Perceived Distance from Hitting with a Stick is Altered by Superimposing Vibration to Palm

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ABSTRACT

We focused on the perceived distance from hitting an object using a handheld stick. A hypothetical mechanical model of a stick and a holding palm told us that hitting at a closer point should induce a stronger vibration at thumb side of the palm, and percussing a farther point should induce equally distributed vibrations in the palm.

Keywords: distance perception, hitting, stick, vibrotactile.

Index Terms: H.5.2 [Information Interfaces and Presentation]: User Interfaces—Haptic I/O

1 INTRODUCTION

Most of us have an experience of perceiving distance by hitting objects with a stick. This perception is quite important in some situations, especially for the visually impaired who use white canes in daily life.

The mechanical characteristics of held objects can be perceived by haptic cues even if the objects are visually occluded [1][2]. This exploratory behavior is known as dynamic touch [3] and has mainly been studied as part of ecological psychology [4][5][6][7]. In recent years, researchers have succeeded in producing the illusion of weight or center of gravity of a virtual object by using haptic devices [8]. Yao and Hayward [9] found that "rolling" small object inside the rod can be expressed by simple vibration.

However, these studies dealt with estimating the mechanical characteristics of the handheld object itself and did not directly consider distance perception from percussing objects with a handheld stick. The contribution of the rotational moment was considered [10], but no clear evidence was revealed.

At the time of impact, a rotational moment and translational force are generated, and they can be perceived from kinetic and cutaneous sensations. In this study, we tried to verify the contribution of cutaneous sensation to this phenomenon.

2 HYPOTHETICAL MODEL OF DISTANCE PERCEPTION BY CUTANEOUS CUES

Figure 1 shows a simplified mechanical model for percussing an object with a handheld rod. P_1, P_2, and P_3 indicate the positions of the object, thumb, and little finger, respectively. We assumed that the hand only contacts the rod with the thumb and little finger to simply the model, although in actual cases the rod is held with the whole palm. F_1, F_2, and F_3 represent the generated forces by percussion, and L_1 and L_2 indicate the distances between P_1 and P_2 and P_2 and P_3, respectively.

As the handheld rod stops after the contact, the total rotational moment and translational force must be zero, which leads to the following equations.

$$F_1 + F_2 + F_3 = 0 \quad (1)$$

$$F_1 \cdot L_1 = F_3 \cdot L_2. \quad (2)$$

From these equations of balance, distance L_1 is obtained as follows;

$$L_1 = \frac{F_3 \cdot L_2}{F_1} = \frac{-F_3 \cdot L_2}{F_2 + F_3}. \quad (3)$$

As L_2 (distance between the thumb and little finger) is constant, this equation means that the distance of percussed object L_1 is directly related to the ratio of F_2 and F_3, which are perceived as cutaneous sensations at the thumb side and little-finger side.

For instance, when the object is quite close, L_1 is nearly equal to zero, which gives $F_3 = 0$ in the equation. This means that the transmitted vibration at the thumb (P_2) is greater than that of the little finger (P_3) (Figure 2, left). In contrast, when the position of percussed object P_1 is far away, L_1 is infinite, which gives the solution $F_2 = -F_3$. Therefore, the intensities of the transmitted vibrations to the thumb and little finger become equal (Figure 2, right).

This simple model shows that the position of percussed object P_1 can be estimated from the ratio of transmitted vibrations to the thumb (F_2) and little finger (F_3). This model is not accurate because we usually grasp the rod with the whole palm, but it shows that we may estimate the position of percussed object by perceiving the position of the "center of gravity" of vibration in the palm. Presenting vibration at multiple sites is known to elicit the perception of a center of gravity, which is called a funneling or phantom sensation [11].

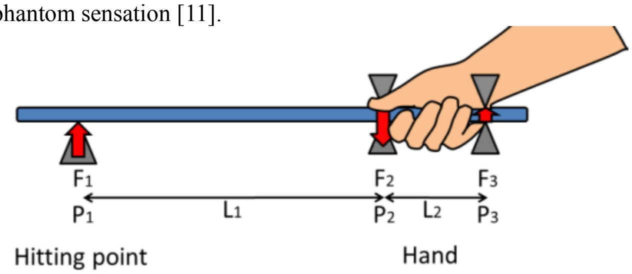

Figure 1: Hypothetical model for distance perception of percussion .

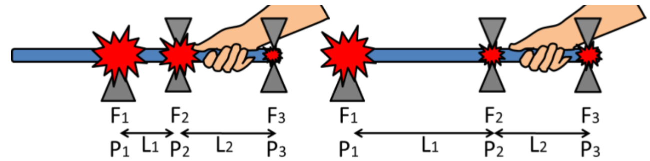

Figure 2: Hitting a closer point (left). Hitting farther point (right).

3 STICK-TYPE DEVICE

To verify our hypothesis, we produced a stick-type device shown in Figure 3. The device comprises an aluminum pipe (diameter: 15

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mm, length: 1000 mm, weight: 110 g), an acrylic grip, a single-axis accelerometer (±250 *g*, ADXL193, Analog Devices), two vibrotactile actuators (Haptuator Mark II, TactileLabs) on the grip, a pre-amplifier circuit, and an audio amplifier (RSDA202, Rasteme Systems Inc.). The accelerometer was placed at the tip of the aluminum pipe to record the real contact, and its analog output was connected to the two actuators through the pre-amplifier circuit and audio amplifier (Figure 4). The two actuators were mounted on the grip beneath the bases of the thumb and little finger. They directly touched the skin surface when the device was grasped. A sponge was installed between the acrylic grip and actuators to avoid possible howling caused by the actuators and accelerometer. The total weight of the device was about 250 g.

Thanks to the simple implementation, the time delay from actual contact to the replayed vibration became imperceptible. Each actuator was connected to the right and left channels of the audio amplifier; the amplitude ratio of the two actuators could be controlled by the balance control knob of the audio amplifier.

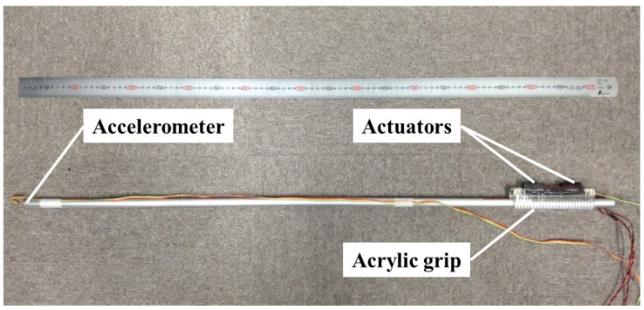

Figure 3: Stick-type device.

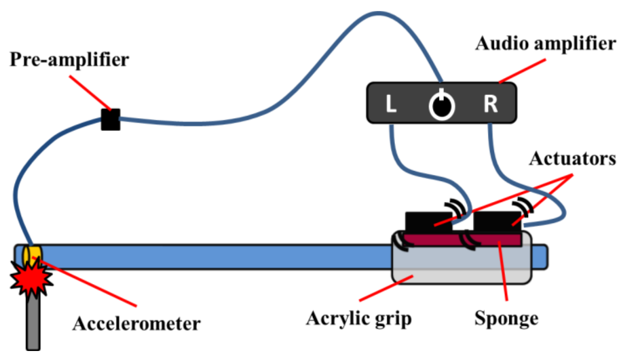

Figure 4: System configuration.

4 Conclusion

We aimed to clarify the mechanism for perceiving distance from percussion with a handheld rod. We proposed a hypothetical model of possible cutaneous perception and a stick-type device was fabricated.

If we consider the cutaneous sensation and vibration center of gravity position, percussing at a closer point should induce a stronger vibration at thumb side, and percussing a farther point should induce equally distributed vibrations in the palm. Based on this idea, we hypothesized that the perceived position of the percussed object can be modified by changing the vibration center of gravity transmitted to the palm. To verify our hypothesis, we fabricated a stick-type device embedded with two actuators positioned at the bases of the thumb and little finger.

In future work, we will conduct an experiment to determine whether the perceived distance of the percussed object is altered by changing the vibration center of gravity transmitted to palm.

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