Humans Sensitivity Distribution in Perceptual Space by a Wearable Haptic Sleeve

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Abstract. It is very important to understand humans' perception when the other communication modalities like 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 haptic sleeve consisted of 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 is projected to increase by 9.7 million over the next 25 years from an estimated 64.6 million in mid-2014 to 74.3 million in mid-2039 [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 way 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 how humans perceive haptic perceptions. Haptics would be the best way to convey messages in some tasks in order to provide 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 supplementation improves postural control mechanisms independent of age due to enhanced perception of self-motion through sensory interaction with the environment. 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 perceptions can be used to assist humans in navigation in unfamiliar environments [6], [7]. There have been some studies demonstrating that haptic feedback can be used to support human navigation [8], [7], [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 used for different purposes to convey messages to humans in previous studies. For example, the study in [9] presented an active belt, which is a wearable tactile display that can transmit multiple directional information in combination with a GPS directional sensor and 7 vibro-actuators. Furthermore, in some studies vibro-tactile displays have used to improve the quality of life in different ways such as reading devices for those with visual impairments [10] to provide feedback of body tilt [11], balance control, and postural stability [12], [13], and navigation aid in different environment [14]. Until now there have been many studies that used vibro-actuator belts for different purposes. 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 has been widely used to stimulate the human skin in most of the previous studies [15], [16], [17], [18]. However, we argue that frequency would be better for persistent perception according to the effective nature of human skin mechanoreceptors . The monotonic nature in amplitude could effect humans' responses.

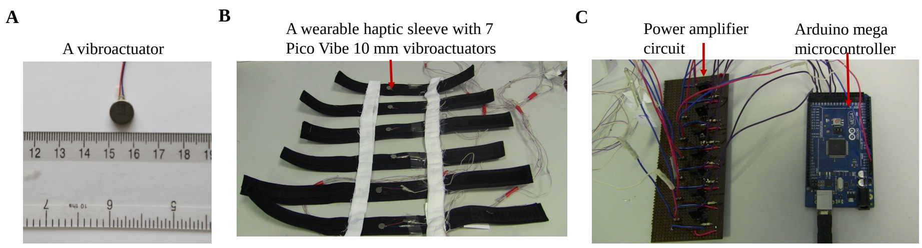

Fig. 1. Hardware design for wearable haptic sleeve: A) Pico Vibe 10 mm vibro-actuator, B) A wearable vibro-tactile actuator arrays with 7 Pico Vibe 10 mm vibro-actuator motors, and C) Arduino Mega motherboard and power amplifier circuit to generate different intensity patterns.

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

The rest of the paper is organized as follows. Section 2 elaborates 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 gives the experimental results of human participants. Finally, section gives a conclusion and future works.

2 Materials and Methods

Pico Vibe 10 mm vibration motor - 3 mm type (Precision Micro-drives) in Fig. 1A was used to make wearable haptic-based pattern feedback system as shown in Fig. 1B. The adjustable sleeve with 7 Pico Vibe 10 mm vibro-actuators arranged in equal distance (7 cm) in the array as shown in Fig. 1B. The 7 Pico Vibe 10 mm vibro-actuators were attached to the seven belts which can be adjusted by strapping securely to arm of the different subjects. The different intensities for the vibrators were generated by Arduino Mega motherboard and the amplitude was modulated by a simple power amplifier circuit as shown in Fig. 1C.

2.1 Haptic primitive templates generation

The standard Gaussian function was used to generate templates. 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

Here we conducted two experiments. The experiment 1 was designed study the humans' sensitivity distribution in perceptual space and experiment 2 was designed to study humans' ability to generalize haptic feedback using templates (different intensities via vibro-actuators were used to generate the templates). In both experiments, subjects wore the haptic-based pattern feedback sleeve as shown in Fig. 2A. Subjects were asked to keep the arm outstretched during the experiments. The smooth curves of Fig. 3 were selected as templates to generate different stimulation patterns for experiment 2 and flat frequency spectrum was played during the experiment 1. During each trial, all vibro-actuators vibrate simultaneously. Single trial ran for an average of 80 ms. Subjects were asked to draw a smooth curve representing what they perceive on an iPad sketching app (Draw free app (Apple Inc)) after each trial as shown in Fig. 2B. Just after the drawing, the next stimulation was given. The number of trials for each experiment and procedure explained later.

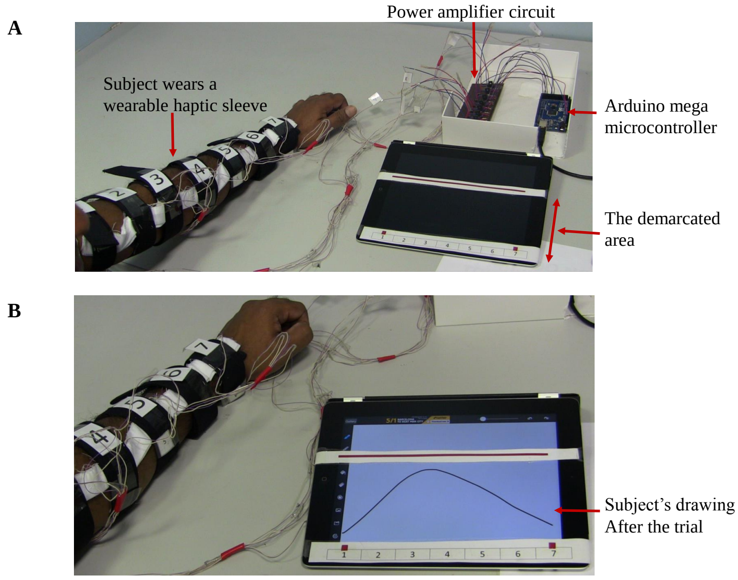

Fig. 2. An experimental trial: A) The subjects wear a wearable haptic sleeve with 7 Pico Vibe 10 mm vibration motor. The drawing area is demarcated and used hardware is shown, and B) The subject drew the intensity felt from the vibro-tactile actuator arrays was during the trial on iPad denarcated area. Draw free app (Apple Inc) software is used as a drawing tool.

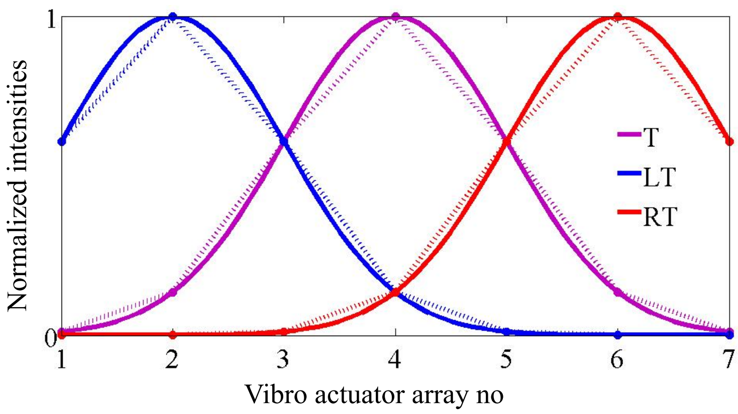

Fig. 3. The templates for experiment 2 : the smooth curves for the Gaussian Template (T), shifted Left (LT), and shifted Right (RT) are shown. $y = gaussmf(x, [sig, c]))$ was used to generate the three different templates. the dashed lines shows the exact intensities templates for the experiment 2.

2.3 Data processing and statistical analysis

The same available pencil in Draw free app (Apple Inc) was used for drawing throughout the experiments. Get Data Graph Digitizer version 2.6 was used to digitize the data (16 digits) on drawn lines. All the data were analysed by MATLAB 2014a.

2.4 Experiment 1: Study humans' sensitivity distribution

Eight healthy naive subjects (4 - male, 4 - female) age between 24 to 38 participated in the experiment 1. The experiment 1 was conducted to understand humans' sensitivity distribution in the perceptual space. Specifically, here we only tested on the sensitivity of the human arm. We are interested to test whether humans' perception is linearly related with actuation frequency. Simply, when we increase the actuation frequency, we are interested to test humans' perceived frequency increased with that. Due to the technical limitation in Pico Vibe 10 mm vibration motor and humans' perception the actuation frequency was limited to only 200 Hz and 300 Hz. 10 trials were played at each actuation frequencies of 200 Hz and 300 Hz .

During the experiment, subjects were asked to wear the vibro-actuator belt. They were told that flat frequencies are played during the trial. Subjects were told that they are supposed to draw a smooth shape directly proportional to the intensities of the vibro-actuators after the stimulation. Even the played frequencies are flat during the trial, subjects are not restricted to draw a line, instead of that they are free to draw a smooth curve proportional to what ever intensities they felt during the trial.

2.5 Experiment 2: To understand how humans generalize haptic-based pattern

Eight healthy naive subjects (4 - male, 4 - female), age between 24 to 26 participated in the experiment 2. Since the experiment 2 independent from experiment 1, it was conducted with a different group from experiment 1. The experiment 2 was conducted to test how humans generalize a primitive Template pattern (T) and how they scale the same template in leftward and rightward when they played in randomly. The three templates that have been used are shown in Fig. 3. Here, the Gaussian template denoted as T. The shifted Right of T denoted as RT, and shifted Left of T denoted as LT. Since it has been shown that humans learn movements through flexible combination of primitives that can be modelled using Gaussian like functions [19], [20] to explore whether human brain has primitive patterns that can be modelled using Gaussian like functions to represent haptic perceptions as well.

Again, subjects were asked to wear the same vibro-actuator belt in experiment 2. They were informed that the intensities of the vibro-actuators in the belt are directly proportional to the height of the template during the stimulation. Subjects were told that they are supposed to draw a smooth curve with

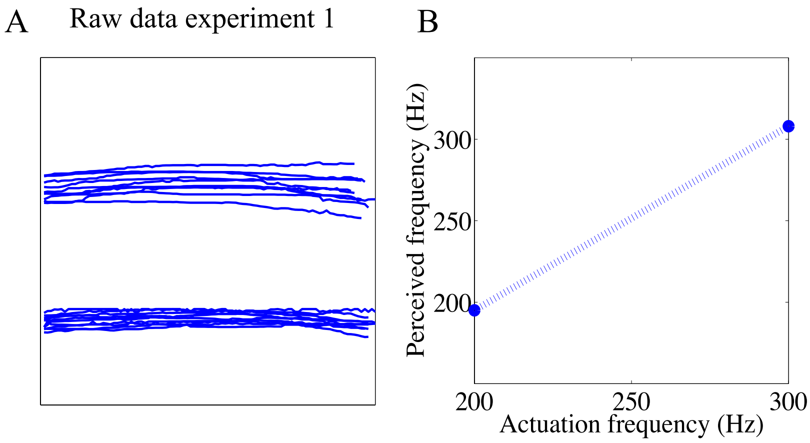

Fig. 4. The raw data for experiment 1: The experiment 1 was designed to understand human sensitivity distribution: A) Raw data representation: one of the subjects' sketch data, the total number of trails are 20 for experiment 1, B) actuation frequency and perceived frequency are shown. Average perceived frequency are shown, 8 subjects participated 10 trials for 200Hz, and 300 Hz actuation frequencies during the experiment 1.

heights directly proportional to the intensities of the vibro-actuators that they felt after the stimulation. The patterns T, RT, and LT were played to test how subjects can generalize the templates when they played pseudo randomly. Subjects participated in 39 trials during the experiments. Each pattern played 13 times during the experiment. The drawing area is restricted to fit to exactly similar to the shown template of the experiments as shown by a demarcated area on the iPad in Fig. 2B.

3 Results

3.1 Experiment 1

The sketched raw data for the flat frequency distribution is shown in Fig. 4A for a selected subject. In general, subjects were able to draw the played intensities as shown in Fig.4A. Subjects were able to distinguish between the 200 Hz and 300 stimulus Hz as shown in Fig.4A. Interesting, perception frequency is linearly increased with the actuation frequency as shown in Fig.4B. 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.

3.2 Experiment 2

The sketched raw data for the pattern T, RT, and LT in experiment 2 are shown in Fig. 5A. The templates are shown by black dashed line. The sketched data in Fig. 5A were regressed against respective templates in Fig. 3. The average regression coefficients are shown in Fig. 5B. In general, in Fig. 5 all regression coefficients have improved in the last one third of the experimental trials except for the template T as shown in Fig. 5B. The average regression coefficients of template T are higher during the first and second third of experimental trials with respect to LT and RT as shown in Fig. 5B. It implies that subjects have a better ability to generalize scaled template after reasonable number of experimental trials when vibro-actuator array generates different stimulations. However, higher variability in last third of the trials could come due to fatigue. This variability could come from physiological factors like muscle tension and psychological factors like attention.

4 Discussion

This paper presents experimental evidence of the capabilities and the limitations of the human somatosensory system to distinguish and generalize a class of primitive haptic feedback patterns. Two consecutive experiments that provide insights into how humans recognize trained cutaneous feedback patterns as well as their scales. The results provide new insights into an important area of tactile input to inform shape/pattern recognition. The subjects' drawings of stimulus waveforms were captured and regression coefficients were used to understand humans' ability to recognize the given stimulations by different templates via a vibro-actuator array. 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. A deeper understanding of humans' ability to generalize and recognize trained templates are important to convey some messages via vibro-actuator stimuli when humans have to work in noisy environments. Moreover, those trained templates could be considered as primitives of a haptic-based language. Those primitives and subjects' responses would give an idea as to how they can be used to increase humans' perception when we want to bring them 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. 5B, the low regression coefficients in first and second half of trials in Fig. 5B suggest that even if recognition of the tactile patterns were good, performance would still be poor if drawing the visual representation was difficult. Therefore, we deliver some psychophysical experiments to understand the degree

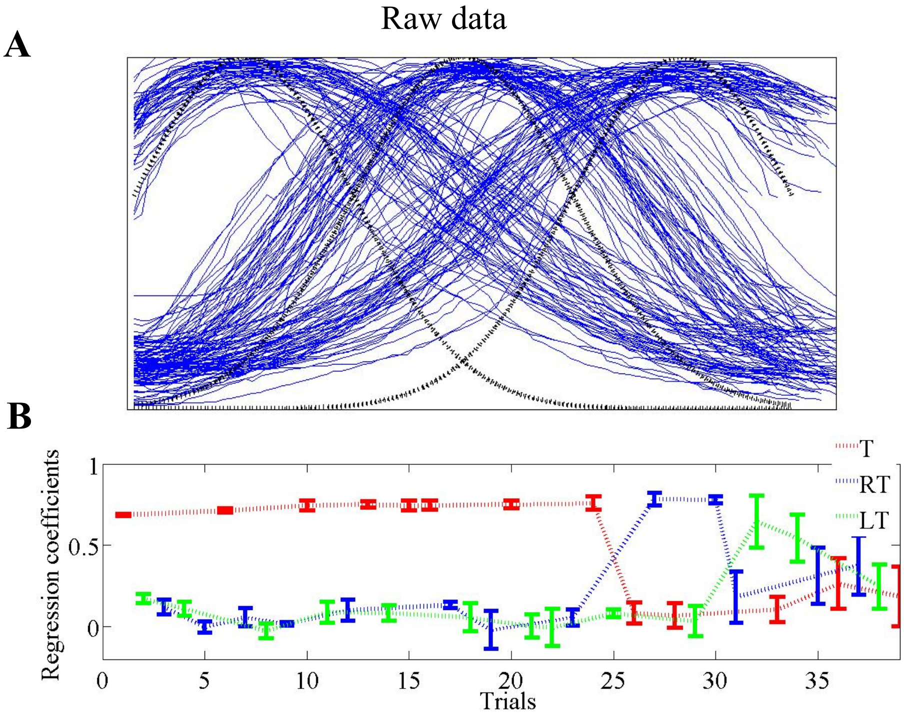

Fig. 5. A, the raw data of experiments are shown. The black dashed line shows the templates, and B) Experiment 2: Average regression coefficients when data regressed with respective template in Fig. 3. Standard deviation of the regression coefficients are shown by error bars.

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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