Can tactile suppression be explained by attentional capture?

Georgiana Juravle and Charles Spence

Abstract— **Tactile suppression significantly affects perception on the moving effector of a goal-directed movement. However, it is unclear whether the movement of one hand affects touch at the other, resting, hand. Here, participants had to discriminate between the intensity of two vibrations delivered to their left forearm. They performed the task during a rest condition (both hands at rest) and a movement condition (left hand at rest, right hand moving). Tactile stimulation was delivered during the specific movement execution time-window in which sensory suppression has been reported previously. Stimulation was only delivered to the resting hand. The hypothesis was that if attentional capture were to be responsible for suppression, then this effect should evidence itself as a significant difference in tactile thresholds measured at the resting hand for conditions of rest versus movement. Comparable sensitivity between the two conditions would, in turn, argue against the attentional capture account. Our results support the latter view, indicating that tactile suppression is, in fact, not reducible to attentional capture. The implications of these results for our understanding of attentional capture in the various senses under conditions of rest/movement, as well as with respect to the rapidly-growing body-mounted haptic interface industry, are highlighted.**

I. INTRODUCTION

Tactile sensory suppression is a pervasive characteristic of movement and has been successfully demonstrated across a wide variety of tasks (see [1], for a recent review). Tactile suppression is defined as a decrement in performance, that is, either in the detection or discrimination of tactile stimuli. When reaching for objects in near (peripersonal) space, tactile sensitivity, as measured on the reaching hand, is significantly impaired, relative to the sensitivity measured at the resting hand (see, e.g., [2]-[5]).

For example, in one of our earlier studies [3], participants had to reach and grasp an object placed on the table in front of them, while tactile stimuli were delivered at different points in time during movement (from movement preparation, through several stages of the execution phase, and finishing with the post-movement phase). Tactile sensitivity was measured with a discrimination task. That is, participants reported which was the stronger stimulus between the two tactors attached to their moving and resting hands. The results indicated that tactile discrimination was poor when the hand was in motion (that is, sensation was suppressed), as compared to both the preparation and post-movement phases, with no significant difference recorded between these two [3]. An additional experiment indicated that tactile suppression was comparable between movements performed with the left hand and the movements performed with the right [3]. Furthermore, in a subsequent study [4], we singled out the preparation period of the movement and delivered stimulation in one condition while participants generally prepared the movement, but they did not know yet which hand was to be moved in that trial, and another condition where they received the stimulation at that point in time when the hand to be moved was already known for the trial. The results indicated that tactile suppression was always present irrespective of whether ‘attention’ was at the hand to be moved or not during the trial in this preparatory phase of the movement [4]. Taken together, results such as these indicate the pervasiveness of tactile sensory suppression and its strong connection to movement.

Because movement is crucial for the elicitation of tactile suppression, a resting effector with comparable sensitivity has traditionally been used as a control site for the suppression measured at the moving hand. The decreased sensitivity for what is felt during movement is modulated by the availability of visual information for the ongoing trial, i.e., performance is worse when vision isn't available at the beginning of the reach [6], and the relevance of the movement effector for the movement, i.e., performance is worse at those body parts that aren’t relevant for the action being performed [7], [8]. Furthermore, tactile processing is also modulated by our own expectations with regard to the sensory stimulation, i.e., performance is affected even in the absence of movement, when we simply prepare a movement, or alternatively, observe an actor prepare the same movement [9].

To date, however, there has not been any demonstration in the tactile suppression literature regarding the influence of a goal-directed movement on what is felt at a resting hand at the specific time when the other hand is moving. More specifically, the question that we sought to address here is whether tactile suppression could be explained as an attentional capture effect instead. The definition of attentional capture (following that traditionally used in vision research) is that of an event that disrupts sensory performance. Although note that even if phrased as attention capture, it results not only in disrupting performance, but also in significantly facilitating performance at the cued location. Given the complexity of the reach-to-grasp movement tested here, we will consider attentional capture as encompassing disruption not only from vision, but also from proprioception and the other senses involved in the movement (see [10], [11], for overviews).

Attention could act as an explanatory factor for the suppression reported in the goal-directed movement literature. For this, one needs to picture movement (including

G. J. was with the Crossmodal Research Laboratory, Department of Experimental Psychology, Oxford University, UK, South Parks Rd, OX1 3UD, Oxford, UK. She is now with the Impact Team U 1028, French National Institute of Health and Medical Research, INSERM, Lyon Neuroscience Research Center, Lyon, France (phone:00-33-(0)4-72-91-34-18; fax: 00-33-(0)4-72-91-34-01; e-mail: georgiana.juravle@inserm.fr).

C. S. is head of the Crossmodal Research Laboratory, Department of Experimental Psychology, Oxford University, UK, South Parks Rd, OX1 3UD, Oxford, UK. (e-mail: charles.spence@psy.ox.ac.uk).

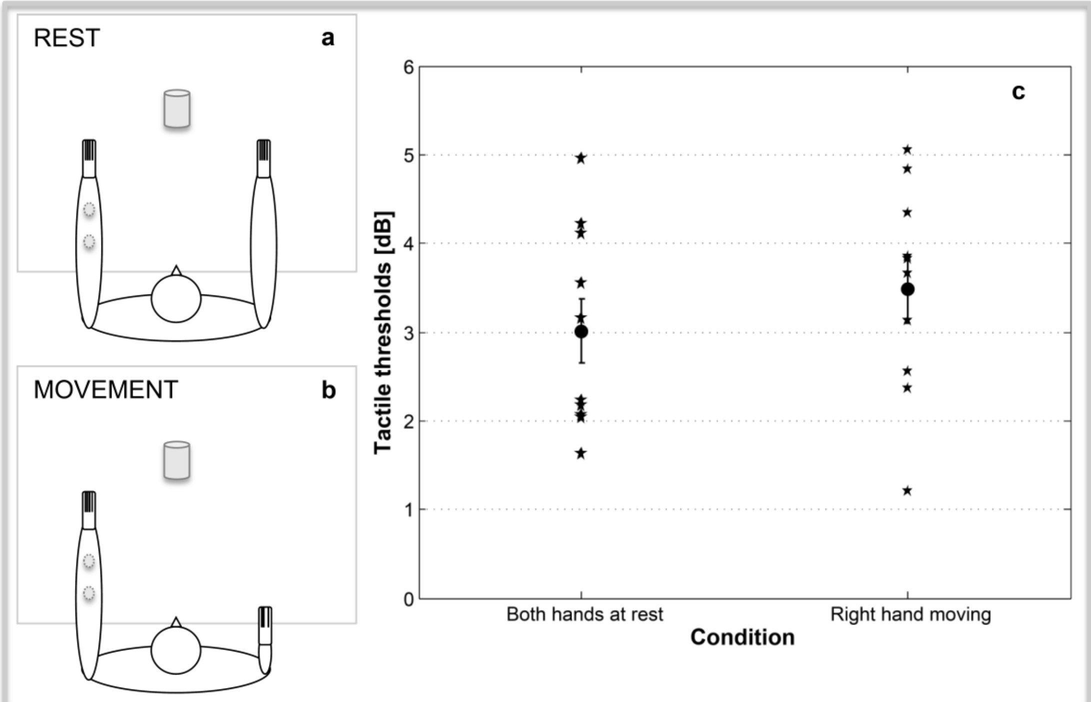

Figure 1. Experimental set-up showing bird's-eye view of the participant's hands positioned for the rest condition (a) and the movement condition (b). The participants had 2 tactors attached to the dorsal part of their left forearm. The goal object to be grasped for the trial (depicted in gray) was located centrally 30 cm in front of the participant. The object served as a visual fixation stimulus in the rest condition. (c) Scatter-plots of the individual threshold data together with the means for the two conditions (rest vs. movement). Vertical error bars represent the standard errors of the means.

both its planning and execution) *per se* as a distraction. That is, as an event that captures attention and consequently disrupts performance in a tactile processing task for stimulation delivered at a resting body part. Indeed, spatial attention is significantly captured (and therefore, performance is worse, at least at locations away from the 'captured' spatial location), when a distracting stimulus enters awareness (see e.g., [12], for early demonstrations; [13], [14], for specifically abrupt visual onsets, or visual motion; see also [15], [16], for multisensory capture). In order to test for any attentional capture resulting from the execution of movement, tactile sensitivity should be investigated under conditions of goal-directed movement and rest. For this, participants in the present study performed goal-directed reach-to-grasp movements with their right hand, or else, kept both of their hands still. Tactile stimulation was always provided to the resting left forearm during the execution period of the movement, where tactile attenuation effects have been reported previously.

If attentional capture from the movement were to be responsible for the previously-demonstrated attenuating effects on tactile perception, then tactile perceptual sensitivity should be significantly higher for stimulation received when both hands are at rest, as compared to a condition in which the participants moved their right hand to grasp the goal object. Alternatively, however, if suppression were to be regarded as a result of both movement and peripheral interference [17], [18], then no such difference ought to be observed between conditions of rest and movement.

II. METHOD

A. Participants

Ten participants (one male, all right-handed) took part in this experiment. The mean age of the participants was 27 years (age range 23-29 years). The experimental session lasted for approximately 30 minutes and the participants received a £5 gift voucher in return for taking part in the study, which received ethical clearing from the University of Oxford, UK.

B. Apparatus

The participants were seated at a table in a large well-lit room. A metallic box (goal object, 5 cm diameter, 6 cm height) was placed centrally on the table surface, at a distance of 30 cm from the participant's chest. The participants wore two tactors (VBW32 skin stimulators, 1.6 x 2.4 cm vibrating surface, Audiological Engineering Corp., Somerville, MA, USA) attached to the ventral part of their left forearm, one at their wrist and the second placed at a distance of 15 cm toward their elbow (see Figure 1a-b for a depiction of the experimental set-up). The tactors were covered in several layers of thin sponge in order to reduce the possibility of the participants hearing the sound of their operation. Participants responded by means of two footpedals, one placed on the floor in front and the other behind their left foot, at a comfortable distance.

C. Procedure

The participants performed two blocks of trials (movement and rest) with a short break in between. In the rest condition, the participants kept both hands at rest on top of sponge-like supports placed on the table. The auditory signal (400 Hz, 50 ms) announcing the start of the trial was followed after a variable time interval (800-1200 ms) by a second higher-pitched auditory signal ('go signal', 800 Hz, 50 ms). 500 ms after this second auditory beep, both of the tactors worn by the participants on their left forearm started vibrating concomitantly (at 250 Hz, for 150 ms).

The movement condition had the same trial definition as the rest condition; see Figure 1a-b for a depiction of the experimental set-up. However, at the beginning of each trial, the participants now placed their right palm at the edge of the table. At the delivery of the auditory go signal, participants had to reach forward and grasp the goal object rapidly, lift it, and replace it on the table in the same position. After having grasped and replaced the goal object, the participants returned their limb to the start position.

At the end of the movement, the participants responded, indicating which vibration they felt to be weaker or stronger, by pressing one or the other pedal with their left foot (see [3], for the exact psychophysical task). Response assignments and the order in which the two conditions were presented were counterbalanced across participants. The experimenter validated the trial and the experiment continued to the next trial in the sequence.

D. Design

The design of this experiment was very similar to that reported previously [3]. In the following, only the methodological differences are highlighted. Each of the experimental conditions (rest vs. movement) used one staircase consisting of a three-interval one-up three-down adaptive procedure, designed to keep perceptual performance at 79.4% correct [19]. The conditions were blocked, such that participants performed one staircase procedure for the rest condition, and another for the movement condition. Both of the tactors worn by the participants on their left arm vibrated at the same time, thus possible interference effects from participants' memory for tactile stimulation [20], or contralateral masking [21], were excluded as possible explanations for any sensory suppression results obtained previously. Participants were given a break at the end of the first experimental block, once the perceptual threshold had been reached for either the rest, or the movement condition.

E. Data analysis and results

On average, the participants needed 88 trials in order to complete the rest condition and 79 trials for the movement condition. This difference between the number of trials needed for the completion of the individual staircases was not significant, $t(9) = 1.30$, $p = .227$; $r = -.37$.

Mean thresholds and individual rest ($M = 3.01$; $SE = .36$) and movement data ($M = 3.48$; $SE = .38$) from all participants are presented in Figure 1c. A paired-samples *t*-test was conducted on the mean threshold data from the experimental conditions (rest vs. movement). The results indicated that movement of the hand did not affect sensitivity on the resting hand, $t(9) = -1.18$; $p = .268$; $r = .42$; $power(1\text{-}\beta) = .74$.

III. DISCUSSION

Tactile suppression is known to significantly affect the reaching hand for goal-directed reaches we use on a daily basis. The specific effect reaching with the hand has on tactile processing in the resting hand has surprisingly not been investigated so far. Here we were interested to investigate for the first time whether this decrement in tactile sensitivity during movement could be explained by an attentional capture effect (i.e., the moving hand 'capturing' the participant's attention and hence, the increased thresholds or the poorer tactile performance relative to a resting condition). Crossmodal links in spatial attention have been demonstrated for a multitude of tasks and sensory pairings, in both the lab and the real world (see [11], [22]). However, as studied here, attentional capture from the moving hand is considered as a sum of various sensory inputs that arrive at our receptors as a consequence of movement. The sensory inputs we were concerned with for the present investigation were mainly those visual ones; Future investigations need to address other proprioceptive and auditory inputs that likely play a role in the movement multisensory experience.

As highlighted by the present results, participants exhibited comparable tactile sensitivity in a resting hand between conditions of rest (when both hands are immobile), and movement (the hand receiving tactile stimulation is at rest, and the other is moving). Results such as these are taken to indicate that visual attentional capture cannot explain the attenuation in tactile sensitivity previously documented in the literature [2], [3]. Most likely, the attenuation in tactile sensitivity previously observed during movement execution results from the combination of the motor command and peripheral interference from the movement itself [17]. Furthermore, tactile sensitivity is liable to significant context influences during goal-directed movement [1]. Here, we demonstrate for the first time that (a likely crossmodal) attention capture from a moving hand cannot be taken as one of the contextual factors modulating the tactile suppression known to occur in goal-directed movement.

These results require the acceptance of the null hypothesis: Note, though, that our data would have made a strong statement no matter whether the null hypothesis was rejected or accepted. In the first case, we would have had to admit that tactile processing at a resting hand is affected by the movement of an object in contralateral space. In the latter case, which happens to be the actual finding of our study, we acknowledge that a moving hand does not actually affect tactile sensation at the resting hand. This result is valuable, though, precisely because it informs us that the findings reported in previous studies of tactile suppression during goal-directed movement are not affected by the distracting influence of attentional capture.

Having found no interference from the moving hand on the tactile processing at a resting hand, we need to evaluate the *distracting* quality of the reach-to-grasp movement. Our results indicate that tactile discrimination thresholds measured at the resting hand are stable enough that they cannot be affected by a stimulus as salient as the movement of our own hand. They do not follow the traditional attention capture effects resulting from motion as studied in the static visual domain (e.g., [14]). The results reported here could thus be considered surprising specifically because our hand is a biologically-relevant stimulus performing a meaningful goal-directed action in near peripersonal space. Future research should investigate whether the lack of attention capture is specific only to the movement of our own limbs, or whether instead it transfers to other types of tasks involving both our own body (movement effectors), and other complex sensory stimuli with potential of attentional capture.

Finally, it may be worth considering the implications of the present results: Note that we have already voiced concern regarding the use of tactile vibratory cues for wearable technology [23]; see also [24]: Because of the existence of tactile suppression, vibrotactile and other kinds of tactile warning signals need simply to be used to signal whether an event is present or not. The results of the present study provide further input to enhance the design of future body-mounted haptic interfaces. While it might seem intuitive to deliver an informative tactile cue at the movement effector, results such as those reported here indicate tactile cues could be equally effective when delivered at a resting body part.

References

[1] G. Juravle, G. Binsted, and C. Spence, “Tactile suppression in goal-directed movement,” Psychon. Bull. Rev., pp. 1–17, Nov. 2016.

[2] G. Buckingham, D. P. Carey, F. L. Colino, J. DeGrosbois, and G. Binsted, “Gating of vibrotactile detection during visually guided bimanual reaches,” Exp. Brain Res., vol. 201, no. 3, pp. 411–419, Mar. 2010.

[3] G. Juravle, H. Deubel, H. Z. Tan, and C. Spence, “Changes in tactile sensitivity over the time-course of a goal-directed movement,” Behav. Brain Res., vol. 208, pp. 391–401, Apr. 2010.

[4] G. Juravle, H. Deubel, and C. Spence, “Attention and suppression affect tactile perception in reach-to-grasp movements,” Acta Psychol. (Amst)., vol. 138, no. 2, pp. 302–310, Aug. 2011.

[5] A. Gallace, S. Zeeden, B. Röder, and C. Spence, “Lost in the move? Secondary task performance impairs tactile change detection on the body,” Conscious. Cogn., vol. 19, no. 1, pp. 215–229, Mar. 2010.

[6] F. L. Colino, J.-H. Lee, and G. Binsted, “Availability of vision and tactile gating: Vision enhances tactile sensitivity,” Exp. Brain Res., vol. 235, no. 1, pp. 341–348, 2016.

[7] F. L. Colino, G. Buckingham, D. T. Cheng, P. van Donkelaar, and G. Binsted, “Tactile gating in a reaching and grasping task,” Physiol. Rep., vol. 2, p. e00267, 2014.

[8] F. L. Colino and G. Binsted, “Time course of tactile gating in a reach-to-grasp and lift task,” J. Mot. Behav., vol. 48, no. 5, pp. 390–400, 2016.

[9] G. Juravle and C. Spence, “Perceptual and decisional attenuation of tactile perception during the preparation of self- versus externally-generated movements,” Exp. Brain Res., vol. 223, no. 1, pp. 109–120, 2012.

[10] C. Folk and B. Gibson, Eds., Attention, distraction and action: Multiple perspectives on attentional capture. Amsterdam: Elsevier Science BV, 2001.

[11] C. Spence and J. Driver, Eds., Crossmodal space and crossmodal attention. Oxford, UK: Oxford University Press, 2004.

[12] M. I. Posner, C. R. R. Snyder, and B. J. Davidson, “Attention and the detection of signals,” J. Exp. Psychol. Gen., vol. 109, no. 2, pp. 160–174, 1980.

[13] S. Yantis and J. Jonides, “Abrupt visual onsets and selective attention: evidence from visual search,” J. Exp. Psychol. Hum. Percept. Perform., vol. 10, no. 5, pp. 601–621, 1984.

[14] A. P. Hillstrom and S. Yantis, “Visual motion and attentional capture,” Percept. Psychophys., vol. 55, no. 4, pp. 399–411, Apr. 1994.

[15] C. Spence and J. Driver, “Audiovisual links in exogenous covert spatial orienting,” Percept. Psychophys., vol. 59, no. 1, pp. 1–22, Jan. 1997.

[16] T. Koelewijn, A. Bronkhorst, and J. Theeuwes, “Auditory and visual capture during focused visual attention,” J. Exp. Psychol. Hum. Percept. Perform., vol. 35, no. 5, pp. 1303–1315, Oct. 2009.

[17] C. E. Chapman and E. Beauchamp, “Differential controls over tactile detection in humans by motor commands and peripheral reafference,” J. Neurophysiol., vol. 96, no. 3, pp. 1664–1675, Sep. 2006.

[18] C. E. Chapman and F. Tremblay, “Tactile suppression,” Scholarpedia, vol. 10, no. 3, p. 7953, Mar. 2015.

[19] H. Levitt, “Transformed up-down methods in psychoacoustics,” J. Acoust. Soc. Am., pp. 467–477, 1971.

[20] A. Gallace and C. Spence, “The cognitive and neural correlates of tactile memory,” Psychol. Bull., vol. 135, no. 3, pp. 380–406, May 2009.

[21] R. Verrillo and G. Gescheider, “Perception via the sense of touch,” in Tactile aids for the hearing impaired, I. R. Summers, Ed. London: Whurr, 1992, pp. 1–36.

[22] C. L. Baldwin, C. Spence, J. P. Bliss, J. C. Brill, M. S. Wogalter, C. B. Mayhorn, and T. K. Ferris, “Multimodal cueing: The relative benefits of the auditory, visual, and tactile channels in complex environments,” in Proceedings of the 56th Human Factors and Ergonomics Society meeting, 2012, pp. 1431–1435.

[23] G. Juravle and C. Spence, “Speed of reaction to sensory stimulation is enhanced during movement,” Acta Psychol. (Amst)., vol. 161, pp. 154–161, 2015.

[24] C. Ho and C. Spence, “Head orientation biases tactile localization,” Brain Res., vol. 1144C, pp. 136–141, 2007.