

Original Article

How does physical guidance affect motor learning and learner's workload?

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Abstract. [Purpose] Physical guidance is routinely used in clinical practices such as rehabilitation to facilitate motor learning. Physical guidance would facilitate motor learning and reduce the workload; however, this relationship is unknown. Thus, we aimed to investigate this relationship using a physical guidance device. [Participants and Methods] Twenty-seven healthy young adults were randomly assigned to three groups and underwent varying practice conditions. The participants used a physical guidance device during practice for 2 days, did not use the device during practice for 2 days, or used the device on the first but not the second practice day. Motor learning was assessed by measuring the instability generated by the participants while maintaining a standing position on the Biodex Balance System. Psychological status was evaluated by analyzing the participants' responses to the National Aeronautics and Space Administration-Task Load Index. [Results] Improved performance was noted in all participants; however, those who used a physical guidance device during practice for 2 days exhibited poor motor learning compared with those assigned to the other two conditions. Frustration was significantly lower in participants who used a physical guidance device during practice than those who did not. [Conclusion] The use of physical guidance during practice can reduce participant frustration, but excessive physical guidance during practice reduces learning efficiency.

Key words: Motor learning, Physical guidance, NASA-TLX

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INTRODUCTION

Physical guidance is a commonly used approach in sports, rehabilitation, and surgical practice to help individuals acquire ideal movement. Physical guidance can be administered in the form of either a therapist's hands, a device to provide proprioceptive information for learners^{1, 2)}, or a means to reduce apprehension by preventing serious error during practice³⁾. In a rehabilitation setting, perspectives of motor learning or physical guidance are often used because they are needed to improve a motor skill that has been impaired by disease, aging, or disuse syndrome. Moreover, therapists can incorporate visual or auditory feedback in their physical guidance approaches to aid in the completion of a target task or to reduce the load of a patient. In recent years, robotic devices have been used to provide physical guidance; multiple studies have used robotic devices in clinical and rehabilitation applications to clarify human movement mechanisms⁴⁾. In the published literature, while physical guidance can yield immediate improvements in task performance during practice^{5–7)}, some studies claimed that

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there is a negative effect on motor learning on physical guidance^{5, 8, 9}). There is a lack of consistency in the results produced by robotic physical guidance, with some studies demonstrating that physical guidance using robots can be effective⁵⁻¹², yet others have shown that this approach was not beneficial^{5, 8, 9}). Additionally, it is known that physical guidance provides psychological influences such as frustration reduction, interest, accomplishment, or motivation¹³⁻¹⁵). In the physical therapy setting, the patient is unsteady in standing and walking due to a stroke or fracture of a lower limb, and this is a psychological burden on patients. Since intense anxiety has been reported to reduce performance¹⁶), physical guidance should reduce the workload on patients. However, the use of physical guidance to reduce the workload increases the amount of physical guidance. Since it has reported that error, which is the difference between intended movement and the actual movement, is necessary for motor learning¹⁷), excessive physical guidance may interfere with motor learning by overly reducing the amount of error. In the present study, we investigated the relationship between the effectiveness of motor learning and workload reduction by physical guidance.

PARTICIPANTS AND METHODS

Twenty-seven healthy adults (mean age, 25.7 ± 2.3 years; 8 females and 19 males) without neurological disorders or orthopedic disorders in the lower limbs were recruited for this study. Before the start of the experiment, all participants were informed of the purpose and methods of the research, and oral and written consent from each participant was obtained. This study received approval from the Ibaraki Prefectural University of Health Sciences Ethics Committee (Approval No. 745).

In this study, the learning task for participants was to maintain a stabilized posture on the Balance system (Fig. 1). In the standing posture, the right foot is put forward by a one-foot length from the closed-legged standing posture. Measurements were taken barefoot, and participants were not given special instructions about the upper limb position or gaze point. Participants were asked to hold the platform for 20 s while being parallel to the floor. The knowledge of results (stability index) was not presented to the participants after the trial.

The Biodex Balance System (Biodex Medical Systems, Inc., USA) was used in this study (Fig. 1). The platform instability of this system can be adjusted from Level 1 to 8, according to the level of difficulty. The most unstable condition, stability level 1, was used in this study. This instrument quantitatively measured the instability of the platform while patients held the standing posture, and measurements were outputted as a stability index (SI) reading to a monitor at the end of the task. The SI was calculated from the following equation, and it reflects the degree to which the platform swings back and forth and left to right during a task. A higher SI implies a greater platform swing, with a maximum value of 20 and a minimum value of 0. “x” indicates tilt angle of the platform in the left and right direction. “y” indicates tilt angle of the platform in forward and backward direction. “n” indicates sampling frequency.

$$\text{Stability Index} = \sqrt{\frac{\sum (0 - x)^2 + \sum (0 - y)^2}{n}}$$

Participants were randomly assigned to the three practice conditions, with the ratio of male to female kept relatively constant for the condition. Measurements were recorded over 3 days. On day 1, each group of participants performed 3 pre-test trials and 10 practice trials (practice 1). On day 2, participants underwent 3 trials of post-test 1 and 10 practice trials (practice 2). On day 3, participants performed three trials of post-test 2. Day 1 and day 2 measurements were taken on 2 consecutive days while day 3 measurements were taken 2 days after day 2. The National Aeronautics and Space Administration-Task Load Index (NASA-TLX) was administered to participants after day 1 and day 2 to assess their psychological status. The NASA-TLX^{18, 19}) is a subjective workload assessment scale consisting of six sub-items, mental demand, physical demand, temporal demand, performance, effort, and frustration¹⁹). For each of the six sub-items, a score from 1 to 100 was obtained using a graphical scale with “low-high” or “good-bad” as its two extremes, and the average value was calculated²⁰).

A self-made physical guidance device was given to participants. This device consisted of a metal frame, a pelvic belt, a metal wire, and 4 pull springs (Fig. 2). Participants wore the pelvic belt at the waist, and the belt was connected to a pull spring via wires from each of the four directions (anterior, posterior, right, and left). The wires and pull springs were fixed to a metal frame attached to the body of the balance system, which was independent of the platform. When posture is swayed, the spring in the opposite direction is stretched, generating tension. Before the start of each trial, the wire length was adjusted so that the spring would be the natural length with the platform tilt fixed at 0°. In this study, a pull spring with a natural length of 169.33 mm and a spring constant of 0.098 N/mm was used, similar to a previous study⁵).

Participants were categorized into three practice conditions. The first condition was physical guidance (PG)/PG group in which participants practiced with the self-made physical guidance device during both practices 1 and 2. The second condition was a PG/non-PG group in which participants practiced with a physical guidance device in practice 1, but not in practice 2. The last condition was a non-PG/non-PG group, where participants did not practice with a physical guidance device in both practices 1 and 2.

To clarify the differential effect of each practice condition on the SI, a two-way analysis of variance was performed with the mean values of 3 trials obtained at each measurement period (pre-test, practice 1, post-test 1, practice 2 and post-test 2) set as the dependent variable and the measurement period and practice condition (PG/PG group, non-PG/non-PG group, PG/non-PG group) as factors. Dunnett’s method for the measurement period and Tukey method for the practice condition



Fig. 1. Biodex Balance System.
The Biodex Balance System consists of a circular platform and a monitor.

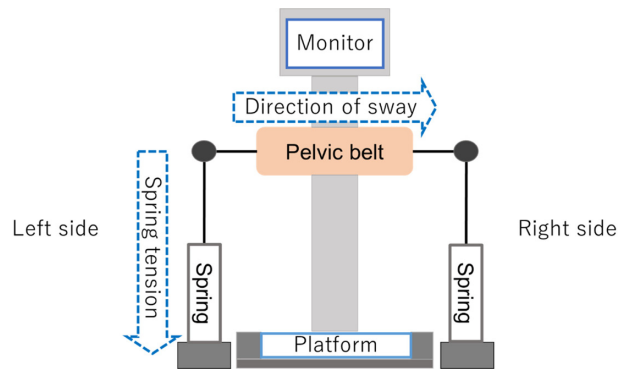


Fig. 2. Schematic of the Balance System and the physical guidance device.
If the participant sway in the right direction, a spring attached to the left side of the pelvic belt is stretched and generates a weak tension on the left side. This spring tension was not enough to prevent participant's fall. The pelvic belt was made of a non-stretching material and was attached to the participant's waist. The monitor shows the stability index for each trial. The participant stood on the platform facing the monitor.

were performed if significant differences were found. Since practice 1 and 2 consisted of 10 trials, the last 3 trials in which performance had stabilized were included in the analysis.

The one-way analysis of variance and Kruskal-Wallis' tests were performed to identify the differences in the practice conditions for each NASA-TLX item at each measurement period (after practice 1 and practice 2). Because the physical guidance device used in this study is expected to affect NASA-TLX, the results of PG/non-PG group on day 1 were divided into PG group and the results of PG/non-PG group on day 2 were divided into a non-PG group. As a result, there were 18 participants in the PG group and 9 in the non-PG group on day 1, and there were 9 participants in the PG group and 18 in the non-PG group on day 2. Mann-Whitney's U-test was performed on the two groups. All statistical analyses were conducted using SPSS ver.24 (IBM Corp., Armonk, NY, USA), with a statistical significance level of 5%.

RESULTS

The SI results for each practice condition at each measurement period are shown in Table 1. Two-way analysis of variance showed a significant main effect on the measurement period ($F_{2,941, 70.573}=56.669, p<0.01$, partial $\eta^2=0.702$) and a significant interaction between the measurement period and practice conditions ($F_{5,881, 70.573}=4.412, p<0.01$, partial $\eta^2=0.269$). Multiple comparisons indicated that the SI for all other measurement periods was significantly lower ($p<0.01$) than the SI for the pre-test for each practice condition. Multiple comparisons analysis also revealed in the practice conditions at each measurement period, only post-test 2 was significantly different, with significantly lower SI results in the non-PG/non-PG group and PG/non-PG group compared to the PG/PG group ($p<0.05$). The task performance was better in the non-PG/non-PG group and PG/non-PG group than in the PG/PG group (Table 1). However, there was no significant main effect on the practice condition ($F_{2, 24}=1.235, p=0.309$, partial $\eta^2=0.093$).

Among the six NASA-TLX items, a significant difference was found only in frustration. To investigate the effect of the physical guidance device on frustration, we divided the data of participants into the two conditions (with and without physical guidance device) and analyzed only the frustration item. The frustration in the PG group on day 1 was significantly lower than the frustration in the non-PG group ($p<0.01$) (Table 2), indicating the non-PG group experienced more frustration than the PG group. There was no significant difference between the two groups on day 2 ($p=0.057$) (Table 3).

DISCUSSION

Our study determined that participants performed better at all measurement periods than at the pre-test in all practice conditions, indicating motor learning had occurred. However, the PG/PG group had a poorer task performance and lower learning efficiency even when given the same amount of practice as the other two groups at the final post-test 2. As there was no significant difference in each practice condition at the time of post-test 1, we suspect that the use of a physical guidance device during practice 2 influenced the results of this study. The PG/PG group used the assistive device in both practices but had a poorer task performance on post-test 2 than the other two groups. It is generally understood that the error between the

Table 1. Means and standard deviations of stability index (degrees) for each period

Condition	Pre-test	Practice 1	Post-test 1	Practice 2	Post-test 2
PG/PG	12.95 (2.81)	8.65 (4.05)	10.49 (2.56)	5.85 (2.72)	10.15* (3.53)
Non-PG/non-PG	10.69 (4.17)	7.76 (3.47)	7.77 (3.37)	6.10 (2.95)	6.31* (2.64)
PG/non-PG	11.46 (3.51)	6.47 (2.63)	8.09 (2.42)	6.76 (2.52)	6.76* (2.05)

PG: physical guidance; Non-PG: non-physical guidance.

*The Tukey test indicated that SI in non-PG/non-PG and PG/non-PG groups were significantly lower than PG/PG group.

Table 2. Means and standard deviations of NASA-TLX (points) (post-practice 1)

Condition	Mental demand	Physical demand	Temporal demand	Performance	Effort	Frustration
PG	62.8 (26.3)	75.3 (18.8)	36.4 (18.5)	56.1 (16.7)	76.9 (12.4)	28.9* (22.8)
Non-PG	45.0 (26.3)	84.4 (5.8)	52.8 (30.4)	58.9 (27.7)	70.0 (17.0)	56.7* (22.5)

PG: physical guidance; Non-PG: non-physical guidance.

*The Mann-Whitney U-test indicated that frustration in PG group was lower than non-PG group.

Table 3. Means and standard deviations NASA-TLX (points) (post-practice 2)

Condition	Mental demand	Physical demand	Temporal demand	Performance	Effort	Frustration
PG	54.4 (23.8)	59.4 (27.0)	31.4 (17.9)	41.4 (22.4)	59.2 (22.6)	25.8 (23.2)
Non-PG	42.2 (23.9)	66.1 (12.7)	45.6 (20.2)	45.6 (24.6)	62.2 (20.3)	38.3 (25.2)

PG: physical guidance; Non-PG: non-physical guidance.

target exercise and the actual exercise is necessary for motor learning¹⁶⁾. Therefore, we believe that the assistive device may have reduced the error required for learning in the PG/PG group and resulted in inferior performance.

While efficient learning occurred in both the non-PG/non-PG group and the PG/non-PG group, there was no significant difference between the two groups. Considering the non-PG/non-PG group was the control group in this experiment, and the above-mentioned PG/PG group showed poor motor learning, it can be speculated that the PG/non-PG group obtained the same learning effect as the control group by combining the practice trials with and without the physical guidance device. An overview of the practice conditions used in the previous studies^{4, 5, 8–12)} indicates multiple studies employ physical guidance to a certain degree throughout the practice trial under the conditions where physical guidance of the movement is added. Conversely, in our study, we used a condition in which trials were conducted with and without physical guidance in a single practice condition. It is possible that successive use of physical guidance, such as in the PG/PG group, may inhibit motor learning, but we believe that these disadvantages can be eliminated by conducting practice trials without physical guidance.

Furthermore, in practice trials using a physical guidance device, we found a specific trend in the learners' standing posture control strategies. When we analyzed the tendency of the platform to sway during practice by dividing the conditions into those with and without a physical guidance device, we found that the platform tended to be tilted in one direction, forward or backward from the center, when the physical guidance device was used. This suggests that the physical guidance device may have influenced the posture control strategies used during the practice and test trials. This study did not give explicit augmented feedback, such as knowledge of results or knowledge of performance, and it did not examine the impact of augmented feedback. Participants were not given knowledge of results or performance as extrinsic feedback on practice trials, but only intrinsic feedback as knowledge of results on the task. The results of the sub-analysis of this study showed that there were differences in the tendency of the platform sway between the practice conditions, so it is possible that the addition of extrinsic feedback could influence the results of this study.

A previous study by Hidler et al.²¹⁾ reported that walking with robotic assistance resulted in a different pattern of muscle activity compared to normal walking. It has been demonstrated that external guidance, such as robots can change movement patterns and strategies. In the present study, we suspect that the postural control strategy differed between the practice and test trials due to the poor learning outcomes from the PG/PG group that continued to use the physical guidance device during the

practice trial. Moreover, participants who used the physical guidance device had lower frustration during practice. A previous study¹⁵⁾ by Marchal-Crespo et al. reported that participants who practiced with disturbances by robots (i.e., increased errors in motion) were less likely to experience interest, enjoyment, and task accomplishment during practice than participants with physical assistance (i.e., decreased errors in practice) and without assistance (i.e., control conditions). Although the results of the comparison with and without physical guidance devices differ from those of the present study, if we focus on the amount of errors that occur during practice due to the different conditions, we believe that the practice conditions with a relatively high amount of errors may indicate that the psychological burden felt by the participant during practice may increase. Therefore, we believe that physical guidance is useful when participants are easily stressed or practicing a difficult task.

The results of this study indicate that excessive physical guidance may inhibit the efficiency of motor learning. However, the use of physical guidance can be effective in reducing patient frustration. This demonstrates that physical guidance can be valuable, especially in rehabilitation settings, in which patients may become easily frustrated by the inability to perform daily activities because of their disabilities. Furthermore, this study suggests that it is necessary to incorporate practice trials without physical guidance into a practice schedule, as it does not interfere with motor learning but takes advantage of the psychological benefits of physical guidance.

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The authors declare that they have no conflicts of interest.

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