Effect of Focus Direction and Agency on Tactile Perceptibility

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Abstract. Prior research has shown that the direction of a user's focus affects the perception of tactile cues. Additionally, user agency over touch stimulation has been shown to affect tactile perception. With the development of more complicated haptic and multi-sensory devices, simple tactile cues are rarely used in isolation and the effect of focus direction and of user agency on the perception of a sequence of tactile cues is unknown. In this study, we investigate the effect of both of these variables, focus direction and agency, on the perception of a cue sequence. We found that the direction of user focus and user sense of agency over tactile stimulation both had a significant effect on the accurate perception of a cue sequence. These results are presented in consideration for developing better haptic devices that account for users' focus on and control over these devices.

Keywords: Tactile perception · Tactile focus · Tactile agency

1 Introduction

Wearable haptic devices have prospered in the consumer world and become the subject of much recent haptics research aiming to expand their capabilities. These devices commonly leverage sequences of tactile cues such as vibration [11,17], skin stretch [1,5], and squeeze [2,13] in a perceptually distinct manner to the other senses, thus avoiding the negative consequences of sensory overload [10]. However, prior work has indicated the perception of tactile stimuli can change due to the direction of a user's focus (also referred to as attention in literature from other fields) [9,16] across the body and across multiple senses [3,8]. For brevity in this paper, we define focus direction as the aforementioned direction of a user's focus, either across the body spatially or across multiple

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senses. To inform future research in developing sequences of tactile stimulation in increasingly complicated environments, one goal of this work is to understand the effect of focus direction on tactile perception.

In addition, there are differences in the perception of haptic cues that are "actively touched," where the user purposefully feels the environment as opposed to "passively touched," where the user reflexively senses a stimulus that has been applied to their skin [7]. These two "modes" of touch differ distinctly in the amount of agency, or control, the user has over the tactile stimulation. The effect of agency on tactile perception has not been well studied and is particularly relevant given new research directions, including studies on how to deliver rich information during active interaction with the environment, such as in responsive virtual reality [13,15], and motion feedback for prostheses [1,18]. Passive tactile interactions have also been investigated in prior work on delivering language cues through phonemes [6,17], and navigation cues [4]. The relevance of this type of research motivates the second goal of this work: to understand the role of agency on tactile perception.

To address these goals, we investigate the effect of focus direction and agency on the perception of tactile cues.

2 Methods

We tested participants' ability to accurately discriminate a single target vibration cue from a sequence of vibrations at different spatial locations on the forearm. We measured participant accuracy as the proportion of correct responses out of all trials presented in each condition while varying focus direction and agency. For this study, focus direction refers to the orientation of the participant's focus, either spatially across the skin or across two sensory modalities (touch and sound). Agency refers to the participant's ability to directly control the onset of stimulation or lack thereof. Our objective was to determine if these variations in focus direction and agency affected participants' ability to complete the task accurately.

2.1 Participants

A total of 18 participants (7 female, 14 right-handed, 19–28 years old, average age 24) took part in this study. All participants in the study were healthy adults and did not suffer any cognitive or motor impairment that would affect their ability to perform the experiment. All participants gave informed consent and all procedures and methods of the experimental protocol were approved by the Rice University Institutional Review Board (IRB-FY2019-49).

2.2 Experimental Hardware

This experiment used a modified version of the Vibro-Tactile Sleeve (VT-Sleeve) used in Macklin et al. [11]. The VT-Sleeve features 6 vibrotactile actuators (Compact Audio Exciter; Tectonic; Part No. TEAX14C02-8) embedded in a compression sleeve (Under Armour) with custom 3D-printed housings. The vibrotactors

Fig. 1. Participant wearing the vibrotactile sleeve, positioned to complete the experimental task. (left) Vibrotactile sleeve used in experiments to deliver vibrotactile cues to the participant via 6 vibrotactors. Tactors were evenly spaced on the participant's forearm between their wrist and elbow with 3 vibrotactors on the ventral side of the arm and 3 vibrotactors on the dorsal side. (right) Participant wearing the vibrotactile sleeve while interacting with the experimental GUI on the monitor and listening to pink noise through headphones. (Color figure online)

were each press-fit into their respective 3D-printed housing, which clipped into slits in the compression sleeve. The vibrotactors were placed 60mm apart on the sleeve when relaxed with 3 vibrotactors on the ventral side of the arm and 3 vibrotactors on the dorsal side. The sleeve held each vibrotactor snugly against the skin as shown in Fig. 1. The sleeve was adjusted on all participants such that the vibrotactors on each side of the forearm were sufficiently separated to satisfy the two-point discrimination threshold reported for successive touch stimuli [12]. Wiring powering each vibrotactor was routed through another small slit in the compression sleeve directly next to the housing element, ensuring no direct contact between the wiring and skin. These wiring elements connected to a quick release ribbon cable connector, which in turn connected the tactors to a custom amplifier.

All tactile cues were 250 ms envelope sine waves presented 400 Hz for the target cue and 100 Hz for the distraction cues. Extensive pilot testing was done to verify that these characteristics resulted in clear and distinct vibrotactile cues. Tactile cues were rendered with Syntacts using a digital-to-analog converter (MOTU 24Ao USB) with signals amplified through the Syntacts V3.0 amplifier [14].

2.3 Experimental Conditions

The experimental task required participants to identify the location of the target cue out of a sequence of 6 vibrotactile cues delivered on the forearm. The cue sequence was randomized such that each vibrotactor vibrated once and the target cue could appear at anytime during the sequence. All sequences had one target cue and five distraction cues. All cue durations were 250 ms, with a 400 ms pause between the presentation of each cue. After each sequence, the participant used their mouse to indicate which vibrotactor they thought delivered the target cue to the forearm. This basic tactile task varied in each condition to shift focus direction or to adjust agency over sequence presentation in each trial. These variations made up the 6 conditions in this experiment to investigate the various combinations of focus direction and agency.

Focus direction was split into three categories: double focus, where participants were given a separate auditory task to perform simultaneously with the basic tactile task (as described above); wide focus, where the participant performed the basic task; and narrow focus, where the participant was told which side of the forearm the target would appear and therefore would only consider 3 of the 6 vibrotactors. The double focus task presented participants with the basic tactile task while simultaneously asking them to perform an auditory task that started in tandem with the tactile sequence. This auditory task presented a sequence of 6 auditory beeps 440 Hz each separated by 750 ms through the participant's headphones. These beeps were presented with two perceptually distinct volumes: one quiet and one loud. The participant was asked to count the number of loud beeps out of the 6 in the sequence while simultaneously performing the basic tactile task. While each participant was instructed to perform both tasks to the best of their ability, we report participant accuracy in completing the tactile task only, as the purpose of the auditory task was only to direct focus across two tasks. The wide focus category presented the basic tactile task with 6 cues in sequence to the participant and asked them to identify the location of the target cue. The narrow focus task informed the participant about which side of the forearm the target cue was going to appear via arrow icons presented in the GUI. This directed the participant's focus onto the 3 tactors on one side of the forearm. The participant then received the sequence of 6 cues and was asked where the target cue appeared.

Agency variations were split into only two categories: active, where the participants had a button to start the vibrotactile sequence; and passive, where the participants were allowed 30 s after each sequence was displayed to provide their response before the trial automatically advanced. The conditions in this experiment crossed these two categories such that there were 6 conditions for each participant presented in a random order: double focus passive, double focus active, wide focus passive, wide focus active, narrow focus passive, and narrow focus active.

2.4 Procedure

Participants were seated in front of a computer screen with their left hand placed on the table and their right hand using a computer mouse. The participant wore the vibrotactile sleeve on their left forearm as described in Sect. 2.2. The participant wore noise canceling headphones playing pink noise throughout the experiment to isolate them from any outside auditory stimulation. After receiving instructions from the experimenter, the participant interacted with a GUI on the computer to begin the experiment. Participants started with 5 practice trials and received feedback on the correct response in each trial. After practice, participants responded to 20 identification trials in a randomly selected condition as described in Sect. 2.3. Participants repeated this process for all six conditions.

3 Results

Participant accuracy was calculated for each condition based on the number of correct responses out of the 20 trials presented. For double focus conditions, accuracy scores were calculated solely on the participant's ability to complete the tactile task. Two participants were non-compliant with instructions and their accuracy scores were below random chance ($\approx$16.7%) for a majority of the experimental conditions. For these reasons the data from these two subjects were excluded from data analysis. The mean and standard deviation for each condition group are reported in Table 1. Figure 2 shows the spread of participant accuracy across the six conditions in this experiment. The narrow conditions showed the highest mean accuracy while the double conditions showed the lowest. Additionally while there was little variation in the means between the active agency and passive agency conditions, the average standard deviations in the active conditions were generally larger than the average standard deviations in the passive conditions.

A two way repeated measures ANOVA was performed to analyze the effect of focus direction and agency on participant accuracy. This ANOVA showed that both focus direction and agency had a statistically significant effect on participant accuracy after Greenhouse—Geisser correction (Focus Direction: $F(2, 30) = 4.05$, $p < .05$, Agency: $F(1, 15) = 5.40$, $p < .05$). There was no statistically significant interaction between focus direction and agency ($F(2, 30) = .60$, $p = .54$). Subsequent post-hoc pairwise t-tests performed between groups also showed no statistically significant difference between groups after Bonferroni correction.

Table 1. Participant mean and standard deviation accuracy scores for each condition

Agency focus direction	Active			Passive		
	Double	Wide	Narrow	Double	Wide	Narrow
Mean (%)	74.38	77.81	84.69	78.75	84.06	85.63
Std. dev. (%)	19.40	17.22	19.95	13.48	17.05	19.48

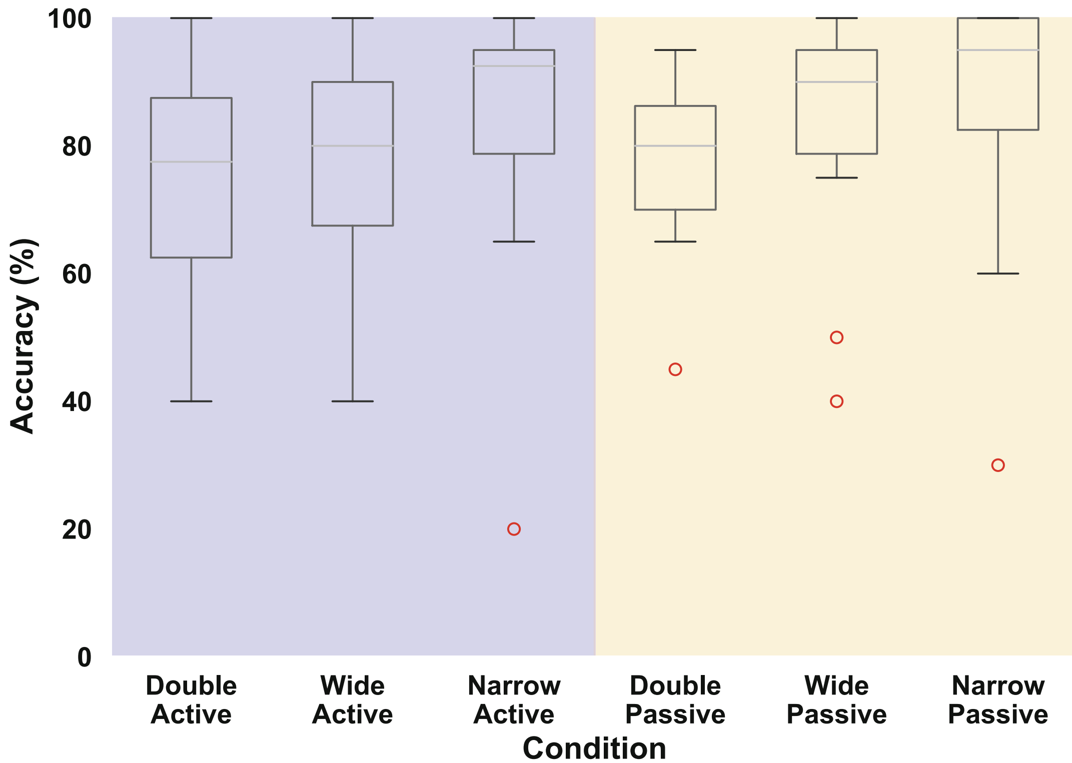

Fig. 2. Participant accuracy for each condition. On the left, the blue shaded region groups the three conditions with active agency and, on the right, the yellow shaded region groups the three conditions with passive agency. The labels double, wide, and narrow correspond to the double task conditions, the wide focus conditions, and the narrow focus conditions respectively. The red circles indicate a participant that varied by more than 3 standard deviations from the condition mean. (Color figure online)

4 Discussion

Results from this experiment confirm that there is a significant effect of focus direction and of agency on a participant's accuracy in perceiving a target tactile stimulus out of a randomly ordered sequence of five distraction stimuli and one target stimulus. This matches our expectations that the direction of participant focus on tactile stimuli and participant agency over tactile stimuli affect their ability to perceive the cue accurately. Contrary to our expectations however, the differences in accuracy between double, wide, and narrow focus and between active and passive agency were smaller than expected. After correction there were no significant differences in between condition groups, despite anecdotal increased confidence in the narrow focus conditions over the double focus conditions. Although between-group results were not shown to be significant in this initial investigation, these results suggest that between-group effects may exist for both focus direction and agency. Follow-up studies with a wider participant pool and designed to look more directly at focus direction and agency may show more granular differences between focus direction and agency groups.

5 Conclusion

We conducted a study to investigate the effect of focus direction and agency on participant accuracy in the perception of sequences of vibrotactile cues. Our experiment used a custom vibrotactile sleeve to deliver sequences of vibration stimuli to a user across six conditions that varied the direction of the participants' focus on and the participants' agency over each trial. Results from this experiment indicate focus direction and agency both have a significant effect on accuracy in perceiving a specific tactile stimulus out of a sequence. Further research is required to learn more comprehensively about specific differences in between levels of focus direction and levels of agency.

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