Humans Sensitivity Distribution in Perceptual Space by a Wearable Haptic Sleeve

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Abstract. Haptic perception plays a major role when vision and audition are partially or fully impaired. Therefore, this paper tries to give a brief overview on humans' sensitivity distribution in perceptual space. During our experiments, a wearable sleeve with 7 vibro-actuators was used to stimulate subjects arm to convey haptic feedback. The basic research questions in this study are: (1) whether humans' perception linearly correlated with the actuation frequency, haptic feedback in our scenario (2) humans' ability to generalise templates via the wearable haptic sleeve. Those findings would be useful to increase humans' perception when humans have to work with fully or partially impaired perception in their day-to-day life.

Keywords: Wearable devices · Haptics · Human-robot interactions
Humans' perceptual space

1 Introduction

According to the Statistical bulletin of national population projection in 2014, the UK population will be increased by 9.7 million over the next 25 years [1]. As the projected population and ageing over the coming years, it is very important think of how to uplift elderly people on daily life, perhaps to become more independent as well. Perception, cognition, and movement control are some of the main concerns of the age related issues when the aged population is grown [2]. When it comes to perceptions, haptics would be the best alternative to enhance their abilities in communication when visual and auditory are impaired fully or partially with ageing. Moreover, there are some situations people have to work in impaired perceptions like indoor fire-fighting, search and rescue, or noisy environments like a factory. In this scenario, having haptic feedback is important. Therefore, it is very important to understand humans' perception in haptic feedback. Haptics would be used to convey messages in some tasks to convey some spatial information when people are partially or fully impaired [3]. There have been some efforts that have been taken to enhance the elderly people daily activities. Some studies focused on effect of haptic supplementation by different methods to support posture stabilization in elderly people [4]. The results of this study concluded that haptic feedback enhances posture control to make them independent. A robotic walker was made to help the elderly people's walking in [5]. In this study, the robotic walker escorts the elderly people. Moreover, previous studies demonstrated that haptic

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perceptions would be the solution to guide humans in unfamiliar/uncertain environments [6–9]. Since haptic feedback has been widely used to convey messages to humans, it is important to understand how humans perceive the haptic feedback.

Vibro-actuators have been widely treated as a good communication equipment in haptic perception in different applications. As an example, the previous study on an active belt with wearable tactile display in [9] can be used to transmit information in multiple direction. In addition to that it can combine with a GPS directional sensor and 7 vibro-actuators. Moreover, there have been some studies on using vibro-tactile displays have showed that it can be used to improve the quality in many ways, for example devices for reading for people with less visual perceptions [10] or to provide haptic feedback of body tilt [11]. Furthermore, haptic feedback has been used in balance control, and postural stability [12, 13] in some studies in the past with some wearable devices. However, our attempt in this paper is to understand humans' arm perception when they wear a haptic sleeve with actuated micro vibrators. The results would give us ideas as to humans' sensitivity and their capabilities in perceptual space.

Amplitude was the most dominant way to convey the messages to humans in most of the haptic-based stimulation in the past [14–17]. However, our argument is that the frequency would be better for persistent perception in order to the nature of mechanoreceptors of the human skin.

This paper focuses on two different experiments. The experiment 1 was de- signed to understand humans' sensitivity distribution in perceptual space by using the wearable haptic sleeve. The experiment 2 was designed to understand humans ability to generalize haptic-based templates when they are trained.

The organization of this paper as follows. Section 2 discusses the experimental methodology to collect data of human participants while they wear the haptic sleeve and the different intensity patterns were played to understand humans' sensitivity and their ability to generalize templates. Section 3 shows the results of experiment 1 and 2. Finally, Sect. 4 presents a conclusion and future works.

2 Materials and Methods

In order to produce wearable haptic based pattern feedback the use of (Precision Microdrives) Pico Vibe 10 mm vibration motor – 3 mm type were used in order to produce a wearable haptic sleeve. In total the Haptic Sleeve consists 7 Pico Vibe 10 mm vibroactuators arranged in equal distance as shown in Fig. 1. In order for the device to be made wearable, the 7 Pico Vibe 10 mm vibroactuators are attached to seven velcro belts allowing the device to be adjusted in order to fit the arm size of the participant as shown in Fig. 1. The different intensities for the vibrations are generated by Genuino Mega 2560 motherboard, However in order to reach the desired and frequency needed to complete the experiment the amplitude is modulated using simple power amplifier circuit as shown in Fig. 1 [18].

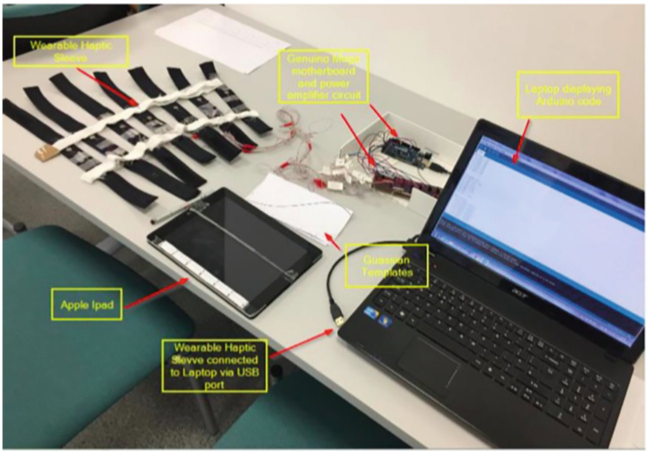

Fig. 1. Experimental Setup: A wearable vibro-tactile actuator arrays, here 7 Pico Vibe 10 mm vibro-actuator motors were attached to the belt. Arduino Mega motherboard was used to different amplitudes. The power amplifier circuit has been used to amplify the signal (amplitudes in here) [18].

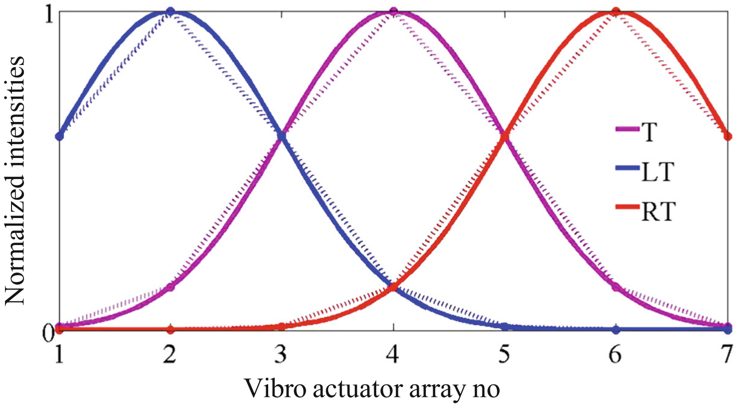

Fig. 2. The templates: The Gaussian Template (T), Gaussian shifted Left (LT), and Gaussian shifted Right (RT) are shown. The standard function $y = gaussmf\ (x,\ [sig,\ c])$ was used to generate the three different templates. the dashed lines shows the real intensities in experiment 2.

2.1 Haptic Primitives (Templates)

To generate templates, the standard Gaussian function was used. The templates were generated by standard MATLAB function called gaussmf ($y = gaussmf\ (x,\ [sig,\ c])$). The MATLAB programming language (The MATLAB Inc, MATLAB 2014b) was used during the analysis, where $sig = std$, and c is the centre of the distribution. The sig for pattern T, LT, and RT is 1.

2.2 Experimental Procedure

During all experiments the subjects was seated at a laboratory desk, with their arm outstretched resting on the desk for the duration of the experimental trails. The subject was required to wear a vibro-actuator belt containing the seven Vibro- actuators this is then adjusted to fit the arm using Velcro strapping. They are then subjected to Vibro-tactile stimulation with the requirement of drawing the intensity pattern after each trial. Each experiment has a duration of approximately one hour.

Experiment 1: Study Humans' Sensitivity Distribution. Eight subjects were recruited for experiment one in order to understand humans sensitivity distribution in perceptual space. The recruitment criteria stated that potential subject must be healthy and between the ages 18–50 years in order to participate in the study. Subjects were required to give their informed consent before any participation. Within those eight subjects both genders are represented equally. All subjects were required to wear the haptic sleeve containing 7 Vibro-actuators for the duration of the experiment. During the experiment, each subject was subjected to vibro tactile stimulation, in the form of a flat frequency pattern played across all seven Vibro-actuators. During each trial, all vibro-actuators vibrate simultaneously, with each trials lasting roughly ten to fifteen seconds. At the end of each trial the subjects were required to draw intensity pattern across using a drawing app on the Apple ipad (Draw free app (Apple Inc)). Raw data each subjects were then digitized using Getdata Graph Digitizer, all processing of Data and all statistical analysis was analysed by MATLAB 2014a.

Experiment 2: Study on How Humans Generalize Haptic-Based Patterns. Using the same experimental set up from Experiment 1, Experiment 2 was carried out to understand how humans generalize haptic-based patterns. Participants again were required to wear the haptic based pattern feedback sleeve. Throughout the duration of the experiment participants were asked to keep the arm stretched and resting on the desk. Three different intensity patterns were selected Standard Gaussian pattern (T), Gaussian pattern shifted to the left (LT), Gaussian pattern shifted to the right (RT), as shown in Fig. 2. The studies in humans' learning in movements showed that humans learnt through flexible combination of primitives that can be modelled using Gaussian like functions [19]. In this study focuses to explore whether human brain has primitive patterns that can be modelled using Gaussian like functions to represent haptic perceptions as well.

Since the experiment 2 independent from experiment 1, it was conducted with a different group ((4 - male, 4 - female), age between 24 to 26) from experiment 1. During the first fifteen trials, participants were shown the templates and the stimulation was given. Participants were only required to draw a smooth curve in order to represent their perception of each image, using an ipad drawing app. The three Gaussian patterns were played pseudo randomly. The drawing area participants was demarcated to match the size of the printed pattern template so that they would not try to scale the image. This was explained to all participants at the start of each experiment.

3 Results

3.1 Experiment 1

The raw data from experiment 1 for the flat frequency distribution is shown in Fig. 3A for a selected subject. In general, subjects were able to draw the played intensities as shown in Fig. 3A. Subjects were able to distinguish between the 200 Hz and 300 stimulus Hz as shown in Fig. 3A. Interesting, perception frequency is linearly increased with the actuation frequency as shown in Fig. 3B. It would be nice to study a wider range of actuation frequencies. However, due to the technical limitation of the vibro-actuators and humans' most desirable perception frequencies, the perception frequencies was limited to 200 Hz and 300 Hz.

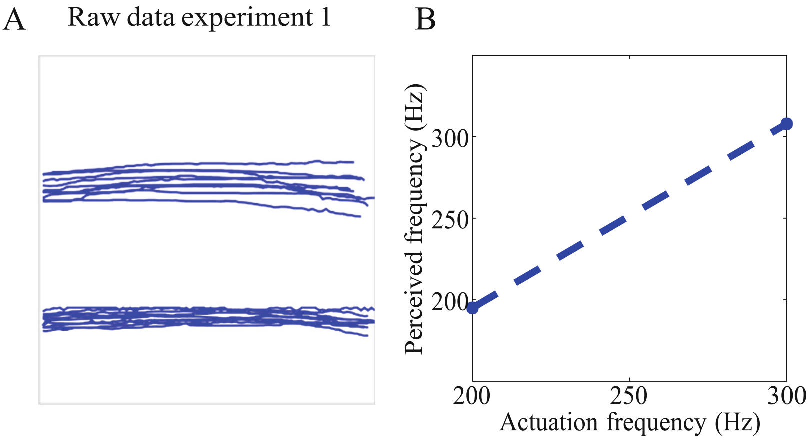

Fig. 3. The experiment 1 was designed to understand human sensitivity distribution: (A) Raw data representation: one of the subjects' sketch data, the total number of trails are 20 for experiment 1, (B) actuation frequency and perceived frequency are shown. Average perceived frequency are shown, 8 subjects participated 10 trials for 200 Hz, and 300 Hz actuation frequencies during the experiment 1.

3.2 Experiment 2

The raw data from experiment 2 for the pattern T, RT, and LT in experiment 2 are shown in Fig. 4A. Here, the black dashed line was used to show templates. The raw data in Fig. 4A were regressed against respective templates in Fig. 2. The average regression coefficients values are shown in Fig. 4B. In Fig. 4, all regression coefficients have increased in the last one third of the experimental trials except for the template T as shown in Fig. 4B. The average regression coefficients of template T are higher during the first and second third of experimental trials compared to LT and RT as shown in Fig. 4B. It implies that subjects have a better ability to generalize scaled template after reasonable number of experimental trials when stimulations are different. However, higher variability in last third of the trials could come due to fatigue. We assume that possible causes for variability could come from physiological factors like muscle tension and psychological factors like attention.

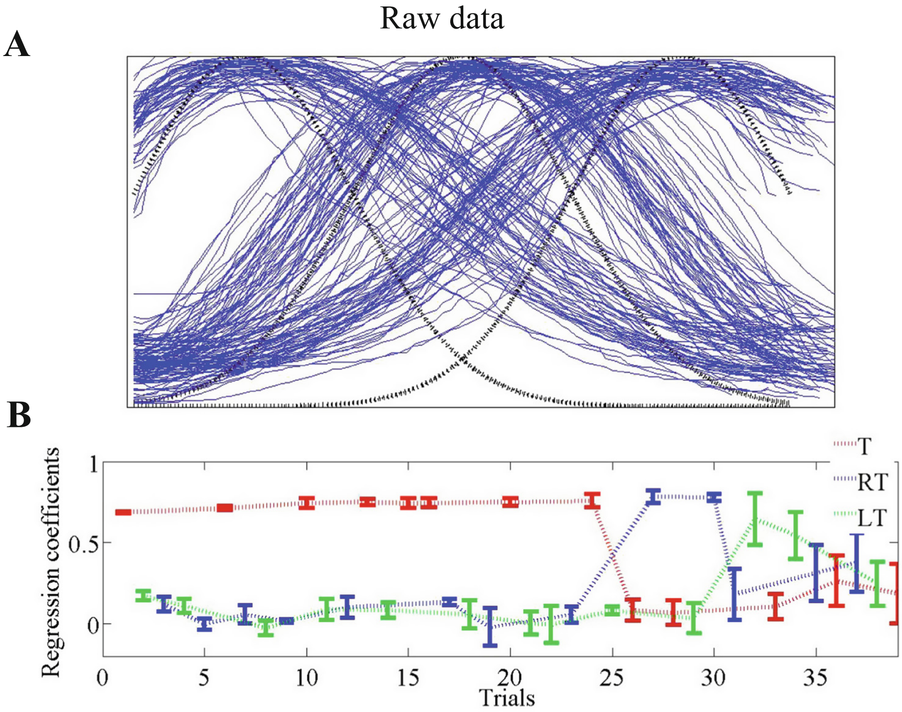

Fig. 4. Sketched data and regression coefficients: (A) The raw data of Experiment 2, and (B) Average regression coefficients when data regressed with templates in Fig. 2. The variability of the regression coefficients are shown by error bars.

4 Discussion

This paper presents experimental evidence of humans perceptions in perceptual space and their abilities to distinguish and generalize a class of primitive haptic feedback patterns after training. The results of the experiments show how humans recognize trained cutaneous feedback patterns as well as their scales. Those results provide us to understand capabilities and limitations of the humans in somatosensory system. Therefore, those preliminary findings could be used to continue our studies to understand humans' sensitivity distribution in perceptual space by using different parts of the body.

In future, we will do more training session to train the templates with human participants. The results of humans' perceptions will give us some degree of freedom to bring humans with less impairments (visual and auditory) more independent: for example, an elderly person living in a house alone with visual and auditory perceptions are impaired due to ageing. Moreover, we can we can use those to enhance the humans' perceptions when they are in noisy environments like in a factory, and search and rescue scenario.

Even though the regression coefficient were improved last one third of the trials in Fig. 4B, the low regression coefficients in first and second half of trials in Fig. 4B suggest that even if recognition of the tactile patterns were high, performance would still be poor if there was a drawing difficulty. Therefore, we deliver some psychophysical experiments to understand the degree of drawing difficulties. This would be the best way to quantify degree of drawing difficulties of the humans. This would be tested on naive and trained participants in the future.

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