# Orchestrating Sensory Harmony: The Distinctive Role of Olfaction in Cross-Modal VR Cognitive Training

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**Background** Olfactory virtual reality (VR) has recently been shown to improve visuospatial processing and memory in healthy older adults, exploiting the direct access of olfactory pathways to the amygdala and hippocampus for cross-modal memory encoding. A 2025 study provided a world-first demonstration that short-term olfactory VR gaming (two sessions one week apart) yields quantitative cognitive improvement in adults aged 63–90[1]. A critical question remained, however: were these gains driven by the high-fidelity visual environment or by cross-modal olfactory–spatial integration itself? To understand the contribution of visual detail under a sensory harmony framework, we investigated whether high visual fidelity is a prerequisite for effective olfactory VR training, or if comparable cognitive benefits can be achieved with simplified environments.

**Methods** Participants completed an interactive "smellscape" task on a Meta Quest 3 synchronized with a custom multi-solenoid olfactory display delivering low-latency odors (orange, lavender, and spearmint, selected via discrimination-triangle tests). Each trial comprised encoding (touching a virtual statue to trigger a target odor and visual cue), maintenance and navigation (moving toward a hidden landmark guided by dynamic odor-intensity gradients), and retrieval (discriminating three odor-emitting clouds to identify the initial target). To isolate visual complexity, participants experienced either a Visually Rich condition (a high-fidelity 3D forest with dense vegetation and detailed landmarks) or a Visually Poor condition (a plain gray background devoid of textures and landmarks); interactive objects and odor delivery were held strictly identical across conditions. Cognition was assessed with the Hiragana Rotation Task (visuospatial processing), a 2D Word Spatial Memory Task (verbal–spatial memory), and Missing Number Detection (executive function), with the Open Essence odor-identification test and the MMSE serving as peripheral-olfactory and global-cognition controls.

**Results** Visuospatial performance improved markedly from pre- to post-training (Hiragana Rotation), while the Time × Group interaction was non-significant, indicating equivalent gains in both conditions. The Word Spatial Memory and Missing Number Detection tasks showed the same pattern—significant effects of time with non-significant interactions. Open Essence and MMSE scores remained stable, confirming that peripheral olfactory function and global cognition were not confounds.

**Discussion** Adding visual detail produced no measurable incremental cognitive benefit. Our results suggest that both high-fidelity and simplified environments support equivalent cognitive gains, demonstrating that the primary mechanism of improvement lies in olfactory-spatial integration rather than hyper-realistic visual backgrounds. In the simplified environment, dynamic odor gradients functioned as highly salient spatial anchors to guide navigation. These findings support a paradigm of "Sensory Harmony", where visual and olfactory cues are designed to function as mutually congruent signals matched to the cognitive architecture of the aging brain, rather than competing for cognitive bandwidth.

**Implications** Optimizing sensory harmony can mitigate potential discomfort, reduce hardware rendering demands, and enable scalable, low-cost multisensory VR therapeutics for cognitive rehabilitation in aging populations. This work supports a roadmap progressing from foundational refinement (2025) and cross-modal verification (2026) toward broader social implementation (2027–2029).

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**References** [1] Sunami, R., Nakamoto, T., Cohen, N., Kobayashi, T., & Yamamoto, K. (2025). *Scientific Reports*, **15**, Article 10805. https://doi.org/10.1038/s41598-025-94693-9