, SD = 1.1). Recruitment took place through physical education classes in a public secondary school setting. Inclusion criteria were regular participation in school physical education, absence of known acute cardiovascular or respiratory illness on the day of testing, and ability to tolerate headset use. Students were excluded if they reported severe motion sickness history, a current panic episode, or medical advice against strenuous or stress-inducing activity.

Resting heart rate was collected during seated quiet rest before exposure. The observed baseline range in the present sample was 63-84 bpm, which remained consistent with normative expectations for adolescents and older teenagers.

All procedures complied with ethical standards for research involving minors. Students younger than 18 years participated only after written parental informed consent and student assent had been obtained, while participants aged 18 or older provided their own written informed consent. Participation was voluntary, and students were informed that they could discontinue at any point without academic consequences. A physical education teacher and school psychologist were present throughout testing, and the scenarios were piloted to avoid excessive psychological distress. The study protocol conformed to the principles of educational beneficence, proportional challenge, and supervised withdrawal.

Figure 1. Two of the participants

3.2. Experimental Procedure

Testing was performed individually. Each session began with a briefing, equipment fitting, and a 5-minute seated adaptation period. During the final 3 minutes of this period, resting heart rate was recorded. Participants then completed a very brief headset familiarization segment to reduce novelty effects unrelated to the experimental tasks.

The first experimental task was a fire emergency simulation designed to create cognitive and emotional pressure without trauma exposure. Students were required to activate the alarm, identify the fire source, locate the extinguisher, operate it correctly, and extinguish the fire under time pressure. The scenario rewarded rapid but accurate sequencing and penalized ineffective or

delayed action. Completion time varied across participants depending on efficiency and errors.
Immediately after the fire task, participants entered the AimXr challenge for a fixed duration of 5 minutes. To improve comparability, the same map, session length, and difficulty setting were used for all students. Participants were instructed to remain active, survive as long as possible, minimize deaths, and defend themselves effectively against virtual opponents. Because the purpose was to elicit controlled cognitive stress rather than violent immersion, the task was framed as a perceptual-motor decision challenge within a gamified environment.
The total active test duration therefore consisted of the individualized fire-simulation time plus the fixed 5-minute AimXr block. Across the full sample, mean total task duration was 7.8 minutes (SD = 0.7), with a mean fire-simulation completion time of 2.8 minutes (SD = 0.6).

3.3. Variables and Measurements

Resting heart rate. Resting HR was defined as the average bpm recorded during the final 3 minutes of quiet seated rest prior to headset exposure.
Minimum, average, and maximum heart rate. During the active VR period, minimum HR reflected the lowest valid value captured, average HR represented the arithmetic mean across the entire test, and maximum HR represented the highest recorded peak. These indices were selected because acute stress reactivity is often expressed through both overall cardiovascular elevation and transient peaks of autonomic mobilization (Kim et al., 2018; Romeo, 2013).
Performance score: task performance was operationalized through a study-specific composite index ranging from 0 to 100 points. The score was constructed to summarize observable behavioral performance across the two virtual reality tasks: the fire-emergency simulation and the AimXr combat-survival challenge. Higher values indicated better overall task performance.
The composite performance score included four components: fire-task time efficiency, fire-procedure accuracy, death avoidance, and combat effectiveness. Each component was first converted to a 0–100 scale so that all indicators had the same direction of interpretation, with higher scores representing better performance.
Fire-task time efficiency reflected how quickly each participant completed the fire-emergency simulation. Because shorter completion times indicated better performance, this variable was reverse-normalized using the following formula:

Fire Time Efficiency = 100 × [(Tmax − Ti) / (Tmax − Tmin)]

where Ti represents the fire-task completion time of participant, Tmax represents the longest completion time recorded in the sample, and Tmin represents the shortest completion time recorded in the sample.

Fire-procedure accuracy reflected the correctness of the emergency-response sequence. Five key procedural steps were evaluated: activating the alarm, identifying the fire source, locating the extinguisher, using the extinguisher correctly, and extinguishing the fire. The score was calculated as follows:

Fire Procedure Accuracy = 100 × (Correct Steps / 5)

where Correct Steps represents the number of correctly completed procedural steps for participant.

Death avoidance reflected survival efficiency during the 5-minute AimXr challenge. Because fewer deaths indicated better performance, this variable was reverse-normalized using the following formula:

Death Avoidance = 100 × [(Dmax − Di) / (Dmax − Dmin)]

where Di represents the number of deaths recorded for participant, Dmax represents the highest number of deaths recorded in the sample, and Dmin represents the lowest number of deaths recorded in the sample.

Combat effectiveness reflected the participant’s ability to respond effectively to virtual opponents during the AimXr challenge. It was based on the number of opponents eliminated and was normalized using the following formula:

Combat Effectiveness = 100 × [(Ki − Kmin) / (Kmax − Kmin)]

where Ki represents the number of opponents eliminated by participant, Kmax represents the highest number of eliminations recorded in the sample, and Kmin represents the lowest number of eliminations recorded in the sample.

The final performance score was calculated using the following weighted formula:

Performance Score = 0.30 × Fire Time Efficiency + 0.25 × Fire Procedure Accuracy + 0.25 × Death Avoidance + 0.20 × Combat Effectiveness

The weighting structure was selected on pedagogical grounds. Greater importance was assigned to emergency-task efficiency, correct action sequencing, and survival-oriented behavior than to opponent elimination alone. This choice was consistent with the educational purpose of the protocol, which was to assess controlled decision-making, situational awareness, and adaptive functioning under pressure rather than gaming ability or aggressive output. Therefore, the performance score should be interpreted as a transparent, study-specific task-performance index, not as a standardized psychological or clinical scale.

Figure 2. Example of HR measured with the wearable device

3.4. Statistical Analysis

Data were analyzed using descriptive and inferential statistics. Means and standard deviations were reported for resting heart rate, minimum heart rate, average heart rate, maximum heart rate, and performance score. The Shapiro-Wilk test was used to assess the normality of the main continuous variables.

To examine cardiovascular activation during the VR protocol, resting heart rate was compared with average heart rate during the active VR tasks using a paired-samples t test. Sex-based comparisons were conducted using independent-samples t tests when distributional assumptions were met. Effect sizes were reported using Cohen's d, with values of approximately 0.20, 0.50, and 0.80 interpreted as small, moderate, and large effects, respectively.

The association between cardiovascular activation and task performance was examined using Pearson correlation analysis between average heart rate and performance score. Statistical significance was set at $p < .05$. All analyses were interpreted cautiously because of the modest sample size and the exploratory nature of the single-session school-based protocol.

4. Results and Discussions

Shapiro-Wilk testing indicated acceptable normality for resting heart rate, minimum heart rate, average heart rate, maximum heart rate, and performance score (all $p > .05$). Therefore, parametric procedures were used for the main comparisons. **Table 1** presents the descriptive statistics by sex and for the total sample.

Variable	Male (n = 25)	Female (n = 25)	Total (N = 50)
Resting HR (bpm)	71.6 ± 5.5	73.9 ± 5.7	72.8 ± 5.6
Minimum HR (bpm)	70.8 ± 6.0	72.1 ± 6.2	71.5 ± 6.1
Average HR (bpm)	103.9 ± 9.4	100.1 ± 8.7	102.0 ± 9.1
Maximum HR (bpm)	137.4 ± 12.6	132.6 ± 12.1	135.0 ± 12.4
Performance score (0-100)	65.8 ± 11.2	58.9 ± 10.9	62.4 ± 11.5

Table 1. Descriptive statistics

Across the full sample, average heart rate during the VR tasks was markedly higher than resting heart rate. A paired-samples t test indicated that the increase from resting HR ($M = 72.8$, $SD = 5.6$) to average task HR ($M = 102.0$, $SD = 9.1$) was statistically significant and large in magnitude, $t(49) = 20.84$, $p < .001$. This result indicates that the combined VR protocol elicited clear acute cardiovascular activation in the participating adolescents.The sex-based inferential comparisons are summarized in **Table 2**.

Comparison	Test statistic	p	Effect size
Resting HR	t(48) = -1.45	.153	d = 0.41
Minimum HR	t(48) = -0.75	.455	d = 0.21
Average HR	t(48) = 1.48	.145	d = 0.42
Maximum HR	t(48) = 1.37	.177	d = 0.39
Performance score	t(48) = 2.21	.032	d = 0.62

Table 2. Inferential comparisons

Sex-based comparisons showed no statistically significant differences in resting heart rate, minimum heart rate, average heart rate, or maximum heart rate. The only statistically significant sex-based difference was observed for performance score, with males obtaining higher scores than females, $t(48) = 2.21$, $p = .032$, $d = 0.62$. The effect size was moderate, suggesting a meaningful but not extreme difference in task performance.

This finding should be interpreted cautiously. The performance score included fire-task time efficiency, fire-procedure accuracy, death avoidance, and combat effectiveness. Therefore, the observed difference may reflect differences in prior familiarity with game-like visuomotor tasks, speed of interaction with the virtual environment, or tactical adaptation during the AimXr challenge, rather than any general difference in stress adaptation capacity.

Correlation analysis showed a weak-to-moderate positive association between average heart rate during the VR tasks and performance score, Pearson's $r = .29$, $p = .041$. This suggests that students who displayed greater cardiovascular engagement during the VR protocol tended to obtain slightly higher task-performance scores. However, the association was modest and should not be interpreted as evidence that higher physiological activation is always beneficial.

Overall, the results support two main observations: first, the VR protocol elicited meaningful cardiovascular activation, as shown by the increase from resting heart rate to average heart rate during task performance; and second, task performance was moderately higher among males, while the main heart-rate indicators did not differ significantly by sex.

The present study examined whether a brief, supervised virtual reality protocol embedded in physical education could elicit measurable cardiovascular activation and generate observable task-performance differences among adolescents. The main finding was that average heart rate during the VR tasks was substantially higher than resting heart rate. This indicates that the protocol produced clear acute cardiovascular activation, even though the scenarios were educationally framed and did not involve traumatic or unsafe content.

This finding is important because it suggests that VR can be used in physical education as a controlled pedagogical environment for challenge, attention, and decision-making under pressure. In contrast to real emergency exposure, VR allows students to experience urgency, uncertainty, and task demands while remaining in a safe and supervised school setting. This is consistent with broader views of physical education as a subject that supports not only motor development, but also self-regulation, health education, social responsibility, and life skills (Bailey, 2006; UNESCO, 2015; World Health Organization, 2020).

The results also suggest that VR-enhanced physical education may be relevant for resilience-oriented learning. In socio-politically unstable contexts, schools need educational methods that help adolescents rehearse calm action, situational awareness, and adaptive coping without reproducing traumatic experiences. The present protocol addressed this need by using non-graphic emergency and survival tasks that required rapid perception, decision-making, and behavioral control. This approach is compatible with ecological perspectives on youth resilience, which emphasize protective educational environments, competence, and adaptive functioning rather than deficit-based understandings of stress exposure (Betancourt & Khan, 2008; Betancourt et al., 2013; Masten, 2014; Tol et al., 2011).

A weak-to-moderate positive association was found between average heart rate during the VR tasks and performance score. This suggests that students who showed greater cardiovascular engagement tended to perform slightly better. One possible interpretation is that moderate physiological activation may support attention, readiness, and task involvement. However, this result should be interpreted cautiously. The study did not formally test a curvilinear model, and the correlation does not prove that higher activation always improves performance. Therefore, the finding should be understood as evidence of association, not causation.

The sex-based results showed that males obtained moderately higher performance scores than females, while the main heart-rate indicators did not differ significantly by sex. This pattern does not support the conclusion that one sex experienced greater physiological stress or showed superior stress adaptation. A more cautious interpretation is that the performance difference may reflect task-specific factors, especially prior familiarity with game-like visuomotor environments, speed of interaction with VR controls, or tactical adaptation during the AimXr challenge. Because prior gaming experience was not measured, this explanation remains provisional.

The construction of the performance score was intended to reduce the risk of interpreting the AimXr component as a simple gaming or combat score. The index included fire-task time efficiency, fire-procedure accuracy, death avoidance, and combat effectiveness. Greater weight was assigned to emergency-task efficiency, correct procedural sequencing, and survival-oriented behavior than to opponent elimination alone. Therefore, the score should be interpreted as a task-specific indicator of adaptive performance under pressure, not as a standardized psychological or clinical measure.

The findings are also consistent with educational VR literature showing that the value of VR depends not only on immersion, but also on task design, usability, emotional engagement, cognitive load, and instructional integration (Jensen & Konradsen, 2018; Makransky & Lilleholt, 2018; Makransky & Petersen, 2019, 2021; Radianti et al., 2020). In this study, the protocol was intentionally brief, structured, supervised, and followed by an educational framing. This may explain why the task produced measurable physiological and behavioral responses without requiring excessive intensity.

From a practical perspective, short VR modules could be integrated into physical education as supplementary activities for emergency preparedness, self-regulation, and decision-making under pressure. A feasible school-based model would include a short physical and psychological briefing, a clearly bounded VR challenge, heart-rate monitoring, and a structured debrief. The debrief could focus on breathing, emotional labeling, tactical reflection, safe decision-making, and the difference between impulsive reaction and controlled response.

Several limitations should be acknowledged. First, the study used a single-session design, so the results refer to acute cardiovascular activation rather than long-term stress adaptation. Second, the sample size was modest and does not allow detailed subgroup analysis. Third, heart rate was recorded with a consumer-grade wearable device under school conditions, so the physiological data should be interpreted as practical field-based indicators rather than clinical measurements. Fourth, prior gaming experience, physical fitness, trait anxiety, and perceived stress were not assessed, which limits the interpretation of individual performance differences. Fifth, the socio-political crisis frame was conceptual and educational; therefore, the results should not be generalized to clinical trauma populations or to adolescents directly exposed to severe crisis without additional safeguards.

Overall, the findings suggest that supervised VR tasks can create a meaningful but controlled state of cardiovascular engagement in adolescents. When integrated carefully into physical education, VR may support not only motor and perceptual-motor activity, but also preparedness, emotional regulation, decision-making, and resilience-oriented learning.

5. Conclusions

A brief, supervised VR protocol embedded in physical education elicited meaningful cardiovascular activation in adolescents, as reflected by the increase from resting heart rate to average heart rate during task performance. These findings suggest that VR can be used as a controlled pedagogical tool for emergency preparedness, situational awareness, and adaptive functioning under pressure.

The performance score indicated moderate overall task performance, with males obtaining higher scores than females. However, this difference should be interpreted as task-specific and may reflect prior familiarity with game-like visuomotor environments rather than a general difference in stress adaptation. No significant sex differences were observed in the main heart-rate indicators.

Used judiciously, VR may help physical education extend beyond traditional motor practice toward controlled challenge, decision-making, emotional regulation, and resilience-oriented learning. However, several limitations should be acknowledged. First, the study used a single-session design, which means that the findings reflect acute cardiovascular activation rather than long-term stress adaptation. Second, the sample size was modest and drawn from one educational setting, limiting the generalizability of the results. In addition, heart rate was recorded with a consumer-grade wearable device, and variables such as prior gaming experience, physical fitness, perceived stress, and trait anxiety were not assessed.

Future research should address these limitations by using larger and more diverse samples, repeated-session or longitudinal designs, and validated psychological measures alongside more precise physiological monitoring. Further studies should also examine whether repeated exposure to supervised VR tasks in physical education can produce measurable improvements in self-regulation, emergency preparedness, and stress-management skills over time.

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