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Paper:

# A Basic Study on Tactile Navigation Using Vibration Motor Braking by Skin Against Vibration and Body Positioning Suitable for Tactile Information Presentation

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**This paper presents results of a basic study on tactile navigation using vibration motors. It includes studies about appropriate position finding for information presentation navigation that used a vibration motor. We examined skin vibration and vibration strength generated by a vibration motor by physical measurement. Section 1 discusses the need for a new car navigation device that meets the needs of those with hearing problems. Section 2 discusses three experiments for measuring (1) skin hardness, (2) vibration, and (3) discrimination threshold. Section 3 discuss results of experiments.**

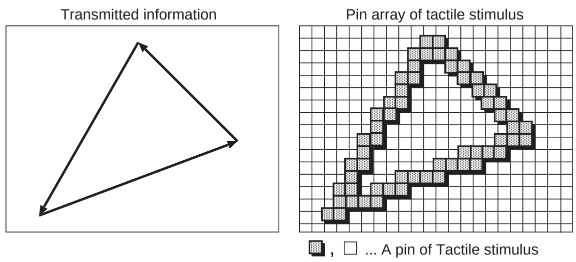


**Fig. 1.** Relationship between transmitted information and pin array of tactile stimulus.

**Keywords:** vibration motor, tactile navigation, vibration strength, discrimination threshold

## 1. Introduction

Japanese traffic authorities require that those applying for a driver's license be able to clearly hear a car horn at 90 db, 10 m from the driver, even using a hearing aid (Enforcement Ordinance Article 23 of the Road Traffic Law). This standard makes a driver's license difficult to acquire for those with severe hearing impairment. The Tokyo Metropolitan Police Department decided to lift this barrier in fiscal 2008 by requiring that vehicles driven by drivers with hearing problems have wide-view mirrors and display signs that the vehicle is driven by someone hearing impaired. This may let those with hearing impairments acquire a driver's license, but will raise problems due to an absence of auditory information. The problem of obtaining information from car navigation only while driving must be resolved as soon as possible from the stand-point of traffic safety. Most currently marketed car navigation systems use voice messages and monitors to provide the driver with information on location and routes to destinations. Those with hearing impairments cannot hear voice messages and obtain only visual information on the monitor. Approaching emergency vehicles are detected by a siren sensor installed in the car and blind spots are caught by CCD cameras whose images are displayed on the car navigation monitor. Trying to access information from currently navigation systems, etc., cause drivers to take their eyes off the road, leading to increasing safety risks. Tactile displays provide sensory information [1, 2]. R&D on tactile displays have led to commercially available devices such as TVSS and Optacon, many of which use a matrix-like array of tactile, that is shown as **Fig. 1**, stimulus elements to present spatial information with which a single information source is presented by multiplexing vibrations of stimulus elements. These devices are limited to specialized uses, however, because of poor portability and difficulty of use [3, 4].

We have been studying novel tactile displays that use a single vibrator element in which vibration is modulated using position information to present graphical information [5–10]. The portability and ease of use of a tactile display would improve dramatically if a single tactile stimulus element could be used for multiplexed information for developing new information display tools for driving navigation, i.e., tactile navigation devices. Information presented by such devices no longer require that drivers take their eyes off the road to read monitors when driving. Since it would present information tactilely, such devices could serve as human-machine interface (HMI) for everybody.

Tactile stimulus elements include vibration motors, PZT vibrators, and voice coil motors. PZT vibrators feature portability, simplicity, easy maintenance, and low cost, but vibrations are weaker than those of vibration motors. Voice coil motors are costly, so we used a coin eccentric-weight vibration motor, which uses a DC motor to rotate an eccentric weight to generate vibration. It generates stronger vibrations than PZT vibrators and features portability, simplicity, easy maintenance, and low cost. It generates a direction-independent sinusoidal stimulus. Mobile phones use vibration motors for vibration mode at low cost. To apply vibration motors to a novel tactile navigation information presentation device, we are establishing application guidelines.

We conducted three experiments for skin hardness vibration measurement, and discrimination threshold measurement to evaluate skin conditions and element vibration strength through physical measurement, then examined their correlation between human senses and human emotions.

Based on our results, we prepared data on skin hardness, firmness, and thickness on the finger, back of the hand, forearm, upper arm, above the knee, shin, and behind the ear; their relationship to the braking against vibration exerted by the skin; and the properties of bodily locations suitable for information presentation.

## 2. Experiment

We conducted the three experiments mentioned above using the same group of subjects, i.e., adults aged 21-31 in good health. Vibration phenomena is accompanied with displacement of a vibrating material. By the difference of the number of times to differentiate this displacement by time, vibration strength can express by displacement, speed, acceleration [11]. We used vibration acceleration as vibration strength.

### 2.1. Skin Hardness Evaluation

There are sixs of skin receptors that sense vibration, including Meissner's corpuscle, Pacinian corpuscle, and Merkel's disc. Even if presented with the same vibration strength, that received by the receptor differs with hardness, thickness, firmness, etc., of skin. We quantitatively examined skin at information presentation sites. The standard for evaluating skin hardness is the modified Rodnan total skin thickness score (m-Rodnan TSS), based on two-step pinching [12]. The m-Rodnan TSS is used to evaluate the stage of skin hardening in scleroderma patients. Two-step pinching is widely used as evaluation with good repeatability, i.e., score results have low variability when compared between different measurements by the same examiner, or by different examiners. Based on the M-Rodnan TSS, we prepared a skin diagnosis table (**Table 1**) and scored the skin condition of parts using two-step pinching. Although in the m-Rodnan TSS, the score is higher when the examiner *cannot* pinch the skin, and the score is lower when the skin is *not* thick, this is reversed in this study. The final score is the sum of the scores of the two modes of pinching: that when a large area is pinched, and when a smaller area is pinched. Based on **Table 1**, scores were obtained for the same subject for skin conditions of seven measured locations: finger, back of the hand, forearm, upper arm, above the knee, shin, and behind the ear. To minimize variability, the same examiner conducted examination and scoring.

**Table 1.** Skin diagnosis table.

| Score | Skin thickness when pinched by large area | Skin thickness when pinched by small area |
|---|---|---|
| 0 | Not possible to pinch | Not possible to pinch |
| 1 | Thick | Thick |
| 2 | Moderately thick | Moderately thick |
| 3 | Thin | Thin |

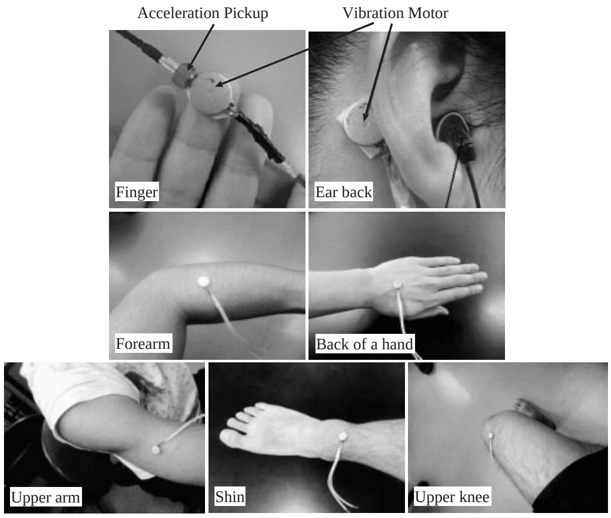


**Fig. 2.** Parts to which vibration motor was attached.

### 2.2. Measurement of Vibration Strength

A coin eccentric-weight vibration motor is attached to the skin, so we examined vibration strength when the skin exerts braking and when there is no braking. We compared no skin braking to the case at the seven locations to obtain how much the skin damps vibration amplitude.

Room temperature was 25.0±1.0 °C. We used a coin eccentric-weight vibration motor (model FM34F, Tokyo Parts Industrial Co.) (12 mm in diameter). To measure vibration strength, we used a piezoelectric acceleration pickup (Yamco103s, CBC Co.) with a charge amplifier (Yamco4200, CBC Co.). The input voltage to vibration motor was 1.8-3.5 V, (the manufacturer's specified voltage range). The vibration motor and acceleration pickup were pasted directly on the skin with adhesive (**Fig. 2**). To measure vibration with no braking by the skin, the vibration motor was suspended in midair to minimize the effects of friction. Cords attached to the motor and acceleration pickup vibrate when the vibration motor is operated, but if they are prevented from vibrating, it affects vibration strength. To minimize the effect of cords, cords were

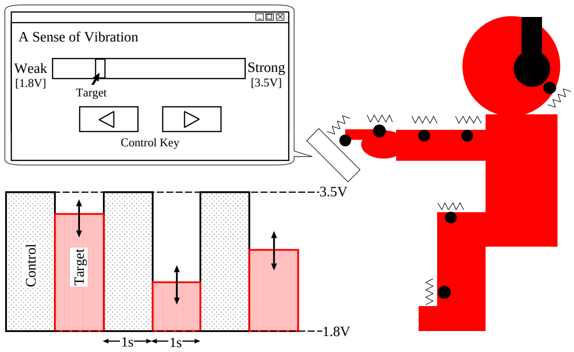


**Fig. 3.** Presentation.

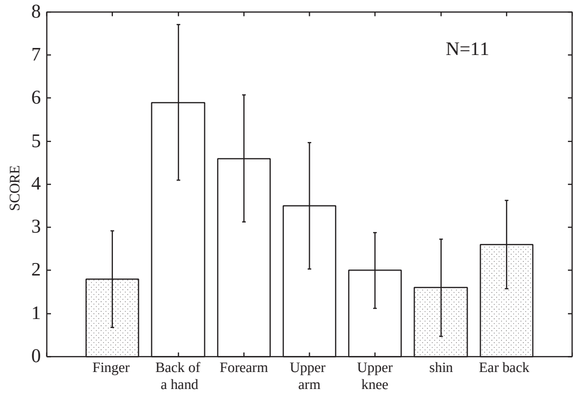


**Fig. 4.** Skin evaluation scores at different body locations.

suspended by a length of about 15 cm (**Fig. 2**). Double-sided adhesive tape was used to attach the motor to the skin uniformly. To minimize physical (muscle) movement on vibration measurement, subjects were asked to remain as still as possible.

### 2.3. Measurement of Discrimination Threshold

With the vibration motor attached to the skin, psychophysical measurement is used to determine the discrimination threshold, i.e., the smallest change that can be detected by the subject when vibration strength is varied, i.e., the discrimination threshold is the smallest change in objective vibration when a subjective change occurs in vibratory sensation (**Fig. 3**). Measurements are taken at the seven locations used in earlier experiments. The vibration motor used a voltage of 1.8-3.5 V and a PC measured voltage adjustment. Using a reference voltage of 3.5 V, the vibration sensation at the reference voltage is defined as the control value. The vibration sensation caused by a voltage that differs from the reference voltage is defined as the target value. The control and target values are alternated at 1-second intervals. Subjects press arrow keys on the PC and adjust the target value until they find the smallest voltage difference that they can discriminate. Conventionally, the discrimination threshold for stimulation is usually determined by moving back and forth between high and low values to narrow the range. In this adjustment, the final result is greatly affected by the initially selected value [11]. To avoid this problem, we took the average of the target value found by lowering the voltage from the reference voltage and that found by raising the voltage from the specified minimum voltage of 1.8 V. Subjects wore a noise canceling earmuff (Peltor H10A) to prevent vibration sounds from affecting judgment. When conducting measurements for the location behind the ear, however, the subject is able to hear vibration regardless of noise canceling, so measurements were taken for both cases, with and without the earmuff. Subjects were asked to judge by relying only on skin sensation rather than sounds.

## 3. Results and Discussion

### 3.1. Skin Hardness Evaluation

**Figure 4** shows skin hardness scores for different locations. Locations with high scores are, in descending order, the back of the hand, forearm, upper arm, behind the ear, above the knee, finger, and shin. We analyzed variation in skin hardness scores, finding significant differences, with 5% significance between all measured locations except for the following pairs: shin-finger, shin-above the knee, finger-above the knee, and above the knee-behind the ear. At the back of the hand, which has the highest score, the skin is softer and there is less subcutaneous fat compared to other locations. At the shin and behind the ear, which have low scores, the skin is relatively taut. We found that some subjects could be "pinched by a large area" (**Table 1**), at the finger, shin, and behind the ear, while others could not. Among locations that cannot be "pinched by a large area," the finger has a small skin area and is covered by thick skin.

### 3.2. Vibration Strength Measurement

**Figure 5** shows vibration strength-terminal voltage relations. **Fig. 5-1** shows vibration strength in no breaking against terminal voltage. **Figs 5-2**, **3**, and **4** show vibration strength at the finger, back of hand and forearm when braking is exerted by skin against terminal voltage. **Fig. 6s** show vibration strength-terminal voltage relations of upper arm, above the knee, shin, and behind the ear. As seen in **Fig. 5-1**, vibration strength reached a saturation of 7.0 G to 7.9 G at 3.2 V terminal voltage, suggesting that saturation is about the limit of the vibration strength of the vibration motor.

Relationship between vibration strength at finger, forearm, upper arm above the knee and terminal voltages are nearly linear and approach saturation of 6.9 G to 7.9 G at 2.7 V of vibration strength at the back of hand with skin braking. Vibration strength is 0.2 to 0.3 smaller than that of "Non brake of vibration strength." At the back of the ear, vibration strength increase linearly up to a terminal voltage of 2.6 V and reaches saturation of 5.5 G to 5.7 G at

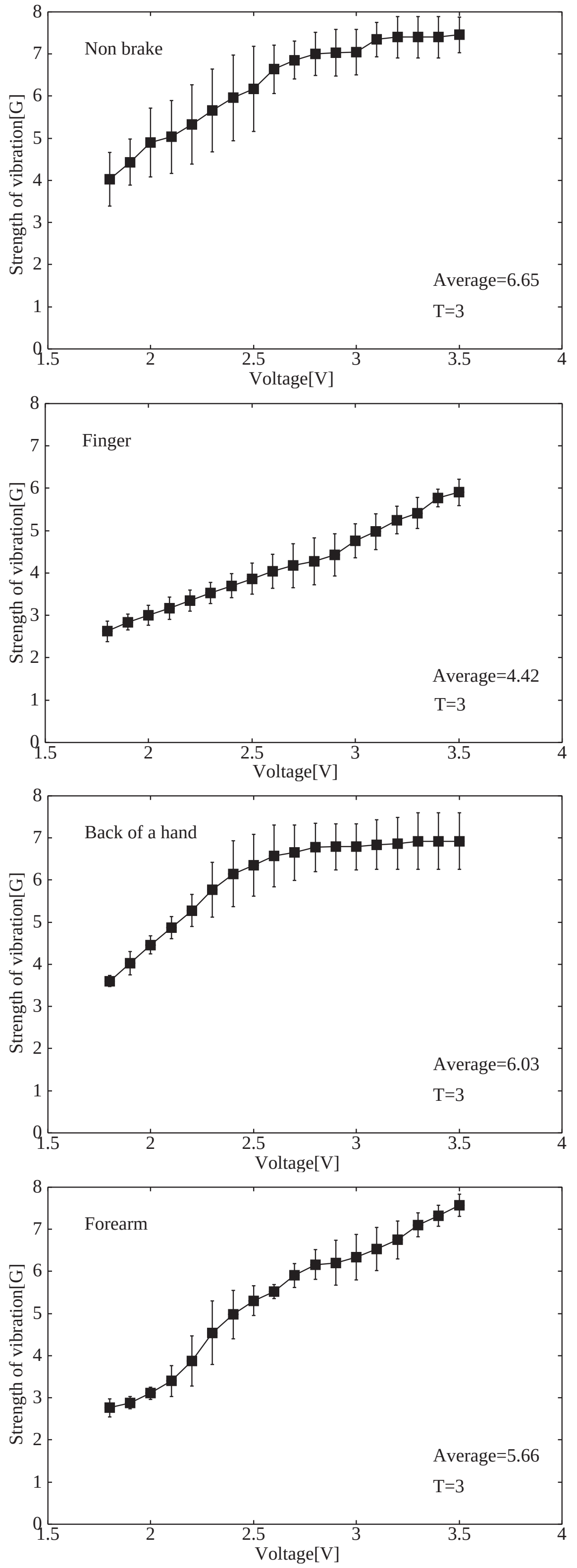


**Fig. 5.** Vibration strength versus voltage. (no braking by skin, finger, back of hand, arm)

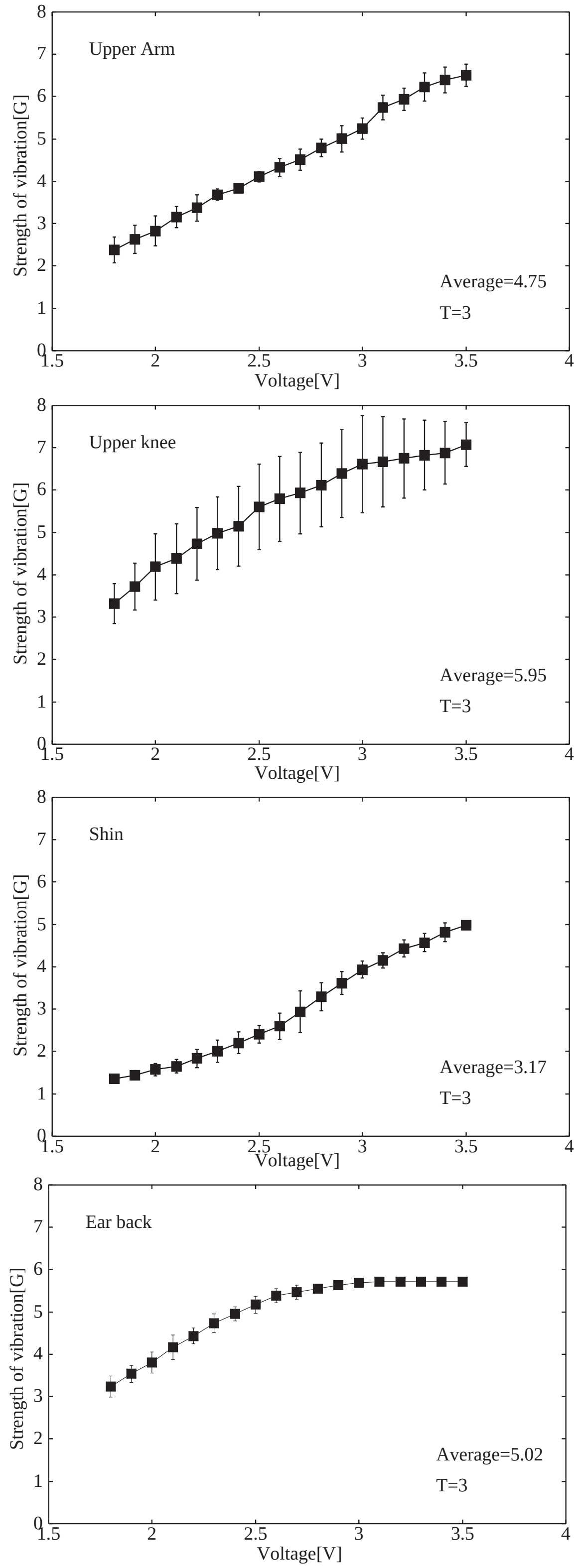


**Fig. 6.** Vibration strength versus voltage. (upper arm, above knee, shin, behind ear)

2.7 at terminal voltage of 2.7 V. The amplitude of the saturated part cannot be directly compared to nonsaturated parts, because vibration strength has boundary condition. To cope, we prepared a table of average vibration strength to substitute real vibration strength (**Table 2**). Vibration motor vibration strength is largest in descending order of nonbraking, finger, back of hand, forearm, upper arm, upper knee shin, ear back of vibration strength terminal voltage.

**Table 2.** Average vibration strength

| Vibration strength | Finger | Back of hand | Forearm | Upper arm | Above knee | Shin | Behind ear |
|---|---|---|---|---|---|---|---|
| Average | 3.22 | 4.01 | 3.89 | 3.79 | 3.47 | 2.55 | 3.64 |

### 3.3. Measurement of Discrimination Threshold

**Figure 7** shows results of discrimination thresholds for various locations. That displaying the smallest discernable vibration strength difference is behind the ear 2 (using the noise canceling earmuff), followed by behind the ear 1 (without the noise canceling earmuff), finger, shin, back of the hand, forearm, upper arm, and above the knee. Analyzing discrimination thresholds, we found a significant difference at 5% significance, between results above the knee and behind the ear 2, perhaps because compared to other locations, the location behind the ear is relatively sensitive and displays low dispersion across the subject group. At the back of the hand, forearm, upper arm, and above the knee, all of which display a large standard deviation for vibration strength, the standard deviation for discrimination thresholds was high. When presenting information using vibration motors, the variation in vibration strength is used to relay information. When the standard deviation of the discrimination threshold is large, it becomes necessary to increase the variation in vibration strength. Since there is a maximum motor vibration strength, the amount of presentable information is reduced when the discernible difference of vibration strength is large. This means that body locations that display discrimination thresholds with a large standard deviation are unsuitable for information presentation. The back of the ear, finger, and shin were locations at which motor vibration strength was low and that display high discrimination sensitivity and low deviation. Skin receptors that sense vibrations include Meissner's corpuscle, concentrated in skin areas with no hair growth such as the face and finger tips, and the Pacinian corpuscle [15]. The high sensitivity at the finger and behind the ear are likely attributable to the presence of Meissner's corpuscles along with Pacinian corpuscles. There is a slight difference in the discrimination threshold between the two measurements taken behind the ear, i.e., when the subject wears a noise canceling earmuff and not. This indicates that auditory information is used along with tactile information to discriminate vibration. The fact that such a difference appears even when the subject is asked to make judgments based only on tactile information shows that the subject fails to completely isolate different sensory sources of information, which are integrated and mutually affect one another due to sensory integration. The skin at the shin is relatively taut, so follicular receptors, which serve to sense vibrations, in this location play a more active role than at other locations. Our measurements show that locations suitable for information presentation using vibration motors are those where skin is relatively taut such as the fingers, behind the ear, and shin.

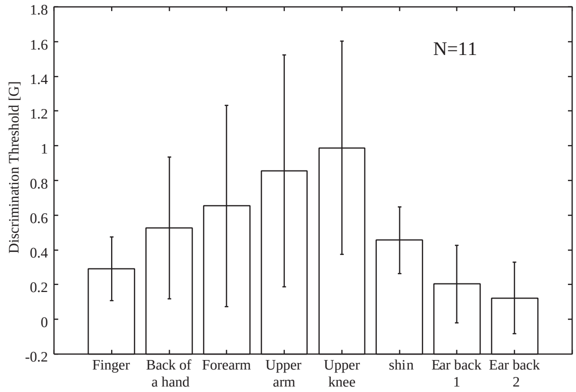


**Fig. 7.** Discrimination threshold.

## 4. Conclusions

We carried out three types of experiments: skin hardness evaluation, vibration strength characteristic measurement, and discrimination threshold measurement, in order to obtain application guideline for information presentation device. We clarified the state of skin which provides vibration strength of element was measured with physical measurement, vibration strength, human sensation or relation between human sense and emotion was measured with psychophysical measurement. We evaluated skin conditions at seven locations – the finger, back of the hand, forearm upper arm, above the knee, shin, and behind the ear – using two-step pinching. From results, we established hardness, firmness, and thickness of the skin at these locations. Using a coin eccentric-weight vibration motor as the tactile stimulating element, we then examined vibration strength when skin exerts braking at these seven locations, and when there is no braking. Results showed that vibration strength varied with the location. Locations where skin is relatively taut, such as the shin and behind the ear, displayed small deviations, showing that braking exerted by the skin is related to hardness, firmness (tautness), and thickness. We next used psychophysical measurement to determine the discrimination threshold, i.e., the smallest change detected by subjects when vibration strength of the vibration motor attached to the skin is varied. Results showed that locations where the skin is relatively taut – the finger, behind the ear, and shin – display low discrimination thresholds. In projected work, we plan to study ways to present the direction of an upcoming turn or the vehicle current distance to the turn point as a means of tactile navigation to assist driving.

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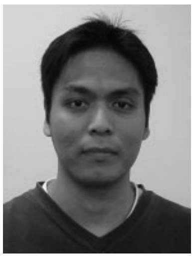

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