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Research report

Predicted reach consequences drive time course of tactile suppression

Lindsey E. Fraser[a,b,*], Katja Fiehler[c]

[a] Center for Vision Research, York University, Toronto, Canada
[b] Department of Psychology, York University, Toronto, Canada
[c] Department of Psychology, Justus-Liebig-Universität Gießen, Germany

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ABSTRACT

Sensitivity to touch is reduced during movement; this *tactile suppression* is likely the result of a mechanism that suppresses self-generated movement consequences. We sought to determine whether tactile suppression is modulated by naturally evoked changes in movement speed driven by task precision demands (Exp.1), and by changes in predicted movement consequences (Exp.2). We measured suppression by comparing detection thresholds for a vibration applied to the finger during reach and at rest. In Experiment 1 we varied reach target size to create a speed-accuracy tradeoff, where participants decelerated more to smaller targets to accurately hit them. We theorized that the reduction in late-reach speed associated with higher precision demands might lead to a reduction in late-reach suppression, consistent with the literature showing a positive relationship between speed and suppression. Contrary to our hypothesis, we found suppression increased towards the end of the reach in all conditions, despite a significant decrease in reaching speed. We postulated this might be a de-emphasizing of the predicted tactile feedback associated with tapping the target. To test this, in Experiment 2 we paired a vibration consequence with a target of a certain colour. We found an increase in late-reach suppression for this target compared to a target of another colour with no associated consequence. Our results indicate that tactile suppression is temporally sensitive and increases as predicted consequences become more likely. We propose the positive correlation between movement speed and suppression previously reported may be driven by the predicted somatosensory consequences associated with increased movement speed.

1. Introduction

Our sensitivity to tactile information is reduced during movement. This phenomenon is known as *tactile suppression,* sometimes called tactile attenuation or gating [1–13]. Tactile suppression is believed to be a product of a feed-forward mechanism for action outcome prediction. That is, as part of movement planning and execution, the brain generates a prediction about the sensory outcomes of the planned movement. This prediction can be compared against the sensory re-afference produced by the movement, allowing an individual to distinguish between self-generated sensory feedback and novel stimuli [14]. It has been shown that the predicted sensory consequences of a movement are perceived as less intense than unpredicted consequences [15,16], suggesting the prediction mechanism de-emphasizes self-generated movement outcomes, presumably in order to free up processing capacity for novel sensory information [5,15]. Sensory suppression is a highly generalized mechanism which affects tactile sensitivity as well as other modalities, such as audition and vision [9,10,17–20].

In the tactile domain, it has been shown that the magnitude of sensory suppression decreases with distance from the moving effector, and is largely restricted to the moving limb [4]. However, when tactile information is relevant, such as in surface texture exploration or in grasping (where tactile feedback about surface friction facilitates grip force estimation), the relevant skin surface, i.e., the fingertip, may experience a relative reduction in suppression compared to other locations on the moving limb [2,8,21,22]. In other words, while suppression still occurs, the amount of suppression experienced at a given site is reduced when tactile information at that site is deemed task-relevant. This suggests that the feed-forward mechanism is sensitive to movement context, taking into account the goal of the movement when forming the appropriate state predictor, and potentially inhibiting suppression at locations and times when tactile feedback is required.

Movement speed is known to play a role in modulating tactile suppression. There exists a minimum speed required for significant suppression to occur, around 50 mm/s [1]; beyond this minimum, many studies have reported a significant positive correlation between reach speed and magnitude of suppression [1,6,12,23]. It has been noted that slower movement speeds are associated with exploratory

* Corresponding author at: Department of Psychology, York University, 4700 Keele St, Toronto, Ontario, M3J 1P3, Canada.
E-mail address: lfraser4@yorku.ca (L.E. Fraser).

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movements; slow speeds may facilitate sensory processing in order to perform exploration [2]. However, studies comparing suppression of different speeds often employ movements that are either continuous and not goal-directed [1,23], or employ unnatural movements (e.g., rapid exploration [2]). It remains to be seen how naturally evoked changes in movement speed for single goal-directed movements (e.g., reaching to touch a target) might affect tactile suppression.

It is possible to manipulate the natural speed profile of a movement by changing the precision demands of that movement. A movement with high precision demands has a relatively longer deceleration period compared to a movement with low precision demands. High precision demands require repeated online motor adjustments to minimize error and improve accuracy in connecting with a goal, and this leads to a characteristic reduction in late-movement speed as the effector nears the target. In contrast, reaches with low precision demands show less or no online adjustment to the initial motor plan, and have a relatively shorter deceleration phase. This speed-accuracy tradeoff is known as Fitts' Law [24,25].

In the present study, we sought to determine whether increasing the precision demands of a reach movement, thus changing the natural speed of the movement, would modulate tactile suppression. The speed-accuracy tradeoff is most evident as the effector approaches the target; thus we predicted a reduction in suppression for high-precision reaches in the later stages of reach, when participants are moving substantially slower than we would expect them to move in a low-precision reach. Participants reached in darkness to tap a target presented on a touch screen with their right index finger. There were three sizes of targets –small, medium and large—which pilot studies suggested corresponded to high, medium and low reach precision demands. We determined tactile detection thresholds for a vibrotactile stimulus applied to the dorsal surface of the reaching finger, which fired at early (~25% completion) and late (~75%) stages in the reach, and calculated suppression effects by subtracting detection threshold at rest from these scores. We predicted that reaching to the smaller targets would be characterized by more movement deceleration and slower late-reach speed, and that the degree of tactile suppression on the reaching finger would decrease towards the end of the reach to the smaller targets. Such a result would indicate that the speed-accuracy tradeoff interacts with sensory suppression, potentially serving to facilitate somatosensory processing of afferent signals from the reaching hand in high-precision reach contexts.

2. Experiment 1 methods

2.1. Participants

Twenty-eight graduate and undergraduate students at Justus-Liebig University Giessen (12 male, 16 female) aged 21–43 (mean age 27 ± 6 years) participated in this study. They all were right handed as measured by the Edinburgh handedness inventory (96 ± 8), [26] and had normal or corrected-to-normal visual acuity. Participants were recruited by word of mouth, or through advertisements sent to undergraduate mailing lists. Participants recruited through university mailing lists received their choice of 8 Euros in cash as compensation or a 1-hour credit toward their Psychology grade. Participants recruited through word of mouth did not receive any compensation. All experiments were approved by the research ethics board at Justus-Liebig University Giessen, and were run in accordance with the principles laid out in the Declaration of Helsinki (seventh revision, 2013).

2.2. Apparatus

Participants were seated at an 80 × 117 cm table with their chair adjusted to a comfortable height. A chin rest was provided. A CRT monitor (Iiyama Vision Master Pro-510 model A201HT) was positioned on the table 52 cm directly in front of the participant. A touch screen (Keytec Magic Touch USB) was mounted on the front of the CRT monitor and was calibrated at the beginning of the test session by the participant. A small keypad (12.5 cm × 8 cm) was positioned 6 cm from the edge of the table under the participant's right hand, approximately 40 cm from the touch screen. A mouse was taped to the table in a position accessible to their left hand.

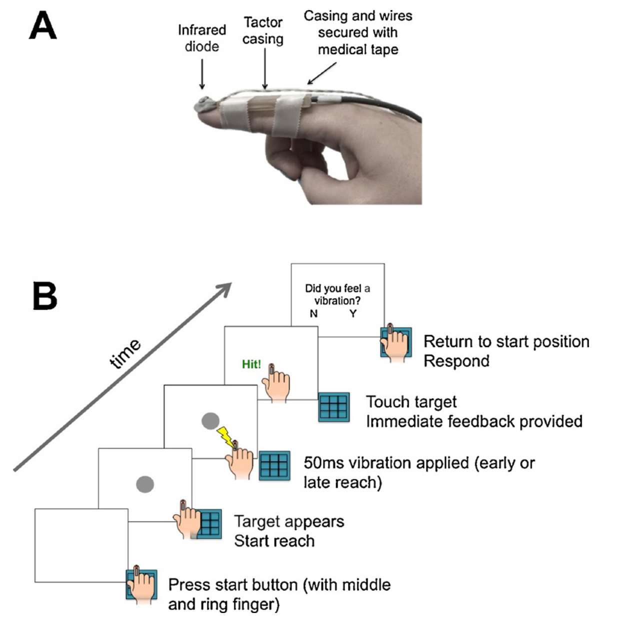

Fig. 1. A) Photo of the vibrotactile device (tactor) and diode attached to a participant's finger of the reaching hand with medical tape. B) Time course of a given trial in the reaching + detection task. In the experiment the computer screen background was black.

A custom-built vibrotactile device (henceforth "tactor"; Engineering Acoustics Inc., Casselberry, FL, USA) was taped to the participant's right index finger such that the vibrating pad (5 mm dia) was located on the dorsal surface of the finger approximately equidistant between the proximal and distal interphalangeal joints (see Fig. 1A). An infrared diode was attached to the participant's fingernail to record motion kinematics of the fingertip during reach. The motion tracking system used was an Optotrak Certus (Northern Digital, Inc., Waterloo, ON, Canada), controlled via Matlab (Mathworks, Natick, MA, USA) using commands from the Optotrak Toolbox created by V. H. Franz (http://www.ecogsci.cs.uni-tuebingen.de/OptotrakToolbox).

2.3. Targets

Three circular reach targets were used in this study, distinguished by their size: large (9 cm dia), medium (1 cm dia), or small (0.5 cm dia). These sizes were chosen based on pilot data suggesting the three sizes elicited different movement times and speed profiles. All targets were a uniform gray, presented on the CRT monitor. The large target always appeared in the center of the display and the small and medium targets appeared in a location randomly chosen from within an area 9 cm in diameter from the center of the screen. By keeping targets constrained to a small area of space we intended to limit the variability of the spatial characteristics of reaches.

2.4. Procedure

Once in a comfortable position with the chin rest adjusted to their height, the participants calibrated the touch screen by briefly touching nine locations on the screen. The experiment consisted of three blocks presented in the same order: a practice block, a baseline block, and a reaching + detection block.