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Visuo-tactile interactions are dependent on the predictive value of the visual stimulus

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ABSTRACT

In this study we aimed to explore the predictive link between visual stimuli moving towards the body and the tactile consequences that follow. More specifically, we tested if information derived from an approaching visual stimulus in the region directly surrounding the body (the peripersonal space) could be used to make judgments about the location and time of impending tactile contact. We used moving arm stimuli, displayed on a computer screen, which appeared to travel either towards the face (middle of the left/right cheek) or slightly away from the subject's face. This stimulus was followed by tactile stimulation of the left/right cheek. The time lag between the visual stimulus and tactile stimulation was also manipulated to simulate tactile contact at a time that was either consistent or inconsistent with the speed of the approaching hand. Reaction time information indicated that faster responses were produced when the arm moved towards the hemispace in which the tactile stimulation was delivered and was insensitive to whether the arm was moving towards the cheek or slightly away from the cheek. Furthermore, response times were fastest when the tactile stimulation arrived at the moment that was consistent with the speed of the moving arm. The effects disappeared when the arm appeared to be retracting from the subject's face. These results suggest the existence of a predictive mechanism that exploits the visual information derived from objects moving towards the body for making judgments about the time and location of impending tactile contact.

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1. Introduction

An experience that almost everyone has had is that of being tickled. An aspect common to this experience is the sensation of being tickled even before the other person's hands touch you. This is an illustration of the predictive link between vision and touch. That is, visual information about an approaching stimulus (here the fingers of another person) results in the anticipation of being tickled. This predictive link not only involves the inference of the imminent tactile sensation caused by viewing the causative object, but, also the modulation of the related neural activity in expectation of the tactile consequence, thereby reducing the need for very elaborate processing following the actual event presentation (James, 1890). Indeed, predictive coding allows us to act, and not solely to react once all relevant information has been presented and fully processed, by making predictions about what to expect next while taking into account the current context and previous experiences integrated across different timescales (Bubic et al., 2010).

There have been several reports of how space closely surrounding the body, *the peripersonal space*, is processed differently than other regions. The neural areas representing the (peri-)personal space have been defined in the monkey brain. These studies show that bimodal neurons in premotor and parietal cortex respond to tactile stimuli on the arm or face as well as visual stimuli nearby, but not far away from that body part (Duhamel et al., 1998; Graziano et al., 1997; Rizzolatti et al., 1981). This distinction between the peri- and extra-personal spaces might be useful for filtering information that is likely to be of significance to us.

Firstly, for obvious practical reasons, objects/people in *only* the space closely surrounding us may be interacted with, thereby allowing us to plan approaching movements towards them (Rizzolatti, 1997; Brozzoli et al., 2014). For instance, Farnè and Làdavas (2000) have behaviourally shown that the use of a tool can dynamically extend the peripersonal space of the hand towards the outward tip of the tool, thereby demonstrating the role of peripersonal space as an interactable space within our surroundings. Furthermore, a study by Brozzoli et al. (2010) showed that when grasping objects, a flash on one side of the target object improved processing of tactile stimuli on the finger that would touch that part of the object at the end of the grasping movement. This effect was particularly clear during execution of the grasping movement.

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These findings suggest a dynamic link between visual information on a nearby object and tactile processing on the approaching hand.

Secondly, objects/people in our close proximity may also pose a threat to us thereby warranting us to initiate defensive movements in response to such perpetrations, such as an object approaching us at high speeds. Detecting this object early would help us either avoid the object, or prepare for contact with it more efficiently. Evidence for such a defensive mechanism can be seen from monkey studies by Cooke and Graziano (Cooke and Graziano, 2004; Graziano and Cooke, 2006) who found that when the regions that respond to looming or nearby objects are artificially stimulated, the animal executes defensive movements like withdrawing or blocking. Similarly, Sambo et al. (2012a,b) have demonstrated that the eye-blink reflex in humans was greater when an external hand was near the subject's face as opposed to when it was further away from the face. Makin et al. (2009) showed that objects that approached a location near the hand (when compared to a location far from the hand) increased cortico-spinal excitability, indicating the preparation of the underlying motor areas of the hand to retract.

Based on these studies, it can be summarised that the space around the body is crucial to monitor in order to protect oneself from an approaching object or to plan movements to interact with a nearby object.

In the context of the *defensive peripersonal space*, we suggest that the mechanism underlying the formation of this defensive zone around our body is visuo-tactile prediction. That is, the time-course and location of an impending tactile stimulus caused by an event/object can be predicted by the visual information conveyed by the same event/object, thereby allowing us to efficiently respond to the object.

The facilitative effects of visual information on detecting tactile stimuli have been demonstrated in behavioural studies investigating the cross-modal allocation of spatial attention (see Driver and Spence, 1998; Macaluso and Maravita, 2010). The main findings of these studies are that when visual attention is directed by a cue to a certain location, the processing of a tactile target at that location is also enhanced. For example, Kennett et al. (2002) showed that judgments about tactile stimuli on the hand were faster when these stimuli had been preceded by a light flash at the same location, and were slower when preceded by a light flash at the opposite hand. Cross-modal allocation of spatial attention, therefore, relies on the physical proximity of the visual cue and the stimulated body-part, by causing visual attention at that location to prioritise the processing of tactile information in the same spatial location.

As physical proximity between the visual cue and the site of tactile target delivery was common to these studies, it is difficult to determine if similar behavioural visuo-tactile interactions can be found when visual information predicts a tactile stimulus, but when the two are not near each other. If visuo-tactile interactions can underlie a defensive strategy, it should also be possible to extract information about the impending location and time of contact with an approaching object, before the object reaches the space near the observer. That is, if a true predictive link is to be established between vision and touch, one has to be able to demonstrate that the information derived from viewing a visual cue at a certain location, can cause the allocation of tactile attention at the implied location of contact, (which may be at a distance from the displayed visual information) and at the implied time of contact. It is also crucial to ascertain that such a spatial shift in attention is caused solely by the *expectation* of a tactile event at that location.

The aim of the current study is to test if such a predictive link between vision and touch can be found. That is, will the information obtained by viewing an approaching object enhance tactile processing at the impending time and location of contact with the object, without having to visually follow the trajectory of the object's motion towards the stimulated site?

In our first experiment, we used videos of a moving human arm approaching the subject's face or moving slightly away from it. These were displayed on a computer monitor placed parallel to the subject. Following this, a tactile target was delivered on subject's face either at a location concurrent to the trajectory of the moving arm, or at a non-concurrent location. The subject was asked to provide a speeded response as soon as the tactile target was detected. The time lag between the visual cue and the tactile target was also manipulated. With this setup, we tested if:

1. The coincidence of the implied *location* of contact with the arm and the *site* of tactile target delivery will cause the tactile target to be detected faster (property 1).
2. The coincidence of the implied *time* to contact with the arm and the *time* of the tactile target delivery will cause the tactile target to be detected faster (property 2).

We also conducted a second experiment in order to verify that any effects found in the first experiment were indeed caused by the arm moving *towards* the subject. In the second experiment, we displayed videos of a human arm retracting from the subject's face. This was followed by a tactile target on one of the subject's cheeks. The subject again was asked to respond as soon as the tactile target was detected. Since the arm was retracting from the subject, we expected that neither the trajectory nor the speed of the arm movement would have an impact on where and when the subject expected the tactile target.

2. Experiment 1

2.1. Methods

2.1.1. Participants

Sixteen subjects (3 males, and 3 left-handers) from Utrecht University between the ages of 18–30 ($M=22.3$, $SD=2.68$) were recruited. All subjects were naïve to the purpose of the study and received either study credit or money as compensation. All subjects gave informed consent and were aware that their information would be kept confidential and that they were free to leave the experiment at any time. The experiment was conducted in agreement with the local ethics and safety guidelines, which are based on the Declaration of Helsinki.

2.1.2. Visual stimulus preparation

The stimuli were a set of images that depicted a moving hand that approached the subject from a distance of 60 cm. They were created in our lab for use in the study.

2.1.2.1. Procedure for capturing images. The images of the hand were created in the lab by photographing a Caucasian male volunteer who was 28 years old. The volunteer was asked to dress in a black full-sleeved shirt. The volunteer sat in a chair in front of a camera. A table was placed in between the camera and the volunteer such that the edge of the table closest to the volunteer was touching his chest and his legs were completely under the table. The camera was placed directly opposite the volunteer, facing him, and this position was fixed for the entire photo-session. The camera lens was level with the shoulder of the volunteer. The volunteer was asked to sit with his hands folded into fists and placed in front of him on the table, with the table still touching his chest. The left and right fists were placed right next to each other and the front of the fist was facing the camera and was at a

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