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Adaptive Performance and Cognitive Regulation in Immersive VR Vocational Training

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INTRODUCTION & AIM

Immersive virtual reality (VR) provides a powerful platform for studying cognitive regulation in complex, realistic task environments. In vocational training contexts, individuals must manage instructional support, regulate cognitive effort, and progressively translate guided actions into independent performance—core processes underlying applied human intelligence. In the present study, cognitive regulation is understood as the ability to manage cognitive effort, monitor performance, and adapt behavior as instructional support is reduced. Despite growing interest in VR-based learning, less is known about how learners adapt when instructional scaffolding is reduced, particularly in tasks that require both procedural knowledge and embodied interaction.

The present study investigates behavioral indicators of cognitive regulation in a VR-based coffee preparation task using hand-tracking interaction. By comparing performance across a fully guided trial and a subsequent reduced-guidance trial, we examine how learners adjust their strategies, efficiency, and perceived workload. Specifically, the study aims to identify how prior VR experience and real-world task expertise influence adaptive performance, with a focus on temporal task metrics, interaction errors, and subjective workload. This work highlights the potential of VR as a tool for capturing fine-grained behavioral markers of learning, adaptation, and applied intelligence in ecologically valid settings.

METHOD

Participants completed a VR-based coffee preparation task using hand-tracking interaction with virtual objects across two trials: Trial 1 with full instructional guidance and Trial 2 with reduced guidance, requiring more independent task execution. Background measures included prior VR experience, hand-tracking comfort, coffee-machine experience, hospitality/barista experience, self-rated espresso skill, motion sickness susceptibility, and fatigue.

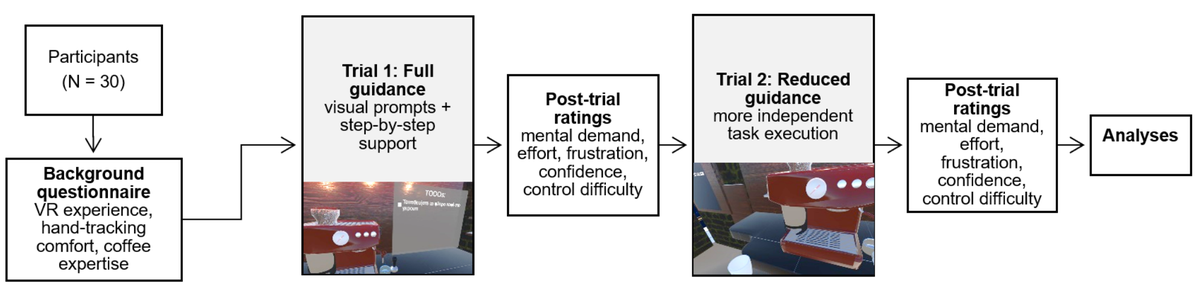

Figure 1. Study design and procedure.

Behavioral performance was assessed using total completion time, segment-level durations, and interaction errors (e.g., object drops) to examine how participants distributed time across task steps and how performance changed when instructional scaffolding was reduced. Differences between trials were interpreted as indicators of adaptation and performance strategy.

After each trial, participants completed a study-specific questionnaire assessing subjective workload, confidence, and hand-tracking interaction difficulty. Workload items included mental demand, effort, and frustration, adapted from NASA-TLX dimensions, together with ratings of confidence, perceived difficulty of object manipulation in VR, realism, training benefit, and overall task approach. A limitation of the present study is that cognitive regulation was inferred from behavioral and self-report indicators rather than assessed using validated neurocognitive measures or standardized cognitive tests.

RESULTS & DISCUSSION

A total of 30 participants completed both trials of the VR coffee-preparation task. Across the sample, mean subjective ratings showed a consistent pattern of adaptation from Trial 1 to Trial 2. Mental demand, effort, frustration, and hand-tracking interaction difficulty were all lower in the reduced-guidance trial, whereas confidence increased. Together, these changes suggest that initial guided exposure supported more efficient and more self-assured task performance once instructional scaffolding was reduced.

To quantify adaptation across trials, a difference score was calculated for each subjective measure:

$$\Delta X = X_{T2} - X_{T1}$$

Where *X* represents the rating for a given measure. Negative values indicate lower workload or interaction difficulty in Trial 2, whereas positive values indicate increased confidence.

Measure	*Trial 1 Mean*	*Trial 2 Mean*	*Change (ΔX)*
Mental demand	2.70	2.10	-0.60
Effort	3.48	2.60	-0.88
Frustration	2.40	1.90	-0.50
Confidence	5.07	5.70	+0.63
Hand-tracking interaction difficulty	4.37	3.47	-0.90

Table 1. Mean subjective ratings across Trial 1 (guided) and Trial 2 (reduced guidance), N=30

Experience-related patterns suggested that both prior VR experience and real-world coffee-machine expertise were relevant to adaptation, but in different ways. Greater VR familiarity and hand-tracking comfort were generally associated with lower perceived interaction difficulty and lower initial workload, whereas prior coffee-machine experience appeared to support procedural confidence during task execution; at the same time, less experienced participants often showed larger improvements across trials, consistent with stronger learning effects under repeated exposure.

Open-ended responses identified hand interaction as the main performance bottleneck, with frequent references to grabbing, pinch gestures, object placement, colliders, and visual feedback. Together, these findings suggest that changes across trials reflected both procedural learning and increasing familiarity with the hand-tracking system, supporting the value of VR-based behavioral and subjective measures for studying adaptive performance and cognitive regulation in ecologically valid vocational tasks.

CONCLUSION

As findings suggest, performance under reduced guidance is shaped both by prior real-world task expertise and by familiarity with hand-tracked VR interaction, highlighting the importance of both procedural knowledge and interface usability in immersive training environments.

FUTURE WORK

Future work should include validated cognitive or neurocognitive measures alongside behavioral data to strengthen the assessment of cognitive regulation. It should also examine VR-specific methodological challenges, such as hand-tracking reliability and interaction fidelity, in larger and more diverse samples.