The Adaptation of Peripersonal Space in Virtual Reality and Age-Related Differences

Summary of the dissertation submitted by Dariusz O'Leary

Background

Peripersonal space (PPS) refers to the space immediately surrounding the body in which our interactions with the environment occur. On a neurocognitive level, PPS is encoded as a multisensory representation that integrates tactile information on the body with visual or auditory information from nearby space. Through this integration of sensory information on the body with that from the nearby environment, PPS is thought to support interactions with the environment, as well as play a significant role in defining the space of the self. Importantly, PPS is not static but rather flexibly reshapes in response to internal and external influences, such as the actions we perform in our environment or changes in bodily experience. This adaptability allows PPS to remain aligned with the current possibilities for interaction as bodily and environmental conditions change.

Despite the central role of PPS in perception and action, the extent to which PPS adapts within virtual reality (VR) environments is not yet fully understood. Given the growing use of VR in research, industry, education, and healthcare, understanding how PPS is represented and adapts in VR is of both theoretical and practical relevance. An additional open question concerns individual differences in PPS adaptability within VR, particularly in the context of aging. Although PPS appears to be preserved in older adults in physical settings, aging is associated with changes in sensory processing and motor function that may influence how PPS is represented and how flexibly it adapts in virtual environments. Examining age-related differences in PPS adaptation in VR is therefore important both for advancing theoretical models of PPS and for informing the design of VR applications that are effective and inclusive across age groups. Accordingly, this dissertation investigates how PPS adapts in VR and whether this adaptation differs between younger and older adults.

Research aims and overview of studies

This dissertation comprises three empirical studies that examine how PPS adapts in VR and whether this adaptability differs between younger and older adults. Each study addresses a distinct but related aspect of PPS adaptation in VR.

Study I investigates whether PPS transfers to the location of a virtual body during a passive multisensory manipulation designed to induce a full-body illusion (FBI) in VR. Specifically, it examines whether inducing an FBI on an avatar body presented from a third-person perspective in VR leads to a remapping of PPS to the avatar's location and whether this transfer differs between younger and older adults.

Building on Study I, Study II focuses on factors that may limit the experience of the third-person FBI and PPS transfer in VR in older adults. It examines whether introducing an initial first-person perspective of the avatar and increasing familiarity with the VR paradigm through repeated exposure over three days can enhance illusion strength and facilitate a PPS transfer to the avatar's location during induction of the third-person FBI in older adults.

Finally, Study III examines PPS adaptation in the context of goal-directed action in VR. It investigates whether tool use in VR modulates PPS and whether this modulation differs between younger and older adults. Moreover, because participants view an avatar from a first-person perspective during tool use, Study III also examines whether the sense of embodying the avatar is influenced by tool use and explores whether individual differences in this virtual embodiment are associated with PPS modulation following tool use.

Methods

The effects of VR-based manipulations on PPS were examined in younger (18 – 30 years) and older (65+ years) adults. In Studies I and II, virtual embodiment was targeted through a stroking paradigm designed to induce a third-person FBI in VR. Study III instead focused on PPS adaptation to action in VR, using a tool-use task performed with a first-person avatar.

To assess the effects of these VR-based manipulations on PPS across studies, an adapted visuo-tactile task was employed. Participants made speeded responses to tactile stimuli presented on their body, either alone or concurrently with task-irrelevant visual stimuli in the VR environment. The visual stimuli appeared at varying distances from the participant and, depending on the study context, either loomed toward or receded away from the participant's viewpoint. The spatial distribution of multisensory facilitation, calculated as the reduction in reaction times in visuo-tactile trials relative to unimodal tactile trials, was used as an indicator of the extent and location of PPS in VR.

Across studies, as a measure of the experience of virtual embodiment, perceived ownership over the presented avatar bodies was assessed using subjective ratings. This allowed the examination of how embodiment-related factors were associated with PPS adaptation in VR.

Main results

Younger adults showed consistent evidence of PPS adaptation in VR. In Study I, induction of the third-person FBI was accompanied by a transfer of PPS to the avatar's location in younger adults. In Study III, tool use in VR was associated with a location-specific modulation of PPS in younger adults. In contrast, PPS adaptation appeared to be reduced or qualitatively different in older adults. In Study I, older adults reported weaker avatar ownership compared to younger adults and did not show evidence of a PPS transfer to the avatar's location during the third-person FBI manipulation. This pattern remained in Study II despite the inclusion of an initial first-person perspective of the avatar and repeated exposure to the VR setup over three days. In Study III, older adults did not show a location-specific

modulation of PPS after tool use in VR, but instead a pattern suggesting a general enhancement of PPS within the VR environment. Notably, this pattern was associated with an increase in avatar ownership after tool use, suggesting that PPS modulation in older adults may have been related to changes in ownership rather than tool use itself.

Discussion and implications

The results in younger adults demonstrate the adaptability of PPS in VR and suggest that PPS in virtual environments can fulfil functional roles that resemble those observed in physical settings, supporting interactions with the environment and defining the space of the self. In contrast, the results for older adults reveal age-related differences in PPS adaptation in VR. Across the three studies, these age-related differences were most consistently associated with the extent of perceived avatar ownership. This pattern suggests that age-related changes in the experience of virtual embodiment may shape the conditions under which PPS adapts in VR.

Together, these findings contribute to a deeper understanding of the multisensory mechanisms underlying PPS, their adaptability in VR, and the individual factors that influence this adaptability. Beyond their theoretical relevance, these findings also have practical implications for the design of VR applications that better accommodate the perceptual and embodied experiences of older users, supporting the development of applications that are effective and age inclusive.