Embodiment in Action: Multimodal Analyses of the Dynamics Between Movement and Cognition (Short paper)

Revital Medenitzki
Tel Aviv University
avezbakiev@mail.tau.ac.il

Ilana Dubovi
Tel Aviv University
ilanadubovi@tauex.tau.ac.il

הגוף בפעולה: ניתוח רב-ממדי של הדינמיקה בין תנועה לקוגניציה (מאמר קצר)

רויטל מדניצקי
אוניברסיטת תל אביב
avezbakiev@mail.tau.ac.il

אילנה דובובי
אוניברסיטת תל אביב
ilanadubovi@tauex.tau.ac.il

Abstract

This study explores the relationship between bodily movements and cognitive processes during immersive procedural learning. Grounded in embodied cognition theory, it examines how students learn within a VR-based simulation. Through multimodal data collection that includes motion tracking (MediaPipe), eye tracking (blink rate), and electrodermal activity (EDA peaks), the study captured real-time indicators of both physical and cognitive engagement. The results indicated that larger embodied reorientations, such as 90° torso turns were positively correlated with blink rate, suggesting moments of reduced cognitive effort. In contrast, hand movements, head turns, and torso rotations were negatively correlated with EDA peaks, suggesting lower mental load. These findings provide evidence of body-cognition coupling, implying that learners use bodily actions to offload demanding aspects of the task and support cognitive processing. The study broadens embodied learning research into professional procedural contexts, highlighting how VR environments can be designed to synchronized bodily engagement with learning goals.

Keywords: Embodiment, Electrodermal activity, Virtual reality simulation, Blink rate.

Introduction

Embodied cognition views thinking as grounded in the interaction between brain, body, and environment. Rather than treating movement as peripheral, this perspective argues that gestures, postures, and sensorimotor activity shape learning processes by anchoring reasoning in action (Barsalou, 2008; Shapiro & Stolz, 2019; Wilson, 2002). Research demonstrates that embodiment can support learning by distributing cognitive load, enhancing meaning-making through action, and integrating social and spatial cues (Castro-Alonso et al., 2024; Zhong et al., 2023).

Despite the growing body of work, most studies have focused on conceptual domains such as mathematics and physics focusing mainly on self-reports or performance outcomes. Much less is known about how embodiment supports procedural learning in professional contexts. Moreover, evidence for direct coupling between bodily engagement and cognitive processes remains limited. Previous studies often rely on performance outcomes or self-reports, while fewer examine real-time physiological and behavioral indices of cognitive effort (Lyu & Deng, 2024; Skulmowski & Rey, 2018). To address this need, the present study integrates multimodal measures that include motion tracking, eye tracking, and electrodermal activity (EDA).

Using these synchronized data streams, we investigate how bodily engagement during a VR based learning within nursing professional context. This approach expands embodied learning research into procedural domains and highlights mechanisms through which movement may support cognitive processing.

Research question

How does bodily engagement during procedural learning impact the cognitive process, as evidenced by blink rate and EDA peaks?

Methods

Research design and procedure

This study examined bodily and cognitive engagement during a VR simulation for nursing students. The simulation was designed to teach the medication administration process in a VR hospital environment.

Students moved through the scenario, interacted with objects, and completed medication-related tasks independently. The present analysis focuses specifically on the procedural learning phase of the simulation, where students practiced actions such as drug preparation and administration. This phase demands real-time coordination of motor activity, attention, and decision-making.(Adler et al., 2025; Anderson, 2015).

Participants and instruments

A total of 37 sophomore nursing students enrolled in a four-year Bachelor of Nursing program at an Israeli university voluntarily participated in the study. Ethical approval was obtained from the university's ethics committee (#0001776-7). All participants completed the learning session individually, and each student underwent the VR simulation once. To assess students' cognitive dynamics, eye-tracking metrics, electrodermal activity (EDA), and real-time motion data were collected using the MediaPipe framework.

Eye movement data were recorded using the Smart Eye Aurora eye-tracking system, integrated with the iMotions 10.1 biometric research platform to create a unified data collection environment. During the learning session, continuous gaze recordings were processed to identify blink rate, a physiological indicator used to reflect variations in cognitive load (Holland & Tarlow, 1972).

The electrodermal activity (EDA) signal was continuously recorded using the Shimmer 3 wristband to capture both the skin conductance level and the rapidly changing phasic response

This study used the MediaPipe framework to collect multimodal movement data, focusing on head, hand, and torso motion (Quiñonez et al., 2022). Pose landmarks consisting of 33 skeletal points, including the shoulders, elbows, wrists, hips, knees, and ankles, were combined with selected FaceMesh landmarks representing the nose, chin, eyes, and mouth to estimate orientation and movement.

Findings

On average, students spent approximately 226 seconds (SD = 112) engaged in the procedural learning phase of the VR simulation. During this phase, they acquired and practiced procedural knowledge by performing tasks such as preparing medications for administration (e.g., selecting the correct drug and calculating the dosage), administering the medication to a virtual patient, and monitoring treatment effectiveness and potential side effects.

Figure 1 illustrates an example of one student's bodily engagement in the VR environment, showing sequences of hand movements, head turns, and torso rotations during a two-minute learning segment.

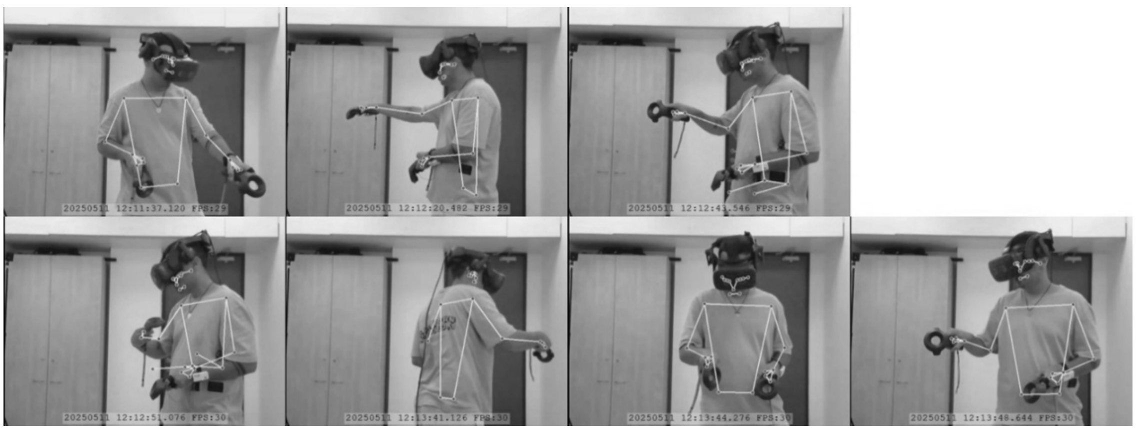

Figure 1. Snapshots of student bodily movements during VR-based learning, captured with MediaPipe landmarks.

Descriptive statistics (Table 1) indicate that approximately 53–56% of segment time was spent on hand and head movements, whereas about 35% was spent on torso rotations. In addition to bodily engagement, we also assessed indicators of cognitive engagement: blink rate (M = 12.8, SD = 7) and EDA rate (M = 27.8, SD = 15).

Table 1. Bodily motion during learning with VR as measured by MediaPipe framework (n = 37)

	Count	Total seconds of active motion	Time percentage %
Hand movements	1207 ± 712	121 ± 64	$53\% \pm 7$
Head turns	186 ± 104	125 ± 78	$56\% \pm 12$
Torso rotations	151 ± 87	77 ± 46	$35\% \pm 10$
15° torso turns	92 ± 54	-	-
90° torso turns	1.3 ± 1.6	-	-

Table 2 presents the results. No significant association was found for overall torso rotations; however, a significant positive correlation was observed between blink rate and 90° torso turns ($r_s = 0.475$, $p < 0.05$). This indicates that larger embodied reorientations, rather than small micromovements, were associated with higher blink rates, reflecting moments of reduced cognitive effort. Additionally, significant negative correlations were found between EDA peaks and hand movements ($r_s = –0.34$, $p < 0.05$), EDA peaks and head turns ($r_s = –0.33$, $p < 0.05$), and EDA peaks and 90° torso turns ($r_s = –0.33$, $p < 0.05$). These relationships suggest that these bodily movements corresponded to lower levels of mental effort.

Table 2. Correlations between Psychophysiological Indicators of Bodily and Cognitive Engagement (n = 37)

	1	2	3	4	5	6	7
1. Blinks per minute	—						
2. EDA per minute	-0.02	—					
3. Hand movements	0.03	-0.34*	—				
4. Head turns	0.08	-0.33*	0.95***	—			
5. Torso rotations	0.08	-0.32	0.94***	0.97***	—		
6. 15° torso turns	-0.12	-0.14	0.67***	0.71***	0.76***	—	
7. 90° torso turns	0.475*	-0.33*	0.48**	0.49***	0.46**	0.57***	—

*p < .05; **p < .01; ***p <.001

Discussion

Procedural learning involves the coordinated actions or processes required to perform tasks effectively (De Jong & Ferguson-Hessler, 1996). It typically develops after declarative knowledge is acquired and requires substantial cognitive effort, as it integrates cognitive and motor processes in real time (Anderson, 1982, 2015).

Analyses of blink rates showed that larger embodied reorientations, such as 90° torso turns, were positively correlated with blink rate, reflecting moments of reduced cognitive effort. In contrast, significant negative correlations were observed between EDA peaks and hand movements, head turns, and 90° torso rotations, indicating that bodily activity corresponded to lower levels of mental load. This pattern implies that learners may use bodily movements to offload cognitively demanding elements of a task, thereby facilitating cognitive processing.

From a design standpoint, the findings underscore the potential of immersive VR environments to enhance procedural knowledge by embedding sensorimotor activity within authentic, task-relevant contexts.

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