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Effect of loading parameters on motor performance during a dynamic weight-shift task

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ABSTRACT

Controlling weight shift (WS) is essential to performing motions safely and smoothly during daily and athletic activities. This study investigated the impact of loading parameters on the motor performance and difficulty level of a dynamic WS task performed while standing. Twelve healthy young adults (21.2 ± 0.9 years, 53.5 ± 7.4 kg) were asked to match the target and their weight loads using visual feedback displayed on a computer monitor. Motor performance was estimated by assessment of loading accuracy and pace of motor skill acquisition, measured as a proxy of difficulty level, was estimated by assessment of learning rate. As predicted, both loading accuracy values decreased with increasing target frequency. Notably, the interaction of loading size and frequency had a significant effect on loading accuracy, which was increasingly impaired as the weight load increased at frequencies greater than 0.5 Hz. Moreover, the pace of motor skill acquisition in a dynamic WS task while standing was affected by the weight-load speed independently of the weight-load size. These results indicate that loading accuracy is affected by both the weight-load size and frequency and that 0.5 Hz is a critical frequency at which the difficulty level increases during dynamic WS tasks while standing in healthy youths. These findings suggest that the adequacy of the initial settings used regarding loading size and frequency is an important consideration in rehabilitative and athletic training aimed at evaluating and improving WS while standing.

1. Introduction

Smooth weight shifting (WS) between the lower limbs is an important aspect of regulating the balance control required to accomplish daily activities [1,2] and performing functional motor tasks [3]. During dynamic and cyclic WS, such as gait regulation, the central nervous system (CNS) coordinates both the postural components that stabilize the body and the prime mover components that transfer the center of pressure (COP) [3], which entails ongoing changes in force and its distribution over the foot [4]. This coordination requires updating of ongoing information with regard to body kinematics and kinetics and is based on an internal representation of body posture that is continuously upgraded by a feedback mechanism [5]. Therefore, voluntary WS requires integration between the sensory and motor system in the CNS [1,2,4–7].

Voluntary WS tasks that are guided by visual feedback task have often been utilized to investigate human postural control and motor skill acquisition and improve motor functions in athletic and clinical settings [1,2,6,7]. The motor performance of a visually guided WS task is influenced by the speed (e.g., speed and accuracy trade-off [SAT] [8,9] and difficulty level with respect to the load frequency and size. Although similar findings have been reported regarding SAT while in a standing posture [1,2,6–9], the findings regarding the effect of load size on motor accuracy have varied among studies [10–12]. To our knowledge, few studies have attempted to confirm the effect of the load size during a dynamic and/or voluntary WS task while standing, and the effect of the weight-load size has been shown to differ in the laboratory compared to clinical settings [7,13,14]. This lack of research and the mixed findings of the few studies that have been conducted have prevented development of an optimal program using the appropriate weight-load sizes for improving motor functions in athletic and clinical settings [1–3,10–14].

The primary purpose of this study was to clarify whether loading parameters affect motor performance (i.e., loading accuracy) during a dynamic, visually guided WS task performed while standing. Additionally, it aimed to estimate the pace of motor skill acquisition using the learning rate [15] to clarify the relationship between loading parameters and the difficulty level of the WS task while standing. By doing so, the study tested the

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hypothesis that increasing the loading parameter decreases the accuracy of performance during a dynamic WS task and that this decrease in accuracy is associated with a change in the difficulty level.

2. Methods

2.1. Subjects

The demographics of the 12 healthy young adults (6 males and 6 females) who agreed to participate in this study are shown in Table 1. All subjects reported engaging in a moderate level of activity (i.e., sporting or recreational activities for more than 1 h every few days). Inclusion criteria were (1) ability to stand with one leg with closed eyes for over 30 s [11] and (2) a decimal visual acuity as assessed with the Landolt ring chart of over 1.0. The exclusion criteria were (1) history of fracture, (2) current disease, or (3) any symptom(s) that could affect mobility in the lower limbs. No subject was treated with medication during this study. All subjects provided informed consent in writing before performing all tasks. The experimental protocol was approved by the Ethics Committee of the Faculty of Health Sciences of Hokkaido University (accreditation number: 08-49) and performed in accordance with the 1964 Declaration of Helsinki.

2.2. Experimental setup and procedure

Subjects stood barefoot in the step stance and placed their leading limb on the force platform (Kistler, Type 9286A, Winterthur, Switzerland; Fig. 1A). The leading limb was defined as the dominant leg and described as the leg that would be used to kick a ball as far as possible [16]. A piece of white paper was fixed to the platform and the foot position was traced to confirm that the positioning would be maintained throughout the entire session. The non-dominant limb was positioned on the platform at the same height as the force platform posterior to the dominant limb [16] and spaced a comfortable step length apart such that the subjects could perform the WS task smoothly. The subjects were then asked to lengthen their neck and trunk to the greatest extent possible and to cross their arms over their chest. The force platform was connected to a PC computer to record changes in WS via measurement of vertical ground reaction force (vGRF) at a 1-kHz sampling rate (National Instruments, Austin, TX, USA). Visual feedback data were continuously displayed through measurement of real-time WS amplitude on a 17-in. monitor positioned in front of the subject (about 1 m at eye level) after being converted from 10-N to 1-mm units (Fig. 1A). All axes on the display were hidden to prevent the subjects from relying on memory regarding the WS amplitude. The upward and downward movement of the circle that appeared on the display corresponded to increases and decreases in the subject's WS, respectively.

Table 1
Participant demographics.

	Males ($n = 6$)	Females ($n = 6$)	All ($n = 12$)
Mean age (years)	21.3 ± 1.0	21.0 ± 0.9	21.2 ± 0.9
Mean height (m)	1.67 ± 0.6	1.55 ± 0.7*	1.61 ± 0.09
Mean body weight (kg)	57.0 ± 6.4	50.0 ± 7.0*	53.5 ± 7.4
Mean decimal visual acuity	1.0 ± 0.1	1.1 ± 0.1	1.1 ± 0.1

Value are presented as mean ± SD.

* Indicates a significant ($p < 0.01$) difference between males and females.

The aim of performance of the WS task was to use visual feedback to assist in the accurate and rapid shift of one's weight cyclically to the leading limb to match with the target without lifting one's toes or heels (Fig. 1A). During performance of the dynamic WS task, target loading was controlled sinusoidally [6,7,17] with a customized program (National Instruments Inc., Austin, TX, USA). No information regarding the task other than the

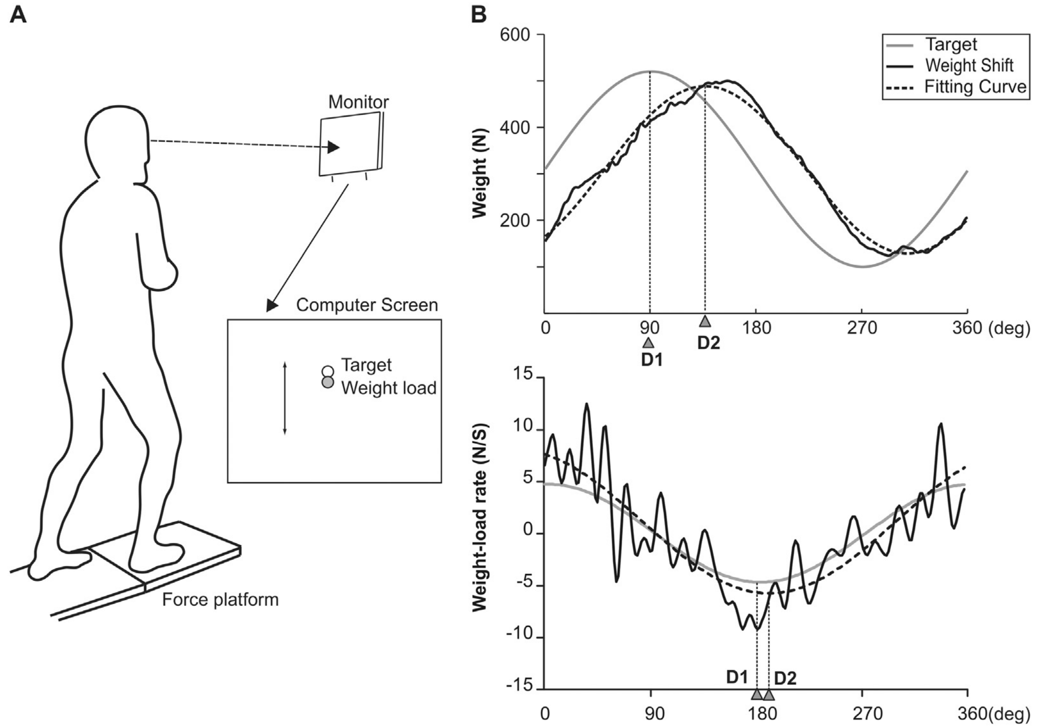

Fig. 1. (A) Schematic diagram of the weight-shifting (WS) task. Subjects were asked to match the target (white circle) with their weight load (black circle) by bearing their body weight onto the force platform. (B) A typical WS (top) and weight-load rate (bottom) graph of a large WS task at a target frequency of 0.5 Hz, with one cycle converted to 360°. The target is the gray line, the weight-load the thick line, and the fitting curve the dashed line. The top (or bottom) points of the WS (or weight-load rate) and the fitting curve to the WS (or weight-load rate) are labeled D1 and D2, respectively. The loading delay was calculated by subtracting D1 from D2.