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REVIEW ARTICLE

Altered Visuo-spatial Processing in the Peri-personal Space: A New Look at the Hand-Proximity Effects

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Abstract | The previous studies have shown the importance of body in the visuo-spatial representation of space and the objects in it. Perception of objects located near the body trigger activations in brain regions involved in making voluntary movements. Such activations are restricted to the peripersonal space (PPS) particularly within a certain distance of the hand and are considered the visual receptive field of this space. Behavioral findings have shown reduced response time and enhanced accuracy for targets presented in the peri-hand space, referred to as the *peri-hand effect*. There has been considerable debate about the nature of these effects with some researchers arguing that it is attentional and others arguing that it is perceptual. In the current review, we summarize research about the PPS with a special focus on the peri-hand space and changes to visuo-spatial processing associated with objects places in this space. We suggest that there is enough evidence in the literature pointing at independent and dissociable perceptual and attentional effects in the peri-hand space. We also highlight the differences in the spatial extent of these effects for perception and attention. We propose that future studies looking at the peri-hand effects should dissociate these effects to better understand the nature of visual processing occurring in the peri-hand space.

Keywords: *Peripersonal space, Hand-proximity effect, Spatial prioritization, Attentional disengagement, Modulated visual pathway (MVP) hypothesis*

Peri-hand effect

1 Introduction

Body plays an important role in the efficient processing of visuo-spatial information from the environment[1–3]. The nature of this processing not only involves representation of objects in relation to the body, but also efficient processing of the actionable characteristics of the objects[4–9], especially when they are near to the body, facilitating the actions on it. The reachable space near the body has been referred to as peripersonal space (PPS)[6, 10]. Neurophysiological studies have given evidence for the role of different brain regions in the processing of objects in the peripersonal space and the space beyond[11, 12]. Neuroimaging studies have shown that common brain regions represent the PPS in humans and non-human primates[13, 14]. Results from neuropsychological studies in patients with brain damage[15] and behavioral studies on healthy participants[16] showed stronger modulation of tactile perception by visual or auditory stimuli presented in the PPS, compared to when they were presented in the extrapersonal space, suggesting the multisensory nature of the neurons representing the PPS. Activations in these brain regions have also been understood by its behavioral correlates of faster response time[17, 18] and improved accuracy[19, 20] for targets in the peri-hand space as well as slower attentional disengagement.

The early theoretical frameworks developed by a majority of these studies have been attention-based[17, 21]. However, there has been accumulating evidence for altered pre-attentive (early perceptual) processing in the peri-hand space[22, 23]. The underlying mechanisms and the precise nature of differences in the visual processing occurring in the peri-hand space remain unclear. The initial section of the manuscript gives the neural correlates associated with the processing of PPS, especially the peri-hand space. We then provide a review of the behavioral studies and the attempts to theorize the influence of peri-hand effect on visual processing. Finally, we propose that dissociating perceptual and attentional effects of hand proximity helps in better understanding of the visual processing differences in the PPS.

Peripersonal space

2 Peripersonal Space

PPS holds tremendous relevance for the organism as it is important for carrying out many voluntary movements such as reaching out to

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pick up an object or moving away from a rapidly approaching object to avoid getting hit. The visuo-motor transformations required to plan and execute such actions which require not only spatial information about objects in the environment and proprioceptive information about the position of the body, but also the integration of both. Researchers have suggested that there are dedicated neural systems representing the PPS that integrates visual or auditory stimuli with somatosensory information[15, 24, 25].

There seems to be at least three body-part-specific PPS representations: for the hand, face, and the trunk. The PPS representation of the trunk acts as the common reference frame for the other two body-part-specific representation[26]. Serino et al.[26] asked participants to respond to tactile stimulation administered either to trunk, hand, or the face, while task-irrelevant looming or receding cues were presented at various distances from the body. The distance at which the cues significantly facilitated the tactile RT was taken as a proxy measure of the PPS boundary. The space near the trunk was found to have the largest extent of PPS representation (between 43 and 62 cms), followed by the face (between 37 and 69 cms) and, finally, the hand (between 5 and 27 cms). In addition, no differences were found in the peri-hand and peri-trunk PPS boundaries when participants placed their hand adjacent to the trunk and responded to tactile stimuli in the presence of the cues. That is, the combined peri-hand-trunk PPS obtained was most comparable to the size of the peri-trunk PPS as found earlier, suggesting that the peri-hand representation was subsumed by the peri-trunk representation. The PPS has also been found to have neural representations that are relevant to the nature of body–object interactions. For example, the hand–object interactions occur within a limited space around the arm[27] and, therefore, have smaller visuo-tactile receptive fields when compared with receptive field of the trunk–object interactions, because these occur in a much larger space, often involving whole-body actions such as walking [28]. Thus, it seems that the receptive fields of multisensory neurons involved in PPS representation have a size appropriate to the potential interactions between an external stimulus and a specific body part[29].

The findings of body-part-specific differences in PPS extensions are compatible with neurophysiological evidences, as well, showing the involvement of specific brain regions such as parietal and frontal premotor cortices, and subcortically the putamen[12, 30, 31]. Rizzolatti et al.[32] found that lesions in these areas lead to visual neglect for objects presented in the PPS, implying altered attentional processing near the hands. Moreover, ablation of the frontal eye field was found to result in attentional deficit for stimuli presented contralateral to the brain lesion, especially when the stimuli were presented in the far space[33], suggesting different brain regions involved in the processing of the peri- and extrapersonal spaces[1, 12, 34–38]. It was also found that the tactile receptive field of Broadmann Area 7 covered almost the entire body, and its visual receptive field was found to be extended up to 100 cms[39–42]. The tactile receptive field of neurons in the Ventral intraparietal (VIP) area was found to be centered on the head and upper trunk region, with the visual[43] or auditory[38] receptive fields limited to the upper space, in the distance range of 10–60 cms. Whereas tactile receptive field of the multisensory neurons in the premotor cortex was found to have relatively smaller visual receptive field centered around the arm, in the distance range of 5–20 cms, and auditory receptive field, in the range of 20–30 cms.

Neuropsychological evidences also suggest differences in the processing of objects in the PPS compared to in the extrapersonal space[44–49]. For example, a recent study by Aimola et al.[50] explored space-related behavioral deficits in right brain damaged patients for stimuli presented either in the peri- or extrapersonal space. A significantly higher rightward detection bias from the body midline was found, for the brain damaged patients in letter cancellation and line bisection tasks compared with the healthy controls, indicative of a typical spatial neglect in the contralesional side. More interestingly, this rightward bias was found significantly more pronounced in the PPS than in the extrapersonal space, suggesting differences in visual processing of objects in the PPS and extrapersonal spaces.

2.1 Peri-Hand Space

More than any other effector, hand is more relevant for action, since it is more frequently used to reach or carryout careful manipulations on objects in the reachable space. Therefore, the space near the hand (peri-hand space) is special, since it is here that many interactions with the environment occur. Objects in the peri-hand space prepare the motor system to act upon it and involve the visual processing of their actionable properties. As is the case with PPS, the nature of visual processing is altered in the peri-hand space and is subserved by regions in the brain that are different from those involved in the processing of objects in the extra-hand space. Researchers have found that lesion to the brain areas of frontal area 6 and the rostral part of the inferior parietal lobe, e.g., in area 7b[39] and the ventral intraparietal area (VIP)[43, 51], led to inattention to stimuli presented inside as compared outside the receptive field of the hand[32]. These regions were found to have neurons that responded only to visual stimuli presented near the hands (tactile receptive field) but not beyond[24, 30, 34, 52]. Some VIP neurons were also found to code an ultra-near space centered on the mouth, most sensitive to stimuli presented very close (5 cm) to the head. Following these studies, Broadmann Area 6 and the rostral part of the inferior parietal lobe have been considered as the anatomical correlate for the coding of peri-hand space.

3 Behavioral Evidences for Biased Visual Processing in the Peri-Hand Space

A number of theoretical accounts have been put forward to explain the visual processing differences in the peri-hand space. Most of the empirical evidences for these theories are drawn from behavioral findings that involve altered response time (RT) and accuracy to targets appearing in the peri-hand space, as compared with those appearing relatively far, on a variety of tasks[17, 19, 21–23, 53]. However, the mechanisms underlying the behavioral changes found in the processing of objects in the peri-hand space are not clear. Not many attempts have been done to relate these findings to either neurophysiological or neuropsychological findings relating to processing in the peri-hand space. The only exception is the modulated visual pathway (MVP) account which hypothesizes possible differences in the visual pathways involved in processing objects in the peri-hand space and the space beyond. Nevertheless, the conclusions are based on behavioral evidence.

3.1 Attentional Prioritization

Reed et al.[17] offered the first theoretical account for altered visual perception in the peri-hand space, by proposing that the space near the hands enjoys attentional prioritization. Their conclusion was based on the findings using a standard covert attention task[54], where participants were required to detect a visual target, while their hand was placed either next to a potential target location on the screen or on their lap. While hand was on the screen, the target could appear on the same side, making it near to the hand or on the opposite side, making it relatively far. Irrespective of the cue validity, participants were found to be faster in responding to targets appearing near the hand compared to those appearing far. The RT facilitation to targets appearing near the hand was explained as due to attentional prioritization of the space near the hand. The attentional prioritization account makes the clear prediction of facilitation or enhancement for all visual tasks in the near-hand space. However, this conclusion is debatable, since target detection was found to be faster for both validly and invalidly cued trials, suggesting that the facilitation was not attentional, but a general, perhaps, pre-attentional advantage. Moreover, their evidence for target facilitation near the hand is not conclusive. The RT for the near condition is not significantly faster compared with the baseline no-hand condition. They interpreted the faster RTs in the near compared to the far condition as their evidence for attentional prioritization. However, this seems more like a cost for targets appearing far from the hand rather than facilitation for targets near the hands.

3.2 Slower Disengagement

Another theory explaining the behavioral changes was given by Abrams et al.[21], who suggested slower attentional disengagement for objects near the hands. In a visual search task, they found relatively steeper search slope for targets appearing in the visual space near the hands compared to when the target appeared far. Since steeper search slopes indicate inefficient search, they concluded slower attentional disengagement in the near regions of the hand, presumably to have detailed visual processing of objects and events occurring in this space. They also found reduced inhibition of return (IOR) and larger attentional blink near the hands in their subsequent experiments, supporting their claim of slower attentional disengagement. In line with the idea of slower attentional disengagement[55], found switching between global and local scopes of attention to be slower near the hands compared to when the hands were kept far.

Modulated visual pathway

Spatial prioritization and delayed disengagement accounts focus on attentional mechanisms to explain the effect of hand proximity on processing. However, purely attention-based accounts have been inadequate in explaining many recent findings[19, 20, 22]. For example, Cosman et al.[22] showed that the presence of hand modulates figure-ground segregation, a process understood to occur pre-attentively[56, 57]. Similarly, Tseng et al.[19] found enhanced change detection near the hands compared to far. This finding as well as that of Cosman et al.[22] was attributed to the effects of hand presence on early, perceptual processing, thus making the attentional accounts inadequate in explaining the peri-hand effects.

Spatial prioritization

3.3 The Modulated Visual Pathway (MVP)

The MVP hypothesis is a recently proposed theoretical account by Gozli et al.[23] and offers a more comprehensive explanation for the peri-hand effects. Gozli et al.[23] proposed that placing an object near an action-relevant effector such as hand would bias processing in favor of the Magnocellular pathway. They also predicted that the processing bias would be very specific and reflect the properties of the M and P-cells; faster processing in the M-pathway due to its relatively larger axon diameters, and thus yielding higher temporal acuity, in comparison to the cells in the P-pathway[58]. Thus, the M-pathway makes it best suited for processing transient stimuli and for detection of rapid changes[59]. However, the larger receptive field of the M-cells, in comparison to the P-cells, yields lower acuity of spatial processing along the M pathway[60, 61]. Thus, Gozli et al.[23] hypothesized that performance in tasks requiring temporal precision would be better near the hands. In contrast, performance requiring spatial precision would be worse near the hands. They tested this hypothesis by having participants perform a spatial and temporal-gap discrimination task in the peri-hand and far-hand space. The spatial-gap detection task required participants to judge whether a briefly presented visual stimulus was an intact circle, or one with a small spatial gap on it. The temporal-gap detection task required participants to determine whether a circle was presented continuously across time, or whether there was a brief blank interval in between two presentations of the circle. As predicted, the temporal-gap detection was found to be enhanced, while spatial-gap detection impaired in the peri-hand space, relative to the far-hand space. More importantly, except for the trade-off between temporal and spatial acuity, no significant differences were found in the accuracy or RT measures between near and far space.

Similarly, Kelly et al.[62] found stimulus-specific sensitivity differences in the peri-hand space. They found that orientation changes were best detected than the color changes in the peri-hand space. The converse was found in the far space, i.e., color changes were best detected than the orientation changes in the far space, highlighting the differential sensitivity of hand presence to orientation and color. Taken together, MVP offers a more comprehensive explanation of the peri-hand effects, as against the attentional explanations of a generic enhancement (spatial prioritization) or impairment (delayed disengagement) of visual processing in the peri-hand space. MVP predicts that the presence of hand lowers the perceptual threshold, and its effects manifested at the early, perceptual stages of visual processing[23, 63, 64]. This assumption nicely fits the earlier findings, as well; enhanced accuracy in change detection tasks[19, 62], enhancement in speeded visual detection task[20], and modulation in figure-ground segregation[22] in the peri-hand space. The MVP account can also sufficiently explain the findings of Reed et al.[17], where they found RT facilitation for targets appearing near the hand, with the assumption of faster early perceptual processing in the peri-hand space modulated by the faster M-channel, rather than as an enhancement of spatial attention. This seems to be the case considering that a cueing task requires responding to a filled-in square, whose onset involves a rapid change in luminance. The M-cells might process this information more efficiently, and, therefore, the MVP account could offer a post hoc explanation for the RT facilitation observed in the peri-hand space.

However, the MVP account fails to explain several findings of delayed disengagement by Abrams et al.[21], especially the finding of reduced IOR in the peri-hand space. Similarly, the MVP fails to explain the findings of Davoli et al.[55], as well, where they found attentional shift between global and local levels to be slower in the peri-hand space. These findings suggesting impairments in attentional mechanisms cannot be explained by M-cell enhancements in the peri-hand space, as assumed by the MVP account. One way of looking at the peri-hand effects would be to consider the effects of hand presence getting reflected in two different stages of visual processing; an early perceptual, and a later attentional stage. Recently, Reed et al.[65] gave evidence for the same by looking at ERP components sensitive to the early and late visual processing, while participants engaged in a target detection task. Their experiment required participants to make a keypress response to indicate whether a stimulus presented in their peri-hand space was a target or not, relative to when it was presented in the far-hand space. RT to targets appearing in the peri-hand space was found to be significantly slower, compared to targets appearing in the far-hand space. More importantly, the amplitude of the P1 component (80–110 ms) was found to be larger for both targets and non-targets appearing in the peri-hand space, reflecting an early sensory gain that is not stimulus-specific. The Nd1 (120–190 ms) and P3 (350–450 ms) components were also found to be larger in the peri-hand space, but only for targets and not for non-targets. Stimulus discrimination occurring in this stage reflects increased attentional allocation, and thus, it was concluded that hand presence affected the later stages of visual processing. Taken together, the ERP findings suggest that the effect of hand proximity is not unitary on either perception or attention. Instead, there seems to be two distinct ways in which hand proximity affects processing: first, a non-selective effect on the early perceptual mechanisms; second, a selective effect on the later attentional processing mechanisms.

The dissociable effects of hand proximity on perception and attention are in agreement with our recent empirical findings as well. The study by Thomas et al.[66] required participants to complete a visual search task with their hand placed either on the computer monitor or on the lap (baseline condition). When, on the monitor, the target could appear either near to the hand or relatively far. The slope and intercept were looked at separately for the near, far, and the baseline conditions. Significantly lesser intercept was obtained for near condition compared to both far and baseline conditions, suggesting faster perceptual processing in the near space. Steeper slope was obtained for the near and far conditions compared to the baseline condition, suggesting slower attentional disengagement. This finding was replicated in a second experiment with a conjunction search, as well, with target present and absent conditions and four different set sizes. The findings give evidence for both faster perceptual processing and slower attentional disengagement for targets appearing near the hand. The MVP cannot account for these two separable effects of hand proximity. Our finding of faster perceptual processing is in line with that of Reed et al.[65], where they give evidence for an early, non-specific effect of hand proximity. Importantly, Thomas et al.[66] also found that the effects of hand presence on perceptual processes was found restricted to the near space only, seen in the form of lesser intercept for the near condition compared to both far and the baseline conditions. However, the effect of hand presence on attention was not found to be spatially graded, as evidenced by similar search slopes obtained for both near and far conditions compared to the baseline condition. Taken together, these findings are in agreement with that of Reed et al.[65]; where they give evidence for an early, non-specific effect of hand proximity, and a late, target-specific, attentional effect in the peri-hand space. Our finding suggests that perception and attention processes the space near the hands differently, and needs to be explored further to better understand the visual processing occurring in the peri-hand space. We add to this finding by giving evidence for differences in spatial gradation for its perceptual and attentional components; lesser for the early perceptual component, and relatively larger for the later attentional component. The differences in the spatial gradations for perception and attention is a new finding to the best of our knowledge, and the possibility of differences in the underlying neural circuitry needs to be explored further. Therefore, future studies looking at the effects of hand proximity should consider understanding the perceptual and attentional components separately. The non-specific nature of enhancement in the early processing[65] that is restricted to the peri-hand space might explain the general preparedness of the motor system towards objects entering this space[23, 67, 68], reinforcing peripersonal space as a defensive shield from potential external threat[68–70]. The detail-oriented processing as explained by the delayed disengagement account[21] occurs at a later visual processing stage that is more specific. It accommodates many other findings arguing for greater attentional allocation, specifically to evaluate the extent of danger in the peri-hand space; approaching threatful auditory[71–73] or visual stimuli[29, 74, 75]. Therefore, discerning the effects of hand presence on perception and attention seems important in better understanding the nature of visual processing in the peri-hand space.

Attentional disengagement

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