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An evaluation of equilibrium motor learning in the seated posture based on the CoP and the trunk motion

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Abstract: This paper aims at evaluating the progression of the motor learning in the balancing task in the seated posture. Our previous paper revealed that an equilibrium perception detecting the subjective upright was affected from a balancing task. To explain the process of this perceptual change, the behavioral evaluation of the motor learning task seems to be required. Here, we evaluated the behavior of the motor learning by the CoP movement and the mean trunk inclination. As a result, the former was categorized into two patterns based on the relative phase of the CoP against the controlled periodic seat movement. On the other hand, the latter was classified into three types with their mean and changing rate during the motor learning.

Keywords: equilibrium, seated posture, motor learning, evaluation, CoP, trunk inclination

1. INTRODUCTION

A study on arm reaching movements reported a somatosensory adaptation accompanying motor learning [1]. Expecting that such an adaptation occurs in other kinds of perception, we have designed experiments of the equilibrium perception and the motor learning. Our previous study found a fact that a kind of equilibrium perception, the subjective upright posture, had been affected after the equilibrium motor learning [2]. However, the same motor learning resulted in a different equilibrium perceptual change in its shift direction, depending on the control experiment before the true experiment of the motor learning [3].

In order to explain our results consistently, we came up to the thought that the extent to which the motor learning on the equilibrium had progressed should be evaluated adequately. Thus, this paper proposes two factors based on the CoP and trunk motion respectively. The next section mentions the experiments of the motor learning on the equilibrium and its setups. The section 3 defines the two factors for motor learning evaluation, and the section 4 shows the results based on them. The final section 5 concludes this paper.

2. MOTOR LEARNING

2.1. Setups

This experiment utilized a stool enabling the lateral slide and the roll rotation. Actually, this stool has three DoFs of motions, the lateral slide, the roll and the pitch rotation of the seat surface, each of which is independently actuated by AC motors. Their motions are controlled by the PC controller every 1m second. During the experiments, the pitch angles are fixed horizontally. Four loadcells are attached at each corner of the seat to detect the center of pressure (CoP) on the seat. Figure 1 shows photos of the stool.

To measure the behavior of participants, a three-dimensional motion capture system was introduced. Two cameras set over the stool can track three LED markers attached on the participants' neck, the roll rotation axis of the stool and a fixed point in the experimental space. Preventing the participants from touching the movable parts directly, the stool had to be covered by a cloth to ensure the safety. Thus, the second marker was pasted on the cloth at the position of the rotation axis. The data was recorded at the rate 60Hz.

The participants was asked to put on a Head-Mounted Display (HMD) which blocked out the visual information from outside as well as provided information on the seat tilt angle graphically.

2.2. Procedure

In the experiments, the participants were instructed to maintain their equilibrium so that the seat surface was being kept horizontal. However, the participants were disturbed by two kinds of stool movement: the lateral slide

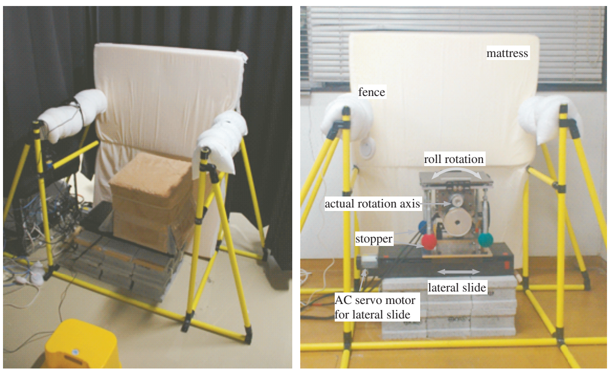
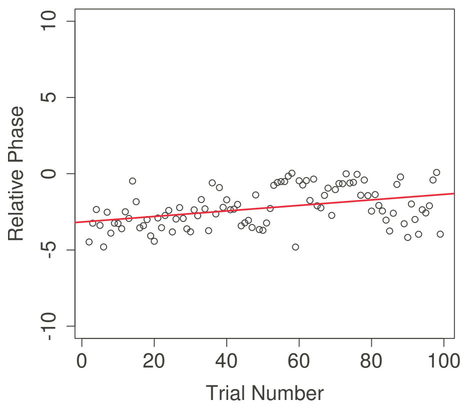
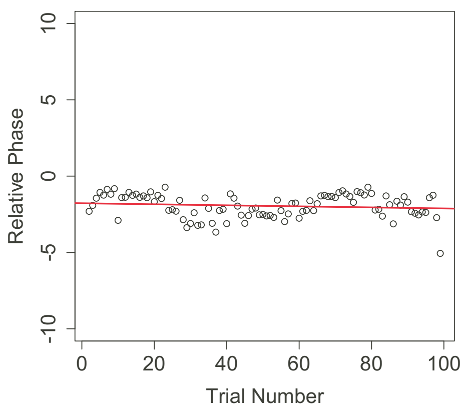


Fig. 1 Experimental setups.

† Satoshi Ito is the presenter of this paper.



(a) The first sample of RIGHT condition (No. 7)



(b) The first sample of RIGHT condition (No. 8)

Fig. 2 Relative phase of CoP with respect to the virtual rotation axis motion at each trial.

and the roll rotation. To apply the disturbance by the roll rotation, we set "a virtual rotation axis": if the CoP of the participant on the seat surface comes to the left of the virtual rotation axis, the seat rotates to the left slowly, even though the CoP is actually located at the right of the mechanical rotation axis of the stool. The moment of the seat rotation becomes larger in proportion to the distance between the virtual rotation axis and the CoP. This virtual rotation axis is realized by the control with the feedback of the force and rotation angle information.

During the experiment, the lateral slide of the stool is synchronized with the shift of the virtual roll rotation axis. As a result, two kinds of disturbances, the inertia force and the seat rotational instability, are applied to the participants. In order to maintain the seat surface horizontal, the participants have to move their CoP to match the shift of the virtual rotation axis.

Two different experimental conditions was tested by changing the disturbance direction, right and left.

In the "LEFT" condition, the stool initially slides laterally to the left in four seconds and then comes back to the right in four seconds: an eight-second return is counted as one trial. Synchronizing with the lateral slide, the virtual rotation axis moves 25mm from the vicinity of the center to the left direction and then goes back in four seconds

Table 1 Linear approximation in relative phase.

No.	cond.	α_1		β_1		resudials
		estimate	p-value	estimate	p-value	
1	LEFT	0.0024	0.421	-1.219	1.76.E-10	0.8169
2	LEFT	0.0158	0.000	-2.505	1.73.E-17	1.1494
3	LEFT	-0.0088	0.162	-3.150	6.44.E-14	1.7194
4	LEFT	0.0076	0.148	-2.573	1.85.E-13	1.4398
5	LEFT	0.0042	0.245	-2.262	1.21.E-18	0.9868
6	RIGHT	0.0031	0.376	-2.083	2.49.E-17	0.9625
7	RIGHT	0.0181	0.000	-3.169	2.05.E-22	1.1884
8	RIGHT	-0.0034	0.224	-1.777	5.39.E-19	0.7639
9	RIGHT	0.0041	0.025	-1.838	8.47.E-32	0.5003
10	RIGHT	-0.0054	0.196	-2.981	1.56.E-21	1.1563
11	LEFT	-0.0181	0.003	-1.938	1.51.E-07	1.6373
12	LEFT	0.0106	0.046	-2.256	4.18.E-11	1.4512
13	RIGHT	-0.0018	0.575	-1.549	9.31.E-13	0.9017
14	RIGHT	0.0025	0.001	-0.472	6.85.E-20	0.1953
15	RIGHT	0.0059	0.146	-1.881	2.51.E-12	1.1224
16	LEFT	0.0046	0.011	-1.885	4.11.E-33	0.4925
17	LEFT	-0.0018	0.594	-1.363	1.68.E-10	0.9126
18	LEFT	-0.0030	0.002	-0.566	3.23.E-17	0.2628
19	LEFT	0.0092	0.123	-2.436	1.99.E-10	1.6387

each. Accordingly, in the LEFT condition, the participants have to incline to the left to make the CoP follow the virtual rotation axis for keeping the seat surface horizontal.

The information on the tilt angle of the seat surface and the current position of the virtual rotation axis is displayed on the HMD with the graphic figure: The color of the graphic tilting bar illustrating the seat tilt turns to the gray when the tilt angle exceeds ± 8 deg, while this is yellow when the tilt angle is within ± 8 deg. The participants are asked to keep the color yellow.

3. METHOD FOR EVALUATING MOTOR LEARNING

3.1. Relative phase between CoP and virtual rotation axis

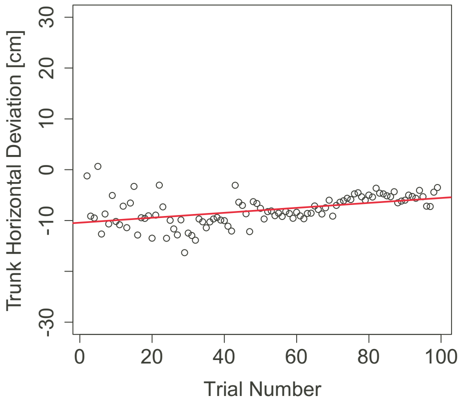
In the motor learning phase, the repetitive lateral shift of the virtual rotation axis were applied to the participants. Because the surface of the stool has to be kept horizontal, the CoP will track the movement of the virtual rotation axis in the preferable participants' action: if not, the surface will rotate due to its instability.

This is why we calculate the relative phase of the CoP movement with respect to the motion of the virtual rotation axis. Actually, the CoP movement was approximated by the sine wave with the same period as the motion of the virtual rotation axis, and the difference in the phase was calculated between them at each trial.

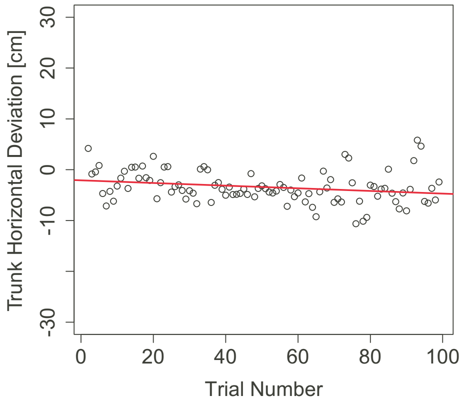
Usually, the CoP movement is delayed against the virtual rotation axis, implying that relative phase is negative at the start of the motor learning. Thus, the increment of the negative relative phase to zero will indicate that the motor learning has made progress.

3.2. Mean deviation of the trunk

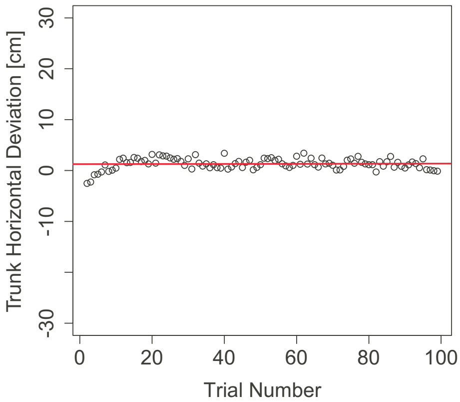
Only the trunk motion can adjust the tilted angle of the seat surface. Thus, the trunk motion can be one of



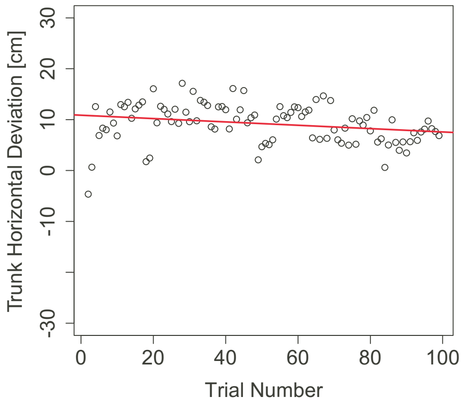
(a) The first sample of RIGHT condition (No. 6)



(b) The second sample of RIGHT condition (No. 10)



(c) The third sample of RIGHT condition (No. 8)



(d) Sample of LEFT condition (No. 4)

Fig. 3 Horizontal deviation of the upper body part from the center of the seat.

important factor to evaluate the motor learning.

The mean value of horizontal trunk deviation relative to the seat during eight seconds of one trial was computed as another evaluation of the motor learning.

4. RESULTS

4.1. Relative phase

Figure 2 shows the relative phases of the CoP with respect to the motion of the virtual rotation axis in the RIGHT condition. Dots present the relative phase at each trial and the red line denotes the linear approximation of them, i.e., $Y = \alpha_1 X + \beta_1$, based on the method of the least squares.

Two kinds of results were observed: the increasing relative phase, as shown in (a) and the decreasing one such as (b). The similar results were obtained in the LEFT conditions. The estimates are summarized with their p-value and the residuals (the root of average of the squared residuals) in Table 1. Unfortunately, the estimates of the slope, α_1 have high p-values in more than a half of the participants.

4.2. Mean deviation of upper body part

The mean horizontal deviation of the trunk were depicted in Fig. 3: (a), (b), (c) are results in the RIGHT condition, whereas (d) is the one in the LEFT condition. Note that the mean deviation was distributed to both sides even in the same RIGHT condition: the right in (a) and (b) with positive mean deviations, while the left in (c) with negative ones. Within the negative mean deviation, both positive and negative rates of the deviation by the trials were observed. In the positive rate, (a), the trunk is getting upright, while the trunk inclination will become larger in the negative rate (b). No increasing mean deviation was observed in the positive mean deviations such as (c).

The same tendencies were found in the LEFT condition. Figure 3(d) will be the symmetrical case to Fig. 3(a).

We also noticed that some participants showed the large deviations like Fig. 3(a), (b) and (d), whereas some participants showed the small deviations as shown in Fig. 3 (c).

The result of the analysis was summarized in Table 2. The approximation equation is $Y = \alpha_2 X + \beta_2$ and the estimates, its p-values, the residuals (the root of average of the squared residuals) and the deviation average over the motor learning phase are listed up.

5. DISCUSSION AND CONCLUSION

The first factor, the relative phase, is expected to increase from the negative value to zero for all the participants. However, a few of participants did not show this tendency. We might not be able to regard the motor

Table 2 Linear approximation in trunk deviation.

No.	cond.	α_2		β_2		resudials	average
		estimate	p-value	estimate	p-value		
1	LEFT	-0.0264	0.0000	4.4029	3.38.E-22	1.6646	3.0711
2	LEFT	0.1363	0.0000	-8.7846	2.31.E-06	8.3675	-1.9025
3	LEFT	0.0309	0.0007	1.9352	2.39.E-04	2.4272	3.4937
4	LEFT	-0.0328	0.0160	10.8589	6.09.E-25	3.7115	9.2010
5	LEFT	0.0150	0.0551	7.0191	2.94.E-28	2.1410	7.7766
6	RIGHT	0.0487	0.0000	-10.4244	6.72.E-34	2.6588	-7.9650
7	RIGHT	0.0134	0.3993	-5.9565	3.83.E-09	4.3976	-5.2782
8	RIGHT	0.0011	0.7799	1.2529	3.45.E-07	1.0951	1.3088
9	RIGHT	0.0197	0.0000	2.4710	3.10.E-32	0.6634	3.4657
10	RIGHT	-0.0260	0.0195	-2.0942	1.36.E-03	3.0385	-3.4092
11	LEFT	0.0103	0.2769	3.6427	1.35.E-09	2.5996	4.1606
12	LEFT	0.0481	0.0001	7.3557	1.56.E-18	3.2242	9.7850
13	RIGHT	-0.0097	0.0712	-4.9480	6.51.E-29	1.4770	-5.4390
14	RIGHT	-0.0019	0.2698	0.9042	3.67.E-14	0.4553	0.8048
15	RIGHT	0.0104	0.1003	3.0377	5.08.E-13	1.7416	3.5643
16	LEFT	-0.0036	0.6757	8.4889	4.74.E-35	1.3785	8.3610
17	LEFT	0.0197	0.0770	17.9752	2.11.E-48	1.7863	18.6838
18	LEFT	0.0390	0.0000	-0.0920	5.04.E-01	0.6572	1.8784
19	LEFT	-0.0098	0.1900	3.6970	1.48.E-13	2.0578	3.2021

learning as having progressed sufficiently in such a case. In addition, the high p-value of the slope estimates indicating no significant differences from the zero slope may have to be taken into consideration for the evaluation of the motor learning progression.

Unexpected results were found in the second factor, the mean of the trunk horizontal deviation. Our expected result was the one in Fig. 3 (a) in which the trunk inclined to the side to the virtual rotation axis deviation and this inclination was decreasing with the trials of the motor learning. However, in Fig. 3 (b) the inclination was enlarged. We might be able to regard this as the failure of the motor learning. In addition, in Fig. 3 (c), the trunk inclined to the opposite side to the deviation of the virtual rotation axis. About this phenomena, one participant said he had bent double the trunk to the side: at first the body was bent to the side of the virtual rotation axis at the lower joint around the pelvis, and then was bent again to the opposite side at the higher waist joint. It was a reasonable explanation consistent to the result in Fig. 3 (c) that can be derived from the sole marker measurement attached around the neck. We should have put the markers on the different points of the trunk to confirm the posture in Fig. 3 (c).

In our future works, we are going to investigate the adaptation of the equilibrium perception with considering these evaluation of the motor learning.

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REFERENCES

[1] D. J. Ostry, M. Darainy, A. A. G. Mattar, J. Wong, and P. L. Gribble, "Somatosensory plasticity and motor learning", *The Journal of Neuroscience*, Vol. 30, No. 15, pp. 5384-5393, 2010.

[2] S. Ito, Y. Ishikawa and M. Sasaki, "Experiments on perceptual change accompanying motor learning in seated balance" *Transaction of SICE*, Vol. 50, No.12, pp. 852-860, 2014

[3] S. Kumagai, S. Ito, K. Matsushita and M. Sasaki: "The Balance Perception Changes by Motor Learning with Active Trunk Movements", *Proc. of 2015 IEEE/SICE International Symposium on System Integration (SII2015)*, pp. 936-941, 2015