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Cognitive Psychology

Temporal Factors Associated With Visual Processing Bias in Peripersonal Space

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The immediate space surrounding the body, reachable to the hands, is referred to as the Peripersonal Space (PPS). The PPS is characterized by anticipatory mechanisms to perform efficient goal-oriented or defensive actions towards objects in the environment on-time. Previous studies have shown visuo-spatial processing bias for stimuli presented in the PPS, reported in the form of faster Reaction Time, better Accuracy and enhanced Visual Sensitivity. However, recent studies show that the PPS-related effects are sensitive to temporal factors associated with the early anticipatory mechanisms in the PPS. The current manuscript highlights the temporal mechanisms underlying the PPS-related visual processing bias. Specifically, the PPS effect is conceptualized as comprising of an early anticipatory component that gives temporal allowance for the manifestation of a late component. The early component accommodates the previous studies that have explained the PPS effects to be perceptual in nature, whereas the late component accommodates the previous studies that have explained the PPS effects to be attentional in nature. To the best of our knowledge, no previous attempts have been made to conceptualize the PPS effects in terms of its time-separable components. The current conceptualization of the PPS-related effects seems more wholistic vis-à-vis the previous explanation that the effect is either perceptual or attentional in nature. Also, the current manuscript attempts to make theoretical integration between Time Perception and Peripersonal Space literature.

1. Introduction

The sense of timing is quintessential in making meaningful interpretations of the noisy, and continuously changing, sensory information from the environment. For instance, grouping sensory information based on their temporal characteristics is important in the perception of music, speech, motion etc. Timing is also vital in performing complex motor tasks such as playing a musical instrument, driving a car, performing more basic actions such as reaching towards an object, or moving away from the trajectory of a fast-approaching object to avoid getting hit.

Along with the sense of timing, a precise representation of space near to the body plays important role in carrying out efficient interactions with objects at the appropriate moment in time. For instance, a dangerous object that is near to the body needs immediate cognitive prioritization than when it is relatively far. This is because, a dangerous object that is nearby, has to be immediately acted upon- on-time- to prevent harm or injuries to the body. Whereas, when the object is relatively far, there is no necessity to adopt immediate defensive actions. Therefore, temporal information seems integrated with spatial information. Perhaps this explains the common neural substrates involved in the processing of spatial and temporal information (Bueti & Walsh, 2009; Petrizzo et al., 2021; Walsh, 2003).

Although judgement of time is predominant in almost all behaviors, unlike other sensory modalities such as vision, audition, gustation, olfaction etc., there exists no dedicated sensory apparatus for time perception. However, the notion that human beings possess some sort of a 'chemical clock' to process time, got derived from multiple studies conducted by François (1927). These studies used the method of diathermy- the passage of high frequency electric current through the body- to investigate the effect of bodily heating on the sense of time elapsed. The basic premise for conducting these studies was that increasing the body temperature would speed-up the chemical clock-

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resulting in greater number of 'ticks' accumulated in the mind- leading to temporal dilation. As expected, François (1927) found the sense of time elapsed to be longer under experimental conditions that induced higher bodily temperature, than a baseline condition which ensured normal bodily temperature. The findings of François (1927) were also corroborated by Hoagland (1935), who performed systematic experiments on his ill wife, and found the sense of time elapsed to be longer when she was in a state of high fever, compared to the temporal judgements made in the state of normal body temperature. Both Francois and Hoagland's work served as a precursor to the Internal Clock Model (Treisman, 1963), and other subsequent models such as the Scalar Expectancy Theory (Gibbon et al., 1984), and the Attentional Gate Model (Zakay & Block, 1995).

2. Models of Time Perception

The Internal Clock Model explains time perception in terms of three components: The Pacemaker-Counter, Long-term Store and a Comparator. The Pacemaker is responsible for generating 'pulses' in a rhythmic manner. The number of pulses generated within a certain time window are assumed to represent time. However, the number of pulses generated is determined by the pacemaker speed, which is assumed to gain more speed- generating a greater number of pulses- at higher levels of bodily arousal. That is, the number of pulses generated is greater when the arousal level of the body is higher, relative to the pulses generated when the body is in homeostasis. In general, time is assumed to be represented in terms of the number of pulses, that gets recorded by the Counter, and these pulses remain in the Long-term Store. However, the process of time perception requires the Comparator to compare the number of pulses accumulated in the Long-term Store with the number of pulses generated for an event of interest that has to be timed. There is dilation in the subjective experience of time for the event of interest, if the number of pulses generated for the event is greater than the pulses stored in the Long-term Store. Whereas, there is contraction in the subjective experience of time, if the number of pulses generated for the event is less than those in the Long-term Store. The internal clock model has been used to explain the role of arousal- and its effect on the pacemaker speed- in influencing the subjective experience of time. However, the Scalar Expectation Theory (SET) adds more components to the Internal Clock model, and accommodates other factors, such as attentional mechanisms, in modulating time perception.

The Scalar Expectancy Theory (SET) was proposed by Gibbon, Church & Meck (1984), based on the early studies done by Gibbon (1977) and Church & Gibbon (1982). The SET explains time perception in terms of two memory stores- namely, the Reference/Long-term Memory Store, the Working Memory Store- and a Switch that connects the Pacemaker and the Accumulator components. The Long-term Memory Store represents time in terms of the number of pulses previously accumulated. The Working Memory Store also represent temporal information in terms of number of pulses; however, pertains to an event currently being timed. When a stimulus or event needs to be timed, the switch closes, allowing the regular flow of pulses from the Pacemaker to the Accumulator. At other times, the switch remains open, breaking the flow of pulses from the Pacemaker to the Accumulator. Making inferences regarding the temporal extent of an event involves making comparisons between the contents of the Working Memory Store and the Long-term Memory Store. If the number of pulses in the Working Memory Store is greater than the Long-term Memory Store, the perceived temporal extent of the event will be overestimated. On the other hand, if the number of pulses in the Working Memory Store is relatively lesser than the Long-term Memory Store, the perceived time will be underestimated.

A subsequent model of time perception proposed by Zakay & Block (1995)- the Attentional Gate Model (AGM)- proposes an additional component- the 'Attentional Gate'- between the Pacemaker and the Switch components. The Attentional Gate component plays important role in determining whether the Switch, linking the Pacemaker and a Cognitive Counter (equivalent to the Accumulator component of the SET model), will close or not. For instance, a task requiring attention to time, opens the Attentional Gate wider, making the Switch to close to allow pulses to flow from the Pacemaker to the Cognitive Counter. However, the Attentional Gate is closed or narrowed down for a task that doesn't require attention to time, such as performing a task that is highly automatic or that require very less cognitive effort. Such instances make the Switch to remain open, thereby ceasing the flow of pulses from the Pacemaker to the Cognitive Counter.

One of the insights drawn from the Attentional Gate Model is on the factors that could modulate the early or late closure of the Switch- subsequently affecting the number of pulses flowing from the Pacemaker to the Accumulator component. For instance, attentional priority to an event-to-be-timed could open the Attentional Gate wider, making the Switch to close early, or/and open late, thereby resulting in greater number of pulses accumulated in the Accumulator (Gil et al., 2009; Zakay & Block, 1995). That is, even if the pacemaker speed remains constant, early closure of the Switch can allow pulses to flow from the Pacemaker to the Accumulator. Similarly, a lag in the opening of the Switch could make the flow of pulses to the Accumulator last longer. Importantly, the changes to Switch/Gating mechanisms seems to be mediated by attentional factors (Brown, 1985; Brown & Perreault, 2017; Srinivasan et al., 2015; Tse et al., 2004). On the other hand, changes to the pacemaker speed seems to be affected by bodily arousal- modulated by factors such as emotion (Arstila, 2012; Droit-Volet & Meck, 2007; Tipples, 2011), and anticipation (Droit-Volet et al., 2010; Fayolle et al., 2015; Harjunen et al., 2022).

3. Time and Bodily Space

Recent studies have highlighted the close coupling of space and time, by reporting differences in the nature of temporal processing, and its effect on vision, especially for stimuli presented in the immediate space surrounding the body that is reachable to the hands (Aday et al., 2019; Qi et al., 2019). The reachable space surrounding the body has been termed as the *peripersonal space* (Blini et al., 2021; Brozzoli et al., 2011; Graziano et al., 1994; Hunley & Lourenco, 2018; Rizzolatti et al., 1997), and is where immediate actions may have to be performed- such as reaching towards an object of desire (E.g., a cup of coffee), or moving away from a potentially dangerous object (E.g., a ferocious animal), at the appropriate moment in time. Studies show that mere presence of objects in the Peripersonal Space (PPS)- and not in the space beyond- automatically generates action plans (Cléry et al., 2015; Costantini et al., 2010; Iachini et al., 2014), prompting researchers to also refer to the PPS as "action space" (Reed & Park, 2021; Rizzolatti et al., 1997). The action plans generated towards objects in the PPS are characterized by biases in visual processing as well (Coello et al., 2012; Iachini et al., 2014; Reed et al., 2006). However, considering the functional significance of the PPS, temporal factors seem to be the underlying basis for the visual processing bias reported in the PPS.

That is, one of the primary roles of the PPS is to act like an anticipatory buffer, giving sufficient time for the motor system to prepare for actions to be performed on objects entering this near-space (Brozzoli et al., 2011; Graziano & Cooke, 2006; Iachini et al., 2014). Also, the anticipatory mechanisms associated with the PPS involves pre-activation of motor resources (Anderson et al., 2002; Phillips & Ward, 2002; Symes et al., 2005), and seems crucial in making more time available for engaging in defensive behaviours (Haselton & Nettle, 2006; Iachini et al., 2017; Schiff & Oldak, 1990; Vagnoni et al., 2017). The *more* time available to execute a successful defensive response, towards an object in the PPS, seem to allow efficient allocation of cognitive resources such as attention (Reed et al., 2006), and memory (Kelly & Brockmole, 2014; Tseng & Bridgeman, 2011) for processing information relevant for an immediate action.

One of the behavioral indicators of the preparatory mechanisms associated with the PPS is in the form of biased collision judgements reported for objects in the PPS (Iachini et al., 2017). The study by Iachini et al. (2017) used a collision judgement task (Andersen & Kim, 2001) that required participants to predict whether two balls approaching towards each other would collide or not. The collision predictions were to be made when the balls were presented in the peripersonal space (PPS) or in the space beyond. Also, the velocity and path of the balls were manipulated to make them actually collide or not, on equal number of trials. Results from two experiments showed that collision prediction in the PPS was specifically affected by changes in the temporal parameters (velocity) than the spatial parameters (path) of the two balls. Importantly, there was higher tendency to predict collisions in the PPS with uncertainties induced by changes in the velocity of the balls and not its path. Moreover, no such effects were seen in the space beyond; both velocity and path of the balls were given equal relevance in the far-space. Iachini et al. (2017) concluded that the nature of bias occurring in the PPS is predominantly affected by temporal factors. Other studies have also shown that stimuli looming towards the body are judged to collide sooner than those objects moving away or are relatively far from the body (Neuhoff, 2001; Schiff & Oldak, 1990). The bias to underestimate the arrival time of looming stimuli reinforces the notion that early anticipatory mechanisms- triggered by objects entering the PPS- are an adaptive response that provides a selective advantage (Neuhoff, 1998, 2001). More importantly, time-to-collision underestimations in the PPS- although an error- seems to be due to the anticipatory mechanisms associated with the PPS, to make sufficient time available to engage in defensive behaviours. Therefore, time seem to play an important role in the successful execution of a motor program, such as moving away from the trajectory of an object in-time to avoid getting hit.

4. Temporal Processing Characteristics in the Reachable Space

An early anticipation to react/act towards an object in the Peripersonal Space (PPS), makes 'more' time available to the motor system. That is, there seems to be differences in the availability of objective time for processing objects in the PPS. Whereas, no such temporal allowance is needed for objects that are beyond the PPS, since they don't have to be acted upon immediately. Within the framework of the Attentional Gate Model (AGM), the availability of more time could result in greater number of ticks recorded by the Cognitive Counter, even if the pacemaker speed remains constant. More importantly, the AGM can explain the anticipatory mechanisms associated with the PPS, in terms of the Attentional Gate opening wider to allow the switch to close early, resulting in greater number of pulses flowing from the Pacemaker to the Cognitive Counter. Therefore, it is expected that the subjective experience of time slows down for objects/events occurring in the PPS. Such slowing down perhaps can account for the efficient allocation of cognitive resources such as attention, to process information in a detailed and in-depth manner (Abrams et al., 2008, 2015). That is, temporal factors seem to underlie the visual processing bias for objects previously reported in the PPS. A recent finding by Qi, Wang, He and Du (2019) is in line with the prediction of temporal dilation in the PPS.

The study by Qi et al. (2019) required participants to reproduce the duration of a grey square displayed on a monitor through mouse click responses. The participant responses were collected with their hands placed either on the sides of the monitor- making the stimulus appear 'near', or on the lap- making the stimulus appear 'far', from the hands. A comparison of the responses obtained from the two experimental conditions revealed greater overestimation in the temporal reproductions for the stimulus presented near the hands relative to when it was presented far. The finding was replicated in one of their subsequent experiments as well, adding strength to their claim of temporal expansion for stimuli presented in the peripersonal space. However, no clear conclusions regarding the contributory factors of the temporal overestimation obtained in the PPS can be drawn from the study by Qi et al. (2019). That is, the temporal overestimation could be either due to the increased pacemaker speed, or the early/late closure of attentional switch/gate. Future studies could explore the underlying mechanisms associated with temporal expansion for stimuli presented in the PPS.

However, there is lack of consistency in reporting temporal distortions in the PPS as well (For example, Aday et al., 2019). In two experiments, that used temporal bisection task and verbal estimation task, respectively, Aday et al. (2019) failed to find temporal distortions for stimuli presented in the PPS. One of the reasons ascribed to the absence of hand-specific effects was the nuanced nature of the effects (Andringa et al., 2018; Dosso & Kingstone, 2018; Schultheis & Carlson, 2013); implying the necessity to have robust experimental design and appropriate experimental task to discern the nature of temporal processing bias in the PPS.

Notwithstanding the inconsistencies, it seems reasonable to assume that the relative availability of 'more' time- due to the early anticipatory mechanisms, triggered by objects entering the PPS- seems to underlie the near-hand specific visual processing bias previously reported (Abrams et al., 2008; Reed et al., 2006). Also, such availability of time gives enough allowance for the allocation of cognitive resources to have further in-depth and detailed processing (Abrams et al., 2008; Davoli et al., 2012), as discussed in more detail in subsequent sections. That is, importantly, temporal factors seem to underlie the PPS effects, and can accommodate the disparate explanations given for these effects.

5. Explanation of Peri-Hand Effects as an Early Phenomenon

Reed et al. (2006) gave one of the earliest explanations for visual processing bias in the Peripersonal Space, by proposing that objects entering the peripersonal space receive increased attentional priority over those objects that are beyond this space. Using a standard covert attention task (Posner & Cohen, 1984), Reed et al. (2006) showed the RT to be faster for targets appearing near the hand compared to those targets appearing far. They explained this finding in terms of faster attentional orienting towards objects entering the PPS, mediated by activations of bimodal neurons in specific brain regions that can respond to both visual and tactile inputs (Graziano et al., 1994; Gross & Graziano, 1995). Although these findings align with the predictions of the anticipatory mechanisms associated with the peripersonal space, the MVP hypothesis explains the PPS-related effects in terms of early perceptual gains that are assumed to be pre-attentive in nature.

The MVP hypothesis primarily draws upon the anatomically and functionally distinct, magnocellular (M cells) and parvocellular (P cells) in the retina. The M and P cells form a pathway from the retina to the striate cortex via the magnocellular and parvocellular cells in the lateral geniculate nucleus (LGN) in the thalamus. The M and P pathway propagates differently to higher levels of the visual system in the cortex, in the form of a dorsal occipito-parietal and a ventral occipito-temporal pathway, respectively (Livingstone & Hubel, 1988; Merigan & Maunsell, 1993; Schiller et al., 1990). The MVP hypothesis predicts that the presence of an object in the PPS automatically prepares the visual system for performing visually guided actions on the object. Such a bias result in the shift of balance of visual processing more towards the magnocellular (M) pathway than the parvocellular (P) pathway. Therefore, those visual tasks that draw upon the magnocellular pathway get boosted if performed in the PPS. Whereas, those tasks that rely on the parvocellular pathway get impaired if performed in the PPS (Goodhew et al., 2013; Gozli et al., 2012, 2014).

This hypothesis was tested by Gozli et al. (2012) in their study where the performance of participants on spatial and temporal gap discrimination tasks was compared in the near and far spaces of the hand. The spatial-gap discrimination task required participants to indicate whether a briefly presented circle had a small spatial gap on it or not (intact). Whereas, the temporal detection task required participants to indicate whether a briefly presented circle was interrupted with a brief blank interval in-between or not. The temporal gap detection was found relatively better when the stimuli were performed in the PPS compared to when presented far, on the other hand, the spatial-gap detection was found to be relatively poor in the PPS when compared to the far-hand space. Moreover, except for the differences in the detection performance between the temporal and spatial tasks, no differences in the RT or accuracy were obtained between the near- and far-hand conditions.

The selective stimulus-specificity in near and far spaces of the hand was also corroborated by previous findings (Kelly & Brockmole, 2014; Taylor et al., 2015). For instance, using a change detection paradigm, Kelly & Brockmole (2014) found detection of changes to orientation information to be better than changes to color information near the hands. On the other hand, they also found the detection of changes to color information to be better than changes to the orientation information in the far space of the hand. The findings imply differential sensitivity of the proximal and distal regions of the hand to orientation (action-oriented) and color (perception-oriented) features, respectively, and in accordance with the MVP hypothesis. The findings, therefore, imply that the hand-specific effects get manifested at an early stage of visual processing (Cosman & Vecera, 2010; Gozli et al., 2012; Suh & Abrams, 2015), and in line with the predictions associated with the anticipatory mechanisms of the PPS.

6. Explanation of Peri-Hand Effects as a Late Phenomenon

On the other hand, there is evidence suggesting that the hand-specific effects occur late in the information processing stage, and predominantly attentional in nature (Abrams et al., 2008; Davoli et al., 2012; Thomas & Sunny, 2017). For instance, Abrams et al. (2008) proposed slowing down of attentional mechanisms as the basis for the PPS-effects. This explanation was based on their findings from a visual search task, where participants completed a standard letter identification task, with both their hands placed either, near a search array displayed on a computer screen, or on the lap (baseline condition). They found the search slope to be relatively steeper in the hands-on-the-screen condition compared to the baseline condition. The steeper search slope- implying a slower search rate- was ascribed to the tendency to spend more time on each search item when participants viewed the search array near their hands. Therefore, they concluded slower attentional disengagement for items in the PPS. That is, there seems to be a high tendency to spend more time on objects that are near to the hands, presumably to thoroughly evaluate the objects, to have potential interactions with them. Results from their subsequent experiments showed reduced inhibition of return (IOR) and larger attentional blink for stimuli presented in the space near to the hands, supporting the slower attentional disengagement explanation. Another study by Davoli et al. (2012) adds to these findings by reporting a relatively slower shift in the attentional scope for stimuli presented near the hands, compared to far. Specifically, in the experiment by Davoli et al. (2012) participants were required to attend to either a wholistic (global) form or its constituent smaller elements (local) form, of two hierarchical shapes presented sequentially. The time taken to identify the global and local forms were compared when performed near the hand versus far. It was found that more time was required to identify the second of the two hierarchical shapes, when presented near the hand, compared to far. The additional time required was ascribed to the delay in attentional disengagement from the first task, and reengage to the second task. The restricted shifts in the attentional scope near the hands was argued to be beneficial in order to facilitate a complete and in-depth analysis of the information presented in the PPS.

Another advantage of the in-depth nature of processing seems to be in the form of enhanced visual short-term memory (VSTM) in the PPS (Tseng & Bridgeman, 2011; for a review, see Davoli & Tseng (2015) and Tseng, Bridgeman, & Juan (2012). For instance, the study by Tseng and Bridgeman (2011) used a standard change detection task (Luck & Vogel, 1997), to look for VSTM differences between the PPS and the far-space. The experimental task required participants to detect a change in a given stimulus array presented in brief succession. The stimulus array consisted of colored squares, and on one half of the trials one of the squares could change its color. The change detection accuracy was found to be enhanced, coupled with slower RT, in the PPS relative to the far-hand space. The finding was explained in terms of efficient allocation of attentional resources to detect rapid onset faster, and allow deeper encoding of information into the visual working memory, but at the cost of slower disengagement in presence of other items due to the equal processing priority enjoyed by all the items. Importantly, the disengagement account implies slowing down of attentional mechanisms, to enable a thorough and in-depth processing of information presented in the PPS.

Therefore, disparate explanations have been given for the PPS-effects. On the one hand there is evidence that the PPS effect is perceptual in nature (Goodhew et al., 2013; Gozli et al., 2012, 2014), but on the other hand there is evidence for the effect to be dominated by attentional mechanisms (Abrams et al., 2008; Davoli et al., 2012). Previous attempts have been made to reconcile these explanations by presuming that space near the hands is characterized by attentional engagement towards an object/an event of interest, and slower disengagement that is nonselective of the content (Tseng et al., 2012). However, this notion that increased attentional deployment, as in the case of slower disengagement, leading to a nonselective effect seems to contrast with the explanations of Reed, Leland, Brekke & Hartley (2013). Reed et al. (2013) argue for stimulus-specific processing characteristics to be mediated by attention, and non-stimulus-specific processing characteristics to be mediated by early pre-attentive factors, in the processing of information presented in the PPS.

That is, the study by Reed et al. (2013) looked at the ERP components while participants were required to indicate whether the stimulus in the space near the hand was a target or a non-target. The target discrimination was found to be relatively faster in the PPS relative to the far-space and in line with previous findings (Reed et al., 2006; Tseng & Bridgeman, 2011). More notably, a larger amplitude was obtained for the early P1 component (80–110 ms) for stimulus presented in the peri-hand space irrespective of whether the stimulus was a target or not. The results imply an early advantage that is not stimulus-specific. However, the amplitude of later components Nd1 (120– 190 ms) and the P3 (350–450 ms) were found larger only for targets, but not for non-targets, in the peri-hand space- implying the increased role of attentional mechanisms. Therefore, the finding of Tseng & Bridgeman (2011) of enhanced change detection accuracy in the PPS seem to reflect an early pre-attentive processing bias, while the slowing down of RT seem to reflect slower shift of attention in order to have a deeper processing of stimuli and a more accurate retrieval of information in the PPS. That is, the PPS effect seem to have two separable components: an early component, followed by a late component.

7. Time-Separable Components of the Peripersonal Space (PPS) Effects

There is empirical evidence suggesting the PPS effect to consist of two separable components (Reed et al., 2013; Thomas & Sunny, 2017). For instance, the study by Thomas & Sunny (2017) required participants to complete a standard letter identification search, while they placed their hands either, next to the search array, or far. The search slope and intercept data were ascertained for targets appearing near and far from the hand. The intercept of the near condition was found to be significantly less relative to the far- implying faster perceptual processing (an early advantage) for stimuli presented near the hands. In contrast, the search slope of the near condition was found to be relatively steeper relative to the far- reflecting a slower search rate for items appearing near the hand. The slower search rate reflects the increased time spent on average on each of the search items- reflecting slower attentional disengagement for objects in the PPS. Similar findings were obtained in their subsequent experiment that used a conjunction search with target-present and target-absent conditions and four different set sizes. The finding is in line with the findings of Tseng & Bridgeman (2011) and Reed et al. (2013), implying that presence of hand could modulate the early as well as later stages of visual processing. That is, there seem to be two separable components in the PPS-related effects: first, a perceptual component that is non-selective, followed by a later attentional component that is selective. Therefore, the PPS-related effect seems to be emerging from two components that have separable temporal markers; making it inadequate to explain the effect unitarily as perceptual (Goodhew et al., 2013; Gozli et al., 2012, 2014) or attentional (Abrams et al., 2008; Davoli et al., 2012) in nature.

8. Temporal Basis of Peri-Hand Effects

The nature of peri-hand effects seems more temporal in nature, comprising of an early perceptual processing stage followed by an attentional stage. That is, the early anticipatory mechanisms associated with the PPS- and its correlates of a perceptual bias- seems important in making sufficient time available in allocating cognitive resources, such as Attention and Visual Short-Term Memory, to carry-out a detailed and in-depth processing of information presented in the peri-hand space. Previous studies have highlighted the effect of early preparatory mechanisms on vision (Witt, 2011; Witt et al., 2008). For instance, tennis players who anticipate well and return serves more successfully, *see* the ball to be moving slower (Witt & Sugovic, 2010). That is, a better and early anticipation of the trajectory and path of the ball gives more time for the motor system to execute a successful motor program (such as returning the ball inbound); thus, slowing down the perceived velocity of the ball. Although such studies don't report on the depth of processing of a stimulus that is associated with early anticipatory mechanisms of the motor system, it seems possible that such slowing down of the visual percept is also accompanied by the efficient allocation of cognitive resources such as attention and memory, resulting in an in-depth processing, boosting the representational strength of the percept. In congruence with this notion, the Attentional Gate Model (AGM) of Time perception will predict that the early perceptual bias associated with the PPS will slow down time, perhaps giving sufficient temporal allowance to allocate cognitive resources such as attention and memory for processing information presented in the PPS. That is, changes to the Attentional Gate/Switch component of the AGM can account for the attentional bias previously reported in the PPS (Abrams et al., 2008; Davoli et al., 2012; Thomas & Sunny, 2017). Therefore, we contextualize the recent finding of slowing down of time in the PPS (Qi et al., 2019), as a reflection of the *'extra'* time associated with the early anticipatory mechanisms of the PPS, to allow for an in-depth and detailed processing of information in the PPS.

It seems reasonable to assume that the relative availability of *more* time- due to the early anticipatory mechanisms, triggered by objects entering the PPS- underlie the near-hand specific visual processing bias previously reported. Also, such availability of time gives enough temporal allowance for the allocation of cognitive resources to have further in-depth and detailed processing. Although the evidence suggesting such a possibility seems elementary, future studies could look into the nature of the early anticipatory mechanisms associated with the PPS. Importantly, temporal factors seem to underlie the peri-hand effects, and can also accommodate the disparate explanations given for these effects.

9. Conclusions

It is important to note that the anticipatory mechanisms associated with the PPS accommodates the pre-attentive explanations given for the peri-hand effects (Goodhew et al., 2013; Gozli et al., 2012, 2014). Also, it seems reasonable to presume that the early preparatory mechanisms associated with the PPS, gives more temporal allowance to allocate cognitive resources, such as Attention (Abrams et al., 2008; Davoli et al., 2012; Thomas & Sunny, 2017) and Visual Short Term Memory (Kelly & Brockmole, 2014; Tseng & Bridgeman, 2011), to have a further detailed and in-depth processing of information presented in the PPS. That is, a more comprehensive explanation of the peri-hand effects could be in terms of the anticipatory mechanisms associated with the PPS- and its correlates of the pre-attentive effects- facilitating allocation of cognitive resources later (to carry-out in-depth and detailed processing). The current manuscript, thus, gives a wholistic explanation of the peri-hand effects- in terms of an early anticipatory component of the effect that is perceptual in nature, giving allowance for a late component to get manifested that is predominantly attentional in nature. The manuscript thus attempts to make connections in the literature between the dimension of time and the peri-hand effects. No such attempts have been made previously, to the best of our knowledge, in stimulating cross-disciplinary empirical work and theoretical integration between Time Perception and Peripersonal Space literature.

Contributions

Contributed to conception and design: AM, TT

Drafted and/or revised the article: AM

Approved the submitted version for publication: TT

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Competing Interests

We are not aware of any conflict of interests in the studies highlighted in this manuscript. Also, no part of this work has been submitted to or published in any other journal.

Data Accessibility Statement

There are no participant data reported in this manuscript, all the cited research works have been included in the references section of this manuscript.

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