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Serial Dependence in Haptic Material Perception*

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I. Introduction

Haptic perception is an integral part of human life helping with critical decisions, e.g., determining whether a surface is smooth or cool enough to touch. Unlike typical experiments, our perceptions are not isolated in trials but unfold and adapt in time to form a continuous stream of experience. How we perceive a stimulus in the present is determined not only by the characteristics of the stimulus itself, but also shaped by our recent interactions [1]. This is reflected in *serial dependence* (SD); the tendency for perception to be influenced by previous perceptual experiences. SD has attracted significant attention in visual perception research yet remains underexplored in haptic perception.

A decade of research have shown that the perception of various visual features such as orientation [1], color [2], and faces is influenced by SD. This temporal dependence is characterized by a perceptual bias toward (*attraction*) or away (*repulsion*) from the stimulus presented in preceding trial(s). For instance, an oriented gabor patch is typically perceived as being tilted more to the left if the gabor in the previous trial was tilted to the left relative to the current one [1]. In this case, SD manifests as an *attractive* bias, meaning that current stimuli are judged to be more like previous stimuli than to the ground truth. In contrast, under certain conditions, a *repulsive* bias can occur, where current stimuli are perceived as more different from preceding ones (e.g.,[3]).

SD is not limited to low-level features but also occurs in emotion, across both visual and auditory modalities [4]. Specifically, valence and arousal ratings have been found to be biased toward previous stimuli (*attraction*). Together, SD seems to be a general mechanism of perception acting on different senses and contributes to the processing of both low-level (i.e., physical parameters) and high-level (i.e., emotions) information. However, thus far, none of the studies investigated SD with active touch – haptics (see [5] for a tactile study). An intriguing question is whether SD occurs during active haptic exploration in our surroundings.

The primary goal of this study is to test whether SD exists in haptic perception, particularly in pleasantness and roughness. As SD is involved in processing both low- and high-level information, another goal of the study is to test whether the SD is grounded in the perceived object or the task at hand. To this end, we selected seven sandpapers in varying grit sizes, as they provide a controlled range of roughness. Participants completed two blocks where they judged the roughness or pleasantness of the same stimuli on two separate days. During the experiment, they rubbed each stimulus with their right index finger and rated its pleasantness or roughness, depending on the block.

II. Methods

A. Participants

30 naïve individuals participated in the experiment (10 males, M_{age} = 24.867, SD = 4.09, age range = 20-36). Participants did not report any sensory or motor impairments. Prior to the experiment, they provided a written informed consent, following the guidelines of the Declaration of Helsinki except preregistration. Participants compensated with 8€/hour or course credit for their time.

B. Stimuli and apparatus

The stimuli consisted of seven sandpapers in grit sizes of 40, 60, 120, 240, 320, 600, and 1000 (425, 269, 125, 58.5, 46.2, 25.8, and 18.3 microns respectively) were used. All stimuli were mounted on a 10 cm × 10 cm wooden block, covering the wood. The stimuli were presented on a plate holding a stimulus to avoid any movement and to keep the distance between participant and the stimuli constant. Participants sat at a table on which the plate was placed. An experimenter sat next to the participant to exchange the stimulus. Since sandpapers could change their structure through repeated exposure, they were replaced with new samples for every six participants.

The pleasantness and roughness of the stimuli was measured with a scale ranging from 0 to 100 (pleasantness: 0 – *very unpleasant*, 100 – *very pleasant*; roughness: 0 – *not at all*, 100 – *very*). Participants could respond with any positive number within this range including decimals. Potential auditory cues were blocked by headphones and visual cues were blocked by an occluder. The experiment was programmed in MATLAB 2022a (MathWorks Inc., 2007) using Psychtoolbox routines. A monitor was used to present instructions and a numpad to collect responses.

C. Design and procedure

The experiment employed a within-participants design with two conditions: roughness and pleasantness. In both conditions, upon providing a written informed consent, participants received the instructions, set at a table, and wore headphones. During the experiment, in each trial, participants rubbed the randomly presented sandpaper samples for 3 seconds, signaled by two beep sounds. After

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the exploration, they rated how pleasant or rough the material felt. Each condition consisted of 168 trials (7 sandpapers × 24 repetitions). The order of the blocks was randomized and took place on different days. The total duration of each block was approximately 45 minutes including instructions and breaks.

D. Data analysis

We first logarithmically scaled the roughness since roughness of our stimuli increases exponentially. This resulted in a loglinear relationship between perceptual ratings and roughness. Conventionally, SD is estimated by calculating the perceptual error in trials as a function of the stimulus difference between those and the trials one before. Since there can be no ground truth rating for pleasantness or roughness, we calculated response biases relative to the rated stimuli. For each participant, we normalized ratings by dividing each stimulus by their maximum rating for that stimulus, scaling values to [0,1]. Next, we plotted the response bias per trial as a function of roughness difference from the preceding trial. For instance, in Fig. 1, the participant shows a repulsive SD, indicated by a negative correlation between roughness bias and roughness difference. SD strength was quantified as the slope of the best fitting linear function.

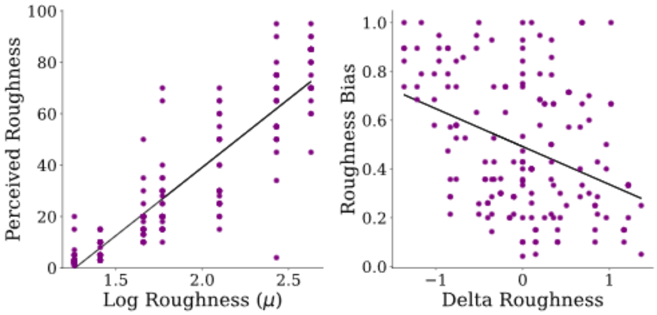

Figure 1. Example participant data showing perceived roughness as a function of grit size (A), and roughness bias as a function of roughness difference from the previous trial (B).

III. Results

To test if SD exists in haptic roughness and pleasantness judgments, we calculated the bias in roughness and pleasantness ratings as a function of roughness difference between stimuli in the currently rated and the previous trials. We estimated the strength of SD from the slope of the best-fitting linear function (Fig. 1). A slope of 1 would indicate a perfect attractive SD, as the rating would increase when the stimulus in the previous trial was rougher. Conversely, a slope of 0 would indicate that participants rated stimuli without any influence from the previous trial. To test the existence of SD in roughness and pleasantness judgments, we conducted one-sample t-tests comparing the estimated slopes against 0. We found a significant repulsive SD for roughness ($t(29)=-9.687$, $p < 0.001$) and attractive SD for pleasantness judgments ($t(29)=3.028$, $p = 0.005$). Next, to test whether SD is unique to the task or perceived object, we compared the SDs for pleasantness and roughness judgments using a paired-samples t-test. We found that the slopes for pleasantness and roughness were significantly different ($t(29) = 6.028$, $p < 0.001$), suggesting different SDs for different tasks of the same objects.

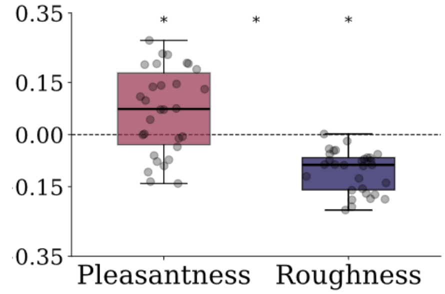

Figure 2. Strength of serial dependence for roughness and pleasantness judgments. Asterixis show significant differences.Circles correspond to invidual participants.

IV. Discussion

In tactile domain, SD has been observed in vibrotaction [5]. However, to the best of our knowledge, the current work – together with unpublished studies from our lab – is among the first to investigate SD in humans within the haptic modality. In current work, we found repulsive SD for roughness and attractive SD for pleasantness. In other words, the perception of roughness was biased away from the previous stimulus, indicating a contrast effect, whereas the perception of pleasantness was biased towards the previous stimuli, indicating assimilation.

Our results also suggest that the SD is not grounded in the object but is unique to the task at hand. In line with this, a previous study on face perception found an attractive effect on gender but repulsive effect on expression judgments for the same stimuli set [3]. Similarly, a previous study on visual orientation found SD even when the task involved judging oriented dot clouds and gabors in interleaved trials [6]. Overall, task-specific nature of SD in haptics might suggest that SD is not a low-level sensory phenomenon bound to physical stimulus properties, but rather a flexible, higher-order mechanism.

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