Digital Synaesthesia: A Systematic Review of Cross-Sensory Integration and Human–Computer Interaction in the Age of Immersive Technologies

Abstract

Background:

Digital synaesthesia is an emerging interdisciplinary field that reimagines the classical phenomenon of synaesthesia—the involuntary blending of sensory modalities—through digital technologies. While traditional studies of synaesthesia have focused on artistic, psychological, and neurological perspectives, recent advances in artificial intelligence, virtual reality, and human-computer interaction have expanded this domain toward computationally mediated cross-sensory experiences. These digital frameworks aim to simulate or evoke synaesthetic perception, transforming data, sound, and visual information into multimodal experiences that merge human cognition with technological representation.

Methods:

This review systematically synthesizes research published between 2021 and 2025 across computer science, neuroscience, psychology, and the arts. A structured literature analysis was conducted to identify theoretical models, experimental designs, and applications of synaesthetic principles in digital systems. Comparative analysis was applied to studies employing virtual reality (VR), augmented reality (AR), and multimodal sensory mapping, including frameworks for auditory-visual translation, tactile data feedback, and sensory substitution in assistive technologies.

Results:

The reviewed literature reveals that digital synaesthesia fosters enhanced multisensory integration and user engagement across a variety of contexts. Virtual reality environments (Taylor et al., 2023) successfully replicated complex synaesthetic sensations, including texture and spatial structure, while augmented reality applications (Shashaank et al., 2022) enabled real-time visualization of auditory stimuli. Corciulo and Bochicchio (2024) identified synaesthesia as a foundational model for Human-Computer Interaction (HCI), highlighting its potential for encoding atypical perceptual pathways within intelligent systems. Further, studies in digital art and sensory design (Wright & Kefalidou, 2021; Xiaoling, 2022) demonstrate how machine algorithms can elicit synaesthetic effects that challenge conventional sensory hierarchies. Collectively, these findings underscore digital synaesthesia's capacity to augment perception, promote inclusivity through sensory substitution, and generate emotionally rich digital experiences.

Conclusions:

Digital synaesthesia represents a significant evolution in the historical pursuit to unify the senses through art, science, and technology. It provides a conceptual and methodological framework for designing systems that engage multiple sensory modalities simultaneously, thereby deepening human-machine interaction and fostering new forms of cognitive and aesthetic engagement. Future research should refine the neurocognitive foundations of these experiences, assess their long-term psychological and educational impacts, and explore their integration into assistive and therapeutic technologies. By merging traditional theories of

perception with contemporary digital innovation, digital synaesthesia extends the timeless human aspiration to make the invisible perceptible through technological means.

Keywords:
Digital synaesthesia; Human-Computer Interaction; Multimodal perception; Virtual and augmented reality; Sensory integration