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# The Balance Perception Changes by Motor Learning with Active Trunk Movements

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***Abstract*— This paper investigates that the motor learning has an influence on the human perception, focusing on an upright balance. In order to apply some disturbances, we have constructed a special stool which moves horizontally as well as rotates around the roll direction. This stool allows us to provide two different conditions for the motor learning phase in whether an active trunk movements for balance maintenance is required or not. The comparison of the balance perception tests before and after the motor learning phase indicates that balance perception, i.e., the subjective upright posture, has changed if the subjects have repeated trunk movements during the motor learning phase.**

## I. Introduction

Human behaviors are planned and performed under some kinds of sensory information. Humans make the most use of such information to know their current situations, and then decide what they should do next. Based on perceptual results from the sensory signals about the environments or their internal states such as posture or spatial position, the motor control or its learning are taking place.

From this causality in the human motor control, an idea, “the sensory information has an effect to the motor control or learning” is naturally deduced. Indeed, feedback control, which is also incorporated in the human motor control, is a mechanism that can suppress disturbances from the environment based on the sensory information. Now, is it possible that the motor behaviors affect sensory properties in reverse? It is not an easy question to answer, because, though the sensory information as the reasons is first and the motor behaviors as the results come next in the general flow of the motor control system, they are inverted in this question.

About the above question, the somatosensory adjustments were reported in the arm reaching movements under the force field conditions [1], which indicates that motor learning can affect the sensory perceptions. This report brought us an idea that this kind of sensory adaptation is not limited in the somatosensory system, and generally takes place in other sensory perceptions. Among many perceptions, we focused on the balance perception. Regarding the balance perception, it has been reported that the visual information, one of the sensory perceptions, affects the balance perceptions [3], [4], or the standing posture [5]. However, the relation between the balance perception and the motor learning has not been discussed.

In our previous study, we demonstrated that the balance learning surely affects the perception of the upright posture even in the seated situations [6]. However, we did not elucidate which factors are crucial for this kind of sensory adaptation in the balancing movement. In this paper, we postulate active trunk movements are essential to the perceptual changes in the balancing task. Then we attempt to show the change of the upright posture perception based on human motor measurements.

## II. Reconsideration of Experiment Method

### A. Purpose

Hypothesizing that balancing perception is adjusted by continual balance maintenance, we performed the following experiments for some subjects [6].

A motor learning task was designed so that the subjects have to maintain the balance to compensate some disturbances. In order to produce the disturbances, we constructed a stool which can move to the lateral direction as well as rotate around the roll axis. The photo of the stool is depicted in Fig. 1.

Before and after the motor learning task, balance tests are performed to clarify the effect of the balance learning by comparing two results. In these experiments, the subjects were divided into two groups, the right group and the left group, by the direction of periodic disturbance caused by the gravitational effect. As a result, the perceptual upright posture tended to change to the opposite side against the disturbance directions.

In that study, we adopted a control experiment such that the subjects just sit on the stool without movements. Before and after this control experiments, the same balance tests were also performed. Because significant differences were not observed in the perceptual upright posture, we concluded that the motor learning had an influence on the balance perception.

However, these experiments did not reveal which factor in the motor learning had a large influence on the balance perception. Thus, this paper investigates such a factor by reconsidering the experiment method from this point of view.

### B. Procedure in the Previous Study

Before changing the experiment method from one in the previous study, we summarize it here.

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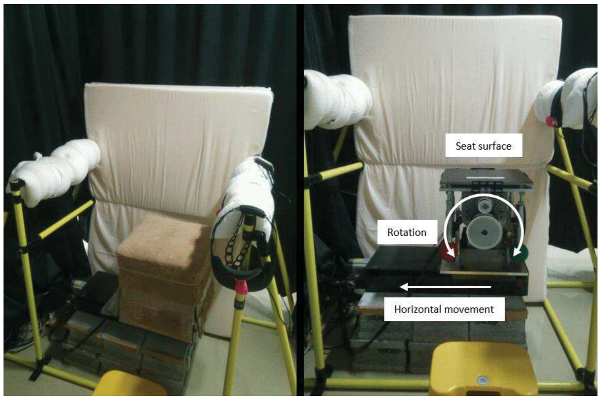



Fig. 1. The stool

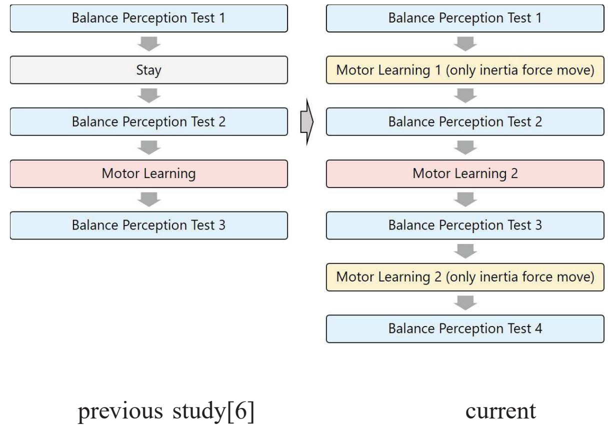



Fig. 3. The experimental procedure

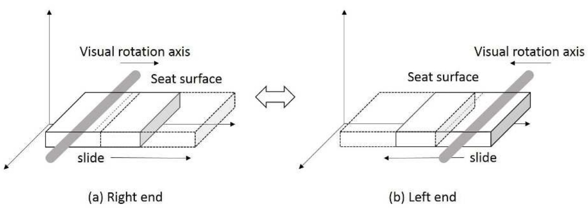



Fig. 2. The visual rotation axis movements

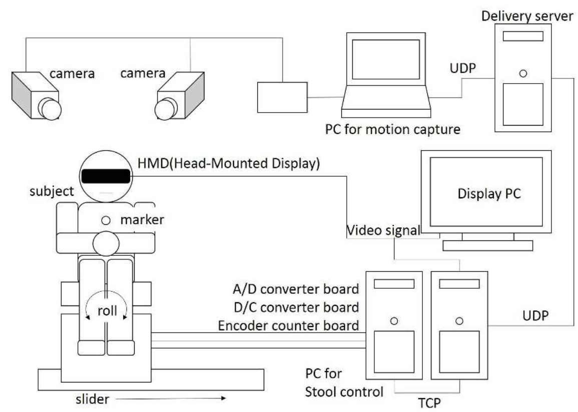



Fig. 4. The structure of this experimental setups

During the motor learning task, two kinds of disturbances were given to the subjects.

One of the disturbances is the rotation of the seat surface around the roll axis: suppose that the roll rotation of the stool is free without any actuations. Then, some displacements of the body weight from this rotation axis will unstabilize the stool surface and tilt it to this side. If this rotation axis could be set at an arbitrary position, it would be a good disturbance because the upper body like a trunk have to follows this position to maintain the balance. Actually, however, the rotation axis is mechanically fixed. So, the movement of the rotation axis are simulated virtually by the actuation of the rotation axis by the control: the rotation angle of the seat surface is controlled to tilt to the direction of the CoP (Center of Pressure) of the body in relation to this virtual rotation axis (in Fig. 2). Under this control, the virtual rotation axis was periodically slid from the center to the side, i.e., to the left (LEFT condition) or to the right (RIGHT condition), to disturb the subjects periodically.

Simultaneously, inertia force disturbance was given by sliding the whole stool laterally. This inertia force disturbance synchronized with displacement of a virtual rotation axis.

## C. Changes in Experimental Procedure

To compensate the disturbance caused by the seat rotation, active movements of the upper body were required. Then, we predicted that the effect of the compensative movements with respect to the displacement of the virtual roll rotation axis was crucial for the balance perception change.

How do we show that compensation movement to displacement of a virtual rotation axis during the motor learning has an influence on balance perception? In this paper, a learning phase during which only the horizontal movement is given with fixing a roll rotation of the seat surface is newly introduced by replacing the motor learning 1 in the original experimental procedure.

In order to evaluate whether the balance perceptual change persists for a while, another motor learning phase without roll rotations is introduced after the original motor learning.

The previous and the current experimental procedure are shown in Fig. 3.

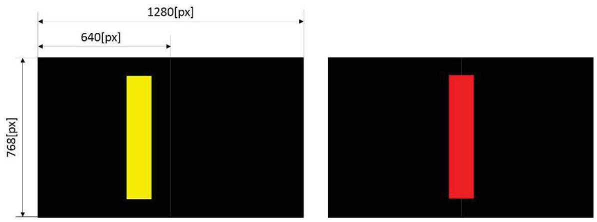



Fig. 5. The picture on HMD in the balance test

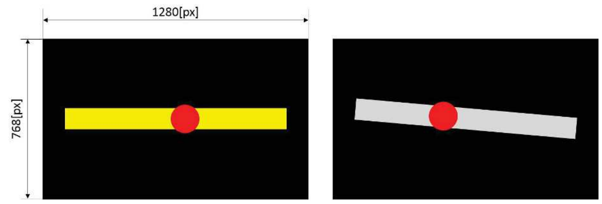



Fig. 6. The picture on HMD in the motor learning

## III. Experiments

### A. Setups

A total view of an experimental setup in the previous section is illustrated in Fig. 4.

In the experiment, a Head-Mounted Display (HMD) was adopted not only to present the visual information but also to instruct a manner of experimental tasks to the subjects. The HMD also has a role that blocks the visual information against the subjects. To measure the lateral sway angle of the subjects during experiments, a three-dimensional motion capture system was introduced. Two cameras installed over the stool tracked three LED lights attached as markers on the head, the neck and the abdomen. This systems enabled us to obtain subjects' movements in the three-dimensional coordinate frame. These data were sent to the display PC through the delivery server.

The GUI (Graphical User Interface) was constructed to allow the experimenter to set all parameters in the experiment, to input the results of the balance tests and to display the monitoring result of the subject motion. This PC for GUI is also connected to HMD that the subject were wearing, which was available to give some information or instruction for the subjects.

On the other hand, the A/D converter board, the D/A converter board and the encoder counter board were equipped on the control PC for the control of the stool motion. The output voltage from the force sensors installed in the stool is input to the A/D converter board through an amplifier, and the force is acquired. The torque of the motors installed in the stool were controlled by the motor drivers that receives the voltage commands from the D/A converter board on this PC. The tilted angle as well as the sliding distance of the stool were measured using the encoder installed in the motors which produces the pulse signals that were sent to and counted at the encoder counter board in this PC.

### B. Procedures

The procedure in this experiments is illustrated in the right of Fig. 3.

Three phases of the motor learning were included. In the second phase, both the horizontal move of the stool and the displacement of the virtual rotation axis were applied as the balance disturbance, while, in the first and the last phases, only the horizontal move was provided to the subjects; the roll rotation was fixed at the center of the stool.

The balance perception tests are performed before and after each motor learning. Therefore, the balance perception tests will be performed four times during one experiment. All balance tests are performed in the same conditions and the identical procedures. The results of the balance tests are compared after the experiment.

The details about the balance perception test and the motor learning are written below.

### C. Balance Perception Test

In the balance perception test, we attempt to detect a subjective upright posture at which the subjects feel not to be inclining to either to the left or to the right. The subjects are asked to take some target postures at which the body actually inclines toward the side direction. At this target posture, the subjects have to answer the following question with "left" or "right", "To which direction do you feel you are inclining?" This question is repeated about fifty in one perception test.

The target posture with the same sway angle will be presented several times during one perception test. But, sometimes the subjects may answer in a different way because this judgment is completely subjective. So, the posture in which the probability that the subjects answer "right" and the probability that the subjects answer "left" are the same is quantified as the subjective upright posture.

In order to lead the subject to the target posture, we utilize the figures drawn with the computer graphics drawn on the HMD as shown in Fig. 5. The figures consist of a yellow vertical bold bar (visual target) and a thin white vertical line at the center of the display. The yellow bar horizontally moves in synchronization with the body's lateral sway, i.e., the lateral displacement of the marker attached on the neck. In this experiment, the bar will shift 4 pixels if the marker shifts 1mm in the real space. The subjects were asked to incline so that the bar stops on the white line at the center of the display. In the case, the color of the bar changes from yellow into red. We instructed the subjects to maintain this target posture.

We can control the target posture by adjusting the initial bar position at the beginning of each question. Namely, the subjects will incline to the left side if the bar is presented to the right side intentionally, while the subject will incline to the right side if the bar is presented to the left side. PEST [2] is used for choice in this initial bar position.

When the perception test ends and the answers from the subjects are collected sufficiently, we calculate the probability to answer "left" in each posture. This probability with respect to the lateral sway angle to the left side is approximated with a logistic function, i.e., the psychometric function. The posture at which the probability takes 0.5 value in this psychometrics function corresponds to the posture at which an answer probability of "right" and "left" will be 0.5 together. This posture is regarded as the subjective upright posture.

### D. Motor Learning

In the motor learning 2, we can apply the subjects two kinds of periodic disturbance: inertia force disturbance by the stool horizontal move, and the displacement of the virtual rotation axis. Then, we set two experimental conditions; the left disturbance and the right disturbance, because the perception will change in a different way between two conditions.

Here, we will only explain about the condition "the LEFT disturbance". About the right disturbance, the direction of the following direction description should be reversed.

The former inertia force disturbance is commonly applied in all three of the motor learning phase by sliding the stool wholly to the left and the right. The amplitude of the stool slide is set to 40 cm in four seconds. In the left disturbance condition, the stool move to the left first. Afterward, the stool returns to the initial location in four seconds.

The latter disturbance is the displacement of the virtual rotation which is given to only the motor learning 2. This disturbance is achieved by virtually moving the rotation axis, 25mm, from 5mm right to 20mm left of the center of the seat surface, in four seconds: this virtual movement is realized by the control method in section II-B.

Afterward, the virtual rotation axis returns to the starting location reversely in four seconds. The subjects are instructed to keep the seat surface horizontal during the motor learning phase. Therefore, they have to move the trunk so that the CoP track the displacement of the virtual rotation axis.

According to the preliminary experiments, we found that it seemed difficult to maintain the level seat surface without any information on the current tilt angle of the seat surface. Thus, the visual feedback using HMD was introduced by drawing the tilt angle of the seat surface using computer graphics as shown in Fig. 6. In this illustrative instruction, a tilted gray rectangle is indicating the current situation of the seat surface in synchronization with the actual seat rotation, and turns yellow when the surface becomes almost horizontal, i.e., the tilted angle decreases within ± 8deg. We instructed the subjects to maintain the situation in which the rectangle is yellow.

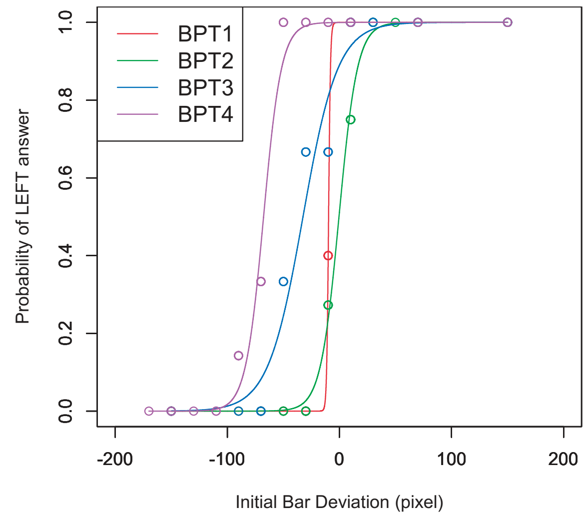



Fig. 7. The result of the subject 4 in RIGHT condition

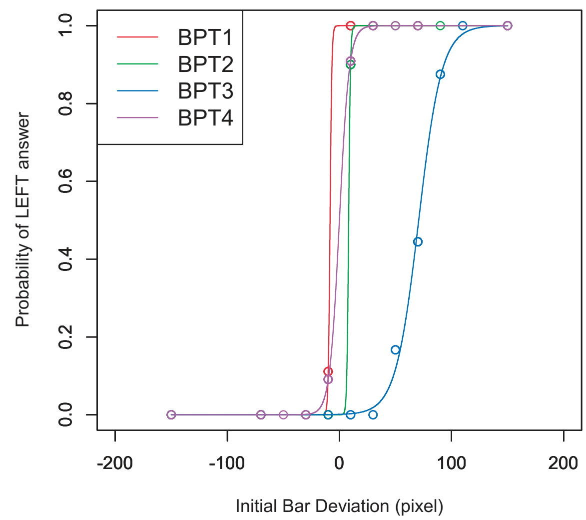
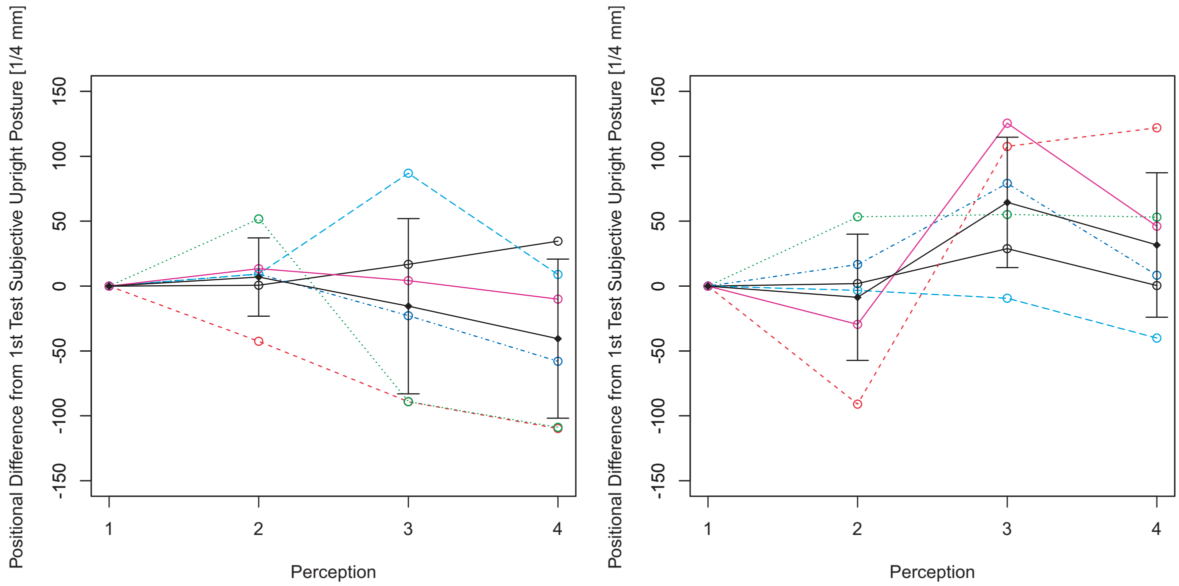



Fig. 8. The result of the subject 4 in LEFT condition

## IV. Results

Twelve subjects who were female or male, 20 to 24 years old and had no knowledge about the contents of this study were recruited. These subjects was divided into two groups of six persons by the disturbance direction in the motor learning phase 2: LEFT in which the subjects learn the way to maintain the balance under the left directional disturbance, and RIGHT in the opposite condition. This experiments was approval by Ethical Review Board of Gifu University School of Medicine (26-55).

As an example of the results of the balance tests, the result




(a) RIGHT (b) LEFT

Fig. 9. The displacement of the subjective upright posture

TABLE I
THE DISPLACEMENT OF THE SUBJECTIVE UPRIGHT POSTURE (PIXEL)

| | TEST1 | TEST2 | TEST3 | TEST 4 |
|---|---|---|---|---|
| R-1 | -11.047 | -9.190 | 17.829 | -10.588 |
| R-2 | 47.388 | -43.540 | 154.994 | 169.322 |
| R-3 | 61.978 | 115.336 | 117.107 | 115.093 |
| R-4 | -8.346 | 8.263 | 70.741 | 0.000 |
| R-5 | 32.561 | 29.239 | 23.170 | -7.489 |
| R-6 | -16.944 | -46.434 | 108.508 | 29.189 |
| L-1 | -7.798 | -5.941 | 21.078 | -7.339 |
| L-2 | -34.653 | -125.581 | 72.953 | 87.281 |
| L-3 | -40.400 | 12.958 | 14.729 | 12.714 |
| L-4 | -26.011 | -9.402 | 53.077 | -17.665 |
| L-5 | 13.191 | 9.869 | 3.800 | -26.860 |
| L-6 | -35.524 | -65.014 | 89.928 | 10.609 |

of subject 4 in the RIGHT is summarized on Fig. 7. The horizontal axis is the amount of the initial bar deviation into the right direction on the HMD (pixel), which is equivalent to the amount of the left inclination at the target posture: for example, when the deviation is +100 pixel, the target posture of the subjects will tilt to the 25 mm left than when the initial bar deviation is 0 pixel. The vertical axis of the graph is the probability, at each target posture, which the subjects answered “left” to the question “To which direction do you feel you are inclining?”.

The colors of red, green, blue and purple show each balance perception test 1, 2, 3 and 4 on the graph. The circles are the data calculated from the results, and the solid line shows the psychometrics function which approximates the measurement data by a logistic function.

It can be observed that this subject answers “left” in 1.0 probability at every balance perception test when the amount of displacement is +100 pixel and the target posture is supposed to be inclined to the left direction largely.

The result of subject 4 in the LEFT is also summarized on Fig. 8. In Fig. 7 and Fig. 8, we can find out, by comparing the balance perception test 2 with the balance perception test 3, that the subjective upright posture has changed to the opposite direction each other.

We calculated the value at which this psychometrics function takes 0.5 in each balance tests: these values obtained from every subjects are shown in Table I.

Biases can be observed in each subjects data on Table I. So, these biases are removed based on the value of the balance perception test 1 in the respective subjects. The change in subjective verticality during the respective balance perception tests in every subjects is shown on Fig. 9. Fig. 9(a) is the subjects data of RIGHT, and Fig. 9(b) is the subjects data of LEFT. According to this data, we find that the pixel value is changing to the minus, i.e., the right direction in the RIGHT group, and to the plus, i.e., the left direction in the LEFT group.

When it is changed for the posture of the subjects, the posture which feels verticality is changing to the right side in the subjects of RIGHT, and changing to the left side in the subjects of LEFT.

TABLE II
THE RESULT OF ANOVA

| | F | p |
|---|---|---|
| Factor R/L | 0.874 | 0.372 |
| Factor Tests | 1.121 | 0.356 |
| Interaction R/L | 3.819 | 0.020* |

To examine whether these changes were significant statistically, ANOVA of two factors was performed. The result in

Table II is F(30,3) = 3.819, $p < 0.05$: it indicates that it has the interaction between the direction of the disturbance and the presence of the motor learning.

So, Tukey tests were conducted to detect the significant difference next. The results are shown in Table III. In these tests, the significant difference was recognized between the balance test 3 of LEFT and the balance test 4 of RIGHT.

TABLE III

THE EVALUATION RESULT OF TUKEY TEST

| | L-2 | L-3 | L-4 | R-1 | R-2 | R-3 | R-4 |
|---|---|---|---|---|---|---|---|
| L-1 | 1.000 | 0.401 | 0.962 | 1.000 | 1.000 | 1.000 | 0.891 |
| L-2 | - | 0.250 | 0.875 | 1.000 | 1.000 | 1.000 | 0.969 |
| L-3 | - | - | 0.954 | 0.429 | 0.576 | 0.178 | 0.026* |
| L-4 | - | - | - | 0.970 | 0.993 | 0.788 | 0.287 |
| R-1 | - | - | - | - | 1.000 | 1.000 | 0.872 |
| R-2 | - | - | - | - | - | 0.995 | 0.756 |
| R-3 | - | - | - | - | - | - | 0.990 |

## V. CONCLUSION

In this paper, we expected that the subjective upright position is changed by the active movements of the trunk and their learning. And we composed an experimental system based on this expectation. The measurement experiments with twelve subjects indicated that

- The subjective upright posture had shifted before and after the motor learning.
- The shift direction of the subjective upright posture was different in two opposite disturbances during the motor learning phase.

However, the significant difference have not detected in the shift of subjective upright posture with respect to the disturbance direction, yet.

As our future works, we should recruit more subjects to obtain the significant difference. In addition, we would like to investigate the relation between the progress of motor learning and the magnitude of the perception change.

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