Short Papers

On the Correlation Between Tactile Stimulation and Pleasantness

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***Abstract*—Several studies in the affective haptics research field showed the potential of using haptic technology to convey emotions in remote communications. In this context, it is of interest to simplify the haptic feedback without altering the informative content of the stimulus, with a two-fold advantage. On one side, it would allow the development of affective haptic devices whose technological complexity is limited, hence more compatible with wearability and portability requirements. On the other side, having a simplified set of stimuli would decrease the amount of data to be transmitted, thus improving the overall quality of remote haptic interactions. In this work, we investigated the correlation between the parameters regulating a caress-like stimulation and the perceived pleasantness. This was done by means of two experiments, in which we asked subjects to adjust the temperature and the motion velocity of a set of stimuli in order to find the most pleasant combination. Results indicated that subjects preferred different values of temperature and velocity of the stimulus depending on the proposed tactile stimulation. A small difference in the pleasantness ratings was observed between caresses provided with linear movements and those given as discrete sequences of taps. In particular, participants preferred linear movements set at $34.5\,^\circ\mathrm{C}$ and $3.4\,\mathrm{cms}^{-1}$. As regards caress-like stimuli provided with discrete sequences of taps, the preferred temperature and velocity were $33.2\,^\circ\mathrm{C}$ and $2.9\,\mathrm{cms}^{-1}$, respectively. The presence of vibration had a little effect on the perceived pleasantness.**

***Index Terms*—Haptic rendering, perception and psychophysics, social communication.**

I. INTRODUCTION

Haptics plays a central role for communicating and understanding the emotional state of other people in social, affective, and intimate relationships [1], [2], [3]. In face-to-face conversation, non-verbal haptic communication is the most profound and direct way of interaction [4], and its meaning is highly dependent on personal, environmental, and contextual factors [5], [6]. Social acceptance of the different types of contact is influenced by the relationship among people involved in the interaction, personality traits, and cultural background [7]. When the communication is mediated by haptic technology, the ability to truthfully convey the emotional aspects of social and affective touch is critical for enhancing the feeling of presence.

In recent years, and even more after the outbreak of the COVID pandemic, there was an increasing interest in mediated social and affective touch for interpersonal interaction at a distance [8]. Today, the challenges of using haptic technology for social touch are well known amongst the scientific community [9]. The employment of haptic technology for detecting, displaying and communicating feelings is referred to as affective haptics [10], and comprises three research fields: affective computing, haptic interfaces, and user experience. Affective computing investigates methods to observe, detect, elicit, and communicate emotions [11]. Haptic interfaces enable the communication of touch, which can be either mono or bidirectional depending on whether the interaction happens with a remote human participant or with a virtual social agent. Finally, user experience tests how adding the haptic layer enhances emotional immersion and the overall quality of the user experience.

Affective haptics involves the three somatosensory channels of touch, i.e. tactile signals, thermal sensations, and kinesthesia [10]. Due to the complexity of touch, an effort has been made to devise methods to simplify the haptic feedback while keeping the informative content of the stimulus. As a result, mediated affective touch is less sensorially rich than actual affective touch, and its effects occur mostly because the haptic feedback is attributed to either another person in a remote location or to an artificial social actor [9].

Among the haptic sensations that can be delivered in the context of mediated affective touch, caress-like stimuli have received a considerable attention. From a sociological point of view, of all emotional social signals a caress from another person is one of the most powerful interactions [12]. Slow motion stimuli like a caress recruit a special class of unmyelinated sensory fibers known as C-tactile afferents (CTs), that are possibly conveying information to the insular cortex along the spinothalamic tract [2]. CT fibers innervate the hairy skin, and their conduction velocity varies between 0.6 and 1.3 m/s, i.e. about 50 times slower than the $A\beta$ myelinated afferents responsible for discriminative and sensorimotor functions of touch [2]. Recently, CTs with characteristics comparable with those in hairy arm skin were found also in the glabrous skin with a relatively low density [13], but their role has still to be investigated. CTs respond to different tactile stimulations, but they are vigorously activated by gentle stroking touch characterized by very low indentation forces in the range 0.3–2.5 mN [14] at typical skin temperature [15]. As reported in [15], CTs fibers respond more vigorously to slow stroking stimuli delivered at the skin temperature as compared

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to hotter or colder cues. These functional properties of CT afferents are in accordance with the hypothesis that the CT system represents a "second touch system" with a specific affective-emotional role [2], [16]. According to this hypothesis, the CT system provides emotional, hormonal, and behavioural responses to affective and pleasant touch, particularly if related to direct skin-to-skin contact between individuals [17]. Moreover, as a further support to CTs role, the stimulation of the CTs in a unique patient lacking myelinated afferent fibers produced an activation of the insular region, but not of somatosensory areas S1 and S2 that are normally activated by discriminative touch [18]. Based on all these evidences, several studies have sought to find the stimulation that best simulates the human caress and evokes the same pleasant sensation. Several stimuli that differed for the used tools, the velocity of the stimulation, the type of tapping [19], the level of force [20], the temperatures [15], and the association with visual stimuli [21] were tested.

In parallel with these results, various technological devices have been developed for the purpose of creating portable systems to stimulate affective touch. These include a scarf [22], a vest [23], a jacket [24], and a sleeve [25]. In [26], the authors examined the affective response to vibrations for a hand held device.

To create a stroking sensation, a variety of actuation techniques have been used. The most widespread consists in directly stimulating the skin using lateral motion [27], [28], [29], [30]. However, stroke length is limited in these direct stimulation devices, typically from $1\,\mathrm{mm}$ to $2\,\mathrm{cm}$. Moreover, as recently reported by Nunez et al. in [31], generating long stroking sensations using lateral stimulation require complex actuation and mechanical design which would likely result in a heavy and bulky device. As an alternative, one research group created a stroking sensation using an air jet [32]. Similarly, this is difficult to implement into a wearable device because it requires access to compressed air.

These limitations have led researchers to create the illusion of motion across the skin using devices equipped with multiple actuators placed in fixed positions on the arm and activated sequentially, rather than relying on a single moving actuator. Numerous studies have explored the use of vibration [33], [34], investigating its potential in generating stroking sensations [26], [35], [36]. In fact, to generate vibrotactile sensations is by far the simplest and most used method of providing haptic feedback in wearable devices [37], mainly because of the ubiquity of actuators and their ease of integration into devices. Huisman and colleagues used an array of 4 vibratory motors on the ventral side of the participant's lower arm to stimulate a stroking sensation [35]. A similar device was created by Israr and colleagues using 6 voice coil vibrotactile tactors on the participant's forearm [36]. In both experiments, the stimulation was rated as pleasant and similar to a caress. Recent studies have demonstrated the generation of a stroking sensation on the arm using only normal force [38]. An example of wearable device able to perform skin indentation to simulate a stroking sensation using a matrix of linear actuators is in [39].

These studies open the possibility of developing wearable devices able to convey emotions or feelings of closeness at a distance through the sense of touch exploiting a simplified set of stimuli. However, vibrations alone do not realistically display the signals used in social touch, thus we decided to combine three different cues (i.e., vibration, pressure, and temperature) to create the best mixture for delivering affective touch.

To the best of our knowledge, the interaction between tapping, vibrations, and temperature has not been systematically investigated yet. Thus, this article aims to address this gap by proposing a careful comparison of different haptic stimuli to identify the best combination for generating a pleasant, caress-like sensation. These results could provide the guidelines to simplify the tactile stimulation in wearable haptics technology while still maintaining the pleasantness of a caress, not only in the interaction between remote human subjects, but also in the human-robot communication domain.

Fig. 1. Participant is using the graphical user interface to tune the temperature of the end-effector while his right forearm is stimulated. To avoid biases in the stimuli evaluation, the participant wears a headset providing white noise, and the cardboard panel prevents him from seeing his forearm during the stimulation.

II. METHODS

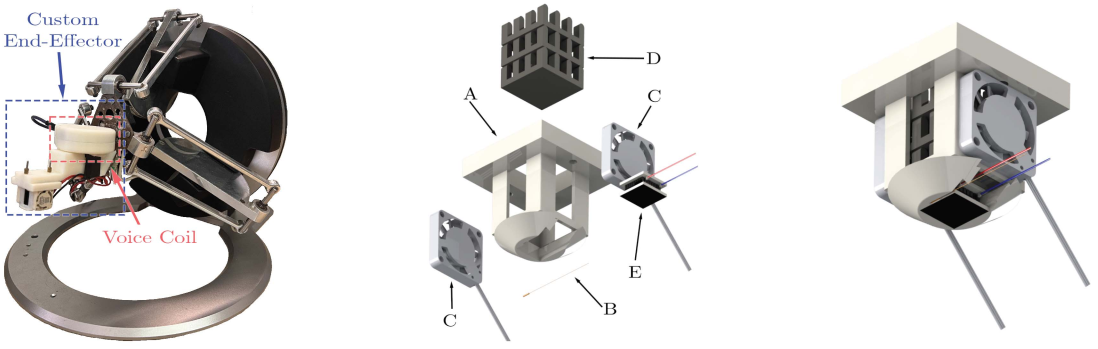
The aim of this study was to investigate the interaction between temperature, vibration, and type of motion to deliver a pleasant stimulus resembling a caress. To this end, we used the method of adjustment [40] and asked participants to find the most pleasant sensation by tuning a set of parameters considered meaningful for the stimulus at hand.

A. Participants

Overall, 27 naïve participants took part in two experiments. The sample size was 14 in the first experiment (7 males and 7 females, average age ± SD: 26.7 ± 3.2), and 13 in the second (6 males and 7 females, average age ± SD: 28.1 ± 2.9). Each participant gave their written informed consent to participate and was able to discontinue participation at any time during the experiments. The experimental evaluation protocols followed the declaration of Helsinki. Data were recorded in conformity with the European General Data Protection Regulation 2016/679, stored on local repositories with anonymized identities (i.e., User1, User2), and used only for the post processing evaluation procedure. No sensitive data were recorded.

B. Experimental Setup

The experimental setup consisted of an Omega.3 haptic device (Force Dimension, CH) with a custom end-effector (see Fig. 2(a)). The Omega.3 has a delta-based parallel kinematics structure with active gravity compensation providing up to $12\,\mathrm{N}$ 3D active force, and a positioning resolution less then $0.01\,\mathrm{mm}$. The haptic interface can be actuated by controlling position, velocity, and applied force of the end effector thanks to the Force Dimension SDK. Taking advantage of this feature, the device was programmed for providing the two kinds of caress-like stimuli examined in this work, that is continuous motion (linear) and tapping (rabbit). The two stimuli are detailed in Section II-C.



(a) (b) (c)

Fig. 2. Haptic interface adopted to stimulate the participants' forearm. In a), the Omega.3 haptic device with a custom end-effector. In b), the exploded view of the terminal part of the end-effector detailing all the embedded components: a 3D printed support (A), the temperature sensor (B), two fans (C), the heat sink (D), and the Peltier Cell (E). In c), the assembled view of the terminal part of the end-effector.

The end-effector was ad-hoc designed for the purpose of this work, and 3D printed in ABS. The rendered images are reported in Fig. 2(b) and (c). The structure embeds two different actuators, i.e. a voice coil (vibro-transducer Vp210, operational frequency range of 20-15000 Hz, Acouve Laboratory, Inc., JP) and a Peltier TEC module (ET-007-10-15, $8 \times 8 \times 3.8$ mm, Adaptive, U.K.), three heatsinks (BGA-STD-015, $14 \times 14 \times 10$ mm, ABL Aluminium Components Ltd, GB), two fans (UF3C3-500TC, $12 \times 12 \times 3$ mm, Sunonwealth Electric Machine Industry Co., Ltd., TW), and an NTC thermistor (GAG22K7MCD419, diameter 0.38 mm, temperature range 0 °C to +70 °C, TE Connectivity, CH). When in contact, the tip of the end effector stimulates a circular area on the skin with a diameter of 10 mm.

The voice coil was driven by an audio amplifier (Lepai LP2020A+, Parts Express, USA). The desired vibratory cue (a sinusoidal wave with a frequency of 30 Hz) was generated using the sound card of the PC. For what concerns the TEC module, the desired temperature was guaranteed using a PI controller. A data acquisition (DAQ) system (USB-6218, National Instruments, USA) was used to actuate the Peltier Cell and acquire data from the temperature sensor. Thanks to its tiny dimension, it was possible to place the sensor on the lateral side of the ceramic substrate instead of on the cell surface, making it unobtrusive and imperceptible by the participants during the stimulation. An ad-hoc electronic circuit was in charge of powering the Peltier TEC module and switching the polarity of the supply voltage to reverse the direction of the heat transfer across the two ceramic surfaces, exploiting the Peltier effect. The ceramic substrate of the thermal actuator placed inside the end-effector was arranged in contact with the heatsinks, and the fans were used to flow air inside the ABS structure and dissipate the heat generated by the TEC module.

The entire system was controlled by means of a custom software developed in LabVIEW (National Instruments, USA).

C. Experimental Protocol

Participants were comfortably sitting on an office chair and placed their right arm on a desk with the dorsal side the forearm facing up. White noise was provided by means of headsets during the experimental session to mask environmental sounds and noise generated by the setup. Visual feedback about the stimuli was prevented by placing a physical barrier (a cardboard panel) between the participant and their arm, so that they could not see their forearm during the stimulation. Participants were guided during the experiments by means of a graphical user interface (GUI) developed in LabVIEW and presented on a PC monitor placed in front of the participant. A picture of a participant during the experiment is reported in Fig. 1.

TABLE I
LATIN SQUARES CONTROLLING THE SEQUENCE OF THE EXPERIMENTAL CONDITIONS PROPOSED TO EACH SUBJECT

User	**1^{st} trial**	**2^{nd} trial**	**3^{rd} trial**	**4^{th} trial**
$\text{User}_{i\%4}$	Linear Without Vibration	Linear With Vibration	Rabbit Without Vibration	Rabbit With Vibration
$\text{User}_{i\%4+1}$	Linear With Vibration	Rabbit Without Vibration	Rabbit With Vibration	Linear Without Vibration
$\text{User}_{i\%4+2}$	Rabbit Without Vibration	Rabbit With Vibration	Linear Without Vibration	Linear With Vibration
$\text{User}_{i\%4+3}$	Rabbit With Vibration	Linear Without Vibration	Linear With Vibration	Rabbit Without Vibration

The subscript i denotes the i-th participant, with $i \in [1, 14]$ and $i \in [1, 13]$ for the first and the second experiment, respectively.

By using the customized version of the Omega.3 haptic interface described in Section II-B and illustrated in Fig. 2, we generated two types of motion stimuli: a continuous stroke (linear motion stimulus) and a discrete sequence of taps (rabbit stimulus). The two stimuli were applied to the hairy skin of the forearm of the participant. In both stimulus types, linear and rabbit, the distance between the starting position and the ending position of the stimulus was 15 cm, while the force applied by the haptic interface at the contact point was 0.3 N. Such force value was selected for having an optimal activation of CT afferents [14]. The experimenter verified that the range of motion of the end-effector was entirely in the forearm of the participants.

The two stimuli were presented with and without vibration of the end-effector. The vibration frequency was set at 30 Hz as, in accordance with [36], low-frequency tactile stimulations are considered more pleasant than high-frequency tactile stimulations. As a result, each experimental session consisted of four conditions tested in four blocks: linear without vibration, linear with vibration, rabbit without vibration, and rabbit with vibration. Each condition consisted of 12 trials, of which six trials started the stimulation from the elbow and the other six from the wrist, in random order. The sequence of the four blocks was counterbalanced across the participants using the *'Latin squares'* showed in Table I. A resting period of 5 minutes was provided between different blocks.

A similar experimental procedure was tested in two experiments. In the first experiment, the velocity of the stimulus was fixed and the participant changed the temperature at the contact point, while in the second experiment the velocity was changed by the participants and the temperature fixed. Hence, in each experiment there were four possible trial initial conditions from the combination between two factors: starting temperature ($18\,^{\circ}\mathrm{C}$ or $42\,^{\circ}\mathrm{C}$) and starting point (wrist side or elbow side) in Experiment 1, and starting velocity ($1\,\mathrm{cms}^{-1}$ or $5\,\mathrm{cms}^{-1}$) and starting point (wrist side or elbow side) in Experiment 2. Each combination was presented three times in random order, for a total of 12 trials per condition, that is 48 trials per experiment. Each experiment lasted about one hour. Meaningful data were logged with a rate of 100 Hz so that the entire experiment could be played back for the purposes of the analysis. Details about each of the two experiments are provided in the two paragraphs below.

D. Experiment 1: Temperature

In all trials, the stimulation velocity was fixed and equal to $3\,\mathrm{cms}^{-1}$, in accordance with [35]. In particular, in the linear modality this velocity coincided with the end-effector linear velocity tangential to the forearm of the participants. For what concerns the rabbit modality, the end-effector tapped the forearm of the participants 5 times with fixed distance between taps equal to $3\,\mathrm{cm}$. The duration of each tap was $100\,\mathrm{m}s$, and the elapsed time between two different taps was $1\,s$ corresponding to a stimulus lateral speed of $3\,\mathrm{cms}^{-1}$.

The starting temperature was $18\,^{\circ}\mathrm{C}$ for half of the trials and $42\,^{\circ}\mathrm{C}$ for the other half, randomly selected. The temperature range upper bound was chosen not to harm the participants [41].

In each trial, the participant was tasked to maximize the pleasantness of the stimulus by adjusting the temperature of the end effector using the GUI. By means of two digital buttons they could augment or decrease the temperature with steps of $1\,^{\circ}\mathrm{C}$, and the temperature change was applied in real time manner while the movement of the end-effector was looping. There was no time limit during the trial, and the participant could change the temperature as many times as needed in order to find the most pleasant stimulation. At the end of each trial, participants were asked to rate the pleasantness of the stimulation on a Visual Analog Scale (VAS) from 1 (low pleasantness) to 10 (high pleasantness). This was done using the same graphical user interface exploited for changing the temperature.

E. Experiment 2: Velocity

In the second experiment, the temperature of the end-effector was fixed and equal to $34\,^{\circ}\mathrm{C}$, i.e. equal to the mean final temperature ($33.84\,^{\circ}\mathrm{C} \pm 3.69\,^{\circ}\mathrm{C}$) computed among the 672 trials (14 participants, 48 trials each) of the previous experiment, regardless the experimental condition. This time, participants were asked to adjust the velocity of the end-effector to increase the pleasantness of the stimulus as much as possible.

For each experimental condition, half of the trials had a starting speed of $1\,\mathrm{cms}^{-1}$, while the others had a starting speed of $5\,\mathrm{cms}^{-1}$, randomly selected. These speeds correspond also to the minimum and maximum stimulation velocities achievable during the trials.

Participants were asked to increase and reduce the end-effector velocity with a step of $0.5\,\mathrm{cms}^{-1}$ using two digital buttons implemented in the GUI to maximize the pleasantness of the stimulus. The velocity changes were applied in real time manner while the movement was looping. There were neither time nor number of velocity changes limits. Once the participants confirmed the final end-effector velocity, they were asked to rate the pleasantness of the stimulation on a VAS scale ranging from 1 (low pleasantness) to 10 (high pleasantness) using the GUI.

III. RESULTS

We used the Linear Mixed Models (LMM) [42] to perform the analysis. For the first experiment, we analyzed whether the stimulation modality (linear/rabbit) or the presence of vibration predicted the selected temperature and pleasantness rating. The same analyses were performed for the second experiment, setting the selected velocity and the rating as a dependent variable. The R package lem4 was used for LMM fitting to the data [43]. The statistical power of the analysis was computed using the R package mixedpower [44]. In Experiment 1, with $N = 10$ the statistical power was $> 80\%$ for both temperature and rating responses (rabbit vs linear effect). In Experiment 2, with $N = 10$ the statistical power was $> 90\%$ for both temperature and rating responses (rabbit vs linear effect).

A. Experiment 1: Temperature

The first experiment was aimed at finding the temperature perceived as most pleasant by the participants at varying experimental condition. For each trial, final temperature, pleasantness rating, and experimental condition were considered for the analysis.

Results showed a statistically significant effect of the type of stimulation on the final temperature ($\beta = -1.22$, $t = -5.22$, $p < 0.001$), while the effect of the vibration was not statistically significant. In particular, participants preferred a temperature significantly lower in the rabbit stimulation ($33.22 \pm 3.98\ ^{\circ}\mathrm{C}$) than in the linear one ($34.45 \pm 3.26\ ^{\circ}\mathrm{C}$). Final temperatures at varying experimental conditions are reported in a boxplot representation in Fig. 3(a).

As regards the pleasantness rating, there was a statistically significant dependence of perceived pleasantness on type of stimulation ($\beta = -1.07$, $t = -18.30$, $p < 0.001$) and presence of vibration ($\beta = 0.13$, $t = 2.16$, $p < 0.05$). On average, the linear stimulus was found more pleasant than the rabbit one (7.46 ± 0.76 and 6.39 ± 1.02 for linear and rabbit, respectively). Similarly, the presence of vibration was rated slightly more pleasant (6.99 ± 1.03) with respect to having no vibration (6.86 ± 1.06). Pleasantness ratings at varying experimental conditions are reported in a boxplot representation in Fig. 3(b).

B. Experiment 2: Velocity

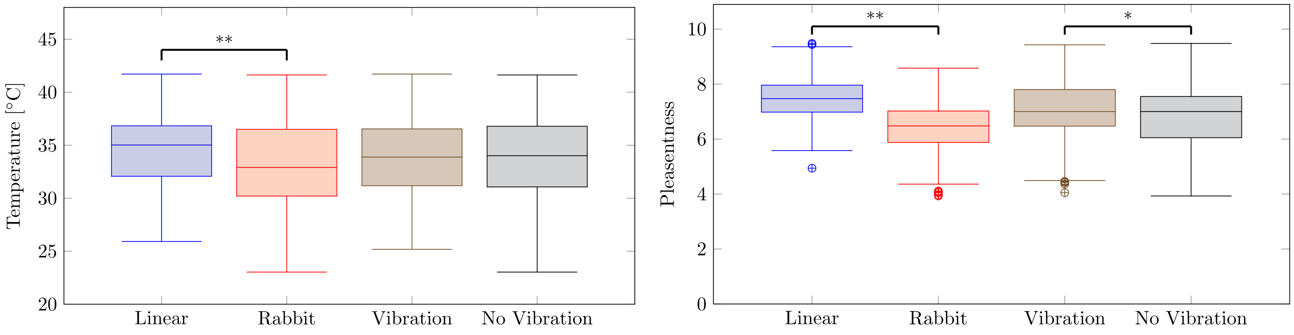
Final end-effector velocity, pleasantness rating, and experimental condition of each trial were considered for the analysis.

As regards the final end-effector velocity, the LMM showed a significant dependence for the modality ($\beta = -0.005$, $t = -7.37$, $p < 0.001$), and no effect for the presence of vibration. The mean selected velocity among the users in the linear modality was slightly higher ($3.40 \pm 1.10\ \mathrm{cms}^{-1}$) than for the rabbit modality ($2.91 \pm 0.72\ \mathrm{cms}^{-1}$). Results are depicted in Fig. 4(a).

Similarly, when considering the pleasantness rating as dependent variable, results of the LMM analysis showed a significant effect for the modality ($\beta = -0.34$, $t = -7.85$, $p < 0.001$), and no effect for the presence of vibration. The linear modality (7.35 ± 1.00) was rated more pleasant than the rabbit one (7.00 ± 0.95). Outcomes of the experiment are visually reported in Fig. 4(b).

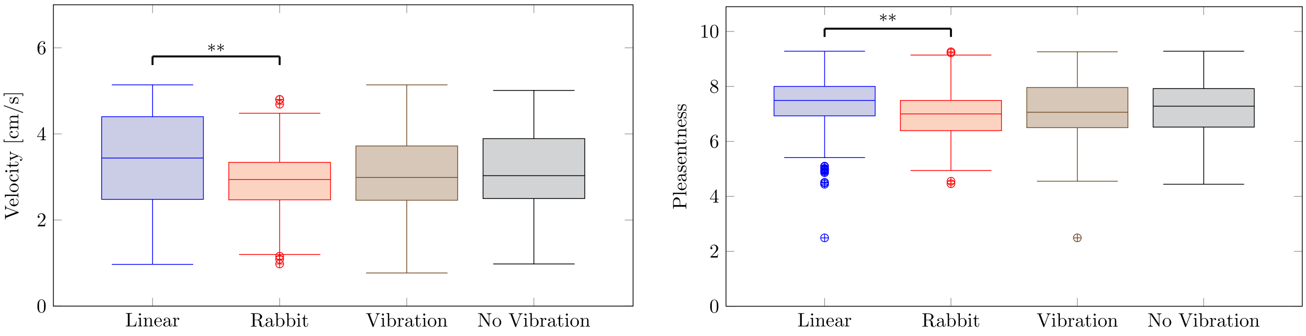
IV. DISCUSSION

Results were consistent across the two experiments. In the first experiment, the velocity of the end-effector was set at $3\,\mathrm{cms}^{-1}$ and participants adjusted the temperature. Although the mean selected



(a) (b)

Fig. 3. Results of Experiment 1. In a), results showed a statistically significant effect of the type of stimulation (Linear vs Rabbit) on the selected temperature, while the effect of the vibration was not statistically significant. In b), outcomes revealed a statistically significant dependence of perceived pleasantness on type of stimulation and presence of vibration. The asterisk (*) and (**) indicate the statistical significance $p < 0.05$ and $p < 0.001$, respectively.



(a) (b)

Fig. 4. Results of Experiment 2. In a), results showed a statistically significant dependence from the type of stimulation (Linear vs Rabbit) of the selected velocity, while the effect of the vibration was not statistically significant. In b), outcomes revealed a statistically significant dependence of perceived pleasantness on type of stimulation and presence, and no effect for the presence of vibration. The asterisk (*) indicates the statistical significance $p < 0.05$.

temperature among all the trials ($33.8\,^{\circ}\mathrm{C}$) was in line with existing literature [45], a lower temperature was preferred in the rabbit condition. We found this significant difference between the two modalities also in the pleasantness rating, as the rabbit modality was found less pleasant than the linear stimulation. Regarding the vibration, the stimulation with vibration was rated as more pleasant than the one without vibration. In the second experiment we set the temperature of the end-effector at $34\,^{\circ}\mathrm{C}$ using the results of the first experiment, and participants had to adjust the stimulation velocity. The mean of the selected velocity among all the trials was equal to $3.2\,\mathrm{cm\,s^{-1}}$, but on average the rabbit condition was set on slower velocity. Like in the first experiment, the rabbit condition was also found as less pleasant than the linear stimulation. Concerning the vibration, a trend with a more pleasant rating for the presence of vibration was found, but this result was not statistically significant.

To sum up, the rabbit modality was set slower and at a lower temperature than the linear modality. About the vibration, our experiments highlighted a small effect on the pleasantness of the stimulation. The results of both experiments agree with the literature about the CT fibers, which pointed out their role in response to caress-like stimuli [2]. Indeed, these fibers respond better to stimuli with a temperature similar to the body temperature and a velocity around $3\,\mathrm{cm\,s^{-1}}$. When they are stimulated with such a stimulus, a participative sense of pleasure is elicited in the person. Given the score of the pleasantness rating, in future work it will be interesting to evaluate whether the CT fibers were also active during the rabbit stimulation. This hypothesis could be confirmed using the microneurography technique during the rabbit stimulation.

The results on the pleasantness of the stimuli are promising in the aim of simplifying the technology complexity while still maintaining a good quality of the stimulus. Indeed, even though the linear stimulation was found more pleasant than the rabbit one in both experiments, the ratings were not markedly discriminating between the two modalities. This is especially true in Experiment 2, where linear and rabbit mean ratings were 7.35 ± 1.00 and 7.00 ± 0.95, respectively. It is worth mentioning that in this case the temperature was fixed at the mean favourite temperature of Experiment 1. On the contrary, in Experiment 1 there was a slight difference between the average favourite velocity retrieved from Experiment 2 (i.e., $3.20 \pm 0.93\ \mathrm{cm\,s^{-1}}$) and the one fixed for the experiment (i.e., $3\,\mathrm{cm\,s^{-1}}$), which could have influenced the perceived pleasantness of the stimulus. This hypothesis is strengthened by the lower ratings received by both modalities (7.46 ± 0.76 and 6.39 ± 1.02 for linear and rabbit, respectively) and their greater variability with respect to those of Experiment 2.

A possible speculation on the findings that a rabbit motion requires a slightly lower temperature and velocity of movement to maximize pleasantness is related to the underlying physical phenomena that regulate heat flow. Following our results, two main factors, namely velocity and temperature of the stimulus, contribute to the pleasant sensation, while vibration does not elicit statistical significant difference. In particular, the preferred average temperatures of the end effector are 34.5 $^\circ$C and 33.2 $^\circ$C for the linear and rabbit cases, respectively, while the preferred average velocities are 3.4 cms^{-1} for the linear motion and 2.9 cms^{-1} for the rabbit one. For both modalities, preferred temperatures are lower than body temperature, potentially indicating a heat flow from the forearm to the Peltier cell. This may suggest that the level of pleasantness could be associated with the amount of heat removed from the skin. Consequently, let us consider the rate of heat flow, which represents the amount of heat transferred per unit of time between the end-effector and the forearm. The formula for the rate of heat flow is given by Fourier's law:

$$\frac{Q}{\Delta t} = -kA\frac{\Delta T}{\Delta x}.$$

Let Q be the net heat transfer, ΔT the temperature difference between the arm and the end-effector, Δt the time taken, Δx the thickness of the conductive material, k the thermal conductivity, and A the surface area of the contact. Since k, A, and Δx are the same for both modalities, we can rewrite the relation as

$$Q = \alpha \Delta t \Delta T$$

being $\alpha = \frac{-kA}{\Delta x}$. Thus, to have the same Q (transferred heat) in a lower amount of time (rabbit case) it is necessary to have bigger ΔT (i.e., tune the Peltier cell at a lower temperature). At the same time, a slower movement allows for more contact time with the end-effector, promoting greater heat dissipation from the skin, and consequently, a higher level of pleasantness. Certainly, this hypothesis necessitates validation through a subsequent experiment involving the measurement of skin temperature. The potential outcomes of these experiments could also be analyzed in light of the results presented in [46].

Another aspect worth mentioning when discussing the difference between pleasantness ratings is the inherent difference between the linear and rabbit stimuli. With linear motion, a larger area of the skin is stimulated, leading to the activation of more mechanoreceptors. This difference in the extent of stimulation could have contributed to eliciting different responses between the two stimuli.

V. CONCLUSION

Nowadays haptic technology is not only a matter of digital touch realism, but also a novel opportunity to emotionally engage people in remote interactions. This second aspect relates to the affective haptics research field, which investigates the ability of a haptic stimuli to communicate emotions, and requires researchers to develop systems that can detect, display, and elicit affects. In addition, there is a great interest in understanding whether the richness of the haptic stimuli can be reduced without losing their effectiveness, especially because the generation of complex haptic signals typically requires devices with high technology complexity. On the contrary, affective haptic devices are often designed to be worn by users [10], and devices with low complexity are more likely to comply with wearability and portability requirements. Moreover, reducing the richness of the stimuli is also important to enhance the synchronisation of audio and video signals with haptic information [47], towards an envisioned communications network with latency low enough to enable perceptually "real-time" interactions (i.e., less than 1 ms latency) [48]. Such communication speed will improve the overall quality of haptic communication solutions [49], as the increase of fidelity of the haptic sensation can cause rejection if it is not rendered in concordance with other sensory feedback [50].

For all the aforementioned reasons, in this work we investigated how a caress-like stimulus provided with haptic technology should be adjusted (in terms of temperature and velocity) to obtain a comparable pleasant sensation when the stimulus is simplified from a continuous movement (linear) to a discrete sequence of taps (rabbit). Based on our knowledge, this was the first study on affective haptics in which participants adjusted the stimulation as they preferred. Indeed, in similar studies reported in literature the parameters were set and kept constant throughout the whole experiment.

Results of our experimental campaign pointed out that, among the proposed caress-like stimuli, participants preferred linear movements set at $34.5\,^\circ\mathrm{C}$ and $3.4\,\mathrm{cms}^{-1}$. Anyway, a small decrease in the pleasantness ratings was observed for caress-like stimuli provided with discrete sequences of taps at $33.2\,^\circ\mathrm{C}$ and $2.9\,\mathrm{cms}^{-1}$. The presence of vibration had a little effect on the pleasantness ratings. These outcomes highlight the significance of selecting optimal parameters for different haptic stimuli to achieve similar perception of pleasantness.

To conclude, our results provide the guidelines to scale down the technological complexity of affective haptics devices without altering the pleasantness of caress-like sensations. The experimental setup we have developed within this study is versatile and adaptable, allowing for the examination of different types of stimuli and their effects on eliciting a wide range of emotions. For instance, future studies can explore different meanings-in-context of touches (e.g., support, affection), diverse gestures (e.g., squeezing, patting), and a broader range of emotions (e.g., anger, fear) to establish a more general protocol allowing effective simplification of haptic signals. Finally, the authors acknowledge that preferred feedback in affective haptics applications is highly subjective. Therefore, the presented findings should consider various factors, including gender, body part, and the interaction of other stimuli (visual/auditory). In future research, we plan to conduct additional studies that specifically focus on exploring differences related to gender and body parts.

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