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Possibility of guiding arm movement in circle drawing

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Abstract – **We tried to guide human action using galvanic vestibular stimulation (GVS). GVS has a possibility of human behavior guidance without any attention. We tried to guide the trajectory of the subjects' hands when as the continuously drew circles. Previous work has mainly dealt with unstable actions, such as walking and reaching in a standing posture. On the basis of the results, it was claimed that GVS is effective for human action guidance. However, in those experiments, GVS influenced just the perception of the direction of gravity direction and balancing. Clarifying the GVS effect for actions performed with stable postures is required. In this work, we verified the effects of GVS with a stable sitting posture under a head-fixed condition in continuous circle drawing as a guided action. The results showed that there are cases in which the hand is guided by GVS. This means that there is a possibility of guiding hand trajectory by GVS even with a stable posture where GVS cannot drastically change balance perception.**

Keywords – **Galvanic vestibular stimulation, drawing, guidance**

I. INTRODUCTION

We are influenced by many types of guiding information in our daily lives even if we are not conscious of being guided. When we walk into an unknown station or building, we are guided by "exit" and "entrance" signs or by instructions from the information desk. In learning by imitation, one of the most fundamental abilities of humans, infants are naturally guided by their parents. It may even be said that a car horn guides a people out of the way of a car. Thus, we are surrounded by many kinds of guidance stimuli in our lives. The development of new and better guiding methods is therefore meaningful in the engineering sense.

Guidance methods can be classified on the basis of whether or not the person being guided is aware of the fact and according to the range of the body guided. Whether the guidance is effective for the whole body or for only some parts of the body is also an important consideration. All of the examples mentioned above, except for the imitation learning, are conscious-guidance methods. In addition, there are few methods for guiding a part of the body. Almost all of the above-mentioned methods are effective for the whole body. When someone instructs or forces someone else to move one or two parts of their body, because all parts of the body are closely connected, only one or two parts of the body cannot be guided easily, except in rare cases such as learning a special skill or a sport.

The question then is whether or not there is a need for unconscious guidance methods or for guiding some specific part the body. Our answer is yes: we can do a lot of things to use attention more effectively if we can be guided unconsciously. Imagine being able to perform two tasks using the right and left hand independently and unconsciously while focusing attention on some other thing. This would be theoretically possible with unconscious guidance. More realistically, consider the idea of being unconsciously guided to the best exit from a large building rather than having to look for and follow exit signs. If a car could avoid obstacles automatically without the driver being aware of the additional movement for the avoidance, the driver could pay more attention to planning the next driving action or selecting routes. Therefore, unconscious-guidance methods would be more important and useful than conscious-guidance methods in terms of the effective attention usage.

Then, this raises another question: Why have no unconscious-guidance methods been put into use? One possible reason is respect for free will. In our liberal society, it is a taboo for people to control others against their will. However, will and consciousness are, of course, different things. We do not consider free will when guiding someone consciously to avoid an obstacle, and possible injury (It's common sense). In addition, in certain situations, unconscious guidance would be better than conscious guidance. Therefore, if respect for free will is not the reason, then is must be simply the difficulty in imagining that someone's arms, hands or feet, could be controlled without any attention and consciousness. It is not a natural situation.

However, unconscious guidance can be achieved by using perceptual illusion. As outlined in Fig. 1, humans normally sense the environment and perform actions to

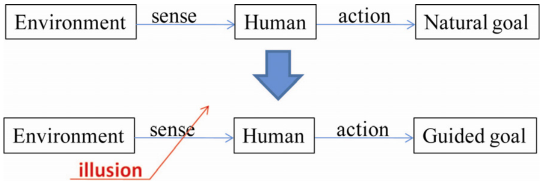

Fig. 1 Unconscious-guidance with illusion

achieve their goal (this goal is called the “natural goal” in Fig.1). If we can change the results of sensing, a goal different from the natural goal can be achieved. We call this the “guided goal”. The human takes actions to achieve the natural goal using his/her feedback system; however, the system senses the situation differently because of the illusion. Then, in this method, the guided goal is perceived as the natural goal. The guided goal is achieved without awareness that it is different from the natural goal. The essential point is that the action is natural. One of the examples of such guidance using with illusion is the walking guidance with galvanic vestibular stimulation (GVS) [1]. GVS has an effect for direction of gravity [2]. The effect makes one’s perceptual posture different from one’s real posture and this difference cannot be perceived. Therefore, the guided person modifies his/her action under consciousness. However, GVS has a limitation: It can only effect the direction of gravity. There is little effective action when GVS is applied without walking. Arm action, like walking, is very useful, but there have been few successful reports about GVS for the arm. Knox et al. reported that when the head is guided by GVS, the arm position is perceived to be different from its real position [3]. In addition, Bresciani et al. reported that when subjects stand and their heads are fixed, GVS invokes a reaching action like pushing a lever forward [4]. These reports have shown some of the possibilities of GVS, but the experiments were related to balancing, such as head movement or standing posture. We think that even when the head is fixed, some changes in balance might be perceived when standing. There is a possibility that this perception could make unconscious arm movement. If GVS can make the effects directory, we can guide stable postures such as sitting. In this work, we conducted an experiment to study arm action in a sitting posture with GVS, and examined the possibility of unconscious-guidance with GVS.

II. GVS

GVS changes the perceptual gravity direction by adding a galvanic stimulation to the vestibular system. When a small direct current is supplied to electrodes placed on the left and right mastoid tips just before the pinnas a DC electric, the perception of the direction of gravity is changed. A GVS device is shown in Fig. 2. The stimulation causes a physiological change, which is a perception of acceleration to the direction of the cathode-side. A standing person turns the body to the anode-side reflexively. The mechanisms involved in the effect are still not completely clear, but it is known that GVS makes ratio of vestibular-evoked myogenic potential amplitudes larger [2, 5].

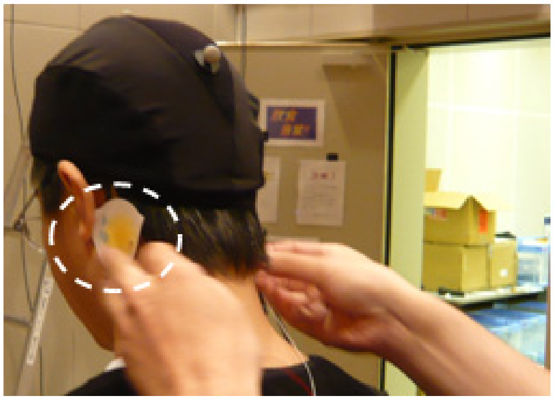

Fig. 2 GVS device of direct current is supplied to electrodes are putt on left and right mastoid tips just before the pinnas.

In experiments using GVS, Brain activity in coma subjects has been evaluated by measuring postural response of the eye [6] and diseases of the nervous system have been treated with random stimulation to the vestibular system [7]. In non-medical research, some actions have been guided using weak milliampere stimuli. Other research has examined guided walking and tried to clarify the influence of GVS on the perceptual coordinating system [9]. However, little research has examined GVS for the unconscious-guidance.

III. Experiments

A. Stimulus presentation and experimental environment

The GVS interface we used was developed by Ando et al [1]. Ando realized a guide system for walking with GVS. The devise is shown in Fig. 2. A current Miller circuit provides a stable current. By using H-bridge circuit, the user can choose the direction of current arbitrarily. The devise can supply current of -2.0 to 2.0 mA. The electrodes are made of gel and are 50 mm x 40 mm in size. They are put on left and right mastoid tips just before the pinnas. Subjects experience the illusion that their bodies lean to the side of the anode. Users can control the resistance to adjust the current based on their perception. We define the stimulation that their bodies lean to the right is positive stimuli, and that to the left is negative stimuli.

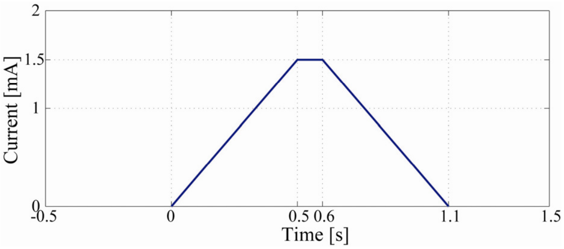

Fig. 3 Temporal shape of current for GVS

We used a maximum current of 1.5 mA, the same amplitude as in Ando's report [1]. The temporal shape of the current is trapezoidal as shown in Fig. 3. The current is increased from 0 to 1.5 mA in 0.5 s, held at 1.5 mA for 1.0 s, and then reduced to 0 mA in 0.5 s. Following the advice of a medical doctor, we restricted the total stimulation time for each participant in each day to less than 1 minute with a 3-minute interval between stimulations.

For measurements, we used an optical motion capture system (MotionAnalysis, MAC3D), which has 12 cameras with 1.3-million-pixels resolution. The accuracy of the system is less than 0.7 mm. The field of the measurement area is 4 m x 4 m. Measurement points were totally 10 points: three on the head, two on the shoulder, one on the right elbow, three on the right hand, and one on the pen point.

B. Circle-drawing experiment

Three participants took part in the experiment. All of them are right-handed. Participants' heads were fixed by a chin rest 0.4 m above the table top and sat on a chair with a backrest as shown in Fig. 4. Participants were instructed to draw circles clockwise continuously. The size of the circles and the drawing speed were not stipulated. Participants practiced beforehand to determine their most stable circle size and drawing speed. In the practice phase, participants' eyes were open, and they continued until they could draw circles stably. In the experiments, we used a sensor to generate positive-direction GVS at the 225-deg point as shown in Fig. 5. This is because preliminary experiments showed that the effect is largest with a positive stimulus at the 225-deg point. Ten trials were conducted for each direction per day. One subject did 30 trials and the others did ten trials in this direction. In the negative stimulus condition, we used random directions without 225-deg so that to prevent participants from guessing the stimulus directions.

C. Result

In Fig. 6, dots represent the movement of the gravity center point of each circle just after GVS and that of the next circle. Upper panel shows the results with positive stimulus; the lower shows those with negative stimulus. The results show a tendency of rightward motion for the positive stimuli. The gravity center point was calculated from the mean of the captured position data in each circle. First, we determined the

Fig. 4. Photograph of the experiment.. The small silver small balls on the head, hand, elbow, and shoulder are reflecting balls for the motion capture system.

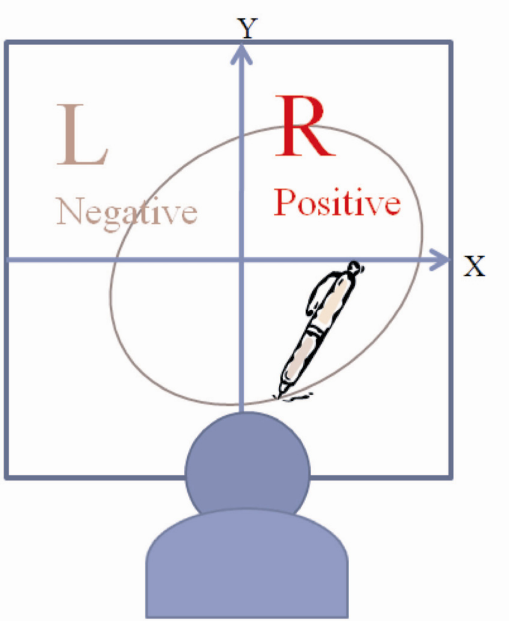

Fig. 5. Trajectory and stimulation point of drawing. Participants drew circles clockwise. GVS was generated when participant's hand was at the 225-degree point.

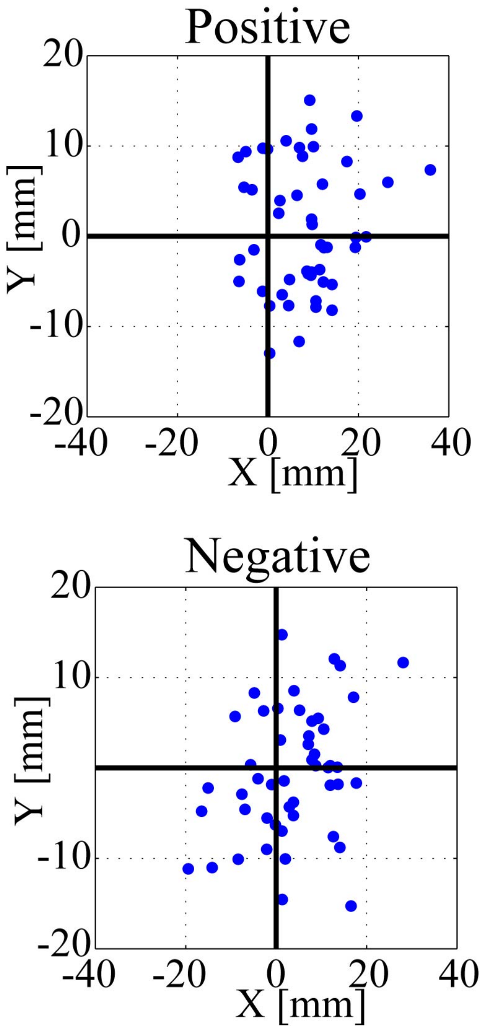

Fig. 6. Changes in the gravity center point of drawn circles. Upper panel: positive-direction GVS. Lower panel: negative-direction GVS. In the upper panel the majority of the dots are on the right side.

center point as the average of all circles for each participant. Then we separated the trajectory to each circle by calculation from hand position to hand angle from the center point. Then, we calculated the gravity center point in each circle.

Fig. 7 shows a bar graph of movement of the gravity center point of each circle in X (left and right). GVS was applied between "b-1" and "a-1", where b-1 stands for "before 1" and means the circle drawn just before GVS, and a-1 stands for "after 1" and means the circle drawn just after GVS. ; a-2 means the next circle of a-1 and b-2 means previous circle of b-1. There is a clear tendency for the gravity center points to move from left to right under this closed eye and after practice condition. Gravity center point moves to the right largely between a-1 and a-2. This change is significant (p<0.001 in T-test). Other differences between

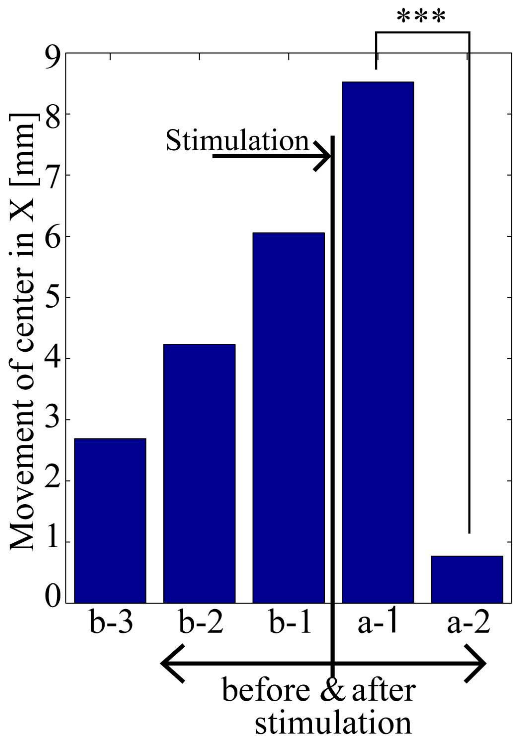

Fig. 7. Changes of the center point of drawn circles before and after GVS, where "b-1" stands for the first circle before GVS, "a-1" stands for the first circle after GVS. The center point significantly changed between the third and second circle after GVS.

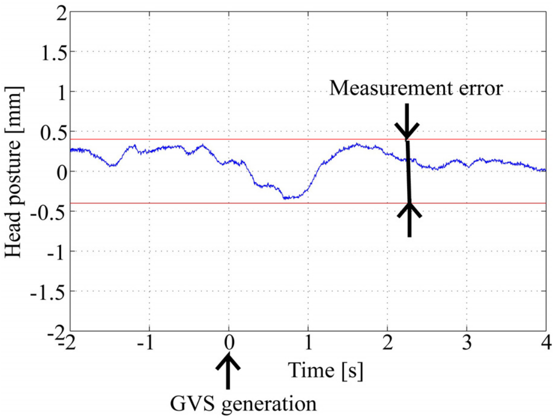

Fig. 8. Trajectory of head movement from -2 to 4 s. GVS was generated at 0 s.

each bar are not significant, but between b-2 and b-1, there was a weak tendency ($p<0.05$ in T-test). In addition, the results for negative GVS indicate no significant effect. Therefore, we conclude that this GVS can guide the hand to the right. This experiment was done with stable posture, sitting with the head fixed. This posture is more stable than in previous work and shows the possibility of GVS effecting in the stable posture condition. We asked the participants to identify the direction of GVS, but they could not always answer correctly. This indicates the stability of their posture. We think that if the participants had taken a standing posture, they would have been able to correctly identify the GVS directions, which means that these results suggest the usefulness of applying GVS when the posture is stable. In addition, we measured head movement with only 0.4-mm measurement error. In Fig. 8, the blue line shows the averaged head trajectory in the X direction. 0 was set as the average of head posture. The two red lines show the measurement error from the 0 point. The area between the red lines is within the measurement error. Time 0 was set when GVS was applied. These data confirm that the participants' heads were fixed.

D. Discussion

The reason the results for positive and negative GVS are different is not clear, though a possible factor is that all of the subjects were right-handed and drew the circles clockwise. This remains as future work.

We examined whether the hand movement by GVS influences vestibular sensation using two control stimuli. Experimental results of electrotactile stimulation and sound stimulation are shown.

Electrotactile stimulation was supplied to the positions (left and right mastoid tips) similar to GVS. The stimulation current used 1kHz burst waveform of which the envelope curve was the trapezoid as was used for GVS. Fig. 9 shows hand movement results in circle drawing with this stimulation. Three participants were instructed to draw circles clockwise continuously. Positive-direction electrotactile stimulation was generated when participant's hand was at the 225-degree point. From the average of three participants, their right hand moved left before three circle drawing times (b-3) of the stimulation beginning and the gravity center point was kept steady. Afterwards, their hand moved right after two circle times (a-2) of the stimulation. However, the moved distance between a-1 and a-2 was about 1.5mm. This change is a weak significant tendency ($p<0.05$).

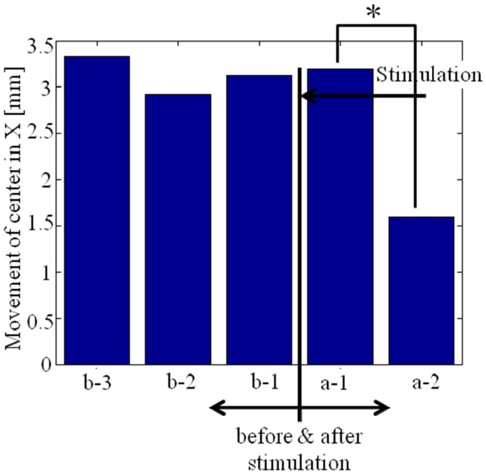

Fig. 9. Change of the center points of drawn circles before and after the electrotactile stimulation, where "b-1" stands for the first circle before the stimulus, "a-1" stands for the first circle after the stimulus.

Next, the earphone was put on participant's ear and hand movement result in sounding beep shown in Fig. 10 was obtained. Three participants were instructed to draw circles clockwise continuously. Positive-direction sound stimulation was generated when participant's hand was at the 225-degree point. The gravity center points of their circle drawing shifted rightward and leftward before-and-after the beginning of stimulation. A significant difference was not admitted in these movements. However, the gravity center point moved to the right side by about 1mm from a-1 to a-2, as well as GVS and electrotactile stimulation.

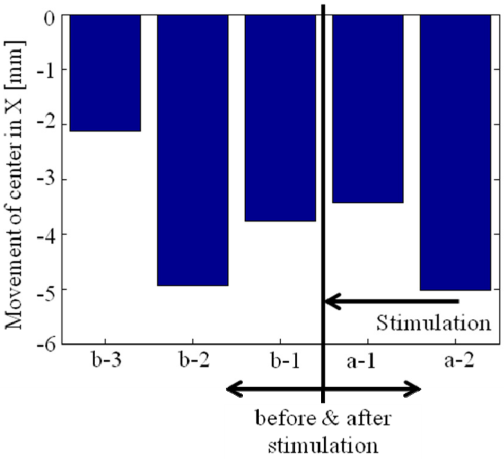

Fig. 10. Changes of the center point of drawn circles before and after sound stimulation, where "b-1" stands for the first circle before stimulus, "a-1" stands for the first circle after stimulus.

From these results, it is shown that GVS can guide the hand in a significant distance when circle drawing. The guidance distance of the hand by GVS is 8mm, and it is longer than 1.5mm of the electrotactile stimulation. The difference is significant. Therefore, the effect of GVS used by our experiment is not equivalent with the electrotactile stimulation and it influences vestibular sensation. And it is considered that the hand movement was guided by causing the acceleration sense of vestibular sensation.

This latency of GVS is considered with related GVS studies. In previous work, the walk latency was about 1 sec. and that of the bar-push was about 240 ms from GVS. It was about 2 sec. in this experiment, which is almost equal to the time it took to draw one circle. One possible reason why the latency is so long in our experiment is that participants could prepare the trajectory of their arm movement for the next circle by the effect of practice. Our interpretation is that they drew the a-1 circle on the basis of the prepared trajectory and at the same time they prepared the trajectory of the next circle and then they drew a-2. After that, we can observe the effect of GVS. This mechanism seems to be same as in the case of walking. In walking, 1 sec. can also be understood as a time it takes to take one step.

The absolute value of the effect of GVS is also important. In the bar-push experiment, the length of push was 0.35 m and effect was about 1 deg [4]. Therefore, absolute distance of guidance of the hand was about 6 mm. Our experiment dealt with circle movement and its gravity center, which makes a comparison difficult. However, the movement of the gravity center was about 10 mm. The current was 3 mA in the bar-push experiment; it was 1.5 mA in ours. This suggests that the absolute value of GVS in this experiment was larger than that in the previous work. However, the length of the action in this experiment was about three times as long. All things considered, we think the two results are close. Of course, this is a very rough discussion. We plan to try to clarify how to produce a large effect to the hand by GVS and discuss the details in future work.

IV. CONCLUSIONS

We measured continuous arm action with stable posture and evaluated the effect of GVS during the circle drawing action. GVS guided the hand to the right in the circle drawing experiment with right-handed sitting participants with a stable posture and head fixed condition. Participants did not feel the GVS direction. In addition, they could not correctly identify the direction of GVS after stimulation. Moreover, measurements with the motion capture system showed that their heads moved less than 0.4 mm, which is the measurement error of the system. The guidance in this experiment was possibly unconscious guidance because participants could not perceive the guidance direction. In our experimental condition, the latency of GVS was 2 sec., the same time it took to draw a circle. The latency is equal in length the one cycle of target action, the same as in the case of walking. The absolute value of the guidance was about 10 mm as the movement of gravity center point. It is roughly about the same order as in previous work. We will try to clarify the details about the latency, the left and right difference, and the duration of the effect.

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