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Intervention of Self-Monitoring Body Movement has an Immediate Beneficial Effect to Maintain Postural Stability

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Abstract

Clinicians in rehabilitation sometimes encourage patients to become consciously aware of somatosensory inputs from the body. However, it is still unclear whether such intervention has any beneficial role on human postural control. The present study conducted two experiments to investigate whether an intervention involving conscious awareness of the body (i.e., self-monitoring) contributes to improved ability of postural control as measured immediately after an intervention of self-monitoring. All participants were subjected to four interventions: (a) self-monitoring actual movement (referred to as "move + monitoring" condition), (b) self-monitoring the imagined movement ("imagery"), (c) actual movement without self-monitoring ("move + arithmetic"), and (d) performing an arithmetic task without movement ("arithmetic"). The amounts of postural sway among measurements after the four interventions were compared. The results showed that, for the unipedal posture, but not for the bipedal posture, postural stability was higher after the move + monitoring intervention. This suggests that the self-monitoring activity is beneficial to postural control when maintaining upright posture is more challenging. Postural stability was also higher after the imagery condition, ensuring that the beneficial effects would have resulted from the activity of self-monitoring itself but not simply from accurate movement. These results were replicated in the two experiments, showing the reliability of the data. Interestingly, such beneficial effects were evident not only when participants self-monitored the movement of the ankle joint, i.e., the joint which is directly involved in upright postural control, but also when they self-monitored movement of the wrist (Experiment 1) or shoulder (Experiment 2).Therefore, the beneficial effects of self-monitoring are likely to be independent of the body parts used for self-monitoring.

Keywords: Postural control; Sensori-motor training; Body awareness; Attention

Introduction

Some clinicians in rehabilitation encourage patients to become consciously aware of body movement. We have recently provided evidence that the intervention involving self-monitoring joint movement at the ankle and wrist is likely to be beneficial to improve the stability of unipedal posture as measured immediately after intervention [1]. During the intervention session (a self-monitoring intervention), participants sat in a chair while blindfolded and moved either their ankle, i.e., the joint which is directly involved in upright postural control [2-5], or their wrist, i.e., the joint which is not likely to be essential for upright postural control. They were asked to concentrate on the position of the limb and try to reproduce the target joint angle as accurately as possible. The results showed that, for unipedal standing, postural stability was significantly higher after the self-monitoring intervention than after the control intervention, during which their self-monitoring of the movement was disrupted with a concurrent arithmetic task. Interestingly, self-monitoring of both the movement of ankle and that of the wrist was effective.

In the present study, two experiments were conducted to further the understanding of the beneficial effects of self-monitoring the body. The purpose of the first experiment was to exclude the possibility that the beneficial effects of the self-monitoring intervention in Yasuda et al. [1] were simply the result of performing more accurate movement under the self-monitoring intervention than under the control intervention. The measurement of the accuracy in reproducing the target angle either by the ankle or by the wrist showed that the reproduction error was significantly higher under the control intervention due to concurrently performing the arithmetic task. It is therefore, possible that the beneficial effects of the self-monitoring intervention may have resulted simply from the beneficial effects of accurate movement but not from the activity of self-monitoring. To exclude this possibility, a new intervention condition called "imagery" intervention was introduced in Experiment 1. During the imagery intervention, participants imagined, but did not actually reproduce, a target angle either with the ankle or the wrist. We hypothesized that, if the activity of self-monitoring itself was beneficial, then upright posture should become more stable when measured immediately after the imagery intervention.

The purpose of the second experiment was to address the meaning of the results in Yasuda et al. [1], in which the beneficial effects of self-monitoring were evident for unipedal standing when both the movement of the ankle and that of the wrist were monitored. There are at least two possible explanations for these findings. First, the beneficial effects of self-monitoring were likely to be independent of the body part used.

If this explanation were the case, then the beneficial effects of self-monitoring would be observed with any part of the body being self-monitored. Secondly, the wrist joint had significant contributions to maintaining postural stability. To determine which explanations were more plausible, the shoulder joint was selected for self-monitoring in Experiment 2. Compared to the contribution of the movement of the ankle joints, the contribution of the movement of the shoulder joint to

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control the upright postural stability is not high. Selecting the shoulder joint was, therefore, suitable to test the validity of the two explanations.

Experiment 1

Method

Participants: Sixteen young adults (8 males and 8 females, ages: 25.4 ± 5.6 years) participated. The mean bodyweight of the participants was 54.76 ± 8.98 kg. Four of them engaged regularly in sports and physical activities (such as cycling, short-distance running, tennis, and walking). All participants provided written informed consent prior to their participation.

Inclusion criteria were (a) no sensory or motor impairments that could have influenced their balance, (b) ability to maintain balance with unipedal standing for more than 30 sec, and (c) scoring of the Movement Imagery Questionnaire-Revised (MIQ-R) [6] exceeding our criteria. For the scoring of the MIQ-R, the participants were first required to execute four purposive movements, immediately followed by the motor imagery of the same movements using the first-person perspective (i.e., as if they were feeling themselves perform the movements from within). The participants then rated their capacity to elicit mental images of the action on different seven-point scales (i.e., high imagery, 7; low imagery, 1). An individual who scored more than five points for an average of four imagined movements was regarded to be suitable for this experiment.

Apparatus: An electronic goniometer (Flexible 2D goniometry, Biodex, USA) was used to measure the joint angle during the intervention sessions. Another goniometer (Standard Goniometer, Medical Arts Press, USA) was also used for the real-time sampling of the joint angle during practice trials preceding the intervention. A metronome (KDM-2, KORG, Japan) was used to maintain the movement speed during the practice trials. Force plates (type9281B, Kistler InstrumenteAG, Winterthur, Switzerland) were used to determine the center of foot pressure (COP) during unipedal bipedal standings.

Procedure

Procedure and interventions: The Tokyo Metropolitan University's ethics committee for human research approved the procedures employed in the study. The entire procedure (Figure 1) was carried out in a postural control study room.

At the beginning of the experiment, a baseline measurement ("pre-test") of postural sway under both unipedal stance with the non-dominant leg (left for all participants) and bipedal stance was conducted as a pre-test. The order of the stance selected for initiating this measurement was counterbalanced among the participants. For measurement under each stance, the participants stood barefoot on a single-force platform with their eyes open while looking at a fixed eye-level target at a distance of approximately 2 m. The participants intended to minimize their postural sway. Each stance consisted of three 30-sec trials with a 10-sec rest between trials.

Two minutes after the end of the pre-test of the postural sway, the participants moved onto a preceding practice session for the interventions. First, the participants were engaged in practice for a joint-angle reproduction task, in which they tried to reproduce a predefined target angle with a joint movement as precisely as possible. For this task and during this session, the participants sat while blindfolded. For reproducing the target angle, the participants moved either their ankle or wrist with the experimenter's assistance until it reached the target angle. The participants were asked to hold the target position for 3 sec to remember the target angle. Holding the position for three seconds was considered to be long enough to identify the position [7]. They repeated this practice five times. Once aware of the target angle, they moved to the next repetition to maintain the speed of the joint movement. For this practice, a metronome was used to maintain the joint movement speed. The participants were required to move the ankle or wrist joints from the start position to the target angle for 2 seconds and then moved back toward the start position for 2 seconds. No assistance from the experimenter was provided for this practice. The order of the joint selected for initiating this practice was counterbalanced among the participants.

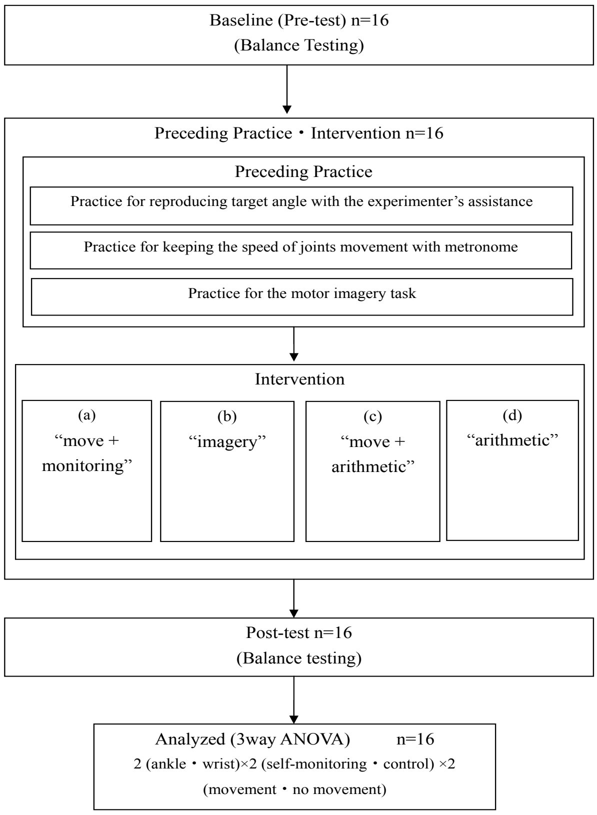

Figure 1: Participants' flow diagram in Experiment 1.

When participants performed an imagery intervention, there was an additional preceding session for creating a clear image of movement. In this session, the participants were asked to imagine the joint reproducing task repeated three times. Imagining the joint movement three times was considered to be sufficient to familiarize the participant with the simple motor imagery task [8,9]. All participants reported that they were able imagine the required movement after completing this preceding session.

After the practice session, each participant was subjected to 2 (self-monitoring, arithmetic) ×2 (movement, imagery/no-movement) interventions for the ankle and wrist. That is, each of the four interventions was (a) self-monitoring actual movement (referred to as "move + monitoring" condition), (b) self-monitoring the imagined movement ("imagery"), (c) actual movement without self-monitoring ("move + arithmetic") and (d) performing an arithmetic task without movement ("arithmetic").

During each intervention, the participants were sitting blindfolded.

For the move + monitoring condition, the participants were asked to concentrate on the position of the limb and try to reproduce the target joint angle (20 degrees) by dorsiflexion of the ankle or extension of the wrist and to move the joint back toward the baseline angle (0 degree) 20 times as accurately as possible. The order of the joint selected for the reproduction task was counterbalanced among the participants. For the imagery condition, the participants were asked to imagine the joint-angle reproducing task 20 times. For the move + arithmetic condition, the participants performed the joint-anglereproduction task 20 times while continuously subtracting 3 from the initial number 100. The subtracting task was intended to prevent the participants from self-monitoring the movement [10]. For the arithmetic condition, the participants performed only the arithmetic subtraction task.

Ten seconds after each intervention session, the participants conducted the measurement of postural sway under bipedal stance and unipedal stance with the non-dominant, left leg as a post-test. All the protocol for this post-test was identical to that for the pre-test.

Outcome measurements: Postural stability was expressed as the mean velocity of sway (total and in the AP, ML direction) and rectangular area calculated using COP data. The COP data, collected at the 20-Hz sampling frequency, was obtained using a Kistler force plate (type 9281B, Kistler InstrumenteAG, Winterthur, Switzerland). The data were low-pass-filtered at 6 Hz, since most of the power of the signal was <2 Hz [11]. Each mean velocity of postural sway and the rectangular area were calculated using the following formula:

$$\text{Mean velocity} = \frac{\Sigma_{i=1}^{n-1}\sqrt{(AX_{i+1} - AX_i) + (AY_{i+1} - AY_i)^2}}{S}$$

$$\text{Mean velocity in the AP direction} = \frac{\Sigma_{i=1}^{n-1}\sqrt{(AX_{i+1} - AX_i)^2}}{S}$$

$$\text{Mean velocity in the ML direction} = \frac{\Sigma_{i=1}^{n-1}\sqrt{(AY_{i+1} - AY_i)^2}}{S}$$

$$\text{Rectangular area} = (X_{max} - X_{min}) \cdot (Y_{max} - Y_{min})$$

To examine the amount of change in the postural sway from the pre-test to the post-test, the values of each measurement at the post-test were subtracted from the values at the pre-test (i.e., a negative value means that the posture became stable at the post-test). These subtracted values were used as the postural stability measures.

To examine the accuracy of movement performed during the interventions, the accuracy of reproducing the target angle (referred to as a joint-angle reproduction error; JRE) was measured for the move + monitoring and move + arithmetic conditions. The mean absolute difference between the reproduced angle and the target angle was calculated with the data of a task reproduced 20 times.

For the imagery condition, to qualitatively evaluate whether participants imagined the required movements accurately in terms of temporal congruence, the ratio of movement times in physically executed movements (E) and imagined movements (I) (referred to as the I/E time ratio) was calculated. The duration of physically executed movements (E) was measured in the "move + monitoring" condition with a digital stopwatch. For recording the duration of imagined movement (I) in the "imagery" condition, the initial cue was given by the examiner and the end of the imagination was indicated vocally by the participants. The imagined movements were considered to be accurate when the I/E time ratio was from 0.8 to 1.2 [12,13].

Statistical analysis: For each dependent measurement on postural control, a statistical test was separately conducted for the bipedal and unipedal standing task. A three-way (self-monitoring, movement, and body part) ANOVA with repeated measures on both factors was performed on each dependent variable with a 0.05 level of significance. A post-hoc comparison was performed to determine which comparisons were different. A paired t-test was used to compare the reproduction error values for each joint between the self-monitoring and control conditions. The level of significance was set at $p < 0.05$.

Results and Discussion

The means and standard deviations of the difference between the measurements at the pre-test and those at the post-test are shown in Table 1. For unipedal standing, the main effect of the self-monitoring was significant on the mean velocity of sway ($F(1,120) = 9.18$, $p < 0.01$). A post-hoc test showed that the velocity of sway was slower under the move + monitoring condition and the imagery condition than under the move + arithmetic condition and the arithmetic condition ($p < 0.01$). No significant interaction was found between self-monitoring and body parts, which indicated that the beneficial effect did not depend on the body parts used for the intervention. No other main effects and interactions were significant for any of the measurements. For bipedal standing, the main effect of the self-monitoring was significant on the mean velocity of sway ($F(1,120) = 5.90$, $p < 0.05$) and the mean velocity of sway in the AP direction ($F(1,120) = 4.46$, $p < 0.05$). A post-hoc test showed that the velocity of sway and the mean velocity of sway in the AP direction were higher under the move + monitoring condition and the imagery condition than under the move + arithmetic condition and the arithmetic condition ($p < 0.05$). No other main effects and interactions were significant for any of the measurements.

The joint-angle reproduction errors (JRE) and imagination/execution (I/E) time ratio are shown in (Table 2a and Table 2b) respectively. A paired t-test showed that, for the ankle and wrist joints, the JRE was significantly smaller under the self-monitoring condition than under

	Move + Monitoring	Imagery	Move + Arithmetic	Arithmetic
Unipedal Standing (n = 18)				
Ankle				
MV	-1.10 ± 0.35	-0.15 ± 0.40	-0.04 ± 0.26	0.04 ± 0.47
MV (AP)	0.34 ± 0.54	0.40 ± 0.99	-0.03 ± 1.06	0.45 ± 0.86
MV (ML)	-0.24 ± 0.73	0.43 ± 0.46	-0.06 ± 0.65	0.04 ± 0.92
REC	-1.36 ± 3.93	-2.31 ± 3.86	-0.83 ± 4.50	0.61 ± 7.28
Wrist				
MV	-0.18 ± 0.23	-0.01 ± 0.22	0.19 ± 0.22	0.06 ± 0.27
MV (AP)	0.56 ± 0.75	-0.09 ± 1.06	0.03 ± 0.71	0.00 ± 0.95
MV (ML)	0.24 ± 0.67	0.26 ± 0.80	0.24 ± 0.57	0.19 ± 0.85
REC	0.82 ± 2.34	-1.30 ± 4.42	-1.40 ± 3.32	1.35 ± 4.76
Bipedal Standing (n=18)				
Ankle				
MV	-0.02 ± 0.44	0.07 ± 0.36	-0.29 ± 0.26	-0.04 ± 0.48
MV (AP)	-0.14 ± 0.34	-0.08 ± 0.41	-0.10 ± 0.29	-0.04 ± 0.29
MV (ML)	0.05 ± 0.35	0.11 ± 0.43	-0.05 ± 0.52	0.22 ± 0.34
REC	0.12 ± 1.67	1.39 ± 3.63	-0.13 ± 2.78	-0.01 ± 1.97
Wrist				
MV	0.03 ± 0.41	0.07 ± 0.35	-0.12 ± 0.39	-0.09 ± 0.39
MV (AP)	-0.21 ± 0.35	-0.05 ± 0.26	-0.18 ± 0.34	0.02 ± 0.29
MV (ML)	0.04 ± 0.52	0.11 ± 0.47	0.12 ± 0.49	0.00 ± 0.39
REC	2.72 ± 7.20	-0.67 ± 2.38	2.16 ± 6.02	1.66 ± 3.40

MV: Mean Velocity (cm/sec); REC: Rectangular Area (cm^2)
A negative value means that the posture became stable at the post-test.

Table 1: Differences in measurements between the pre-test and post-test in each measuremen tin Experiment 1 (Mean ± SD).

the control condition ($p < 0.01$). All the I/E time ratios were within an acceptable limit (0.8-1.2) (Table 1 and Table 2).

The results showed that the beneficial effects of self-monitoring were evident for both the move + monitoring condition and the imagery condition. The values of the I/E time ratio ensured that, in the imagery intervention, the participants were able to imagine the joint movement accurately in a chronological sense. These results suggest that the beneficial effects would have resulted from the activity of self-monitoring but not simply from accurate movement.

The results replicated the findings of our previous study [1] that the immediate beneficial effects of the activity of self-monitoring were evident for unipedal standing but not for bipedal standing. In fact, the intervention of self-monitoring was rather detrimental on maintaining postural stability during bipedal standing. The results indicated that the beneficial effect of self-monitoring is beneficial only for a more challenging postural task. The results also replicated our previous findings that the beneficial effects of self-monitoring were evident when both the movement of the ankle and that of the wrist were monitored. Possible explanations are presented below.

Experiment 2

The results of experiment 1 replicated our previous findings that beneficial effects of self-monitoring were evident when both the movement of the ankle and that of the wrist were monitored. To address possible explanations for the results, the shoulder joint was selected as a body part to be self-monitored. If the beneficial effects of self-monitoring were observed even after self-monitoring the movement of the shoulder, then the beneficial effects of self-monitoring were likely to be independent of the body part used. If no beneficial effects were found, then the wrist joint tactile and/or proprioceptive inputs regarding the hand location significantly contributed to maintaining the postural stability.

Methods, results, and discussion

Methods: Eighteen young adults (9 males and 9 females, ages: 24.7 ± 3.8 years) participated in this experiment. The mean bodyweight of participants was 53.59 ± 6.78 kg. The inclusion criteria were identical to those used in Experiment 1. Five participants regularly engaged in sports and physical activities (such as mountain climbing, cycling, karate, taekwondo, and walking). Each participant gave written informed consent prior to participation.

The procedure was generally identical to that used in Experiment 1, except that three body parts (i.e., the ankle, wrist, and shoulder) were used. With regard to the activity of self-monitoring the shoulder joint, the participants were asked to reproduce a target angle (20 degrees) with abduction of the left shoulder and to move it back toward the baseline angle (0 degree) 20 times. During the MI condition, the participants tried to imagine the same movements as accurately as possible.

Results and discussion: Regarding postural stability, the means and standard deviations of the difference between the measurements at the pre-test and post-test are shown in Table 3. Regarding unipedal standing, a three-way ANOVA showed that the main effect of self-monitoring was significant on the mean velocity of sway ($F(1,240) = 9.57$, $p < 0.01$). A post-hoc test showed that the velocity of sway was lower under the move + monitoring condition and the imagery condition than under the move + arithmetic condition and the arithmetic condition ($p < 0.01$). There was no significant interaction between self-monitoring and body parts, which indicated that the beneficial effect did not depend on the body parts used for the intervention. Regarding bipedal standing, a three-way ANOVA showed that the main effect of self-monitoring was significant on the mean velocity of sway ($F(1,240) = 4.57$, $p < 0.05$). A post-hoc test showed that the velocity of sway was higher under the move + monitoring condition and the imagery condition than under the move + arithmetic condition and the arithmetic condition ($p < 0.05$). No other main effects and interactions were significant for any of the measurements.

A)

	Bipedal Standing (n = 18)		Unipedal Standing (n = 18)	
	Move + Monitor	Move + Arithmetic	Move + Monitor	Move + Arithmetic
Ankle	4.16 ± 1.28**	6.78 ± 1.63	3.87 ± 1.32**	6.94 ± 1.54
Wrist	3.22 ± 1.03**	5.64 ± 1.28	2.71 ± 0.71**	5.03 ± 1.71

B)

	Bipedal Standing (n = 16)	Unipedal Standing (n = 16)
Ankle	1.05 ± 0.04	1.06 ± 0.04
Wrist	1.05 ± 0.04	1.04 ± 0.05

**p<0.01

Table 2: A) Average absolute joint reproduction error in Experiment 1(Mean ± SD). p values were derived from paired t-tests.

B) Average imagination/execution time ratio in Experiment 2(Mean ± SD).

	Move + Monitoring	Imagery	Move + Arithmetic	Arithmetic
Unipedal Standing (n = 18)				
Ankle				
MV	-0.06 ± 0.34	-0.13 ± 0.40	-0.03 ± 0.36	0.07 ± 0.45
MV (AP)	-0.08 ± 0.71	-0.05 ± 0.60	-0.13 ± 0.70	0.06 ± 0.81
MV (ML)	-0.13 ± 0.84	0.16 ± 1.02	-0.07 ± 0.92	-0.13 ± 0.83
REC	-1.25 ± 3.07	-1.55 ± 3.23	-1.13 ± 4.11	-1.69 ± 5.87
Wrist				
MV	-0.15 ± 0.15	-0.08 ± 0.30	0.11 ± 0.25	-0.04 ± 0.27
MV (AP)	-0.40 ± 0.62	0.14 ± 0.61	-0.24 ± 0.50	0.01 ± 0.54
MV (ML)	0.46 ± 0.77	0.03 ± 0.74	0.18 ± 0.83	-0.33 ± 0.72
REC	0.84 ± 2.39	-1.20 ± 3.81	-0.34 ± 2.41	-0.28 ± 3.22
Shoulder				
Ankle				
MV	-0.15 ± 0.26	-0.01 ± 0.27	0.06 ± 0.19	0.00 ± 0.22
MV (AP)	-0.18 ± 0.67	-0.37 ± 0.75	0.02 ± 0.73	0.08 ± 0.78
MV (ML)	0.37 ± 0.58	0.26 ± 0.68	0.14 ± 0.80	-0.05 ± 1.02
REC	1.31 ± 1.97	-1.46 ± 3.75	-0.60 ± 2.09	0.15 ± 4.02
Bipedal Standing (n=18)				
Ankle				
MV	0.01 ± 0.47	0.16 ± 0.44	-0.21 ± 0.30	0.01 ± 0.51
MV (AP)	-0.04 ± 0.14	-0.01 ± 0.16	-0.05 ± 0.19	-0.08 ± 0.16
MV (ML)	0.10 ± 0.31	-0.01 ± 0.49	-0.02 ± 0.42	0.01 ± 0.54
REC	0.12 ± 1.56	0.82 ± 1.66	0.32 ± 2.28	0.08 ± 1.55
Wrist				
MV	-0.03 ± 0.43	-0.01 ± 0.36	-0.06 ± 0.41	-0.07 ± 0.42
MV (AP)	-0.04 ± 0.17	0.00 ± 0.18	-0.03 ± 0.17	-0.02 ± 0.19
MV (ML)	-0.04 ± 0.34	-0.03 ± 0.49	-0.01 ± 0.35	-0.18 ± 0.29
REC	0.57 ± 1.98	-0.46 ± 1.98	0.59 ± 1.89	1.50 ± 2.78
Shoulder				
MV	0.04 ± 0.34	0.07 ± 0.28	-0.08 ± 0.33	-0.01 ± 0.33
MV (AP)	-0.08 ± 0.24	-0.02 ± 0.16	-0.04 ± 0.16	0.04 ± 0.18
MV (ML)	-0.10 ± 0.47	-0.07 ± 0.41	-0.08 ± 0.42	-0.02 ± 0.34
REC	0.72 ± 1.95	-0.14 ± 2.00	0.79 ± 1.94	1.18 ± 2.07

MV: Mean Velocity (cm/sec); REC: Rectangular Area (cm^2)
A negative value means that the posture became stable at the post-test.

Table 3: Differences in measurements between the pre-test and post-test in each measurement in Experiment 2 (Mean ± SD).

A)

	Bipedal Standing (n = 18)		Unipedal Standing (n = 18)	
	Move + Monitor	Move + Arithmetic	Move + Monitor	Move + Arithmetic
Ankle	5.36 ± 1.28**	6.57 ± 1.63	4.18 ± 1.32**	6.27 ± 1.54
Wrist	3.22 ± 1.03**	5.64 ± 1.28	2.65 ± 0.71**	5.64 ± 1.71
Shoulder	5.52 ± 1.39**	6.17 ± 1.83	5.02 ± 1.32**	6.51 ± 1.54

B)

	Bipedal Standing (n = 16)	Unipedal Standing (n = 16)
Ankle	1.05 ± 0.04	1.06 ± 0.04
Wrist	1.05 ± 0.04	1.04 ± 0.05

**p<0.01

Table 4: A) Average absolute joint reproduction error (degree) in Experiment 2 (Mean ± SD). p values were derived from paired t-tests.

B) Average Imagination/Execution time ratio in Experiment 2 (Mean ± SD).

The mean reproduction errors and imagination/execution (I/E) time ratio are shown in (Table 4a and Table 4b). A paired t-test showed that, for the ankle, wrist, and shoulder joints, the reproduction error was significantly smaller under the self-monitoring condition than the control condition. All the I/E time ratios were within an acceptable limit (0.8-1.2) (Table 3 and Table 4).

The results showed that, for unipedal standing, the beneficial effects of self-monitoring were evident even when themovement of the shoulder was monitored. This suggests that the beneficial effect appeared to be independent of the body parts used for the movement. It is likely that the central nervous system can use not only the tactile and/or proprioceptive inputs from the lower limbs but also those from the whole body. The present results replicated the findings of Experiment 1 in that (a) the beneficial effects of self-monitoring were evident for both the move + monitoring condition and the imagery condition, and (b) the activity of self-monitoring was beneficial for unipedal standing but not for bipedal standing. These findings ensured the reliability of the findings.

General Discussion

The results of experiment 1 showed that the beneficial effects of self-monitoring were evident both when involving actual movement condition and when involving motor imagery. The same result was replicated in Experiment 2, showing the reliability of the findings. These findings suggest that the beneficial effects would have resulted from the activity of self-monitoring but not simply from accurate movement. The present results also showed that the beneficial effects of self-monitoring were evident not only when the movement of the ankle, i.e., the joint that is directly involved in upright postural control, was monitored but also when the movements of the wrist and shoulder were monitored. This suggests that the beneficial effect appeared to be independent of the body parts used for the movement. Notably, the activity of self-monitoring was beneficial for unipedal standing but not for bipedal standing. These findings seem to suggest that the intervention of self-monitoring may have been effective only for the performance of more challenging postural tasks. Such an explanation was consistent with a previous finding showing that tactile information is effective to modulate postural control under a more challenging postural task [14]. Furthermore, postural control for bipedal standing is a stable condition and familiar action pattern experienced in daily life [2,3]. Therefore, unlike postural control for unipedal standing, self-monitoring of body movements may promote conscious control of movements and result in interference with automatic motor control processes. In conclusion, the present study showed that self-monitoring has in itself some beneficial effects for the improvement of postural stability when maintaining the stability is challenging. This conclusion supports an intuitive understanding of the importance of self-monitoring when performing physical exercises [15-22].

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