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Comparing the Psychophysical Capabilities on Fingertip and Wrist using Method of Adjustment*

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***Abstract*— Haptic technology, which refers to creating the sense of touch artificially, offers a crucial source of communication between humans and computers or machines. While conventional haptic devices are designed to render vibrotactile information on the fingertip, recent trends in the field expand the tactile communication to other body locations, like the wrist. Even though the literature has many successful applications showing the validity of such haptic applications, there is no study comparing the user perception for meaningful virtual or teleoperated task scenarios due to the lack of calibration methods between alternative body locations. In this paper, we attempt to compare the perceived intensities at the fingertip and the wrist through psychophysical experiments and to answer: (i) Is there a perpetual difference between the haptic stimuli on the wrist compared to the fingertip? (ii) Is possible to form a reasonable, linear relationship (or a pattern) between the stimuli rendered at the fingertip and the wrist? (iii) If so, do different users require different relationships that would need to be obtained through calibration? We designed a user study with 13 healthy participants, receiving three levels of haptic stimuli at their fingertips while adjusting the intensities of the stimuli rendered at their wrist using the method of adjustments. Our results indicate that there is a linear pattern between the vibrotactile stimuli rendered at the fingertip and the wrist, and each participant exhibits a different pattern. Our results can be used to equalize the perceived intensities of different forms of tactile stimuli for future research investigating the perceived performance under different haptic scenarios.**

Keywords*— *Psychophysics, Haptics, Absolute Threshold, Just Noticeable Difference

I. INTRODUCTION

Vibrotactile haptic devices directly interact with the skin surface and render an artificial sense of touch, which can be used for teleoperation tasks [1], Virtual Reality (VR) interactions [2], or even more generic human-computer interaction [3]. They have many advantages, such as their compact and lightweight design, availability in the market, versatility, and low latency. The literature has many examples of vibrotactile actuators designed to render useful and rich haptic information to the user in the form of haptic displays [4] (e.g., smartphones), holdable haptic devices [5] (e.g., gamepads and joysticks), or wearable devices [6]. While both devices have certain advantages, wearable devices become prominent for allowing for a more precise and effective interaction, portability, ability to move naturally, and ability to provide continuous interactions.

Compared to the other body locations, fingertips, fingers, and hands have the highest density of mechanoreceptors [7, 8]. This leads the hapticists and designers to create haptic devices to render feedback on these locations as well [6, 8, 9]. While wearable fingertip devices can be quite useful, they also have certain drawbacks. For example, the limited available space and the variability of the anatomical sizes of the fingers and fingertips might challenge the designers to place and secure the actuators robustly. In addition, haptic devices interacting with the hands and fingers can easily be integrated with VR applications, where users are completely isolated from the environment around them and are not expected to interact with real objects. On the other hand, Mixed Reality (MR) systems do not isolate the users from the real environment. In fact, users are still encouraged to interact with real tools or objects while interacting with virtual entities in the meantime. This can only be possible by leaving the hands and fingers free from haptic devices; thus, fingertip devices cannot be integrated with MR systems.

As a potential solution, it is possible to use the forearm or the wrist to mount wearable vibrotactile devices and take advantage of unused skin locations [10]. The wrist is an attractive location that leaves the hand unencumbered and provides more area for actuation and stimulation. Wrists have been used as locations for haptic communication in event-based notification cues (e.g., in smartwatches and fitness trackers) [11, 12], non-visual haptic guidance [13-15], social interactions [16-18] meditation/healthcare [19], or VR interactions [20-22]. These applications use the wrist as a location to create a new communication channel.

Independent research studies show the efficacy of rendering haptic feedback during different applications on the fingertips and on the wrist [23]. Despite the potential of rendering haptic information on the wrist, the quality of haptic information rendered through the wrist compared to the fingertips is still unknown. However, it is crucial to compare the perceptual, performance, and user experience capabilities of both body locations for haptic rendering to make fully informed design choices. The biggest reason why

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the literature still lacks such comparative research is the lack of understanding of how to equalize the perceived stimuli rendered on different body locations.

In this paper, we aim to explore the capabilities of using psychophysical methods to create equal perceived intensities between vibrotactile feedback rendered on the fingertips and the wrist. Implementing a classical psychophysical method, we seek answers to the questions:

- *Are there perceptual differences in how participants perceive haptic stimuli on the wrist compared to the fingertip? (RQ1)*
- *Can we obtain an average linear model between the stimuli rendered at the fingertip and the wrist? (RQ2), and*
- *Is this linear model between the stimuli rendered at the wrist and the fingertip consistent and non-subjective?* (RQ3)

If this research is deemed to be successful, (i) the proposed methods in this research could potentially be implemented as a future calibration method, which allows users to feel different stimuli to be comparable such that the perceptual differences of both body locations can be investigated more objectively. Also, (ii) this method will be a model for haptic rendering research for VR/AR interactions.

The rest of this paper goes as follows: Section II presents the classical psychophysical methods, Section III describes the experimental setup, Section IV discusses the results, Section V provides the discussion and future work, and Section VI concludes the paper.

II. CLASSICAL PSYCHOPHYSICAL METHODS

Psychophysics employs three general techniques to ascertain the human thresholds of their perception: identification, detection, and discrimination. Identification entails a person's capacity to classify stimuli without explicitly referencing them [24]. On the other hand, measuring the sensory thresholds of stimulus perception is a necessary step in detection and discrimination. The literature has two common concepts of research: the absolute threshold and the differential threshold.

The absolute threshold is the bare minimum of stimulation needed for a person to detect a signal or triggered sensation [25]. If comparisons are to be made between experiments, the experimental conditions under which the absolute threshold is measured for most sensory systems must be clearly described [26]. Therefore, the absolute threshold measures change in variables in which a user/participant can just barely detect the intensity.

The difference threshold is the smallest difference in a stimulus that a person can notice. It refers to the smallest intensity difference between a changeable comparison stimulus and a constant standard stimulus needed to cause a just noticeable difference (JND). Also known as Differenz Limen, the difference threshold addresses sensations across the whole stimulus range to which the participants may respond. The differential threshold is in some ways more practically useful than the absolute threshold [27]. Classical approaches for tracking thresholds can be studied with psychophysical methods. With these methods, we can create psychometric curves to detect a stimulus (absolute threshold) or to distinguish between two stimuli (difference threshold) [26].

One very recurring topic is the possibility of connecting these three perception techniques (whether to obtain absolute or difference thresholds) in which stimuli are scaled according to their apparent magnitude and intensity to form a law that would guide psychophysical research [28, 29]. In this research, participants are generally given two stimuli either consecutively or simultaneously, one rendered as a reference stimulus and the other rendered as a controlled (adjusted) stimulus. In an experimental setting, participants are given the reference stimulus and are asked to adjust the controlled stimulus until it feels "as intense" as the reference one. The literature has three common psychophysical methods that differ from each other based on how the participants can tune the controller stimulus: method of limits, method of constant stimuli, and method of adjustments.

A. Method of Limits

The method of limits is used to evaluate the absolute thresholds – especially since it is efficient and time-effective [25]. The method is presented in three ways, it first requires an extreme value that is easily identified, a level that has yet to be discovered, and then numerous levels between the method of limits. The participants are asked to detect the absence or presence of the stimulus (i.e., perceived sensation) as they are presented with a stimulus in ascending or descending order well above or below the reference threshold. For the method of limits, multiple ascending and descending series would be performed to bias the consistencies caused by the human factor. The reported levels of barely detected stimulus intensities as a response to ascending and descending series are averaged to form the perceived absolute threshold [26, 27].

Even though the method of limits was originally created to obtain absolute thresholds, they can also be adjusted to obtain different thresholds as well. In this scenario, the method of limits can determine the difference threshold using two consecutive stimuli, such as two lights flashing one after the other. One stimulus is defined as a reference, whose intensity remains constant through the investigation while the other stimulus is adjusted compared to the reference. This comparison stimulus is provided either in descending order, which is initially more substantial than the standard stimulus, or in ascending order, which is initially weaker [30]. The time period when the individual cannot detect any difference is used to compute the differential threshold. Errors of habit and anticipation are two sorts of errors that are connected to the method of limits.

B. Method of Constant Stimuli

The method of constant stimuli is possibly the most popular standard experimental technique for determining absolute and differential thresholds. In this method, the experimenter selects five to nine equally spaced stimuli presented randomly based on earlier explorations; typically 20 trials per stimulus [31]. When stimuli are presented in ascending or descending order, this method lessens expectation errors that come from human perception of specific scenarios. In an experiment, the experimenter records observations of whether or not the stimulus was noticed after each presentation. This is essential to determine both the absolute and difference threshold peradventure, the stimulus intensity was higher or lower than a standard.

The difference between the method of constant stimuli and the method of limits is that this method is more accurate than the method of limits. However, it is not efficient in terms of the time consumption.

C. *Method of Adjustments*

As compared with the other methods, here, the participants are allowed to adjust the intensity of a stimulus until it is barely noticeable (i.e., JND). Although absolute thresholds can be measured, the adjustment approach has primarily been employed to measure differential thresholds [30]. It is considered to be one of the most widely used methods thanks to its capability to measure physical stimulus over a wide range with a straightforward interpretation and speed [32, 33].

Similar to the other methods, participants are asked to adjust the intensity of a controlled stimulus until its intensity is perceived to be equal to the reference stimulus. While the other methods allow participants to adjust the controlled stimulus in pre-determined quantities, the method of adjustment offers them the full liberty to alter the stimulus by moving a slider or turning a knob. In this method, experimenters are often interested in the deviation from the participants' observation compared to the standard stimulus [25]. The cumulative responses from participants are then used to plot a psychometric curve. From this curve, the experimenter can deduce a specific point where an observer can perceive two stimuli, i.e., the standard and comparison stimuli, as the same. This point is called the point of subject equality (PSE), which is used mostly to understand the perception of participants.

D. *Comparisons between Psychophysical Methods*

Despite discussing the three methods, each psychophysical method has its unique strength fit for various research and experiments. For a particular type of experiment, a particular method might be more appropriate than another method based on the specific user study requirement of the experiment. Selecting the appropriate method can be crucial for an experimenter as it will help optimize the experimental design for accurate and reliable results. For example, the method of constant stimuli is more appropriate for measuring the visual detection threshold of light flashes at different intensities [34], while the method of limits is more suited for experiments that require rapid determination of sensory thresholds like determining the hearing threshold of sound intensity [35]. Also, the method of adjustment is best suited for when an experimenter needs participants to match stimuli like interocular matching [36] or haptic feedback matching.

Since our research is focused on matching haptic feedback from the wrist to that of the fingertip, the most suitable method is the method of adjustment as it is one of the quickest and most straightforward when it comes to matching problems. The success of any psychophysical method usually hinges on the little details, such as participants receiving additional feedback from the visual display (approaching the limits of the range for the controlled stimulus). These are pivotal decisions that are specific to each participant [33].

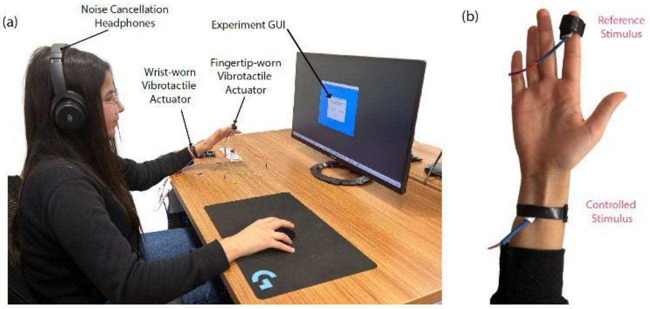


Figure 1. Experiment setup: (a) A participant wears the fingertip-worn and wrist-worn haptic bands, each consisting of a vibrotactile actuator and a noise cancellation headphone while interacting with the GUI. (b) A detailed view of the fingertip-worn haptic band rendering the reference stimulus and the wrist-worn vibrotactile actuator rendering the controlled stimulus.

III. EXPERIMENT SETUP

In this paper, our motivation is to explore the ability to perform psychophysical experiments to obtain the PSEs for the haptic stimuli rendered on users' wrists compared to the reference stimuli rendered on their fingertips. We are investigating whether or not (i) a linear model can be obtained between the two forms of haptic stimuli to be used for future VR interaction-based research, and (ii) the same model can be extended for any possible participant or should be personalized for each participant through a calibration phase, similar to the previous work [20]. For this study, we select three reference intensity levels (i.e., 0.3, 0.4, and 0.5) to capture a broad range of data points to obtain a linear relationship between the reference stimuli and the participants' perpetual response. From this linear relationship, we can successfully predict the point of subjective equality for any given intensity level. Figure 1 (a) shows the experiment setup designed for a user study. In this setup, participants wore two haptic bands, one at their dominant index fingertips and one for their dominant wrists. Each band secured a vibrotactile actuator at the fingertip and the ventral side of the wrist. A microcontroller unit triggered the actuators and received commands from the main computer. In this computer, a Graphical User Interface (GUI) allowed the participants to interact with the rendered stimuli and to adjust the intensity of the controlled stimulus, which was rendered on the wrist. They were asked to wear noise cancellation headphones to minimize the environmental noise and the actuator's varying sound, which may influence their choices.

A. *Hardware Design: Fingertip-Worn and Wrist-Worn Haptic Bands*

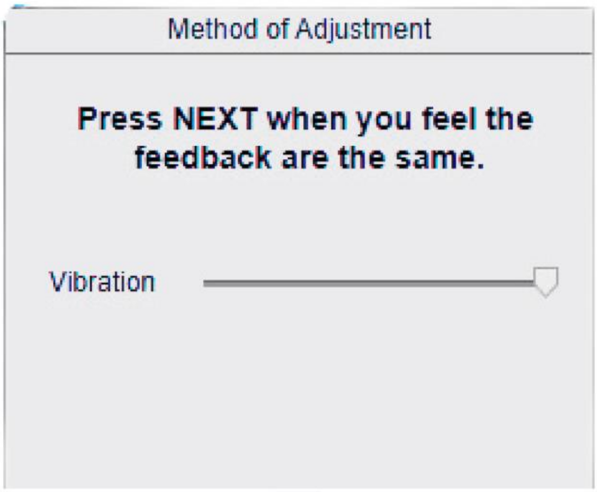
Figure 1 (b) shows a user wearing both fingertip-worn and wrist-worn haptic bands based on a Velcro strip. Each band holds a vibrotactile actuator on the designated body location, whether it is at the center of the fingertip of the dominant index finger or at the ventral side of the wrist right above the wrist bone. ERM (Eccentric Rotating Mass) actuators were chosen due to their low cost, easy drivability, and output sensation rendered on users' skin. Each vibrotactile actuator was attached to the Velcro strip band through smaller Velcro pieces glued on the actuator so that the stimuli locations could be adjusted at the exact required location around the wrist and on the fingertip.

Generic ERM actuators are used to comply with the 5V input-output levels of the microcontroller board. Since the rendered signals vary across ERM actuators sold by different manufacturers, the selected actuators were tested for identical current draw and internal resistance. Since the power requirement was measured to be within the output power specification of the microcontroller board, no motor driver was used. The microcontroller board was connected to a desktop PC with a USB cable. Communication between the microcontroller board and the host desktop PC was established via Universal Asynchronous Receive and Transmit (UART) protocol at a baud rate of 115200 baud.

An Arduino Mega 2560 microcontroller board with Atmel ATmega 2560 was used to control ERM actuators and communicate with a host PC. 490Hz Pulse Width Modulation (PWM) capable pins of the controller board were utilized to adjust the feedback intensity of the ERM devices by varying the duty cycle of the signals applied to the actuators. Although the controller board offers 980Hz PWM outputs for two pins, we utilized the 490Hz pins to have consistency between the actuators. In this case, consistency is prioritized over potentially faster dynamic response to reduce possible perceptual bias.

B. *Software Design: Graphical User Interface (GUI)*

A desktop PC was utilized for conducting the experiment which included data collection, calculation, and transmission of parameters related to rendered haptic stimuli to the microcontroller board. Figure 2 shows the Graphical User Interface (GUI) created using MATLAB's App Designer[1], a tool specifically designed for developing professional applications. The GUI was designed to interact with two vibrotactile actuators connected to an Arduino Mega for communication, as commanded by the participants.



Method of Adjustment

Press NEXT when you feel the feedback are the same.

Figure 2. Graphical User Interface (GUI) for the method of adjustments. Participants are asked to tune the intensity of the controlled stimuli by moving the slider until it reaches the same intensity perceived at the fingertip.

For this experiment, we selected the method of adjustment based on efficiency as it requires few trials and flexibility – especially because participants can easily adjust the intensity of the controlled stimulus compared to other methods. The interaction GUI in Figure 2 was specifically tailored for the Method of Adjustments in which each trial rendered a constant reference stimulus at the fingertip, and participants were asked to use a slider to adjust the intensity of the controlled stimulus rendered at the wrist. They were allowed to move right and left (i.e., increase and decrease the intensity of the controlled stimulus) until they felt confident that both stimuli provided the same intensity levels. Both reference and controlled stimuli were rendered simultaneously. The trial was terminated when participants pressed "Next".

C. *Experiment Procedure*

Upon arrival, participants were given an overview of the study and asked to complete a demographic survey. The experimenter helped them wear the fingertip-worn, wrist-worn haptic bands with vibrotactile actuators and the noise cancellation headphones, as displayed in Fig. 1. We designed a two-factor experiment protocol with one factor as the initial intensity level for the controlled signal (i.e., from max to down and from zero to up) and one factor as the reference intensity level (i.e., 0.3, 0.4, and 0.5). Ultimately, we had 6 different conditions, each repeated 5 times – leading to a total of 30 trials. The conditions were offered to the participants as a block with a counterbalanced order. For the experiment, 5-10 minute breaks were given to avoid fatigue. During all trials, the reference stimuli were rendered at the fingertip while the participants were asked to adjust the stimuli at the wrist accordingly. As participants interacted with the slider on the GUI, it instantly triggered the stimuli of both the fingertip and the wrist, with the fingertip receiving constant reference stimuli and the controlled stimuli of the wrist varying based on the movement of the slider for about 30 seconds.

D. *Participants*

A total of 13 participants (6 females and 7 males) participated in this study among university students, with ages ranging from 19 to 26 years (22.4 ± 2.2). 10 participants reported being right-handed, and 3 left-handed. Participants wore the vibrotactile actuators in Figure 1 (a) on their left hands/wrists while they interacted with the GUI using their right hand, regardless of their hand dominance by request. Only 4 participants reported actively using or having used a smartwatch with vibration feedback. All participants verbally confirmed that they did not suffer from any upper limb injuries, musculoskeletal issues, or neurological disorders in their medical history. Kadir Has University Review Board approved the experimental protocol, and all participants gave informed consent.

IV. RESULTS

During the experiments, we recorded the point of subjective equal intensities (i.e., PSEs) for the controlled stimuli at the wrist in response to the reference stimuli rendered at the fingertip. In addition, we asked participants to

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[1] https://www.mathworks.com/products/matlab/app-designer.html

report on their experience with haptic feedback acting on both locations.

A. Point of Subjective Equalities (PSEs)

We analyzed the PSEs in terms of the PWM signals rendered by the vibrotactile actuators on the wrist as a response to different levels of reference on the fingertips. Figure 3 shows the average PSEs in bar plots, where both axes express the PWM signals, indicating the intensity of the rendered feedback on both body locations (i.e., fingertip and wrist). We analyzed the results via two-way repeated measure of analysis of variance (RM-ANOVA) using SPSS to examine the two factors we used in our experiments: one factor being the effect of different reference intensities and the other factor being the direction of change initiated for the participants (from maximum to minimum and minimum to maximum).

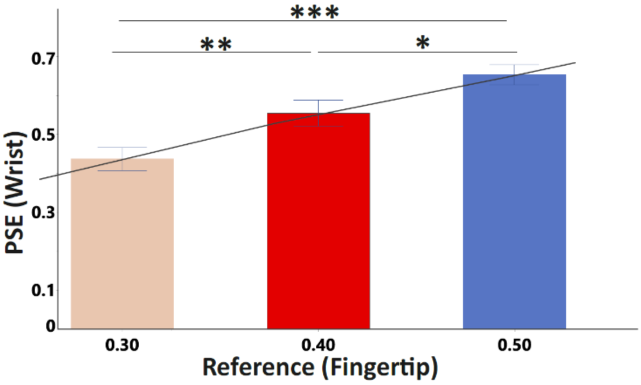

Figure 3. Average PSEs among all participants and all trials for the method of adjustments. Statistical significant reference values were indicated with stars for each method (* indicates p < 0.05, ** indicates p < 0.01, and *** indicates p < 0.001.)

Fig. 3 shows that an increase in the reference stimuli (i.e., 0.3, 0.4, 0.5) results in a solid increase in the intensity perceived (i.e., PSE). In fact, RM-ANOVA results (F(2,36)=13.787, p<0.001) indicate that the PSEs obtained from different intensity levels are statistically significantly different than each other. Table I summarizes further post-hoc analyses, which study the comparisons between each reference intensities. In particular, PSEs for each reference intensity were found to be more statistically significant than each other: average PSEs for reference intensity 0.3 is statistically the lowest while for reference intensity 0.4 is statistically the highest. These findings indicate that participants could successfully discriminate between the measured group thresholds.

TABLE I. POST HOC ANALYSIS BETWEEN GROUPS

	0.3	**0.4**	**0.5**
0.3	-	0.007	<0.001
0.4	0.007	-	0.022
0.5	<0.001	0.022	-

We also investigated differences among the individual models formed between the fingertip and the wrist stimuli intensities to be used for future user performance applications for other psychophysical methods. Figure 4 which shows the data obtained from each participant separately, and then their fitted line following a second order polynomial – to observe the trend of the data better. Our results indicate that the slopes (and the offset) of the linear model obtained for each participant are highly different than each other and from the average model.

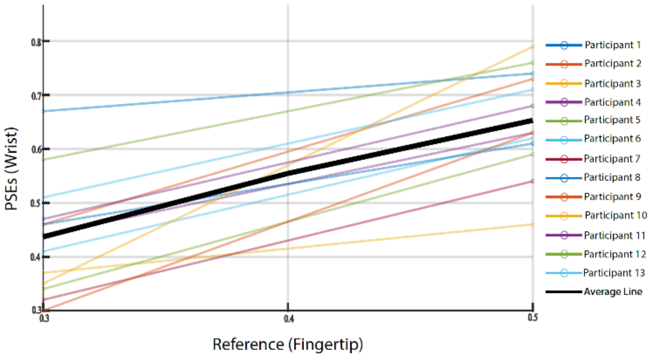

Figure 4. Fitted line between average data points collected from each participant using Method of Adjustments

B. Subjective Questionnaire

Participants also completed a post-experiment questionnaire on their experience and impressions. We specifically asked them about their impression of the psychophysical method. 10 participants reported that they enjoyed the experiment, further claiming "*It was easy to compare the vibrations with the adjustment.*" and "*It gives a more fluid response, making it easier for me to distinguish the separate vibrations*", while the other 3 participants believed that having great control over the stimuli would be easier because they can either increase and decrease it slowly at their pace.

We also asked participants to rate the task easiness and mental/physical fatigue from the experiment on a 7-point Likert scale. The Table II shows the summary of their ratings. Participants reported no serious mental or physical fatigue, indicating that they found the task relatively easy.

TABLE II. POST EXPERIMENT QUESTIONNAIRE RESULTS

	Method of Adjustment
Task Ease	4.8 ± 1.7
Mental Fatigue	2.5 ± 1.8
Physical Fatigue	1.7 ± 0.6

Finally, we asked participants to rate the pleasantness of the vibrotactile actuation they received on their fingers and wrists on a 7-point Likert scale. On average, their ratings were found to be equally pleasant when haptic feedback was rendered on the fingertips (4.3 ± 1.7) and on the wrist (4.3 ± 2.0).

V. DISCUSSION AND FUTURE WORKS

In this study, we employed one of the psychophysical methods, namely the method of adjustment, to assess participants' ability to compare vibrotactile feedback at the wrist (controlled) with constant haptic feedback at the fingertip (reference). We designed an experimental protocol that provides simultaneous feedback at both the fingertip and wrist, allowing us to investigate the perceptual capabilities of participants. Participants' subjective feedback through post-experimental questions indicated a great admiration for the method in terms of task ease with a moderate level of mental fatigue and a lower level of physical fatigue.

Fig. 3 shows that PSEs perceived on the wrist are statistically significantly different than the reference intensities perceived on the fingertip, as expected. Our findings suggest that participants perceive stimuli rendered on the fingertip and wrist statistically differently but can still compare them. From the results, participants performed well in discriminating simultaneous varying vibrotactile feedback at the wrist in comparison to constant reference haptic feedback given at the fingertip. The data obtained from the method of adjustment indicate significant differences between each reference group. This implies that the two body locations can be fairly compared in terms of participants' perceptual abilities and that there is a difference in participants' perception of the haptic feedback from the wrist compared to the fingertip. Based on these results, we can conclude our RQ1, stating that *there are perceptual differences in how participants perceive haptic stimuli on the wrist compared to the fingertip.*

Fig. 3 also indicates that the average PSEs can be modeled with a linear relationship between stimuli intensities rendered at the fingertip and the wrist. This hypothetical relationship line was calculated to have a slope of 0.11 and an offset. Going back to our original motivation, we could claim the following observations:

- On average, we can form a linear relationship between the pre-determined stimuli rendered at the fingertip and reported perceived intensities by the participants related to stimuli rendered at the wrist.
- The perceived change of stimuli intensities rendered at the wrist is slower than the change of stimuli intensities rendered at the fingertips. This observation aligns with the literature, claiming that the fingertip is a more sensible body location compared to the wrist [37].
- In addition, following the trend obtained by the linear relationship between the reference and PSE stimuli, we observe that the line does not pass from the origin. This might have two possible outcomes: firstly, an offset threshold is needed to render at the wrist, creating an equal perceived sensation as rendering no feedback at the fingertip. Secondly, by expanding this research to include more reference points to even lower reference intensity stimuli, we might find a region with a nonlinear relationship instead of a linear one. Future research should investigate the possible reasons behind this observed offset from the origin.

Regarding RQ2, these observations validate that an average linear model can be obtained between the stimuli rendered at the fingertips and the wrist. This model is crucial for future research investigating the perceptual differences of haptic rendering at the fingertips or the wrist in various VR/AR interactions. For example, if participants are expected to receive 0.35 stimulus intensity at the fingertip, we could estimate the expected levels of intensities for the stimulus to be rendered at the wrist – even if such information was not obtained empirically.

In response to our RQ3, we investigated the possibility of deriving a consistent non-subjective model and linear relationship between the vibrotactile stimuli on the fingertip and the wrist. From our results, we discovered participants demonstrated high performance in distinguishing the difference between the stimuli presented to the wrist (control) compared to the fingertip (reference). This psychophysical method yielded a linear model in comparing feedback between the fingertip and wrist, resulting in more consistent and reliable data Figure 4.

In addition, it is surprisingly promising that participants rated the pleasantness of haptic stimuli rendered at the fingertip and the wrist. It is possible that these comments are highly influenced by the fact that the stimuli rendered on both locations were very subtle and not excessive, uncomfortable, or unbalanced at all times during the experiment. In addition, we also speculate that at the point of equality in terms of the stimuli intensity, there might not be much difference between the stimuli rendered on both locations – once the participants get familiarized with the haptic sensation.

In future works, we intend to investigate these research questions further with other methods from the literature as well, e.g., the method of constant stimuli. While both methods investigate the same question, the differences between the adjustment methods might cause the obtained intensities to be statistically significantly different than each other. If so, whether or not these differences are actually perceived by users through user experience questionnaires is also unknown. In addition, we hope to investigate if there exists a linear relationship between these two methods by preparing a user study that would require using a vibrotactile device on the fingertip and the wrist concurrently. In our study, the 4 people who attested to have used a smartwatch performed well in discriminating the various vibrotactile feedback on the wrist compared to the fingertip. We believe that their experience in using a similar device on the wrist informed their performance. Hence, in the future, we will gather an equal amount of participants who are more familiar with using the smartwatch and those who are not and investigate whether there will be perpetual difference in their performance. Also, we will explore more insights based on hand dominance and how it can significantly increase performance.

VI. CONCLUSION

This study uses one of the psychophysical methods to compare perceived intensities at the fingertip and wrist, aiming to establish a linear relationship between these stimuli. Our results show that using the method of adjustment, there is a linear pattern between vibrotactile stimuli at the fingertip and wrist in terms of the fitted model and user experience. In the future, we will use the fitted model obtained using the Method of Adjustment to conduct user experiments in the VR environments to explore the perceptual differences they create in more complex and meaningful task settings.

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AUTHORS` CONTRIBUTIONS

All authors have participated in drafting the manuscript. All authors read and approved the final version of the manuscript.

CONFLICT OF INTEREST

The authors certify that there is no conflict of interest.

DATA AVAILABILITY

The data supporting the findings of this study are available upon request from the authors.

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