The human perception of transient frictional modulation

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Abstract. The frictional forces that we experience while exploring and manipulating everyday objects and textures around us has been repeatedly shown to be a crucial component of our tactile perception. In this study, we take advantage of transient pulses of ultrasonic vibration with stabilized amplitude delivered in controlled passive touch condition to study the human perception of subtle frictional cues. Our results show that humans are able to perceive very small transient changes in friction modulation. On average, the threshold corresponded to an 8% change in friction relative to baseline. However, thresholds differed by up to a factor three across participants.

Keywords: psychophysics, ultrasonic lubrication, tactile perception, friction

1 Introduction

A more realistic haptic feedback will be implemented in new generation tactile devices. A high fidelity technique for tactile rendering is yet to be developed, and the request for this technique is ever-growing. Different approaches are available to produce tactile sensations on a user fingertip. Among them there is the modulation of the friction of an active surface for a sliding finger. Finger position tracking mechanism allows the generation of a spatio-temporal relationship leading to the generation of texture [1]. The modulation involves ultrasonic vibrations to reduce the sliding friction between the contacting finger pad and the display [2]. The effectiveness of the principle to modulate friction is not in doubt and has been preliminary estimated in a recent study [3], but a precise study on the influence of various parameter on the perception and friction modulation of this device has never been performed. This is essential to understand the technological requirements to provide an effective stimulation to the users and to test the validity of different proposed mechanisms. In this paper, the influence of amplitude of vibration and nature of explored surface to the human perception threshold will be investigated in controlled experimental conditions.

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2 Materials and Methods

Data were first collected from 12 healthy volunteers aged between 27 and 53. Gaussian white noise was played at a comfortable listening level through headsets in order to mask auditory cues.

We used a full custom robotic platform designed to apply a controlled stimuli to the fingertip in passive touch condition similar to the one presented in [4]. The subject's index finger was fixed in a support that maintains a constant angle of approximately 20° between the finger and the stimulating plate, which is a typical angle adopted during grasping and tactile exploration. An ATI Nano 43 (ATI, USA) load cell was mounted on the robot and served for controlling the normal force applied by the robot as well as for recording the interfacial forces occurring during the presentation of the stimuli against the fingertip.

The friction was modulated with a novel tactile display integrated with the acquisition and control chain of the robot. The display is based on a modified version of the STIMTAC [5], where the full body of stimulator has been modified to be mounted on the force sensor of the robot and the vibration amplitude of the device was controlled in closed loop. The implemented control ensures the stability of the vibration with a resolution of 50 nm with different surfaces glued and a vibration rise time of 1.5 ms. For this study, three materials were used at the skin-plate interface in separate blocks: the bare aluminum plate of the device, a glued polypropylene (PP) sheet and a glued polyurethane (PU) sheet. These materials were chosen to investigate the effect of different frictional properties of the materials on the participant's capacity to sense the modulation of the tangential force. Aluminum (hydrophilic) and PP (hydrophobic) have similar dynamic coefficients of dynamic friction (CF) but differ by their bonding of water molecules while PU has typically a higher CF and is hydrophobic.

The study was made in passive touch conditions. The robotic platform was programmed to deliver a precise stimulation of the fingertip. The stimulation consisted in a sliding of 5 cm at a speed of 2.0 cm/s and with a constant force of 0.7 N against the fingertip of the right index finger, which was kept at the precise same location by the finger holder of the robotic platform. For each trial, the platform performed two consecutive sliding against the finger. In one of the slidings (randomly chosen), ultrasonic vibrations were displayed for two intervals of 100ms, which were programmed to precisely start at 22 mm and 25 mm of sliding (See Figure 1). Participants had to perform a forced-choice task to find out which of the slidings contained the signal. The stimulation levels were 0.1, 0.2, 0.3, 0.5, 0.7 µm and each of them were pseudo-randomized and presented 10 times within a 50 trials long session. The 75% just noticeable difference (jnd) was then computed by fitting a logistic psychometric function to the proportion of correct response compared to the level of stimulation. The fitting was done using the PALAMEDES toolbox [6]. The relative reduction of friction was computed for each trial by comparing the ratio between the tangential force (TF) averaged over the 100 ms preceding the start of each of the two ultrasonic pulses and the corresponding averaged TF over following interval with reduced friction. Since NF was kept constant, this measure reflected also the relative decrease in the coefficient of dynamic friction.

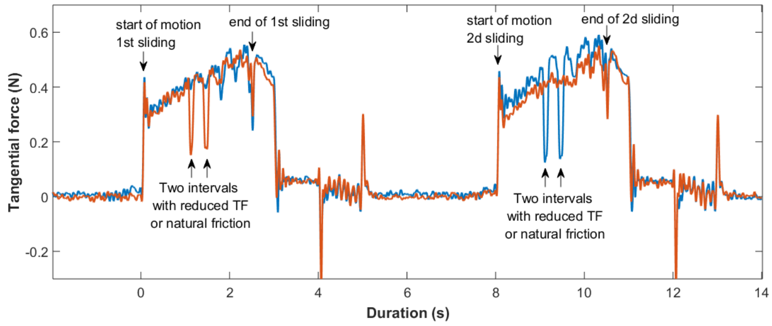

Fig. 1. Participants performed a forced-choice task in which they had to decide which of two consecutive trials contained the transient change in friction. The tactile display slided against the finger twice per trial. The transient reduction of tangential force, which participants had to detect, was applied either in the first sliding (red trace) or in the second one (blue trace).

3 Preliminary results

3.1 The 75% just noticeable difference of the amplitude of vibration

For each of the three materials used in the experiment, we evaluated the 75% jnd for all participants in order to obtain an estimate of the human ability to perceive applied modulations of friction. We first computed the mean thresholds for each material separately and found out the average a 75% jnd for the amplitudes of ultrasonic vibration to be respectively 0.24 ± 0.15 µm, 0.27 ± 0.09 µm and 0.31 ± 0.11 µm (mean ± s.d.) for the aluminium, polypropylene and polyurethane (See Figure 2). We then ran a non-parametric 1-way ANOVA test between the three different conditions justified by the non-normal distribution of the thresholds. Surprisingly, despite the different properties of the three materials, the thresholds did not differ depending on the interfacial material (Friedman test: $\chi^2 = 3.957$, $p = 0.14$).

3.2 Computing the relative reduction of TF at the threshold

We then mapped the amplitude of vibration at the threshold to the corresponding relative reduction of tangential force. The value of the relative reduction of friction at the threshold vibration amplitude was obtained by intercepting it with the actual reduction of TF obtained by linear interpolation of the average reduction of TF recorded for the nearest levels of vibration up and down the threshold value.

The results show that, at the threshold, the percentage of the TF's relative reduction is 8.4 ± 6 % for aluminum, 6.9 ± 4.1 % for polypropylene and 8.0 ± 4.6 % for polyurethane.

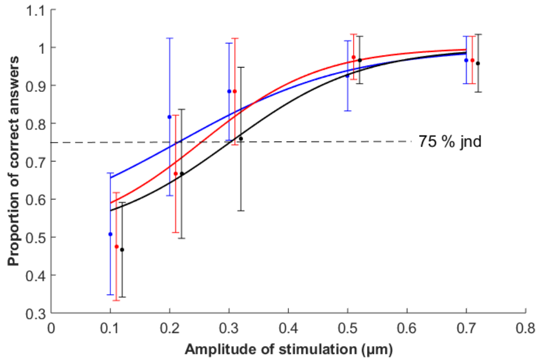

Fig. 2. Psychometric curves and corresponding error bars for aluminum (blue), polypropylene (red) and polyurethane (black) fitted to the proportion of correct answers for each stimulation level (mean ± s.d.). The error bars are slightly shifted for better visibility.

4 Conclusion

Although it is known that the frictional properties of surfaces are well perceived during tactile exploration [7], very little is known about the minimal modulation of friction necessary to elicit a difference in tactile perception.

In this study, participants demonstrated an extremely fine discrimination of ultrasonically induced transient frictional cues with different surface materials. A mean discrimination of the 8% of the frictional value was perceived by the users.

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