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THE EFFECT OF HAND POSITIONING ON RESPONSE TIME IN THE PERIPERSONAL SPACE

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Abstract

The effects of limb positioning on representations of the peripersonal space (PPS) have been well studied over time. However, most research relies on older experimental designs in which static images and older methods of data analysis are applied. In this master thesis new experimental designs and dynamic paradigms are applied. This study will test what changes in peripersonal space representation when hand positioning changes in the trajectory of a dynamically approaching visual stimulus. This study was able to determine the critical spatial limit at which visual stimuli significantly start enhancing tactile processing compared to unimodal (i.e. tactile) stimuli, by correcting data to baseline response times (unimodal) and submitting it to a repeated measures ANOVA and one-sample t tests. By applying this new baseline-corrected method, this study was able to determine the critical spatial limit (62cm from our hands), but was unable to show any differential effects of hand positioning on tactile processing and peripersonal space representation. Therefore, future studies should implement other methods of data analysis to further investigate the effects of hand positioning on peripersonal space representation and tactile processing.

Keywords: hand positioning, response time, peripersonal space, dynamic visuo-tactile stimulation, tactile processing

Introduction

We live in a dynamic world where the environment is constantly moving. We have to interact accordingly with this constant moving world to ensure proper interactions with our surroundings (Canzoneri et al., 2012). One way of interacting with our environment accordingly is for our brains to be predictive machines. By predicting we can prepare appropriate responses according to probable consequences of contact with our environment (i.e. other people, traffic etc.; de Haan et al., 2016). To support perception and action, the brain needs to reduce prediction-error by constantly trying to match sensory input to top-down controlled predictions (Clark, 2013). Therefore, prediction is a neural top-down process that helps us to determine if certain events will occur with more certainty than just by chance. Two sensory modalities that have shown to be particularly useful in predictive behaviour are vision and touch. Touch is critical for predictive behaviour to monitor the physical contact between external objects and our bodies. Vision on the other hand gives us feedback about events that are happening in the space surrounding our bodies before there is any physical impact (Macaluso & Maravita, 2010). For example, if you see a hand approaching you, you will eventually anticipate that it will touch you if it keeps moving closer (Cléry et al., 2015).

Environmental cues have been shown to be processed differently when they occur in different regions surrounding our bodies (Kandula et al., 2015; di Pellegrino et al., 1997). One of these regions is the peripersonal space (PPS). These are the regions directly surrounding our body-parts (Canzoneri et al., 2012). If tactile stimulation takes place when a visual or auditory stimulus enters the PPS, response times (RTs) will be faster compared to RTs of tactile stimulation when visual or auditory stimuli are outside of the PPS (di Pellegrino et al., 1997; Làdavas et al., 1998; Làdavas et al., 1998). The representation of the PPS in macaque monkeys brains shows that bimodal neurons in the fronto-parietal and premotor cortex react to tactile stimuli on the arms and face, but also to visual stimuli that are close to those body parts (Duhamel et al., 1998; Graziano et al., 1997; Rizzolatti et al., 1981). This suggests that the spatial distance between the stimulated body part and the approaching object is an important factor of representing the boundary of the peripersonal space.

Stimulation of these PPS neurons triggers certain patterns of arm movements in macaque monkeys linked to avoidance and defensive behaviour (Cooke and Graziano, 2004; Graziano and Cooke, 2006; Rizzolatti et al., 1981). The function of PPS is thus suggested to be a safety zone which allows us to filter information that might be important to us (Kandula et al., 2015). By filtering this information we can assess how to interact accordingly with approaching stimuli (Graziano and Cooke, 2006; Sambo et al., 2012). Thus, the underlying mechanism of forming this defensive PPS is suggested to be visuo-tactile prediction. This means that the spatial location and the time course of an approaching tactile stimulus caused by an object can be predicted by visual information about that same object. This allows us to react more efficient to that object (Kandula et al., 2015).

To be able to form a proper multisensory representation of the PPS, vision and touch are integrated in associative brain regions (Gross & Graziano, 1995). A study by Maravita, Spence & Driver (2003) has shown that representations of the PPS entail some spatial limitations. For example, when visual stimuli are presented at an exact spatial location, tactile processing at this specific visual spatial location will be enhanced. In turn, a fMRI study by Macaluso & Driver (2005) has shown that this process occurs because of supramodally (transcending individual sensory modalities) working fronto-parietal systems that control the process of spatial attention. This ultimately leads to mechanisms of feed forward convergence of sensory specific visual and tactile neural regions to associative regions in the fronto-parietal cortex. It also leads to mechanisms of crossmodal (interactions between two or more sensory specific cortices) influences within the sensory specific modalities. These mechanisms are very likely a result from feedback projections of multisensory brain regions (i.e. fronto-parietal cortex) to the sensory specific brain regions (Macaluso & Driver, 2005). The predictive link between vision and touch also modulates associated neural activity in the probability of a tactile event. By predicting this event, tactile processing is reduced when the tactile event actually occurs (Kandula et al., 2015).

As Canzoneri et al. (2012) noted, most studies on peripersonal representation have only focussed on the effects of presenting visual and auditory stimuli at two fixed locations (in and out of the PPS) on tactile processing. However, a fMRI study by Bremmer et al. (2001) has shown an increase in brain activity in the ventral premotor cortex and the ventral intraparietal sulcus when visual stimuli were presented in an approaching trajectory compared to a static image. This suggests that the multisensory processing is also sensitive to dynamic stimulations.

The peripersonal space seems to be a dynamically extendable space within our surroundings (Farnè & Làdavas, 2000; Iriki et al., 1996). According to the behavioural study by Farnè & Làdavas (2000) the boundary of the peripersonal space of our hands can be extended by using tools. Another study by Macaluso et al. (2005) has shown that the representation of peripersonal space also takes posture changes in account. This finding is supported by a study of Serino et al. (2015) in the auditory modality. This study found significant differences in peripersonal space representation when the hand was placed closer to the trunk compared to further away from the trunk. This study also showed that auditory stimuli start enhancing response speed significantly sooner in the trajectory of a looming sound when the hand was close to the trunk compared to further away from the trunk. The authors suggest that if the hand is near the trunk, it is encased in the PPS of the trunk.

Multiple studies have shown that the bimodal neurons in the fronto-parietal and premotor regions, that are involved in integrating visual and tactile information, encode the presence of visual signals about the position of our limbs (Brozzoli et al., 2012; Farnè, 2000; Graziano, 2000). This visual signal must transmit congruent information by making an association between the actual position of the body part in space and the visual image of that body part. The relationship between touch and vision for constructing a proper representation of our PPS is so evident that even an imitation limb can enhance tactile perception, as long as this limb is spatially congruent to the visual and tactile stimulus (Brozzoli et al., 2012; Farnè et al., 2000). These findings show that representations of the PPS are very flexible and that these peripersonal space boundaries can change to maintain spatial alignment of multisensory stimuli within the PPS (Macaluso & Maravita, 2010).

The novelty of this study entails the combination of changing hand positions, dynamic visual stimuli, tactile stimulation at multiple visual distances, baseline-corrected data and a relatively new form of data analysis to answer our research question: What changes in peripersonal space representation when hand positioning changes in the trajectory of a dynamically approaching visual stimulus.

There are two spatial factors involved in this study. The first factor is the distance between the approaching visual stimulus and the hand. The second factor is whether the hand is in the trajectory of the visually approaching stimulus. By submitting our data to a baseline correction we will try to find evidence for a critical spatial range that we consider the PPS representation of our hands. To determine this critical spatial range we will compare response times at six different visual distances with a baseline (unimodal tactile) response time which is set at zero. The spatial limit at which visual stimuli enhance tactile processing significantly compared to baseline will be considered the boundary of the peripersonal space of our hands.

We hypothesize that having our hands in the trajectory of a dynamically approaching visual stimulus (HIT) enhances overall tactile processing significantly compared to not having our hands in the trajectory of a dynamically approaching visual stimulus (HOT). We expect to find evidence for this hypotheses because previous studies have shown that tactile perceptions can be enhanced by getting visual signals about our body parts (Farnè, 2000; Farnè et al., 2000; Graziano, 2000).

We also hypothesize that the critical spatial range is larger in the HIT condition compared to the HOT condition. We expect this outcome because previous studies have shown that the peripersonal space is a dynamically extendable space within our surroundings that take body part positioning into account (Brozzoli et al., 2012; Canzoneri et al., 2012; Farnè & Làdavas, 2000; Macaluso et al., 2005; Macaluso & Maravita, 2010; Serino et al., 2015).

Methods

Participants

We tested 16 healthy participants (13 males, mean age = 25.6 years old, standard deviation = 3.9 years old, age range = 21-35 years old) with normal or corrected-to-normal visual acuity. An a priori power analysis has been carried out to determine our sample size. This study took about 30 minutes from start to finish. Participants could receive course credits as a compensation for their time and effort. Participants filled out an informed consent prior to the experiment and were naïve to the purpose of our study. This study was conducted according to the protocol of the ethic committee of the faculty of social and behavioural sciences of Utrecht University and in accordance with the Declaration of Helsinki.

Task and Stimuli

This study consisted of two experimental conditions, a control condition and catch trials with no tactile stimulation. The first experimental condition consisted of having the left or right hand (depending which experimental block was presented) in the trajectory of a visually approaching stimulus (HIT). The other experimental condition consisted of not having the left or right hand in the visual trajectory (HOT), in this case on a stool 20cm from each of the participant’s side. This resulted in the positioning of the hand and the time points of tactile stimulation as our independent variables and their respective reaction times as our dependent variables.

The total experiment consisted of a combination of six trials for each of the seven tactile stimulation points. 42 trials for each hand positioning condition. In each hand positioning condition six control trials were also programmed. This control condition consists of tactile stimulation without a visually approaching stimulus. This unimodal (tactile) response time functioned as a baseline response time to compare multisensory (visuo-tactile) response times with. In each hand positioning condition there were also 42 catch trials in which no tactile stimulation was presented during the visually approaching trajectory to prevent people from anticipating experimental tactile stimuli at every trial. This resulted in a total of 168 trials.

Experimental, control and catch trials were randomized within each block with a different condition per block. Between each block there was a one minute break and one minute of instructions. Each block consisted of a different hand positioning condition for the left and right hand. This resulted in a total of four blocks that were counterbalanced for each participant. Before the real experiment started a couple of practice trials were presented to ensure that the participant understood the given task. The experiment lasted about 25 minutes. The total procedure took approximately 30 minutes.

Procedure

Participants were seated in a darkened room at 15 cm away from the short end of a wide flat screen LCD monitor (Philips BDT5530EM/06, screen dimensions 122 x 68 cm) that is placed horizontally flat on a table. The heads of the participants were comfortably stabilised in a fixed chinrest to optimize visibility of the screen. The toes of their right food were placed on a foot switch, which the participants used to register their response to a tactile stimulus. Participants were instructed to press the footswitch as fast as possible every time they felt a tactile stimulus. The tactile stimulus was given by motors, that vibrated at 180hz for 100ms, and were attached to the index finger of the right and left hand, which in its turn might have been placed dorsal side up on a green preprogrammed spot on the LCD monitor 20 cm from the edge of the screen (depending on the experimental condition). Participants received one minute of instructions after each break about hand positioning. These instructions explained if their index finger should be positioned on the green preprogrammed spot or if their hand should be placed on the stool beside their bodies. The opposite hand was always instructed to be placed on their lap.

Before the experiment started participants were instructed to keep their eyes focussed on the spot where the fixation cross was presented before the visual stimulus started making its approaching trajectory. This fixation cross was presented in the middle of the screen in a fixation period of variable duration before each trial.

The entire experiment and all of the visual and tactile stimuli were coded in Matlab with PsychToolBox and the experiment ran on a Windows platform. Participants saw a white sphere (sphere dimensions 5 x 5 cm) approaching them. The end of the trajectory of the white sphere was at the preprogrammed spot of 20 cm from the edge of the screen. During each trial a tactile stimulus might have been given at random at seven different distances of the visual stimulus.

Each block was preceded by an 60 second interval where instructions were given on hand positioning. Each trial started and ended with 200ms of an empty screen. After the 200ms the white sphere appeared and started its approaching trajectory. The trajectory ended after 2500ms of the visual onset, which was followed by 200ms of an empty screen (the entire trial will be 2900ms). Each trial was followed by a 1500ms inter-trial interval in which a black screen was presented. Each trial was preceded by fixation period of variable duration in which the fixation cross was presented. Participants could have randomly received tactile stimulation (TS) at seven (visual) distances in the course of each trial. The first tactile stimulation (TS1) was administered at 100ms of the visual onset (300ms after the initial start of the trial) at 76cm from the green preprogrammed spot where the index finger should have been placed in some conditions. The second tactile stimulation (TS2) was administered at 650ms from the visual onset (850ms after the initial start of the trial) at 62cm from the preprogrammed spot. Tactile stimulation three (TS3) was administered 1200ms from the visual onset (1400ms after start of trial) at 48cm from the preprogrammed spot. The fourth tactile stimulation (TS4) was administered at 1750ms after the visual onset (at 1950 from trial beginning) at 34cm from the preprogrammed spot. The fifth tactile stimulation (TS5) was administered at 2300ms of the visual onset (at 2500ms of trial beginning) at 20 cm from the preprogrammed spot. Tactile stimulations were also administered at 2700ms (TS6) at 6cm from the green preprogrammed spot.

For our analyses we also needed a unimodal (tactile) control condition. Therefore tactile stimulations were administered at random at 1ms (TS0) after the start of a trial. These tactile stimuli were administered at static baseline in the 200ms preceding the visual onset.

In the HOT condition no preprogrammed green spot was presented because the hand was not placed on the screen, but on the stool beside their bodies. The respective spatial distances, at which tactile stimulation was administered, remained the same as in the HIT condition.

Six spatial distances, at which tactile stimulation was administered, were coded in our experiment to determine at which spatial distances, dynamic visual stimuli start enhancing tactile processing significantly compared to the unimodal, tactile only, condition (TS0). This particular spatial range will be what we will consider the PPS of our hands. We tested and compared these results for each hand positioning condition.

Analyses

The main purpose of this study was to test what changed in peripersonal space representation when hand positioning changes in the trajectory of a dynamically approaching visual stimulus. This study was a within-subject design with three factors:

1) Hand positioning (HIT; hand in trajectory or HOT; hand out of the trajectory).
2) Presence of a tactile stimulus (catch trials or experimental trials).
3) Tactile stimulations (TS0-6).

Before we started analysing our data, response times per tactile stimulation point were averaged for each participant. This resulted in a total of 14 variables per participant (seven for HIT; seven for HOT). Each averaged RT got subtracted from the averaged RT at the unimodal tactile stimulation point (TS0) per hand positioning condition. RTs at TS0 were not used afterwards because it merely functioned as a static baseline to compare the subtracted averaged remaining RTs (TS1-6) with. These six baseline-corrected RTs (TS1-6) were submitted to a variety of analyses.

A 2 (hand positioning; HIT and HOT) x 6 (TS1-6) repeated measures ANOVA was measured to analyse if there was an interaction between hand positioning and tactile stimulation (Girden, 1992).

If there was a significant interaction effect and main effect of hand positioning on RTs, two separate one-way ANOVAs could be measured to test the main effects of each hand positioning condition on RTs and overall RTs at each tactile stimulation point. If no significant interaction effect was found, the main effects may be interpreted by looking at the Bonferroni-corrected pairwise comparisons (Field, 2009). These analyses helped us determine which hand position resulted in overall faster tactile processing. This determined if having our hand in the trajectory of a visual stimulus resulted in overall faster tactile processing. These analyses also showed which RTs were significantly ($p < 0.05$) faster from the other RTs. This determined if tactile processing gets significantly faster when visual stimuli got closer to our hands.

However these analyses still did not explain anything about the critical spatial range at which multisensory RTs at TS1-6 are significantly enhanced compared to the unimodal tactile stimulation point (TS0) or the differential effects of hand positioning on this possible critical space range what we considered the peripersonal space of our hands. By applying the same method of data analysis as Noel et al. (2015) and Serino et al. (2015) we tried to find this possible critical spatial range. By submitting our baseline-corrected data for each hand position to a Bonferroni-corrected one-sample t test we determined at which visual distance (TS1-6) multisensory input enhances RTs significantly ($p < 0.05$) compared to 0. By comparing the differences in spatial range sizes we were able to determine what the effects of different hand positions were on peripersonal space representation. By applying this method we tried to study if having our hand in the trajectory of a visually approaching stimulus resulted in a larger representation of PPS compared to not having our hand in the trajectory of a visually approaching stimulus.

By submitting our data to these analyses we answered our research question: What changes in PPS representation when hand positioning changes in the trajectory of a dynamically approaching visual stimulus, with more certainty. We were testing at what critical spatial range visual stimuli start enhancing RTs significantly compared to a unimodal baseline for each hand. We also determined if having our hands in the trajectory of a visually approaching stimulus resulted in overall faster tactile processing and PPS spatial range compared to not having our hands in that trajectory.

Results

Participants were excluded from further analyses if they missed 30% of the total trials or more (mean miss = 12.87%), which resulted in exclusion of three participants. The remaining data was used for baseline-correction. If the mean response time of a participant exceeded two standard deviations of the mean response time or more, the particular participant was excluded from further analysis, which resulted in exclusion of one more participant.

The remaining baseline-corrected response times were submitted to a 2 (hand positioning: hand in trajectory & hand out trajectory) x 6 (tactile stimulation points: TS1 through TS6) repeated measures ANOVA. The findings showed no significant hand positioning X tactile stimulation interaction effect ($F(2.464, 27.109) = 2.859$, $p = 0.065$). Also no significant main effect for hand positioning has been found ($F(1, 11) = 0.559$, $p = 0.470$). Unlike hand positioning, there was a significant main effect for tactile stimulation ($F(2.322, 25.540) = 25.508$, $p < 0.001$, partial $\eta^2 = 0.699$). The Bonferroni-corrected multiple comparisons for the significant main effect for tactile stimulations can be found in Table 1 and are graphically presented in Figure 1. These Bonferroni-corrected multiple comparisons showed us that as visual stimuli get closer to our hands mean differences in response times are significantly larger.

In order to identify the critical spatial range where visual stimuli start enhancing tactile processing significantly compared to unimodal baseline, we submitted our data to Bonferroni-corrected one-sample t tests for each hand positioning condition. These analyses showed that RTs at each distance (TS2-6) in both of the hand positioning conditions were significantly faster ($p < 0.05$ Bonferroni corrected) than the unimodal tactile baseline (see Table 2 and Figure 2).

Thus, based on these results we were able to state that the dynamic visual stimulus came to interact and modulate tactile processing significantly compared to baseline when the visual stimulus was at an approximate distance of 62cm (respective distance TS2) from our hands in both hand positioning conditions.

Discussion

In this study we applied a dynamic paradigm to study the peripersonal space representation of our hands. The main purpose of this study was to investigate what changes in peripersonal space representation when hand positioning changes in the trajectory of a dynamically approaching visual stimulus. By using a dynamic visual stimulus, we were able to study such critical distance along a continuous spatial range with six different distances, connecting the near and far space, which determines the boundaries of PPS representation around our hands. In this study tactile stimuli started integrating with a visually approaching stimulus (at approximately 62cm from our hands) regardless of different hand positions. The finding of a critical spatial range is supported by multiple studies which have also shown that there is a critical spatial range that we would consider the peripersonal space of our hands (de Haan et al., 2016; Farnè, 2000; Graziano, 2000; Macaluso & Maravita, 2010; Spence et al., 2000; Spence et al., 2004).

We also found a significant large main-effect for overall response time which means that mean differences in response times get significantly larger when visual stimuli are getting closer to our hands. These findings are also supported by previous research, which has extensively shown that tactile processing, on the hand and face, in the peripersonal space is influenced by approaching visual (Cléry et al., 2015) and auditory (Canzoneri et al., 2012) stimuli in both humans and macaque monkeys (Graziano and Cooke, 2006). This enhanced response speed effect for dynamic stimuli is probably caused by greater activation of fronto-parietal systems (Macaluso & Driver, 2005), which also functions as a predictive machine to interact successfully with objects that are getting closer to us (Clark, 2013; Cléry et al., 2015; de Haan et al., 2016; Kandula et al., 2014).

Interestingly, unlike we hypothesized, no significant main-effect and interaction effects of hand positioning are found for overall response time. We also have not found a hand positioning difference in the size of the critical spatial range that we consider the peripersonal space of our hands, unlike what multiple studies have previously reported (Brozzoli et al., 2012; Farnè, 2000; Graziano, 2000; Macaluso et al., 2005; Macaluso & Maravita, 2010; Serino et al., 2015).

The fact that we were unable to find a significant effect of hand positioning on peripersonal space representation and overall tactile processing does not necessarily mean that hand positioning does not affect peripersonal space representation at all. We were unable to find evidence for this hypothesis with our design and analysis. Therefore future studies need to explore the possible effects of hand positioning on PPS representation even further. However, because we were unable to show a significant effect of hand positioning on tactile processing and PPS representation, we have to take a closer look at the limitations of this study that might have affected our outcome.

One of the reasons why we have not found a significant interaction effect or main effect for hand positioning on overall tactile processing might be because we submitted our baseline-corrected data to the repeated measures ANOVA, instead of our raw averaged data. By baseline correcting our data we also could have eliminated differences between overall tactile processing of each hand positioning condition. We chose to correct our data to baseline and submit it to the repeated measures ANOVA because it is still a relatively new method of data analyses which, to our knowledge, has only been tested by Noel et al. (2015) and Serino et al. (2015). We tried applying the same method of data analyses to analyse our data because it is the most conservative criterion to present a facilitating effect on tactile processing due to visual presentation and spatial location compared to the quickest tactile (unimodal) response time (Serino et al., 2015). We wanted to test if this method would work for our visuo-tactile study as well, but future studies might better submit their raw averaged RTs to the repeated measures ANOVA.

We also have not found a difference in PPS representation between hand positioning conditions. However other, more conventional, methods of peripersonal space representation analyses might be able to explore these boundaries more accurately. Mathematical curve fitting, for example, has been shown to determine PPS boundaries successfully in multiple peripersonal space studies across different sensory modalities (Canzoneri et al., 2012; de Haan et al., 2016; Taffou et al., 2014). Data used for curve fitting is not baseline-corrected, which means that these datasets are composed of the raw means per tactile stimulation point for each subject, compared to our baseline-corrected dataset.

The differences between data correction and data analyses might yield different effects of hand positioning in peripersonal space representation and overall tactile processing. Therefore, to further explore the possible effects of hand positioning on PPS representation and overall tactile processing, we would recommend a similar study to ours, but with different data analyses in which raw averaged data is submitted to a repeated measures ANOVA to test the effects of hand positioning on tactile processing and curve fitting to study the effects of hand positioning on peripersonal space plasticity. We expect to find different results compared to our study, because previous research has shown that the boundaries of peripersonal space can be dynamically extended when visual information about limb positioning is present (Brozzoli et al., 2012; Farnè, 2000; Graziano, 2000; Macaluso et al., 2005; Macaluso & Maravita, 2010; Serino et al., 2015).

The novelty of this study entailed the combination of changing hand positions, dynamic visual stimuli, tactile stimulation at multiple visual distances and a relatively new form of data analysis which to our knowledge have not been combined in previous studies. Our study has explored a lot of different experimental, analytical and procedural methods which means that we can give practical and theoretical implications that can help explore peripersonal boundaries even better. Based on our results we can say that baseline-correcting our data and submitting them to repeated measures ANOVAs and one-sample t tests is an efficient method to explore the (boundaries of) peripersonal space of our hands. However to be able to examine the effects of different hand positions on overall tactile processing and peripersonal space representations we suggest other more conventional methods of data analyses.

To conclude, our study produced an efficient method to determine the proximity of PPS representation. Our baseline-corrected method defined the link between the position of a visual stimulus in space and tactile processing along a spatial range can be beneficial to effectively localize the boundaries of peripersonal space representation of our hands. We showed that dynamic visual stimuli get integrated with tactile perceptions very quickly after they start moving towards us. When a visual stimulus crosses a certain spatial limit, at which multisensory reaction times were significantly faster than a unimodal tactile baseline, we would consider this limit the boundary of peripersonal space representation of our hands. However, we were unable to determine differences in peripersonal space representation when hand positioning changed in or out of the trajectory of a visually approaching stimulus or any effects of hand positioning on overall tactile processing. Therefore this method can be applied to successfully examine the boundaries of the peripersonal space of our hands, but might not be completely suitable for studying the effects of hand positioning on overall tactile processing and peripersonal space plasticity.

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Appendices

Table 1

Bonferroni-corrected Multiple Comparisons of Tactile Stimulation Main Effect

Tactile stimulation point	Tactile stimulation point mean differences (standard error)					
	TS1	TS2	TS3	TS4	TS5	TS6
TS1	-	21.35 (6.07)	35.07 (9.57)	46.59* (11.95)	69,62* (12.24)	79.73* (10.28)
TS2	-21.35 (6.07)	-	13.72 (4.22)	25.24 (7.57)	48.27* (8.13)	58.38* (8.51)
TS3	-35.07 (9.57)	-13.72 (4.22)	-	11.51 (6.11)	34.55* (5.74)	44.65* (7.68)
TS4	-46.59* (11.95)	-25.24 (7.57)	-11.51 (6.11)	-	23.04* (5.51)	33.14 (10.21)
TS5	-69,62* (12.24)	-48.27* (8.13)	-34.55* (5.74)	-23.04* (5.51)	-	10.10 (6.60)
TS6	-79.73* (10.28)	-58.38* (8.51)	-44.65* (7.68)	-33.14 (10.21)	-10.10 (6.60)	-

Note. Mean differences of response times between each tactile stimulation point are presented above and below the diagonal. Negative numbers show us that the mean response time at that tactile stimulation point were faster compared to the mean response time at another tactile stimulation point. Positive numbers show us that the mean response time at that tactile stimulation point was slower compared to the mean response time at another tactile stimulation point. This table shows us that as visual stimuli get closer to our hands mean differences in response times are significantly larger. * $p < .05$ Bonferroni corrected.

Table 2

Baseline-corrected Multisensory Response Times Compared to Unimodal Response Times

		One-Sample Test			
		Test Value = 0			
Hand positioning	Tactile stimulation point	t	df	Mean Difference	95% CI
Hand in trajectory	TS1	-3.26	11	-26.31	[-48.06, -9.29]
	TS2	-4.10*	11	-36.38	[-64.58, -19.49]
	TS3	-3.73*	11	-44.71	[-82.25, -21.24]
	TS4	-4.04*	11	-81.34	[-112.89, -33.27]
	TS5	-5.16*	11	-115.26	[-142.86, -57.41]
	TS6	-6.87*	11	-114.41	[-142.03, -73.08]
Hand out trajectory	TS1	-1.94	11	-18.30	[-29.86, 1.86]
	TS2	-4.63*	11	-49.01	[-63.97, -22.72]
	TS3	-5.28*	11	-65.98	[-86.56, -35.60]
	TS4	-4.43*	11	-67.51	[-93.95, -31.59]
	TS5	-7.02*	11	-89.85	[-107.42, -56.16]
	TS6	-8.83*	11	-100.41	[-118.16, -70.99]

Note. Differences between baseline-corrected multisensory (visuo-tactile) response times and baseline unimodal (tactile) response times are presented in the table above. Significant (*; $p < 0.05$ Bonferroni corrected) negative t values mean that multisensory response times were faster than response times at unimodal baseline. This critical spatial range, at which response times are significantly enhanced compared to baseline unimodal response times, is what we would consider the representation of the peripersonal space (PPS) of our hands. We will consider the limit of this critical spatial range the boundary of the PPS. Based on these results the boundary of PPS in both of the hand positioning conditions is somewhere between TS1 and TS2 (respective distance 76-62cm from our hands).

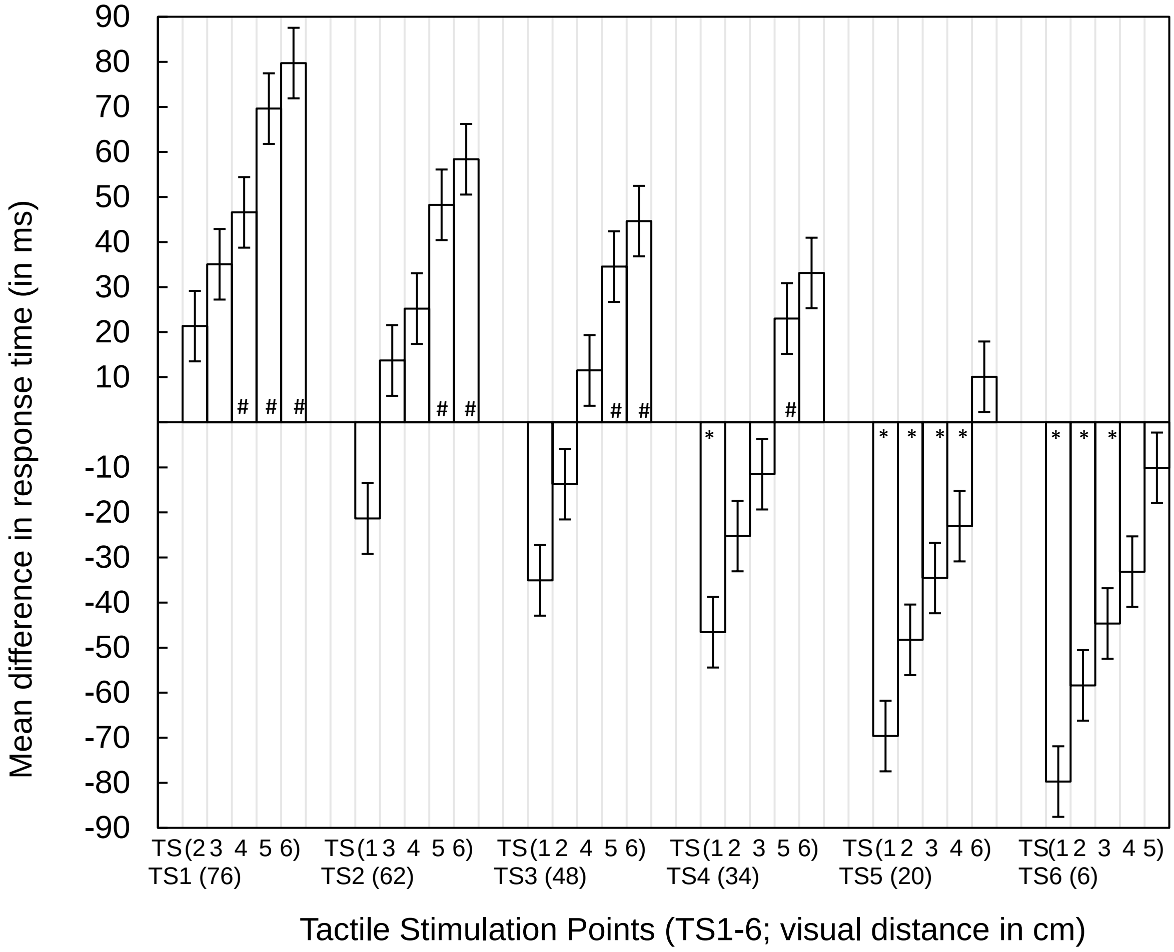

Figure 1. Bonferroni-corrected multiple comparisons of mean response times at different tactile stimulation points. Graphic display of Table 1. Mean differences response times between each tactile stimulation point are presented in the figure above. Positive numbers show us that the mean response time at that tactile stimulation point was slower compared to the mean response time at another tactile stimulation point. # indicates significantly slower response times ($p < 0.05$ Bonferroni-corrected) at a tactile stimulation point compared to other tactile stimulation points. Negative numbers show us that the mean response time at that tactile stimulation point was faster compared to the mean response time at another tactile stimulation point. This figure shows us that as visual stimuli get closer to our hands mean differences in response times are significantly larger. Error bars indicate +/- 1 S.E.M. * $p < 0.05$ Bonferroni-corrected

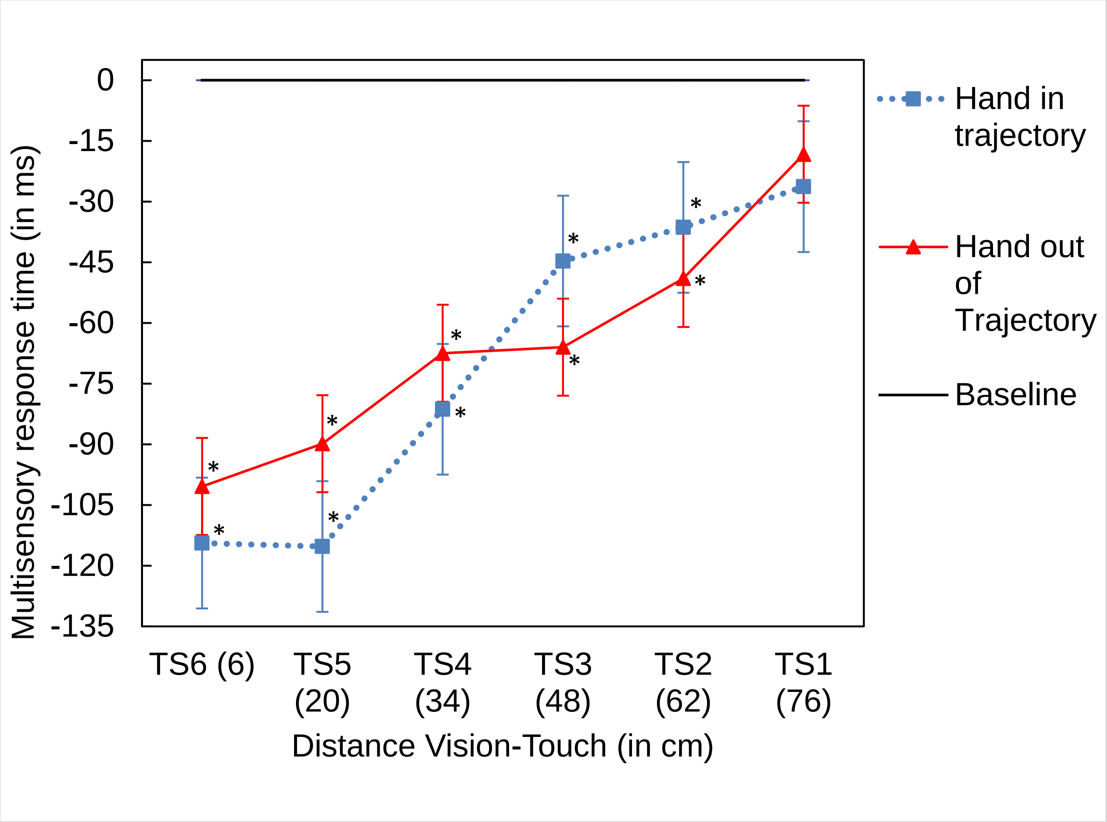

Figure 2. Peripersonal space representation comparison between different hand positioning conditions. Multisensory (visuo-tactile) response time (in milliseconds; negative values mean that multisensory response time < baseline unimodal response time) as a function of tactile processing at different visual distances (TS6 indicates the smallest distance from the index finger, TS1 indicates the largest distance from the index finger) for different hand positions in the trajectory of a dynamically approaching visual stimulus (HIT, Hand in trajectory; HOT, Hand out of the trajectory). The black dashed line indicates baseline response times to a unimodal (tactile) stimulus. * indicates significantly faster tactile processing compared to unimodal baseline ($p < 0.05$ Bonferroni-corrected). Error bars indicate +/- 1 S.E.M. This figure shows us that approaching visual stimuli start enhancing tactile processing significantly from unimodal baseline at 62-76cm from our hands, regardless of hand positioning in or out of the trajectory of a dynamically approaching visual stimulus. We can consider these critical spatial limits the boundary of the peripersonal space of our hands.