DISSERTATION FOR A DEGREE OF DOCTOR OF PHILOSOPHY IN HEALTH SCIENCE

TOKYO METROPOLITAN UNIVERSITY

FUNDAMENTAL FEATURES OF PERFORMANCE ACCURACY IN LATERAL BODY WEIGHT-SHIFTING: FOCUSING ON CENTRAL TENDENCY EFFECTS, LATERAL DIFFERENCES, AND SUPPORT BY THE UPPER LIMBS

Miyoko Watanabe

Tokyo Metropolitan University
Graduate School of Human Health Sciences
Department of Health Promotion Sciences

July 2013
TABLE OF CONTENTS

Contents.............................................................................................................i
Acknowledgement ..............................................................................................iii
Abstract ..............................................................................................................iv
Lists of Tables and Figures.................................................................................vii

Chapter 1  Introduction .......................................................................................1

Chapter 2  Review of Literature ........................................................................4
  2.1 The Feature of Lateral Body Weight-Shifting Tasks.................................4
     2.1.1 Practical meanings of lateral body weight-shifting tasks in rehabilitation
     2.1.2 General methods of therapeutic exercise with respect to feedback in lateral body
         weight-shifting task
     2.1.3 Performance characteristics of lateral body weight-shifting in patients with
         orthopedic complaints or hemiparesis
  2.2 Fundamental Factors Affecting the Accuracy of Lateral Body Weight-Shifting Tasks.....14
     2.2.1 Central tendency effects of different amounts of target loads on the accuracy of
         lateral body weight-shifting
     2.2.2 Lateral difference in motor abilities with the use of lower limbs
     2.2.3 Effects of support by the upper limbs on quiet standing and gait

Chapter 3  Aim of This Study and Research Rationale......................................24

Chapter 4  Experiment 1....................................................................................28
Features of Performance Accuracy of a Lateral Body Weight-Shifting Task in Patients
with Orthopedic Complaints Compared with Healthy Participants
  4.1 Introduction
  4.2 Methods
  4.3 Results
  4.4 Discussion
Chapter 5  Experiment 2………………………………………………………………………………..44
Fundamental Features, Such as Central Tendency, Lateral Difference, and Support by the Upper Limbs on Performance Accuracy of a Lateral Body Weight-Shifting Task in Healthy Participants
  5.1  Introduction
  5.2  Methods
  5.3  Results
  5.4  Discussion

Chapter 6  Experiment 3……………………………………………………………………………….57
Effects of Reciprocal Interlimb Weight-Adjustment on Performance Accuracy in a Lateral Body Weight-Shifting Task in Healthy Participants
  6.1  Introduction
  6.2  Methods
  6.3  Results
  6.4  Discussion

Chapter 7  General Discussion……………………………………………………………………………….74
  7.1  Central Tendency Effects of Different Amounts of Target Loads on Accuracy of Lateral Body Weight-Shifting
  7.2  Lateral Difference of Performance Accuracy
  7.3  Effects of the Support by Upper Limbs and Reciprocal Interlimb Weight-Adjustment on Performance Accuracy in a Lateral Body Weight-Shifting
  7.4  Practical Implications for Rehabilitation
  7.5  Limitations of this study

Chapter 8  Conclusions………………………………………………………………………………………..81

References………………………………………………………………………………………..83
ACKNOWLEDGMENTS

During my six years of study, Professor Kuniyasu Imanaka provided conscientious guidance on all aspects of my research. Along with research techniques and approaches, he taught me to see the interesting aspects of analyzing human performance from a variety of perspectives.

Professor Ichiro Kita and Associate Professor Takahiro Higuchi also provided both constructive comments and warm encouragement of my dissertation and presentation in seminars.

I am also grateful to all of professors and students in the Department of Health Promotion Sciences in Tokyo Metropolitan University’s Graduate School of Human Health Sciences. The continual support they provided made my graduate school experience an enjoyable and rewarding one.

I would also like to thank Professors Hitoshi Maruyama, Hiroaki Tani, and Kazuo Kurosawa of International University of Health and Welfare, who always give me valuable insights, both as physiotherapists and instructors. Finally, I would like to express my heartfelt appreciation to my always-supportive family and friends.

Miyoko Watanabe

July 9, 2013
ABSTRACT

The lateral body weight-shifting task is used in a typical therapeutic program for patients with orthopedic complaints or hemiparesis, and is considered effective in helping patients recover from asymmetric weight distribution in affected and unaffected lower limbs during bipedal standing. This study examined the effects of fundamental features, such as central tendency effects, lateral differences, and light touch support by the upper limbs on performance accuracy in the lateral body weight-shifting task.

In Experiment 1, the features of performance in lateral body weight-shifting were examined for patients with orthopedic complaints (N = 11) compared with age-matched elderly healthy participants (N = 11). They were asked to accurately load one or two thirds of their body weight on a target (affected and unaffected for the patients and the left and right for the healthy participants) lower limb. They were allowed to use light touch support by placing their upper limbs/hands on horizontal parallel bars during the task. The accuracy of task performance was examined with constant error (CE), variable error (VE), root mean squared error (RMSE), and coefficient of intra-trial variation (CV). The features of the task specific to the patients with orthopedic complaints appeared in RMSE, which showed that the RMSE scores were larger when they loaded the two-third of the body weight than when they loaded one-third on the affected lower limb. Furthermore, the load on upper limbs was smaller for the patients with orthopedic complaints than that for the age-matched healthy participants. The results of CE scores showed biasing errors of both overshooting the one-third target load and undershooting the two-thirds target load, which indicated central tendency effect, in both the patients with orthopedic complaints and healthy participants. Therefore, the central tendency effects may well
occur in lateral body weight-shifting for both patients with orthopedic complaints and healthy people in common.

Experiment 2 examined the fundamental feature of central tendency effects, which may occur in common with patients and healthy people, in relation to lateral differences and light touch support by the upper limbs in lateral body weight-shifting, testing healthy participants. Forty right-handed and -footed participants were assign to one of two groups differing in the use of support by the upper limbs; the support group (N = 24) and the no support group (N = 16). For the support group alone, the mean CE score indicated an undershooting (i.e., a relative or partial central tendency effect) and the mean RMSE score indicated lateral differences. The mean CV score for the support group was smaller than that for the no support group, indicating a benefit of the use of support by the upper limbs for performance stability.

Experiment 3 examined the effects of the support by upper limbs on task performance, particularly the feature of central tendency effects, in lateral body weight-shifting in healthy participants (N = 23). To this end, the relationships between the respective loads on the upper and lower limbs during body weight-shifting were examined in terms of correlation analyses. This showed that the participants often used reciprocal interlimb weight-adjustment between the upper and lower limbs. Furthermore, correlation analyses showed that the reciprocal interlimb weight-adjustment correlated both with the degree of overshooting at the condition of one-third target load and with the degree of undershooting at the condition of two-thirds target load.

To summarize, the features of the patients with orthopedic complaints and the fundamental feature in common to both the patients with orthopedic complaints and the healthy participants were shown in Experiments 1 to 3. First, the central tendency effects generally occurred in lateral body weight-shifting. Performance accuracy of the patients with orthopedic complaints showed an undershooting when the relatively heavy amount of the body weight was
loaded on the affected lower limb. Second, the support by upper limbs had both positive (stable task performances) and negative (large undershooting) effects on performance accuracy of lateral body weight-shifting. Finally, the reciprocal interlimb weight-adjustment correlated with the degree of overshotting and undershooting in lateral body weight-shifting.
LISTS OF TABLES AND FIGURES

Table 1. Characteristics of patients with orthopedic complaints. ...........................................29

Figure 1. (a) Experimental task and time course, (b) experimental setting consisting of 2 force plates and parallel bars, and (c) a schematic view of foot pressure (vertical axis) as a function of time during lateral body weight-shifting, with the last second being used for error/load data collection. .................................................................30

Figure 2. Mean CE/w scores in patients with orthopedic complaints (a) and healthy elderly participants (b) for both the one-third and two-thirds target loads in the affected and unaffected side for the patients and the leftward and rightward for the healthy participants body weight-shifting. ..........................................................................................35

Figure 3. Mean VE/w scores in patients with orthopedic complaints (a) and healthy elderly participants (b) for both the one-third and two-thirds target loads in the affected and unaffected side for the patients and the leftward and rightward for the healthy participants body weight-shifting. ..........................................................................................36

Figure 4. Mean RMSE/w scores in patients with orthopedic complaints (a) and healthy elderly participants (b) for both the one-third and two-thirds target loads in the affected and unaffected side for the patients and the leftward and rightward for the healthy participants body weight-shifting. ..........................................................................................37

Figure 5. Mean CV scores in patients with orthopedic complaints (a) and healthy elderly participants (b) for both the one-third and two-thirds target loads in the affected and unaffected side for the patients and the leftward and rightward for the healthy participants body weight-shifting. ..........................................................................................38

Figure 6. Mean upper limb loads in patients with orthopedic complaints (a) and healthy elderly participants (b) for both the one-third and two-thirds target loads in the affected and unaffected side for the patients and the leftward and rightward for the healthy participants body weight-shifting. ..........................................................................................39
Figure 7. Mean CE/w scores in the support group and the no support group for both the one-third and two-thirds target loads in the leftward and rightward body weight-shifting. .......49

Figure 8. Mean VE/w scores in the support group and the no support group for both the one-third and two-thirds target loads in the leftward and rightward body weight-shifting. .......50

Figure 9. Mean RMSE/w scores in the support group and the no support group for both the one-third and two-thirds target loads in the leftward and rightward body weight-shifting. .......52

Figure 10. Mean CV scores in the support group and the no support group for both the one-third and two-thirds target loads in the leftward and rightward body weight-shifting. ...............53

Figure 11. Mean upper limb loads in the support group for both the one-third and two-thirds target loads in the leftward and rightward body weight-shifting. .........................54

Figure 12. The mean scores of correlation coefficients, which were performed inverse Z-transformed correlation coefficients, between the two limbs in the condition of (a) the 1/3 leftward, (b) the 2/3 leftward, (c) the 1/3 rightward, and (d) the 2/3 rightward.................62

Figure 13. Scatter plots for CE/w and the size of Z-transformed correlation coefficients between (a) the right lower and the left upper limb in the one-third target load at leftward shift, (b) the left lower and the right upper limb in the two-thirds target load at leftward shift, (c) the right lower and the right upper limb in the two-thirds target load at leftward shift, (d) the left and right lower limbs in the one-third target load at rightward shift, (e) the left and right lower limbs in the two-thirds target load at rightward shift...............................64

Figure 14. (a) Mean CE/w scores and (b) mean z-scores of CE/w for both the one-third and two-thirds target loads in the leftward and rightward body weight-shifting....................65

Figure 15. (a) Mean VE/w scores and (b) mean Z-scores of VE/w for both the one-third and two-thirds target loads in the leftward and rightward body weight-shifting....................66

Figure 16. (a) Mean RMSE/w scores and (b) mean Z-scores of RMSE/w for both the one-third and two-thirds target loads in the leftward and rightward body weight-shifting....................68
Figure 17. Mean CV scores for the condition of one-third and two-thirds target load in the leftward and rightward body weight-shifting………………………………………………….69

Figure 18. Mean upper limb loads for both the one-third and two-thirds target loads in the leftward and rightward body weight-shifting………………………………………………….70
Chapter 1  Introduction

The aim of this study is to clarify the effects of fundamental features, such as central
tendency effects, lateral differences, and light touch support by the upper limbs on performance
accuracy in a lateral body weight-shifting task. The lateral body weight-shifting task is used in a
typical therapeutic program for patients with orthopedic complaints (e.g., fracture, ligament
injury, and osteoarthritis and so on) or hemiparesis, and considered effective for helping patients
recover from asymmetric weight distribution in affected and unaffected lower limbs during
bipedal standing.

Patients with orthopedic complaints often show asymmetric weight-distributed posture,
tilting to the unaffected side/lower limb. Viton et al. (2000) examined the duration of single
support phase in lower limbs during walking in patients after unilateral knee arthritis. They
showed that the duration of the support phase on an affected lower limb were shorter than that
of the unaffected lower limb. These asymmetric postures may be associated with suffering
abnormal standing and walking, and this would lead to a risk of fallings (see Chapter 2).
Therefore, the lateral body weight-shifting task is important for patients to improve asymmetric
posture and thus prevent falls.

In the lateral body weight-shifting task, patients are asked to shift and maintain a
certain load to the affected lower limb, generally with support by placing both the upper limbs
on horizontal parallel bars to prevent falls. In the early stage of rehabilitation, a relatively light
target load such as one third of the body weight is utilized, whereas in the later stage, a heavy
target load such as two thirds of the body weight is utilized. The clinical purpose of the use of a
light target load in the early stage of rehabilitation is to avoid negative effects from excessive
weight in an affected lower limb (Solomon et al., 2011). This is because the bone after injury is
unexpectedly displaced in various directions from correct positions. In contrast, in the late stage, a heavy target load enables patients to fully regain normal standing and gait (see Chapter 2). Participants are therefore needed to shift a target load to the affected lower limb in the lateral body weight-shifting task under different clinical purposes.

The lateral body weight-shifting task is considered relatively easy to perform compared to gait tasks. Nevertheless, patients often encounter difficulties in accurately shifting a part of their body weight in accordance with the instruction given by therapists. The therapists may also have difficulties in providing appropriate instructions to patients. A likely reason for this is a lack of knowledge about the fundamental features of this task, such as performance accuracy in shifting a different target amount (e.g., one third and two thirds) of the body weight to a single lower limb, central tendency effects, lateral differences, and light touch support by the upper limbs. The natures of such fundamental features have not yet been fully examined so far.

Shifting a different target amount may be affected by the central tendency effects. The central tendency effects are a general biasing effect such as overshooting of a light/low/weak target and undershooting of a heavy/high/strong target, that occurs during various perceptual and motor tasks (e.g., Jenkins, 1946; Stelmach et al., 1970; see Chapter 2). Such biasing effects may impede performance accuracy of both the light and heavy loads used in lateral body weight-shifting task and may affect recovery from injury in both early and late stage.

Lateral differences may also be influential to performance accuracy of lateral body weight-shifting task. Although lateral differences have been examined in a number of studies using quiet standing and gait (see Chapter 2), the studies have shown equivocal findings of whether lateral differences occur or not occur in motor tasks (Sadeghi et al., 2000). It is therefore far from clear whether lateral differences occur in lateral body weight-shifting as well.
If some lateral differences occur in the lateral body weight-shifting task, patients who are injured at a dominant/superior side would become slow in its recovery.

Support by upper limb also may affect performance accuracy of the lateral body weight-shifting task. Previous studies (e.g., Ashton-Miller et al., 1996; Kuan et al., 1999, see Chapter 2 for detail) suggested that the support by upper limb with assistance devices, such as a cane, crutches, and horizontal parallel bars, improves postural stability during quiet standing and gait. Support by upper limbs may therefore be effective in performing the lateral body weight-shifting task as well, although the likely positive (or negative) effects of support by upper limbs have not yet been examined so far.

To examine the fundamental features of lateral body weight-shifting, three experiments were performed in this study. In Experiment 1, the performance characteristics of patients with orthopedic complaints were examined in comparing those of healthy participants. Features in common to the patients with orthopedic complaints and healthy participants were also examined. In Experiments 2 and 3, the feature of lateral body weight-shifting was examined in detail, particularly central tendency effects, lateral differences, and light touch support by the upper limbs/hands. To examine the effects of fundamental features in healthy participants may lead to understanding of the fundamental and general features (which are independent of the effects of injury and/or operation) of lateral body weight-shifting regardless any injury involved in patients.
Chapter 2  Review of Literature

2.1  The Feature of Lateral Body Weight-Sifting Tasks

The lateral body weight-shifting task has been used in rehabilitation for patients with orthopedic complaints or hemiparesis. In this task, patients are asked to shift and maintain a certain load to the affected lower limb (Kajiwara et al., 2003; Nabekura et al., 2004; Hol et al., 2010). This task contributes to recovery from asymmetric posture. This section shows the feature of lateral body weight-shifting tasks, such as practical meaning and characteristics, general methods, and performance characteristics in patients with orthopedic complaints or hemiparesis.

2.1.1  Practical meaning of lateral body weight-shifting tasks in rehabilitation

Practical meaning of the lateral body weight-shifting task differs for the early and late recovery stages. In the early recovery stage, patients had better prevent themselves from loading excess loads on the affected lower limb. Solomon et al. (2011) tested a lateral body weight-shifting task for patients with orthopedic complaints who underwent surgery for fracture of the lateral tibial plateau, which was treated by screws and a plate. The results showed that although the load was adequately light (small), unexpected displacements of the tibia occurred in various directions from the screwed positions in the affected lower limbs. This finding suggested that the use of an adequately light (small) target load is crucial in lateral body weight-shifting tasks in the early stages of rehabilitation. However, this does not mean that patients should not necessarily shift any load toward the affected lower limb. Yagi et al. (2003) examined electromyogram patterns of muscle activity during gait in patients after anterior cruciate ligament reconstruction in the early (non-weight bearing) term and the late (weight
bearing) term. Their results showed that the muscle activity of quadriceps femoris muscle (particularly vastus medialis muscle) increased in the late (weight bearing) term alone. This result therefore indicated weight bearing on the affected lower limb after operation may lead to increase muscle activity of the lower limb. Jan et al. (2009) examined motor functions for both weight bearing and non-weight bearing exercises in patients with knee osteoarthritis, and showed that the weight bearing exercise improved position sense in knee joint and increased muscular strength in knee extensor. Findings from these studies indicated that it was necessary for patients after operation not to load any amounts but to load appropriate amounts on the affected lower limb.

In the late recovery stage, a heavy load is generally used in the lateral body weight-shifting task. This enables patients to successfully regain muscular and joint strength as well as postural and motor skills, such as independent standing and normal gait. A number of previous studies (e.g., Sugawara et al., 1993; Pai et al., 1994; Titianova et al., 1995) showed that patients with hemiparesis who shifted a heavier load toward their affected lower limbs in late stages of rehabilitation showed better recovery in both postural stability during quiet standing and independent normal gait. Sugawara et al. (1993) showed that both walking speed and independence (i.e., with no support by others) of walking in patients with hemiparesis were highly correlated with the ability to shift a large partial amount of his/her body weight towards the affected lower limbs. Some previous studies reported significant correlating relationships between the abilities of body weight-shifting and walking (Titianova et al., 1995; Kubota et al., 2004; Bowden et al., 2006; Yamasaki et al., 2007; Balasubramanian et al., 2007; Akezaki et al., 2009) and stability during the quiet standing (Pai et al., 1994; Marigold et al., 2006). Moreover, some studies showed the ability of shifting the body weight toward the affected lower limb was related with the performances of a sit-to-stand task (Lomaglio et al., 2005; Christiansen et al.,
2010), task performance of going up and down stairs (Akezaki et al., 2008), and fall (Maki et al., 1994). These findings indicated that patients should shift a heavy load toward the affected lower limb in the late recovery stage to recover of independent standing and gait.

From a viewpoint of measurements of the effects of rehabilitation treatment, the lateral body weight-shifting task may be a reliable assessment index to indicate the effects of rehabilitation treatment. Eng et al. (2002) examined the test-retest reliability over 2 separate days for weight-bearing ability in a standing task in patients with hemiparesis, showing that the ability of the weight-shifting had high reliability (Intraclass correlation coefficients which indicate the degree of reliability were 0.93-0.99) and may serve as a useful measure for stroke patients. Kubota et al. (2004) examined the test-retest reliability, measuring a lateral weight shift speed twice in 24 hours in patients with hemiparesis, and showed that the reliability of the task was high (Intraclass correlation coefficients were 0.84-0.93). Genthon et al. (2008) examined COP displacements which indicated the amount of the body weight shifted, showing that COP moved 10 mm from one side to the other side (indicating a shift of 5% body weight). These results indicated that the lateral body weight-shifting task was a reliable index of assessment and useful index.

2.1.2 General methods of therapeutic exercise with respect to feedback in lateral body weight-shifting tasks

The effective methods and instruction to be used for the lateral body weight-shifting task has not yet been well established. A likely reason for no effective methods for various patients, such as patients with hemiparesis, patients with orthopedic complaints, and elderly participants, is because the lateral body weight-shifting task is widely exercised for various diseases in therapeutic programs and effective instructions should differ for different cases.
Winstein et al. (1996) examined appropriate timing of providing feedback in a partial weight-bearing task. They compared the effects of practice with feedback provided during (concurrent feedback) and after (post-response feedback) the task in healthy participants. Their results showed that the concurrent feedback was more effective to perform the task accurately and consistently than that of post-response feedback in the acquisition phase, whereas in the retention phase, the error scores of the concurrent feedback group were larger than that of the post-response feedback group. This suggested that practice with concurrent feedback is beneficial to the accuracy of partial weight-bearing tasks only in the immediate performance but not in the long term learning.

Cheng et al. (2004) examined the effects of visual feedback on training of a rhythmic weight shift following acute stroke, and showed that visual feedback decreased occurrence of falls in patients with hemiparesis. This indicated that training of weight-shifting with visual feedback may improve dynamic balance.

Furthermore, a number of previous studies showed that some types of feedback, such as feedback information on a lateral and anterior/posterior position of COP and weight distribution between the lower limbs, were useful for improving asymmetric posture. Shumway-Cook et al. (1988) examined the effectiveness of biofeedback of postural sway which was shown with position of COP (i.e., COP feedback) as a conventional physical therapy technique used in patients with hemiparesis. Their result showed that a group provided with COP feedback showed a greater improvement in decreasing lateral displacement of postural sway than control groups who practiced while being provided verbal, tactile, and visual (mirror) cues of body alignment and symmetry. Gray et al. (1998) compared three conditions of feedback, which showed the degree of weight-shifting, to improve partial weight-shifting performance accuracy; a bathroom scale, a therapist’s hand, and a force-monitoring of a forceplate in a partial
weight bearing task in healthy participants, and showed that when participants performed the
weight-shifting task with a force-monitoring of a forceplate, their performance of a partial
weight bearing task was significantly more accurate than other ways of a bathroom scale and
therapist’s hand. This indicated that COP feedback improved performance of the weight shift
task in patients with orthopedic complaints or hemiparesis. Wong et al. (1997), using a new
standing biofeedback training device, examined the effects of the training device in patients
with hemiparesis, showing that the use of the training device improved stance symmetry. Cheng
et al. (2001) examined the effect of a rehabilitation program with the standing biofeedback
training device developed by Wong et al. on learning of symmetrical posture in patients with
hemiparesis, and showed that the use of the training device improved symmetrical posture and
decreased the risk of falls. Hershko et al. (2008) compared COP feedback and instruction (and
advice) by physical therapists in partial weight bearing during walking in patients after
orthopedic surgery. They showed that patients of the COP feedback training group performed
the task more accurately than the group with instruction/advice by the physical therapist. These
findings suggested that biofeedback (e.g., feedback of COP and ground reaction force) was
effective to improve performance accuracy of the body weight-shifting task.

There are also some review articles about the effects of COP feedback used to improve
postural balance and asymmetry of body weight distribution between the two lower limbs.
Nicoles (1997) reviewed literature on the effects of balance retraining using COP feedback in
hemiplegia, focusing on three aspects, such as steadiness, symmetry, and dynamic stability
during standing. Nicoles showed that the COP feedback benefited patients to improve both
asymmetry and dynamic stability of posture but did not improve steadiness in postural control.
Barclay-Goddard et al. (2004) reviewed literature on the effect of COP feedback training after
stroke, showing that the COP feedback benefited patients with hemiparesis to improve postural
symmetry in standing. However, COP feedback was not effective to improve performance of both Berg Balance Scale (BBS) and Timed up and Go test (TUG). Geurts et al. (2005) reviewed literature on therapeutic exercises used for improving posture with their asymmetric weight distributions during quiet standing in patients with hemiparesis, showing that force feedback (i.e., COP feedback), aids (i.e., orthoses and canes), perturbation training, visual-deprivation training, and influences of cognition all improved posture in quiet standing. Although these types of training improved asymmetric weight distributions, some studies (Walker et al., 2000; Geiger et al., 2001; Chen et al., 2002; Cheng et al., 2004) suggested that COP feedback was not effective to improve postural control and asymmetric weight distributions. Peppen et al. (2006) reviewed literature on the COP feedback after stroke, and showed that COP feedback did not significantly provide beneficial effects on asymmetric weight distribution in bilateral standing, postural sway, BBS, TUG, and gait speed. The findings previous studies of effects of COP feedback showed equivocal effects for performance accuracy of the body weight-shifting task.

2.1.3 Performance characteristics of lateral body weight-shifting in patients with orthopedic complaints or hemiparesis

Although the effectiveness of exercises for loading partial amounts of the body weight on the affected lower limb has long been examined so far, a most effective exercise for this task is not well established yet. Both patients with orthopedic complaints and with hemiparesis therefore suffer from asymmetric postural balance and risk of falling. Titianova et al. (1995) examined the duration of swing and stance during gait in both patients with hemiparesis and healthy participants. Results showed that the patients with hemiparesis swayed more laterally than did healthy participants and favored their unaffected lower limb to rely on. This implies that their gait pattern showed prolonged swing of the affected side with long time for stance on the unaffected side. Dickstein et al. (2000) examined postural sway in paretic and nonparetic
body side during quiet standing in patients with hemiparesis. They showed that patients with hemiparesis showed asymmetrical posture with larger sway of the paretic than the nonparetic body side. These findings suggested that patients with hemiparesis perform asymmetric standing and walking with posture shifted to nonparetic side.

Both patients with orthopedic complaints and with hemiparesis showed asymmetric weight distributions in posture and tended to show asymmetric weight distributions in standing posture tilting to the affected side. Patients with hemiparesis after stroke typically showed asymmetric posture. Goldie et al. (1996) examined the ability of body weight-shifting to a single lower limb in both lateral and forward directions in patients with hemiparesis and healthy (control) participants. Godie et al. showed that the patients with hemiparesis shifted a less amount of body weight to the affected lower limb than that in the healthy participants. Hasse et al. (1997) examined gait posture in patients with hemiparesis and showed that both the swing phase length and step length were shorter when starting with unaffected lower limb than when starting with affected lower limb. Particularly, patients with hemiparesis indicated a larger medio-lateral sway when starting with affected lower limb than that when starting unaffected lower limb. de Haart et al. (2005) examined the speed of lateral weight-shifting in patients with hemiparesis and showed that the patients shifted to the affected side more slowly than that to the unaffected side. Kubota et al. (2006) examined the characteristics of lateral body weight-shifting in patients with hemiparesis, measuring moved distance, moving speed, and track length of COP. Their results showed that the patients with hemiparesis decreased COP moving speed and track length when shifting their weight toward the affected lower limb. King et al. (2008) examined the lateral stepping strategies in patients with Parkinson’s disease, and showed that the patients initiated lateral stepping slowly with a smaller step length than that of healthy participants. All these findings suggested that the patients with disease in the central nervous system (e.g.,
patients with hemiparesis after stroke and patients with Parkinson’s disease), were usually who
impair lateral stability during standing and/or walking, have difficulties in shifting body
weight smoothly from one to other lower limb compared with healthy participants.

Patients with orthopedic complaints who were injured a lower limb also often show
asymmetric posture during standing and/or walking. Viton et al. (2000) examined the feature of
the initial phase of gait, in terms of various features, such as COP displacements, ground
reaction force, step length, and the range of knee motion of lower limbs in patients with
unilateral knee arthritis. Their results showed that gait was initiated slower and the duration of
single-support phase of the affected lower limb was shorter than that of the unaffected lower
limb. Moreover, both step length and range of knee motion decreased in patients irrespective of
the side of supporting lower limb. This suggested that the patients adopted a strategy of
shortening the single-support phase on the affected lower limb.

Tveit et al. (2001) measured the accuracy of 30 % body weight-bearing on crutches
during walking for five different conditions (level, uphill, downhill, upstairs, and downstairs) in
patients with hip replacement. Their results showed that the patients loaded more than 30 % of
their body weight during walking in all the five conditions. Vasarhelyi et al. (2006) examined
body weight-shifting during a voluntary partial weight-bearing task in young and elderly
patients with fracture of lower limbs. Their results showed that the young patients increased the
amount of body weight-shifting to the affected lower limb, whereas the elderly patients had
difficulties in increasing the amount of the body weight on the affected lower limb. This
suggested that the ability of body weight-shifting to the affected lower limb dependent on age.
These findings suggested that patients with orthopedic complaints had difficulties in shifting
their body weight toward the affected lower limb like patients with hemiparesis.

Both the patients with orthopedic complaints/hemiparesis and healthy people may
have difficulties in performing accurately a lateral body weight-shifting task. Dabke et al. (2004) examined the accuracy of partial weight bearing with shifting a 30 kg load during three-point crutch walk (i.e., stepping on a crutch, the affected limb, and then the unaffected limb) in patients with orthopedic complaints of lower limb and healthy participants. Their results showed that neither patients nor healthy participants reproduced the proper loads of partial weight bearing. This indicated that in both patients and healthy participants, partial weight bearing was difficult to perform correctly. Malviya et al. (2005) examined the reproducibility of partial weight bearing performed immediately after and 60 min after the training of it in healthy participants and showed that most participants reproduced closely the learned target load for both the immediate and 60 min conditions. Standard deviations among participants were less for the dominant lower limb than that for the nondominant side. Both the healthy and patient participants had similar problems in accurately shifting the body weight to one to another lower limb. These findings suggested that both patients with orthopedic complaints/hemiparesis and healthy people had difficulties in mastering lateral body weight-shifting and that the recovery from disabilities of postural stability in both quiet standing and gait may be affected by such difficulties in body weight-shifting, particularly in patients with orthopedic complaints or hemiparesis.

There are many patients suffering from asymmetric posture. The lateral body weight-shifting task is often used for such patients in attempting to improve the ability of body weight-shifting toward affected lower limbs. Asymmetric posture may cause postural instability and sometime a risk of fall. Genthon (2005) examined the relationships between asymmetric posture and postural sway, and showed that increasing asymmetry of weight distribution between lower limbs increased postural sway during standing. Anker et al. (2008) examined COP (center of pressure) velocity in four conditions of asymmetric weight distributions between
the left and right lower limbs with 45% vs. 55%, 40% vs. 60%, 30% vs. 70% and 20% vs. 80% during upright standing in healthy participants. Their results showed that the postural stability decreased as the weight-bearing asymmetry increased. This suggested that the decrease in lateral postural stability in patients who show asymmetric weight distribution may increase the risk of falling. Therefore, it is crucial for patients to learn how to perform good lateral weight-shifting in attempting to recover from injury/operations of affected lower limbs.
2.2 **Fundamental Factors Affecting the Accuracy of Lateral Body weight-shifting Tasks**

Patients often encounter difficulties in accurately shifting a target load in accordance with the instruction given by therapists, and the therapists may also have difficulties in providing effective instructions. A likely reason for this is a lack of knowledge about fundamental (general) features of this task, such as performance accuracy in shifting a different target load (e.g., one and two thirds of body weight), lateral differences in shifting the target load (e.g., leftward and rightward), and effects of light touch support by the upper limbs. This section introduces some previous studies about these fundamental (general) features of the lateral body weight-shifting task.

2.2.1 **Central tendency effects of different amounts of target loads on the accuracy of lateral body weight-shifting**

For the different target loads used in lateral body weight-shifting tasks, therapists usually use one third of the body weight at an early recovery stage as a light target load to be shifted to an affected lower limb, whereas in a relatively late recovery stage, they use two thirds of body weight as a heavy target load. The difference in target loads for the early and late recovery stages may cause different effects of ‘central tendency’, which is well known as a feature of perceptual motor characteristics. The central tendency effect is a general biasing effect, which indicates overshooting of a light/low/weak target and undershooting of a heavy/high/strong target that occurs during various perceptual and motor tasks. Such biasing effects may give rise to negative effects on recovery in both the early and late stages of rehabilitation. A light target load used in the early stages of rehabilitation may cause overshooting, probably resulting in negative effects such as inflammation and displacement of the joints and bones of the affected limbs, whereas a heavy target load used in the late stages may cause undershooting, leading to insufficient improvement in muscle strengths and motor
skills. Nevertheless, the issue of central tendency effects in lateral body weight-shifting tasks has not been examined in detail.

The central tendency effect appears in the recall of force task. Jenkins (1946) examined the accuracy of reproducing the pushing force of the upper and lower limbs using a stick (upper limb) and rudder pedal (lower limb) in healthy participants. Results showed that participants reproduced heavier force than the target force when they attempted to adjust their force to relatively light target force, whereas they reproduced lighter force than the target force when they attempted to adjust their force to relatively heavy target force in both the upper and lower limb task. Ito et al. (1984) examined recall errors in the reproduction of isometric force, showing that participants overshot a small force, whereas undershot a large force. These results indicated that central tendency effects were shown in a force recall task like discrimination tasks, and it therefore seems that central tendency effects may occur in lateral body weight-shifting tasks as well. Moreover, the central tendency effect has typically been examined in discrimination tasks, such as position of arm movement and length of some different lines. Stelmach et al. (1970) examined kinesthetic reproduction of arm movements using recall position of a lever task, showing that participants showed overshoot errors when they recalled small range movements, whereas they showed undershoot errors when they recalled large range movements. The central tendency effect appears in some perceptual and motor performance, such as tracking (Ghez et al., 1989), discrimination between five different lengths (Teigen, 1977), and discrimination for Muller-Lyer bias (Crawford et al., 2000). Therefore, the central tendency effect is fundamental feature of perceptual and motor tasks.

For lateral body weight-shifting or partial weight-bearing, some previous studies reported central tendency effects. Lis et al. (2001) examined vertical ground reaction force during partial weight bearing in three-point crutch gait under 10, 50, and 90% of the body
weight. They showed that peak vertical ground reaction force was larger than the target load for 10% of the body weight, whereas it was smaller than the target load for 90% of the body weight. Tivet et al. (2001) examined the accuracy of weight bearing of 30% body weight with two-point crutch walk (i.e., stepping on both a crutch and the affected limb, and then the unaffected limb) under 5 conditions (level, uphill, downhill, upstairs, and downstairs) in patients who had been operated total hip arthroplasty. Their results showed that patients overshot 30% of their body weight on the affected lower limb for all walking conditions. Hirota, et al. (2003) also examined the accuracy of partial weight bearing with one third and two thirds of the body weight with two-point crutch walk in patients with orthopedic complaints after anterior cruciate ligament reconstruction. The results showed that patients overshot the target load at the affected lower limb in the one-third target load condition, whereas they undershot the two-thirds target load. Ebert et al. (2008) examined whether patients after autologous chondrocyte implantation accurately replicated and retained weight-bearing, showing that patients shifted more than the target, that is, oversooting the target loads of 20%, 40%, and 60% of the body weight, and undersooting the 80% of the body weight. Although these results showed central tendency effects in lateral body weight-shifting or partial weight-bearing, fundamental features of central tendency effects were not examined in these studies.

2.2.2 Lateral difference in motor abilities with the use of lower limbs

It seems to be difficult for patients with orthopedic complaints or hemiparesis to shift their body weight toward paretic side or affected lower limb. The paretic side and affected lower limb include not only the impediment side but also the feature of left/right side.

Peripheral parts (i.e., upper and lower limb) of the body have dominance for motor performance. Dominance in peripheral motor performance may well exist in various aspects,
such as anatomical properties, weight distribution during quiet standing, walking, and running. In an anatomical aspect, Chhibber et al. (1970) compared muscle weight of the left and right limbs in ten cadavers, showing that the total limb weight of left side were larger than that of the right side in seven out of ten adult cadavers. Furthermore, Chhibber et al. (1972) examined anatomical differences in the left and right limbs of nine human fetuses, showing that the total weight of muscles and bones were greater on the left limbs in seven fetuses. This result was comparable to those of adults. Levy et al. (1978) compared the size of the left and right feet of 150 adult individuals, showing that right-handed participants showed significant association between sex and foot size asymmetry: The right foot was bigger than the left foot in males, while the left foot was bigger than the right foot in females. Pomerants et al. (1980) also compared the size of the left and right feet of 62 children, showing that there was no significant difference between the left and right feet. Levy et al. (1981) reviewed the literature of dominance of left and right limbs, showing equivocal results. Difference in foot size did not differ for the left and the right and did or did not correlate with either sex or dominant hand. Research findings have thus been far from clear for dominance of left and right in anatomy aspect. In performance aspect, Chapman et al. (Chapman et al., 1987a; Chapman et al., 1987b) proposed their literature on measurement scale of handed and footed which were consisted of 13 (hand) and 11 (foot) questionnaire items. Their scales are well known as Chapman tests.

For quiet standing, Hart et al. (1997) examined the stability during one-leg standing in left and right footers. They showed that both left and right footer participants indicated good stability during standing on the right lower limb. Murray et al. (1973) examined weight distribution during quiet standing on the left and right lower limbs in healthy participants, showing that most participants shifted their body weight toward the right lower limb, with no statistical significance. Similarly, Gutnik et al. (2008) examined the profile of ground reaction
force on each lower limb during bipedal standing in healthy participants, showing that the
duration of loading on the right lower limb was significantly larger than that of the left lower
limb. Moreover, Rougier et al. (2009) examined the relative contribution of each lower limb to
COP trajectories in healthy participants. They showed that the participants tended to shift the
COP toward the right side. On the contrary, Dickstein et al. (1984) examined the pattern of foot
ground pressure in healthy participants, showing that the participants tended to shift the center
of foot ground pressure toward the left lower limb. Sackly et al. (1991) examined the weight
distribution between the left and right lower limb in normal participants, showing that the
participants tended to shift their body weight toward the left side. These studies indicated that
the weight distribution during quiet standing showed asymmetrical balance, whereas the
direction of tilting of the body was not consistent among studies.

For dynamic performance, such as walking and running, Singh (1970) assessed the
function of the lower limb during walking, kicking, and lifting a ball in right-handed healthy
participants. Their results showed that most participants were not always to use both lower
limbs when performing these activities. Maupas et al. (1999) examined the movements of left
and right knees, using electrigniometers during walking in healthy participants. They showed
that most participants performed asymmetrical flexion-extension movements with more than 5 °
difference between the two knees during walking. Hirasawa (1980) examined the contact areas
between the ground surface and foot sole and the relationships between the area of ground-foot
contact and postural stability during standing in healthy participants. The results showed that the
area for the left foot was larger than that for the right foot in most participants. Furthermore, a
participant whose left foot was larger than the right foot showed good stability during standing.
This result suggested that the left foot was superior to the right foot in supporting posture. Miki
(1999) also examined the relationships between the area of contact between the ground-foot and
muscle strength in the right and left knee extensor in normal participants, showing that the left foot was larger in contact area than the right foot, with no significant difference between the left and right knee muscle strength. Diopa et al. (2004) examined relationships between age, gait speed, and ground reaction force in normal children aged four to ten years old. They showed that the children of four to six years old showed a significant difference between the left and right ground reaction forces at a high speed of walking. It seemed that the right lower limb has a role of propulsion power, while the left lower limb has a role of support of the body in four to six years children but not in older children. Wang et al. (2012) examined ground reaction force and COP velocity for dominant and non-dominant lower limbs during gait. They showed that variability of peak force in the non-dominant lower limb was greater than that in the dominant lower limb, and that COP velocity at a terminal phase of stance was greater in the dominant lower limb than that in the non-dominant lower limb. In contrast, Hamill et al. (1984) examined the ground reaction force of left and right lower limbs during the support phase of both walking and running in healthy participants, showing no significant difference in ground reaction force between the left and right lower limbs. Pierotti et al. (1991) examined electromyographic (EMG) patterns of right and left knee muscle activities during gait, showing that most muscles exhibited symmetrical EMG patterns for both the left and right knees. Seely et al. (2008) examined ground reaction force for both dominant and nondominant lower limbs during gait, showing no significant bilateral differences in both vertical and propulsive ground reaction forces. Sadeghi et al. (2000) reviewed the literature on differences between left and right lower limb (i.e., symmetry and asymmetry) in various aspects, such as ground reaction force, joint angle, muscle activity, and gait parameters, showing no consistent findings among studies. These studies indicated that the feature of laterality was equivocal in various performances.

Dominance of motor performance in left or right side of the body would relate to
laterality in the cerebral hemispheres. Dominance of postural control is considered to depend on the feature of right cerebral hemisphere. Titianova et al. (1995) examined the duration of swing and stance during gait in patients with left and right hemiparesis, showing that both types of patients showed asymmetric posture, particularly the patients with right hemisphere damaged (i.e., left hemiparesis) had higher asymmetry than the patients with left hemisphere damaged (i.e., right hemiparesis). Rode et al. (1997) examined the characteristics of postural sway in patients with left and right hemiparesis and healthy participants with age matched. Results indicated that patients with hemiparesis showed a large sway area and lateral displacement of COP toward the side of the lesion compared to healthy participants. Furthermore, patients with left hemiparesis (i.e., the right hemisphere damaged) showed a greater sway area and larger lateral displacement than those of patients with right hemiparesis (i.e., the left hemisphere damaged). These findings suggested that the right hemisphere was superior to the left hemisphere in postural control. Furthermore, Hanna-Pladdy et al. (2001) compared errors of gesture performances of an unaffected limb in patients with the left and right cerebral hemisphere damaged in examining the existence of qualitative differences between these groups. They showed that the right hemisphere damaged group had difficulties in keeping their posture spatially and temporally. Spinazzola et al. (2003) examined the occurrence of apraxic or postural deficits in the execution of a trunk movement in patients with the left and right cerebral hemisphere damaged and showed that postural instable reactions occurred significantly more frequently among the patients with right-hemisphere damaged. These findings suggested that the postural representational system may be preferentially located in the right hemisphere.

The right hemisphere dominance in postural control may relate to spatial attention. Regarding this, many studies showed that the right cerebral hemisphere has laterality in distribution of attention. Weintraub et al. (1987) examined a shape cancellation task in patients
with unilateral hemisphere damaged at either the right or left hemisphere. Results showed that the patients with the right hemisphere damaged omitted more visual targets on the left side of the test page than the patients with the left hemisphere damaged. In contrast, the patients with the left hemisphere damaged omitted targets on the right side of the page than the patients with the right hemisphere damaged did. Moreover, the patients with the right hemisphere damaged also omitted targets on the right/ipsilateral side. This suggested that the left hemisphere was dominant for directing attention to the contralateral right hemispace alone, whereas the right hemisphere has dominance for directing attention to both the contralateral and ipsilateral hemispheres. Nishizawa et al. (1987) examined lateral difference in spatial discrimination ability of the left and right hands. Participants were asked to judge whether thumb abduction angle was larger or smaller than the target angle. The results showed that the left thumb was more sensitive in discriminability than that of the right thumb. Nishizawa (1991) further compared both spatial and weight discrimination tasks with thumb abduction movements, and showed that there was no significant difference between the right and left thumbs in the weight discrimination task, whereas the left thumb discriminated more sensitively than the right thumb in the spatial discrimination task.

The lateral body weight-shifting task needs to control posture and body orientation in spatial. Therefore, lateral dominance of the right hemisphere in spatial information processing may influence the accuracy of lateral weight-shifting, and this was therefore examined in this dissertation study.

2.2.3 Effects of support by the upper limbs on quiet standing and gait

Patients with orthopedic complaints or hemiparesis usually use assistance devices, such as a cane, crutches, and horizontal parallel bars during walking and standing. Using such
assistance devices may well improve postural stability. Joyce et al. (1991) classified various assistance devices, such as canes, crutches, walkers, bars and rails on the basis of the function of the device and gait patterns with the device. Van Hook et al. (2003) showed a flowchart of how to select assistance devices according to deficits of motor functions.

Previous studies measured the amount of support by the upper limbs in various assistance devices. Anglin et al. (2000) measured the load on the upper limbs in the use of a cane during walking for healthy participants. They showed that the resultant average load of the upper limb was 18% of the body weight. Chen et al. (2001) also measured the load of the upper limb on a cane during walking for patients with hemiparesis, and this resulted in that the average vertical force on the cane was 12.7% of the body weight. These findings indicated that the load on the upper limbs ranged from 10 to 20% of the body weight regardless of the type of disabilities, and that the support by the upper limbs then improved postural stability.

Support by a single upper limb on both limbs on assistance devices may well benefit stable posture. Ashton-Miller et al. (1996) examined whether the use of a cane reduces postural sway during standing on an unstable surface in patients with peripheral neuropathy. The results showed that the use of a cane significantly reduced the risk of losing balance. Kuan et al. (1999) also examined the effects of cane use during gait in patients with hemiparesis, showing that the use of a cane improved the motor ability of shifting the center of body mass toward the unaffected lower limb during preswing phase in the affected lower limb. Positive effects of the use assistance devices were also showed by Milczarek et al. (1993); Maeda et al. (2001); Laufer (2003). In contrast, Bateni et al. (2004) suggested negative effects of the assistance devices on motor performances. They examined step lengths of lateral stepping reactions during lateral perturbation with or without assistance devices, showing that the use of assistance devices interfered stepping reactions when responding to lateral postural perturbation. This may be
because participants avoided collision to the assistance devices. Moreover, Bateni et al. (2005) reviewed literature of the positive and negative effects of the use of assistance devices for various aspects, such as clinical evidence for fall, biomechanical stabilization, somatosensory cues, and attentional and neuromotor demands. Many previous studies (e.g., Ashton-Miller et al., 1996; Kuan et al., 1999) indicated that assistance devices are effective for postural stability, whereas some studies indicated negative effects of the use of assistance devices.

Various previous studies (e.g., Jeka et al., 1994; Jeka, 1997) indicated that only fingertip contact (i.e., light-touch support) improves postural stability. Jeka et al. (1994) examined postural sway during quiet stance under 3 conditions of fingertip contact: no contact, light-touch contact (<0.98 N), and force contact. This study showed that light-touch contact was as effective as force contact in reducing postural sway. It was suggested that somatosensory cues from the fingertip contributed to reduce body sway. Many studies reported similar effects of light-touch support for healthy participants (Jeka et al., 1996; Jeka, 1997; Krishnamoorthy et al., 2002; Dickstein et al., 2004; Vuillerme et al., 2006; Hausbeck et al., 2009), elderly people (Tremblay et al., 2004; Johannsen et al., 2009), patients with hemiparesis (Boonsinsukh et al., 2009), and elderly patients with visually impaired (Maeda et al., 1998). In contrast, the effect of light-touch support on postural stability did not occur for patients with sensory neuropathy due to diabetes mellitus (Dickstein et al., 2003) and healthy participants with no finger tactile feedback in terms of tourniquet ischemia (Kouzaki et al., 2008). In the condition in which feedback of somatosensory cues is not provided at the fingertip, light-touch support has no positive effect on postural stability.
Chapter 3  Aim of This Study and Research Rationale

Aim of this study was to clarify the effects of fundamental features, such as central tendency effects, lateral differences, and light touch support by the upper limbs on performance accuracy in the lateral body weight-shifting task. The lateral body weight-shifting task is commonly used in therapeutic programs for patients with orthopedic complaints or hemiparesis. This task is considered effective for helping patients recover from asymmetric weight distribution in affected and unaffected lower limbs during bipedal standing. In this task, patients are asked to shift and maintain a certain load to the affected lower limb (Kajiwara et al., 2003; Nabekura et al., 2004; Hol et al., 2010). In the early stage of rehabilitation, a relatively light target load, such as one third or a half of body weight is utilized to promote bone healing and stability (Brumback et al., 1999), muscle activities (Yagi et al., 2003), and position sense (Jan et al., 2009). Whereas in the late stage, a heavy target load, such as two thirds or three fourths of body weight is utilized to gain normal or symmetry gait performance (e.g., Sugawara et al., 1993, Titianova et al., 1995) and standing posture (e.g., Pai et al., 1994; Marigold et al., 2006), and to become recovery normal (e.g., Maki et al., 1994; Lomaglio et al., 2005).

Practical meaning of the lateral body weight-shifting task is different between the early and the late recovery stage. The clinical purpose of using a light target load in the early stage of rehabilitation is to avoid negative effects from excessive weight in an affected lower limb. Solomon et al. (2011) tested patients with orthopedic complaints after underwent surgery for fracture of the lateral tibial plateau, which was treated by screws and a plate. The results showed that although the load was adequately light (small), there were unexpected displacements of the tibia in various directions from the screwed positions in the affected lower limbs. This finding suggests that the use of an adequately light (small) target load is crucial in
lateral body weight-shifting tasks in the early stages of rehabilitation. In contrast, in the late stages, a heavy load is generally used. This enables patients to successfully regain muscular and joint strength, as well as postural and motor skills such as independent standing and normal gait. A number of previous studies (Sugawara et al., 1993; Pai et al., 1994) showed that patients with hemiparesis who could shift a heavy load toward their affected lower limbs in late stages of rehabilitation showed better recovery in both postural stability during quiet standing and independent normal gait (see Chapter 2).

Although the respective use of light and heavy target loads in the early and late stages of rehabilitation is well documented (Sugawara et al., 1993; Pai et al., 1994; Solomon et al., 2011), it is far from clear whether there are other crucial features that may affect performance of the task. The potential results are the central tendency effects, lateral differences, which may be masked by injury on one side of the lower limb; and light touch support, which may improve postural stability during quiet standing (Jeka et al., 1994; Jeka, 1997). The central tendency effect is a general biasing effect that occurs during various perceptual and motor tasks, which indicates overshooting of a light/low/weak target and undershooting of a heavy/high/strong target. Such biasing effects may give rise to negative effects on recovery in both the early and late stages of rehabilitation. A light target load used in the early stages of rehabilitation may cause overshooting, probably resulting in negative effects such as inflammation and displacement of the joints and bones of the affected limbs; in contrast, a heavy target load used in the late stages may cause undershooting, leading to insufficient improvement in muscle strengths and motor skills. Nevertheless, the issue of central tendency effects in lateral body weight-shifting tasks has not been examined in detail, with only a few studies (Hirot et al., 2003; Ebert et al., 2008) having briefly reported this feature with regard to central tendency effects.
Lateral differences may be a crucial feature of lateral body weight-shifting, potentially affecting the performance of this task. Lateral differences have been examined in a number of studies (see Chapter 2). It is also far from clear whether lateral differences occur in lateral body weight-shifting tasks. This would potentially affect task performance, although the fundamental features of lateral differences may be masked in rehabilitation by injuries to the lower limbs.

It is well known that light touch support by the upper limbs/hands improves postural stability during quiet standing and treadmill walking (see Chapter 2). Therefore, light touch support may also be effective in lateral body weight-shifting tasks, although this has not yet been studied.

To examine the effects of fundamental feature, such as central tendency effects, lateral differences, and light touch support by the upper limbs on performance accuracy in lateral body weight-shifting, this study consisted of three experiments. First, Experiment 1 examined the characteristics of performance accuracy of lateral body weight-shifting in patients with orthopedic complaints compared with age-matched healthy participants. The aim of Experiment 1 was to elucidate both difference between, and similarity to, the patients with orthopedic complaints and healthy participants in the feature of task performance of this task.

Experiment 2 examined the feature of task performance appearing in common with both patients and healthy participants, on the basis of the results of Experiment 1. Experiment 2 therefore focused on central tendency effects, lateral differences, and light touch support by the upper limbs in lateral body weight-shifting, testing healthy participants alone. Although the findings of Experiment 2 showed results from healthy participants alone, these findings could provide useful information about some fundamental and potential feature of task performance of lateral body weight-shifting, which may be in common with both healthy people and patients with orthopedic complaints.
Experiment 3 further examined the fundamental features of lateral body weight-shifting, particularly focusing on the effects of upper limb support and interlimb weight-adjustment among the upper and the lower limbs. The primary aim of Experiment 3 focused on the effects of reciprocal interlimb (i.e., upper and lower limb) weight-adjustment on performance accuracy of lateral body weight-shifting, again testing healthy participants. This is because the use of upper limbs in participants should be affected and modified by specific characteristics of injuries and operations performed on the patients and thus the fundamental and potential feature of the effects of upper limb use and interlimb weight-adjustment would not appear clearly when testing participants.

In sum, Experiment 1 examined both different and similar characteristics of task performance of lateral body weight-shifting in patients with orthopedic complaints and healthy participants. On the basis of the findings of Experiment 1, Experiment 2 and 3 examined likely fundamental and potential feature of task performance of lateral body weight-shifting in healthy participants, particularly focusing on the central tendency effects in Experiment 2 and upper limb support in Experiment 3. For this purpose, young healthy participants, rather than patients with orthopedic complaints or hemiparesis, were used to avoid the likely effects of injuries or paresis. Fundamental feature, such as central tendency effects, lateral differences, and light touch support by the upper limbs should be inherent in the feature of the lateral body weight-shifting task in both healthy participants and patients, whereas task performance may be further influenced by injuries or paresis. The findings of Experiment 1 to 3 were discussed with respect to fundamental feature of lateral body weight-shifting, which is often used for patients with orthopedic complaints or hemiparesis in rehabilitation.
Chapter 4  Experiment 1

Features of Performance Accuracy of a Lateral Body Weight-Shifting Task in Patients with Orthopedic Complaints Compared with Healthy Participants

4.1  Introduction

The aim of Experiment 1 was to comprehend practical features of patients with orthopedic complaints compared with age-matched healthy participants performing the lateral body weight-shifting task. This experiment then examined whether central tendency effects occurred and lateral differences (affected and unaffected lower limb) affected performance accuracy of the lateral body weight-shifting task in patients with orthopedic complaints compared with control participants.

4.2  Methods

4.2.1  Participants

Eleven right-handed patients with orthopedic complaints after operations (a man and 10 women, see Table 1) with mean age 71.6 (SD = 9.3), height 152.8 (SD = 6.7) cm, and weight 59.0 (SD = 9.6) kg, and eleven healthy elderly participants (3 men and 8 women) with mean age 72.9 (SD = 2.3), height 155.4 (SD = 5.3), and weight 55.4 (SD = 6.8) participated in this experiment. A t-test on mean age showed no significant difference between patients with orthopedic complaints and health elderly participants (t = 0.44, p > 0.05). This experiment was approved by the local ethics committee (No. 09-149 and 10-02) of the International University of Health and Welfare, Kanagawa, Japan.
Table 1. Characteristics of patients with orthopedic complaints (N = 11)

<table>
<thead>
<tr>
<th>patients</th>
<th>diagnosis</th>
<th>operative method</th>
<th>days after operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>sub.1</td>
<td>knee osteoarthrosis</td>
<td>Total Knee Arthroplasty (left)</td>
<td>9</td>
</tr>
<tr>
<td>sub.2</td>
<td>knee osteoarthrosis</td>
<td>Total Knee Arthroplasty (left)</td>
<td>17</td>
</tr>
<tr>
<td>sub.3</td>
<td>knee osteoarthrosis</td>
<td>Total Knee Arthroplasty (left)</td>
<td>23</td>
</tr>
<tr>
<td>sub.4</td>
<td>knee osteoarthrosis</td>
<td>Total Knee Arthroplasty (left)</td>
<td>25</td>
</tr>
<tr>
<td>sub.5</td>
<td>knee osteoarthrosis</td>
<td>Total Knee Arthroplasty (left)</td>
<td>30</td>
</tr>
<tr>
<td>sub.6</td>
<td>knee osteoarthrosis</td>
<td>Total Knee Arthroplasty (left)</td>
<td>64</td>
</tr>
<tr>
<td>sub.7</td>
<td>knee osteoarthrosis</td>
<td>Unicompartmental Knee Arthroplasty (right)</td>
<td>8</td>
</tr>
<tr>
<td>sub.8</td>
<td>knee osteoarthrosis</td>
<td>Total Knee Arthroplasty (right)</td>
<td>12</td>
</tr>
<tr>
<td>sub.9</td>
<td>knee osteoarthrosis</td>
<td>Total Knee Arthroplasty (right)</td>
<td>28</td>
</tr>
<tr>
<td>sub.10</td>
<td>osteonecrosis</td>
<td>Unicompartmental Knee Arthroplasty (right)</td>
<td>14</td>
</tr>
<tr>
<td>sub.11</td>
<td>femoral neck fracture</td>
<td>Total Hip Arthroplasty (left)</td>
<td>8</td>
</tr>
</tbody>
</table>

4.2.2 Lateral Body Weight-Shifting Tasks

Participants performed quiet upright standing with a single lower limb on a force plate and then shifted a partial load (either one or two thirds of their body weight) toward the other (affected and unaffected for the patients and the left and right for the healthy participants) lower limb on a second separate force plate, maintaining the final lateral body weight balance for approximately 3 s (Figure 1a). Participants were allowed to balance themselves by using light touch support by placing their upper limbs/hands on horizontal parallel bars (Figure 1b) during the task.
4.2.3 **Apparatus**

Foot pressure of each lower limb was measured on the two separate force plates (made-to-order, Kyowa, Japan). Analogue outputs from the 2 force plates were amplified through 2 YB-503A amplifiers (Kyowa, Japan), converted into digital data with a sampling rate of 200 Hz, and stored in an NR-2000 data collection system (Keyence, Japan). Five practice trials were performed prior to data collection in experimental trials, with visual feedback of analogue outputs of foot pressure being presented on a Tektronix TDS-2014 (Tektronix, Beaverton, OR, USA) digital oscilloscope monitor as shown in Figure 1c.
4.2.4 Procedures

Participants first performed 5 practice trials per experimental condition. For the practice trials, the digital oscilloscope presented analogue outputs of their foot pressure on the destination side (i.e., the side to which the participants shifted a target load of their body weight). After the completion of practice trials, the digital oscilloscope monitor was covered with an opaque sheet, and participants were instructed to gaze at a fixed point 1.5 m above the ground in front of them. Each experimental data collection trial started with quiet standing on either the left or right lower limb as the starting limb, and then participants shifted a target load of either one or two thirds of their body weight toward the other lower limb as the destination side and maintained the load for about 3 s. Participants performed 10 trials per condition, for a total of 40 trials, with a counterbalanced presentation order in a Latin square design. The intertrial interval was 6 s. The respective foot pressures on the starting and destination lower limbs were measured with the two force plates.

4.2.5 Experimental Design

Independent measures were two factors; target load (one and two thirds of the body weight) and directions of body weight-shifting (affected and unaffected lower limb for the patients and the left and right for the healthy participants). Dependent measures were constant error (CE), variable error (VE), root mean squared error (RMSE), and coefficient of intra-trial variation (CV), (see below Analyses for details).

4.2.6 Analyses

Foot pressure. Analogue outputs of foot pressure were analyzed for the last 1 s of each trial, because foot pressure was relatively stable in the 1 s period. Trials with any artifacts
or deviations in foot pressure more than three times larger or smaller than the standard deviation from mean foot pressure for the 1-s analysis period were discarded from subsequent analyses.

**Error scores.** Three error scores were calculated; constant error (CE) indicates the directional/biasing error; variable error (VE) indicates variability (Schmidt et al., 1999), root mean squared error (RMSE) indicates the overall error (or total error, see Henry, 1975), and coefficient of intra-trial variation of load performance (CV) indicates variability intra-trial. The numerical formulas of these indexes were shown below (Xi indicates the score at trial ‘i’, T shows target load, and n indicates the number of data).

\[
CE = \frac{\sum_{i=1}^{n} (X_i - T)}{n}
\]

\[
VE = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \bar{X})^2}{n}}
\]

\[
RMSE = \sqrt{\frac{\sum_{i=1}^{n} (X_i - T)^2}{n}}
\]

\[
CV(\%) = \frac{VE}{\bar{X}} \times 100
\]

Both the CE and RMSE were calculated for each trial on the basis of 200 samples collected during the 1-s analysis period and then normalized by the participants’ body weight (w), resulting in CE/w and RMSE/w. Individual representative error scores of CE/w and RMSE/w were calculated as the mean value of 10 trials per condition, and those of VE/w were calculated as SD of CE/w for 10 trials per condition.
**Upper limb loads.** Total upper limb loads were calculated by subtracting the total load of two lower limbs from the body weight. This was also normalized by the participants’ body weight.

**Statistical analyses.** In each participants group, separate two-way analyses of variance (ANOVAs) were performed on the CE/w, VE/w, RMSE/w, CV, and upper limb loads respectively, with repeated measures of both factors of the target load (one and two thirds of body weight) and the direction of body weight shifting to the affected and unaffected lower limb for patients and leftward and rightward for healthy participants. One-sample t-tests were performed on CE/w to analyze the significance of undershooting and overshooting. Moreover, t-tests were performed on each error score and upper limb loads to compare those between patients with orthopedic complaints and healthy elderly participants.
4.3 Results

4.3.1 Constant Error

One-sample t-tests. In the patients with orthopedic complaints (Figure 2a), one-sample t-tests on the mean CE/w scores showed significant overshooting for both the affected (t = 3.93, p < 0.05) and the unaffected (t = 2.40, p < 0.05) shift at the one-third target load but did not show significance for either the affected (t = -0.92, p > 0.05) or unaffected (t = -1.16, p > 0.05) shift at the two-thirds target load. For the healthy elderly participants (Figure 2b), one-sample t-tests showed neither significant overshooting nor undershooting for any condition (p > 0.05).

Two-way ANOVA. In patients with orthopedic complaints, an ANOVA of the mean CE/w revealed a significant main effect for target load (F_{1,10} = 15.34, p < 0.05), with the mean CE/w for the one-third target load (M = 7.70, SD = 2.20) being significantly larger than that for the two-thirds target load (M = -4.30, SD = 3.60). Neither the main effect for direction of body weight-shifting (F < 1) nor interaction between the two factors (F < 1) was significant. In healthy elderly participants, an ANOVA revealed a significant main effect for target load (F_{1,10} = 9.06, p < 0.05), with the mean CE/w for the one-third target load (M = 3.00, SD = 2.60) being significantly larger than that for the two-thirds target load (M = -6.10, SD = 3.40). Neither the main effect for direction of body weight-shifting (F < 1) nor interaction between the two factors (F < 1) was significant. These results indicated a typical ‘central tendency effect’, with overshooting for the light (one third of the body weight) target load and with undershooting for the heavy (two thirds of the body weight) target load.
Figure 2. Mean CE/w scores in patients with orthopedic complaints (a) and healthy elderly participants (b) for both the one-third and two-thirds target loads in the affected and unaffected side for the patients and the leftward and rightward for the healthy participants body weight-shifting. The filled and unfilled bars represent the one-third and two-thirds target loads, respectively.
4.3.2 Variable Error

In the patients with orthopedic complaints (Figure 3a), neither the main effect for target load (F < 1) nor direction of body weight-shifting (F_{1, 10} = 1.07, p > 0.05) was significant, with no significant interaction between the two factors (F_{1, 10} = 1.35, p > 0.05). In the healthy elderly participants (Figure 3b), neither the main effect for target load (F < 1) nor direction of body weight-shifting (F_{1, 10} = 1.77, p > 0.05) was significant, with no significant interaction between two factors (F_{1, 10} = 2.49, p > 0.05).

Figure 3. Mean VE/w scores in patients with orthopedic complaints (a) and healthy elderly participants (b) for both the one-third and two-thirds target loads in the affected and unaffected side for the patients and the leftward and rightward for the healthy participants body weight-shifting. The filled and unfilled bars represent the one-third and two-thirds target loads, respectively.

4.3.3 Root Mean Squared Error

In the patients with orthopedic complaints (Figure 4a), neither the main effect for target load (F < 1) nor direction of body weight shift (F < 1) was significant, whereas the interaction between the two factors was significant (F_{1, 10} = 6.9, p < 0.05). Subsequent simple
main effect tests indicated that for the shift to affected side, the mean RMSE/w for the one-third target load \((M = 8.73, \text{SD} = 3.65)\) was significantly \((p < 0.05)\) smaller than that for the two-thirds target load \((M = 1.55, \text{SD} = 8.19)\), whereas no significant difference appeared for the shift to unaffected side \((p > 0.05)\). The simple main effect for direction of body weight-shifting was significant for the one-third target load alone \((p < 0.05)\), with the mean RMSE/w for the affected side shift \((M = 8.73, \text{SD} = 3.65)\) being significantly smaller than that for the shift to unaffected side \((M = 13.83, \text{SD} = 7.05)\). In healthy elderly participants, mean RMSE/w scores are shown in Figure 4b. Neither the main effect for target load \((F < 1)\), nor direction of body weight-shifting \((F_{1, 10} = 2.08, p > 0.05)\), nor the interaction between the two factors \((F_{1, 10} = 1.14, p > 0.05)\) was significant.

Figure 4. Mean RMSE/w scores in patients with orthopedic complaints (a) and healthy elderly participants (b) for both the one-third and two-thirds target loads in the affected and unaffected side for the patients and the leftward and rightward for the healthy participants body weight-shifting. The filled and unfilled bars represent the one-third and two-thirds target loads, respectively.
4.3.4 Coefficient of Intra-Trial Variation

In the patients with orthopedic complaints, an ANOVA on the mean CV scores (Figure 5a) showed that neither the main effect for target load ($F_{1, 10} = 2.63, p > 0.05$) nor direction of body weight-shifting ($F < 1$) was significant, with no significant interaction between the two factors ($F < 1$). For the mean CV scores (Figure 5b) in healthy elderly participants, neither the main effect for target load ($F < 1$) nor direction of body weight shift ($F < 1$) was significant, with no significant interaction between the two factors ($F < 1$).

Figure 5. Mean CV scores in patients with orthopedic complaints (a) and healthy elderly participants (b) for both the one-third and two-thirds target loads in the affected and unaffected side for the patients and the leftward and rightward for the healthy participants body weight-shifting. The filled and unfilled bars represent the one-third and two-thirds target loads, respectively.
4.3.5 Upper Limb Loads

In the patients with orthopedic complaints, an ANOVA on the mean upper limb loads (Figure 6a) revealed a significant main effect for target load ($F_{1,10} = 5.44, p < 0.05$), with the mean upper limb load for the one-third target load ($M = 19.70, SD = 2.70$) being significantly larger than that for the two-thirds target load ($M = 15.90, SD = 2.60$). Neither the main effect for direction of body weight-shifting ($F < 1$) nor the interaction between the two factors ($F < 1$) was significant. In the healthy elderly participants, an ANOVA on the mean upper limb loads (Figure 6b) revealed a significant main effect for target load ($F_{1,10} = 41.35, p < 0.05$), with the mean CE/w for the one-third target load ($M = 38.34, SD = 1.60$) being significantly larger than that for the two-thirds target load ($M = 25.40, SD = 1.90$). Neither the main effect for direction of body weight-shifting ($F_{1,10} = 1.13, p > 0.05$) nor the interaction between the two factors ($F_{1,10} = 1.70, p > 0.05$) was significant.

Figure 6. Mean upper limb loads in patients with orthopedic complaints (a) and healthy elderly participants (b) for both the one-third and two-thirds target loads in the affected and unaffected side for the patients and the leftward and rightward for the healthy participants body weight-shifting. The filled and unfilled bars represent the one-third and two-thirds target loads, respectively.
4.3.6 Comparison of Mean Scores Each Error Score and Upper Limb Loads between Patients with Orthopedic Complaints and Healthy Elderly Participants

A t-test on the mean scores of upper limb loads showed significant difference between the patients with orthopedic complaints and the healthy elderly participants ($p < 0.05$), with the mean upper limb loads for the patients with orthopedic complaints ($M = 17.86$, $SD = 9.56$) being significantly smaller than that for the healthy elderly participants ($M = 31.97$, $SD = 10.38$). A t-test on the mean scores of VE/w showed a significant difference between the patients with orthopedic complaints and the healthy elderly participants ($p < 0.05$), with the mean VE/w for the healthy elderly participants ($M = 4.32$, $SD = 2.00$) being significantly smaller than that for the patients with orthopedic complaints ($M = 5.46$, $SD = 2.94$). T-tests on neither CE/w ($t = -1.13$, $p > 0.05$), RMSE/w ($t = -0.40$, $p > 0.05$), nor CV ($t = 0.47$, $p > 0.05$) showed any significance for the patients with orthopedic complaints and the healthy elderly participants.
4.4 Discussion

4.4.1 Central Tendency Effects

Results of CE/w indicated a ‘central tendency effect’, such that the mean CE/w scores (Figure 2) showed an overshooting at the one-third target load and an undershooting at the two-thirds target load in both groups. An ANOVA on CE/w showed a significant main effect for the target load, with the mean CE/w score being significantly smaller for the one-third than that for the two-thirds target load in both the patients with orthopedic complaints and the healthy elderly participants. Several previous studies (Tveit et al., 2001; Hirota et al., 2003; Ebert et al., 2008) in which patients performed a lateral body weight-shifting task reported similar findings of central tendency effects, although they did not explain their results in terms of ‘central tendency effects’. Therefore, the central tendency effects may generally occur in lateral body weight-shifting tasks, irrespective of patients and healthy people.

The central tendency effect may probably give rise to a negative effect on recovery from disabilities in patients with orthopedic complaints. In the early recovery stage, patients usually perform lateral body weight-shifting with a light target load, probably overshooting the light target load. This may result in that the patients suffer from inflammations or pain of the affected lower limb. For the late recovery stage, patients usually perform this task with a heavy target load probably undershooting the heavy target load and therefore result in a negative effect on regaining normal ability of standing and gait.

4.4.2 Lateral Difference

For the patients with orthopedic complaints, showed the mean RMSE/w (Figure 4) at the affected side shift was significantly smaller, for the one-third target load than that for the two-thirds target load, while at the one-third target load, the mean RMSE/w was significantly
smaller for the affected side shift than that for the unaffected side shift. These results indicated that the scores of RMSE/w were larger when the patients with orthopedic complaints loaded relatively heavy amounts of the body weight on the affected lower limb (i.e., shifting the two-thirds target load toward the affected lower limb and the one-third target load toward the unaffected lower limb) than when they loaded relative light amounts of the body weight on the affected lower limb (i.e., shifting the one-third target load toward the affected lower limb and two-thirds target load on the unaffected lower limb). However, the feature of lateral differences (i.e., leftward and rightward) was equivocal, depending on experimental conditions, clear in this experiment.

4.4.3  Upper Limb Loads

Upper limb loads (Figure 6) for the patients with orthopedic complaints were smaller than that for the healthy elderly participants. This was not predicted in this experiment. Patients with orthopedic complaints usually have difficulties in standing, therefore often using a light support by the upper limbs on horizontal parallel bars. The result of Experiment 1 showed that the patients did not largely support their shifted body weight by the upper limbs during the lateral body weight-shifting task, compared with the healthy participants. In contrast, in both the patients with orthopedic complaints and the healthy elderly participants, the mean upper limb load for the one-third target load was significantly larger than that for the two-thirds target load. This suggests that the light support by the upper limbs may be more important for the one-third target load than for the two-thirds target load.

4.4.4  Features of Patients with Orthopedic Complaints

Different features for the patients with orthopedic complaints and the healthy elderly
participants were shown in the results of the upper limb loads and VE/w. In the patients with orthopedic complaints, the mean scores of CE/w for the one-third target load showed significant overshooting for the one-third target load condition. This may be because they did not fully support the target load by the upper limb and this may enhance overshooting.

For VE/w, the mean score of VE/w was significantly larger for the patients with orthopedic complaints than that for the healthy elderly participants, indicating the feature of variability and inconsistency of the patients with orthopedic complaints in lateral body weight-shifting task.
Chapter 5  Experiment 2
Fundamental Features, Such as Central Tendency, Lateral Difference, and Support by the Upper Limbs on Performance Accuracy of a Lateral Body Weight-Shifting Task in Healthy Participants

5.1 Introduction

The aim of Experiment 2 was to clarify the fundamental feature of whether central tendency effects, lateral differences, and light touch support by the upper limbs/hands affect performance accuracy of lateral body weight-shifting tasks. For this aim, young healthy participants, rather than patients with orthopedic complaints, were used to examine fundamental feature of task performance avoiding likely effects of injuries on performance. The task was performed under four conditions, namely, two target loads (one and two thirds of the body weight) and two directions of weight-shifting (leftward and rightward).

The central tendency effects tend to occur in both the patients with orthopedic complaints and the healthy elderly participants according to the findings of Experiment 1. The central tendency effects probably impede recovery from disabilities in patients with orthopedic complaints in both the early and late stages of recovery. Therefore, it is important to understand how extent the central tendency affects performance of lateral body weight-shifting. Experiment 2 therefore examined the fundamental, general feature of the central tendency effects in healthy people to avoid any effects of injury.

Experiment 1 showed that lateral differences occurred in only the patients with orthopedic complaints, such that the overall error (i.e., RMSE/w) was larger when the patients shifted a relative heavy load to the affected lower limb than when loading a relative light load. In Experiment 1, lateral differences did not appear clearly. Experiment 2 therefore examined
whether lateral differences occur in performance accuracy. Experiment 1 indicated that light touch support by the upper limbs affected performance accuracy, and this would affect lateral differences as well as the central tendency effects. Therefore, to examine whether support by the upper limbs would affect performance accuracy of lateral body weight-shifting, participants were assigned to either one of two groups with and without support by the upper limbs.
5.2 Methods

5.2.1 Participants

Forty right-handed and right-footed healthy young adults participated in this experiment. They were assigned to one of two groups which different in support by the upper limbs on the horizontal parallel bars (support and no support groups). For the support group, twenty-four (13 men and 11 women) participants with mean age 19.0 (SD = 0.7), height 165.6 (SD = 7.4) cm, and weight 58.8 (SD = 9.6) kg, participated. For the no support group, sixteen (5 men and 11 women) participants with mean age 21.7 (SD = 3.6), height 162.4 (SD = 7.2) cm, and weight 57.3 (SD = 8.2) kg, participated. Experiment 2 was approved by the local ethics committee (No. 07-21) of the International University of Health and Welfare, Kanagawa, Japan.

5.2.2 Lateral Body Weight-Shifting Task

The lateral body weight-shifting task was performed in the same way as in Experiment 1. During the task, the support group was allowed to balance themselves by using light touch support by placing their upper limbs/hands on horizontal parallel bars, whereas the no support group placed on the side of the body their upper limbs.

5.2.3 Apparatus and Procedures

The apparatus and procedures were the same as in Experiment 1.

5.2.4 Experimental Design

Three independent variables were manipulated: shifting target load (one and two thirds of the body weight) and directions of body weight-shifting (leftward and rightward) as within participant factors; and group (support and no support group) as a between participant factor.
Dependent measures were the same as used in Experiment 1 (i.e., CE/w, VE/w, RMSE/w, and CV). Upper limb loads were measured for the support group alone.

5.2.5 Analyses

Separate three-way ANOVAs were performed on the CE/w, VE/w, RMSE/w, and CV, respectively. A two-way ANOVA was performed on the loads on the upper limbs loads in the support group.
5.3 Results

5.3.1 Constant Error

**One-sample t-tests.** The mean CE/w scores (Figure 7) showed that the support group undershot the target loads for all conditions. One-sample t-tests showed significant undershooting for the leftward shift (t = -2.86, p < 0.05), except the rightward shift (t = -0.94, p > 0.05), at the one-third target load and both the leftward (t = -3.82, p < 0.05) and rightward (t = -3.95, p < 0.05) shift at the two-thirds target load. This indicated a relative central tendency effect, with a clear-cut larger undershooting for the heavy (i.e., two thirds of the body weight) target load condition than those for the light (i.e., one third of the body weight) target load (which showed either a light but still significant undershooting or non-significant undershooting). In contrast, the no support group showed neither significant undershooting nor overshooting for any condition (p > 0.05).

**Three-way ANOVA.** The results of ANOVA on mean CE/w scores revealed a significant interaction between target load and group (F<sub>1, 38</sub> = 6.22, p < 0.05). Subsequent simple main effect tests indicated that for support group, the mean CE/w score for the one-third target load (M = -2.11, SD = 5.34) was significantly smaller (p < 0.05) than that for the two-thirds target load (M = -5.27, SD = 6.97), whereas no significant difference was appeared for the no support group (p > 0.05). The simple main effect test also indicated that for the two-thirds target load, the mean CE/w score for the support group (M = -5.27, SD = 6.97) was significantly smaller (p < 0.05) than that for the no support group (M = 3.04, SD = 8.94), whereas no significant difference appeared for the one-third target load (p > 0.05). The main effect for group was significant (F<sub>1, 38</sub> = 15.79, p < 0.05), with the mean CE/w score for the support group (M = -3.70, SD = 8.00) being smaller than that for the no support group (M = 1.5, SD = 10.0). Neither the main effect for target load (F < 1) nor direction of body weight-shifting (F < 1) was
significant.

Figure 7. Mean CE/w scores in the support group and the no support group for both the one-third and two-thirds target loads in the leftward and rightward body weight-shifting. The filled and unfilled bars represent the one-third and two-thirds target loads, respectively.
5.3.2 Variable Error

The results of ANOVA on VE/w (Figure 8) revealed a significant main effect for target load ($F_{1,38} = 29.01, p < 0.05$), with the mean VE/w score for the one-third target load ($M = 3.30$, SD = 1.0) being significantly smaller than that for the two-thirds target load ($M = 4.90$, SD = 3.0). Neither the main effect for direction of body weight-shifting ($F < 1$) nor group ($F < 1$) was significant. However, the interaction between target load and direction of body weight-shift was significant ($F_{1,38} = 7.38, p < 0.05$). Subsequent simple main effect test indicated that for the two-thirds target load, the mean VE/w score for the rightward shift ($M = 4.54$, SD = 2.0) was significantly smaller ($p < 0.05$) than that for the leftward shift ($M = 5.34$, SD = 1.97).

Figure 8. Mean VE/w scores in the support group and the no support group for both the one-third and two-thirds target loads in the leftward and rightward body weight-shifting. The filled and unfilled bars represent the one-third and two-thirds target loads, respectively.
5.3.3 Root Mean Squared Error

An ANOVA on RMSE/w (Figure 9) showed a significant main effect for target load ($F_{1,38} = 27.57$, $p < 0.05$), with the mean RMSE/w score being smaller for the one-third target load ($M = 5.90$, $SD = 4.0$) than that for the two-thirds target load ($M = 9.0$, $SD = 5.0$). Neither the main effect for direction of body weight-shifting ($F < 1$) nor group ($F < 1$) was significant. The three-way interaction between target load, direction of body weight-shifting, and group ($F_{1,38} = 7.92$, $p < 0.05$) was significant.

Subsequent simple interaction test at the support group indicated that the interaction between target load and direction of body weight-shifting was significant ($F_{1,38} = 9.18$, $p < 0.05$); subsequent simple-simple main effect tests indicated that for the leftward shift, the mean RMSE/w score for one-third target load ($M = 4.85$, $SD = 1.90$) was significantly smaller ($p < 0.05$) than that for the two-thirds target load ($M = 9.75$, $SD = 3.44$), whereas no significant difference appeared for the rightward shift ($p > 0.05$); and the simple-simple main effect tests also indicated that for the one-third target load, the mean RMSE/w score for the leftward shift ($M = 4.85$, $SD = 1.90$) was significantly smaller ($p < 0.05$) than that for the rightward shift ($M = 6.70$, $SD = 3.64$), whereas for the two-thirds target load, the mean RMSE/w score for the rightward shift ($M = 7.52$, $SD = 3.21$) was significantly smaller ($p < 0.05$) than that for the leftward shift ($M = 9.75$, $SD = 3.44$).

Furthermore, the subsequent simple interaction tests at the rightward shift indicated that the interaction between target load and group was significant ($F_{1,1} = 4.37$, $p < 0.05$). The simple-simple main effect tests indicated that for the no support group, the mean RMSE/w score for the one-third target load ($M = 5.67$, $SD = 2.87$) was significantly smaller ($p < 0.05$) than that for the two-thirds target load ($M = 9.83$, $SD = 5.52$).
5.3.4 **Coefficient of Intra-Trial Variation**

An ANOVA on the mean CV scores (Figure 10) revealed a significant main effect for the group ($F_{1,38} = 79.48, p < 0.05$), with the mean CV score for the support group ($M = 1.70, SD = 2.0$) being significantly smaller ($p < 0.05$) than that for the no support group ($M = 4.0, SD = 2.0$). The main effect for target load was also significant ($F_{1,38} = 12.09, p < 0.05$), with the mean CV score for the two-thirds target load ($M = 2.70, SD = 1.0$) being significantly smaller ($p < 0.05$) than that for the one-third target load ($M = 3.10, SD = 1.0$). The main effect for direction of body weight-shifting was not significant ($F < 1$). The interaction between target load and group was significant ($F_{1,38} = 59.24, p < 0.05$). For this significant interaction, subsequent simple main effect tests indicated that the mean CV score of the support group for the one-third target load ($M = 1.47, SD = 0.41$) was significantly smaller ($p < 0.05$) than that for the
two-thirds target load (M = 1.98, SD = 0.69), whereas the mean CV score of the no support group for the two-thirds target load (M = 3.35, SD = 1.46) was significantly smaller (p < 0.05) than that for the one-third target load (M = 4.70, SD = 1.77).

Figure 10. Mean CV scores in the support group and the no support group for both the one-third and two-thirds target loads in the leftward and rightward body weight-shifting. The filled and unfilled bars represent the one-third and two-thirds target loads, respectively.

5.3.5 Upper Limb Loads

A two-way ANOVA on the upper limb loads (Figure 11) for the support group showed a significant main effect for target load ($F_{1, 23} = 13.31, p < 0.05$) with the mean upper limb load for the two-thirds target load (M = 9.95, SD = 6.87) being significantly smaller (p < 0.05) than that for the one-third target load (M = 15.02, SD = 7.69). The main effect for direction of body weight-shifting was also significant ($F_{1, 23} = 12.45, p < 0.05$), with the mean upper limb load for the rightward shift (M = 10.32, SD = 6.44) being significantly smaller (p < 0.05) than that for
the leftward shift ($M = 14.64$, $SD = 8.12$). The interaction between the target load and the direction of body weight-shifting was not significant ($F < 1$).

Figure 11. Mean upper limb loads in the support group for both the one-third and two-thirds target loads in the leftward and rightward body weight-shifting. The filled and unfilled bars represent the one-third and two-thirds target loads, respectively.
5.4 Discussion

5.4.1 Central Tendency Effects

The results of CE/w showed a clear-cut undershooting for the two-thirds target load and a small or non-significant undershooting for the one-third target load (Figure 7). This indicated a relative central tendency effect, although no overshooting appeared for the light (one-third) target load. Such a central tendency effect appeared for the support group alone and did not appear for the no support group. A plausible reason for the central tendency effect appearing for only the support group seemed that participants did not well shift their body weight toward the opposite side because of the support by upper limb instead of support by the lower limbs. Bateni et al. (2004) suggested that the use of a cane or a walker impeded full lateral stepping reactions. The present finding that the support by upper limbs caused a large central tendency effect seems consistent with Bateni et al. suggestion. Specifically, in the support group, they generally undershot the target load for both the light and heavy loads. This indicated that the support by upper limbs may have reduced loads on the target lower limb. Such an undershooting may impede a full recovery in the late recovery stage, and the feature of upper limb support was therefore examined in Experiment 3 of the present study.

5.4.2 Lateral Difference

The results of RMSE/w (Figure 9) showed a significant three-way interaction between the target load, the direction of body weight-shifting, and the group. The significant three-way interaction indicated that lateral difference in RMSE/w differed for the support group and the no support groups, suggesting that lateral differences in RMSE/w seem to depend on the use of upper limbs. This was evident in the results of upper limb loads (Figure 11), showing lateral differences, such that the upper limb load for the rightward shift was significantly smaller than
that for the leftward shift. The lateral difference may therefore relate with the use of the support by upper limbs in lateral body weight-shifting.

5.4.3 **Coefficient of Intra-Trial Variation**

The mean CV score for the support group was significantly smaller than that for the no support group. Since CV scores indicate the extent of inter-trial variability of lateral body weight-shifting, the support by upper limbs may contribute to stable performance of lateral body weight-shifting.

5.4.4 **Effects of Support by Upper Limb**

On the basis of the results of CE/w, RMSE/w, and CV, it is suggested that the effects of the support by upper limbs may have both positive and negative effects. The support by upper limbs may stabilize lateral body weight-shifting performance, although this also gives rise to a undershoot and lateral differences. Previous studies (e.g., Ashton-Miller et al., 1996; Kuan et al., 1999; Bateni et al., 2004) suggested that the support by upper limbs may enhance stable posture and gait, with negative effects, such as interference in lateral stepping reactions (see Chapter 2, *Effects of support by the upper limbs on quiet standing and gait*). Experiment 3 therefore examined the feature of the use of the support by upper limbs.
Chapter 6  Experiment 3
Effects of Reciprocal Interlimb Weight-Adjustment on Performance Accuracy in a Lateral Body Weight-Shifting Task in Healthy Participants

6.1  Introduction

The aim of Experiment 3 was to clarify the feature of the use of the support by upper limbs in the lateral body weight-shifting task. To this end, the effects of reciprocal interlimb (i.e., upper and lower limb) weight-adjustment on performance accuracy were examined in healthy participants. The results of Experiment 2 showed that the support by upper limbs had both positive and negative effects on performance accuracy and stability of this task, such that a large undershooting (a relative central tendency effect) appeared clearly when using the support by upper limbs and this related with low performance of this task. Experiment 3 therefore examined whether the use of upper limbs, that is, reciprocal interlimb weight-adjustment, affected task performance, particularly the features of overshooting and undershooting in CE/w scores.

Reciprocal interlimb weight-adjustment (coordination) usually occurs in gait. Haddad et al. (2006) examined the feature of interlimb (between left and right) and intralimb (within a limb) coordination during gait with asymmetrical weight distribution on both lower limbs, showing that interlimb coordination of lower limbs showed a high correlation coefficient between the two lower limbs during various weight distribution. Stephenson et al. (2009) also showed that interlimb coordination (the correlation coefficient was more than 0.4) among the upper and lower limbs occurred during gait in both healthy participants and patents with hemiparesis. These findings indicated that interlimb coordination may well contribute to smooth gait performance. Therefore, it is likely that reciprocal interlimb weight-adjustment also
contribute to increasing performance accuracy in lateral body weight-shifting.

To examine the likely effects of interlimb weight-adjustment in lateral body weight-shifting, the respective loads of each upper limb were measured with two load cells placed on a pair of horizontal parallel bars as well as the loads of both the left and right lower limbs. The correlation coefficients among the lower and upper limbs were calculated to analyze the feature of interlimb weight-adjustment, such that a negative correlation coefficient should indicate reciprocal interlimb adjustment. Moreover, correlation coefficients between the correlation coefficients of interlimb weight-adjustment and performance errors were calculated to examine the effects of interlimb weight-adjustment on performance errors.
6.2 Methods

6.2.1 Participants

Twenty-three (10 men and 13 women) right-handed and right-footed healthy young adults with the mean age 21.5 (SD = 1.0), height 164.8 (SD = 9.8) cm, and weight 58.6 (SD = 9.4) kg participated in Experiment 3. This experiment was approved by the local ethics committee (No. 10-41) of the International University of Health and Welfare, Kanagawa, Japan.

6.2.2 Apparatus

Apparatus was almost the same as that used in Experiments 1 and 2. In addition, two load cells (LUR-A-1KNSA1, Kyowa, Japan) were placed on each of horizontal parallel bars to measure respective loads of the upper limbs during lateral body weight-shifting.

6.2.3 Tasks, Procedures, and Experimental Design

The tasks, procedures, and experimental design were the same as those in Experiments 1 and 2.

6.2.4 Analyses

Hand pressure. Hand pressure was analyzed with the same way as that for foot pressure in Experiments 1 and 2. Analogue outputs of hand and foot pressures were analyzed for the last 1 s of each trial, because foot pressure (which was used in examining performance errors) was relatively stable in this period. A three-way ANOVA was performed on the load of upper limbs with repeated measures of all factors, namely, target load (one and two thirds of body weight), direction of body weight-shifting (leftward and rightward), and side of upper limb (left and right upper limb).
Normalizing error scores. In addition to the mean scores of CE/w, VE/w, and RMSE/w, which were calculated as the mean value of 10 trials, the z-scores (M = 0.0, SD = 1.0) of CE/w and the respective Z-scores (M = 50.0, SD = 10.0) of VE/w and RMSE/w were calculated to eliminate individual differences in relative error scores between the four conditions. Separate two-way ANOVAs were performed on both the mean error scores (CE/w, VE/w, RMSE/w, and CV) and the normalized error scores (z-scores of CE/w, Z-scores of VE/w, and Z-scores of RMSE/w) with repeated measures of both factors of the target load (one and two thirds of body weight) and the direction of body weight shifting (leftward and rightward).

The use of upper limbs and interlimb weight-adjustments. To analyze interlimb weight-adjustment in weight-shifting, correlation coefficients between the respective loads of the two lower limbs, such as the destination (i.e., the target load was to be shifted to this side) and starting (i.e., the target load was to be shifted from this side) lower limbs, and the two upper limbs were calculated (i.e., total of six pairs of interlimb weight-adjustments) for each trial per participant. The correlation coefficients were transformed by Fisher’s z-transformation method into individual Z-transformed correlation coefficients. For each condition, the mean Z-transformed correlation coefficients were calculated on the basis of 10 trials per participant.

The relationships between the degree of Z-transformed correlation coefficients and the mean scores of CE/w were analyzed with coefficient of correlation. The analyses of inter-limb weight-adjustments with the Z-transformed correlation coefficients were performed according to the methods of Jaric et al. (2006) and Stephenson et al. (2009).
6.3 Results

6.3.1 Reciprocal Interlimb Weight-Adjustments in each condition

The mean of 23 participants correlation coefficients for six pair of score in each condition were showed in Figure 12, which each correlation coefficient was inverse transformed value from Z-transformed correlation coefficient. One-sample t-tests were performed on the Z-transformed correlation coefficients for each pair of the interlimb correlation coefficient. The reciprocal interlimb correlation coefficients showed similar pattern in all condition. Significantly (p < 0.05) negative correlation coefficients between the two lower limbs and between the destination lower and upper limbs (i.e., the left lower and upper limbs in the condition of leftward shift and the right lower and upper limbs in the condition of rightward shift) appeared in all conditions. Correlation coefficients between the starting lower and destination upper limbs (i.e., the right lower and left upper limbs in the condition of leftward shift and the left lower and right upper limbs in the condition of rightward shift) were significantly positive correlation coefficients (p < 0.05). The other was no significant interlimb correlation coefficients (p > 0.05).
Figure 12. The mean scores of correlation coefficients, which were performed inverse Z-transformed correlation coefficients, between the two limbs in the condition of (a) the 1/3 leftward, (b) the 2/3 leftward, (c) the 1/3 rightward, and (d) the 2/3 rightward. Llow and Rlow were left and right lower limbs and Lupper and Rupper were left and right upper limbs.
6.3.2  The Relationships between the Degree of Reciprocal Interlimb Weight-Adjustment and CE/w scores

Correlation coefficients between the size of Z-transformed correlation coefficients (i.e., the degree of reciprocal interlimb weight-adjustments) and CE/w scores were calculated for all the four conditions. In the condition of one-third target load in leftward shift (Figure 13a), the degree of reciprocal interlimb weight-adjustment between the starting (i.e., right) lower limb and the left upper limb was somehow significantly correlated in positive direction with CE/w ($r = 0.36, p = 0.09$). In the condition of two-thirds target load in leftward shift (Figure 13b), the degree of reciprocal interlimb weight-adjustment between the destination (i.e., left) lower limb and the right upper limb was significantly correlated in positive direction with CE/w ($r = 0.45, p < 0.05$). Results for the same condition, namely, the condition of two-third target load in leftward shift (Figure 13c), also showed that the degree of reciprocal interlimb weight-adjustment between the starting (i.e., right) lower limb and the right upper limb was significantly correlated in negative direction with CE/w ($r = -0.45, p < 0.05$). In the condition of both one-third (Figure 13d) and two-thirds (Figure 13e) target load in rightward shift, the degree of reciprocal interlimb weight-adjustment between the starting (i.e., left) and destination (i.e., right) lower limbs was significantly correlated in negative direction with CE/w ($r = -0.50$ and -0.39 for the one- and two-thirds target load conditions, $p < 0.05$, respectively).
Figure 13. Scatter plots for CE/w and the size of Z-transformed correlation coefficients between (a) the right lower and the left upper limb in the one-third target load at leftward shift, (b) the left lower and the right upper limb in the two-thirds target load at leftward shift, (c) the right lower and the right upper limb in the two-thirds target load at leftward shift, (d) the left and right lower limbs in the one-third target load at rightward shift, (e) the left and right lower limbs in the two-thirds target load at rightward shift.
6.3.3 Constant Error

Mean scores of CE/w. The mean CE/w scores (Figure 14a) showed neither significant undershooting nor overshooting for any condition ($p > 0.05$). The results of two-way ANOVA on the mean scores of CE/w showed that the main effect for neither target load ($F_{1, 22} = 3.42, p = 0.08$) nor direction of body weight-shifting ($F < 1$) was significant. The interaction between the two factors was not significant ($F < 1$).

z-scores of CE/w. An ANOVA on the mean z-scores of CE/w (Figure 14b) revealed a significant main effect for the target load ($F_{1, 22} = 5.35, p < 0.05$), with the mean z-scores of CE/w being significantly smaller for two-thirds target load ($M = -0.29, SD = 0.98$) than that for the one-third target load ($M = 0.29, SD = 0.90$). This indicated a relative central tendency effect. Neither the main effect for direction of body weight-shifting ($F < 1$) nor interaction between the two factors ($F_{1, 22} = 1.81, p > 0.05$) was significant.

Figure 14. (a) Mean CE/w scores and (b) mean z-scores of CE/w for both the one-third and two-thirds target loads in the leftward and rightward body weight-shifting. The filled and unfilled bars represent the one-third and two-thirds target loads, respectively.
6.3.4 Variable Error

Mean scores of VE/w. An ANOVA on the mean VE/w (Figure 15a) showed a significant main effect for target load ($F_{1, 22} = 5.06, p < 0.05$), with the mean VE/w score being significantly smaller for the one-third target load ($M = 3.61, SD = 1.52$) than that for the two-thirds target load ($M = 4.42, SD = 1.83$). Neither the main effect for direction of body weight-shifting ($F < 1$) nor the interaction between the two factors ($F < 1$) was significant.

Z-scores of VE/w. An ANOVA on the mean Z-scores of VE/w (Figure 15b) showed a significant main effect for target load ($F_{1, 22} = 7.51, p < 0.05$), with the mean VE/w score being significantly smaller for the one-third target load ($M = 46.81, SD = 9.00$) than that for the two-thirds target load ($M = 53.19, SD = 9.82$). Neither the main effect for direction of body weight-shifting ($F < 1$) nor the interaction between the two factors ($F < 1$) was significant.

![Figure 15](image.png)

Figure 15. (a) Mean VE/w scores and (b) mean Z-scores of VE/w for both the one-third and two-thirds target loads in the leftward and rightward body weight-shifting. The filled and unfilled bars represent the one-third and two-thirds target loads, respectively.
6.3.5 Root Mean Squared Error

Mean scores of RMSE/w. An ANOVA on the mean RMSE/w (Figure 16a) showed that neither the main effect for target load ($F_{1, 22} = 1.51$, $p > 0.05$) nor for direction of body weight-shifting ($F_{1, 22} = 2.05$, $p > 0.05$) was significant, with somehow significant interaction between the two factors ($F_{1, 22} = 3.11$, $p = 0.09$). Subsequent simple main effect tests indicated that for the leftward shift, the mean RMSE/w for the one-third target load ($M = 5.47$, $SD = 2.30$) was significantly ($p < 0.05$) smaller than that for the two-thirds target load ($M = 7.18$, $SD = 2.48$), whereas no significant difference appeared for the rightward shift ($p > 0.05$). The simple main effect for direction of body weight-shifting was significant for the one-third target load alone ($p < 0.05$), with the mean RMSE/w for the leftward shift ($M = 5.47$, $SD = 2.30$) being significantly smaller than that for the rightward shift ($M = 7.37$, $SD = 3.63$).

Z-scores of RMSE/w. An ANOVA on the mean Z-scores of RMSE/w (Figure 16b) showed that the main effect for neither target load ($F_{1, 22} = 1.53$, $p > 0.05$) nor direction of body weight-shifting ($F_{1, 22} = 2.55$, $p > 0.05$) was significant, with marginally significant interaction between the two factors ($F_{1, 22} = 3.90$, $p = 0.06$). Subsequent simple main effect tests indicated that for the leftward shift, the mean RMSE/w for the one-third target load ($M = 44.45$, $SD = 8.46$) was significantly ($p < 0.05$) smaller than that for the two-thirds target load ($M = 51.48$, $SD = 9.90$), whereas no significant difference appeared for the rightward shift ($p > 0.05$). The simple main effect for direction of body weight-shifting was significant for the one-third target load alone ($p < 0.05$), with the mean RMSE/w for the leftward shift ($M = 44.45$, $SD = 8.46$) being significantly smaller than that for the rightward shift ($M = 52.71$, $SD = 11.0$).
Figure 16. (a) Mean RMSE/w scores and (b) mean Z-scores of RMSE/w for both the one-third and two-thirds target loads in the leftward and rightward body weight-shifting. The filled and unfilled bars represent the one-third and two-thirds target loads, respectively.
6.3.6 Coefficient of Intra-Trial Variation

An ANOVA on the mean CV scores (Figure 17) revealed a significant main effect for target load ($F_{1, 22} = 32.3, p < 0.05$), with the mean CV score for the two-thirds target load being significantly smaller ($M = 2.19, SD = 1.36$) than that for the one-third target load ($M = 4.19, SD = 2.52$). Neither the main effect for direction of body weight-shifting ($F < 1$) nor interaction between the two factors ($F < 1$) was significant.

Figure 17. Mean CV scores for the condition of one-third and two-thirds target load in the leftward and rightward body weight-shifting. The filled and unfilled bars represent the one-third and two-thirds target loads, respectively.
6.3.7 Upper Limb Loads

A three-way ANOVA on the upper limb loads (Figure 18) revealed that the three-way interaction between target load, direction of body weight-shifting, and side of upper limb was significant ($F_{1, 22} = 7.03, p < 0.05$). Subsequent simple interaction tests indicated that for the two-thirds target load, the interaction between direction of body weight-shifting and side of upper limb was significant ($F_{1, 22} = 8.54, p < 0.05$). Subsequent simple-simple main effect tests indicated that for the leftward shift, the mean load for the left upper limb ($M = 1.78$, $SD = 2.07$) was significantly smaller ($p < 0.05$) than that for the right upper limb ($M = 4.02$, $SD = 4.20$), whereas for the rightward shift, the mean load for the right upper limb ($M = 2.29$, $SD = 2.12$) was significantly smaller ($p < 0.05$) than that for the left upper limb ($M = 5.00$, $SD = 5.00$).

Figure 18. Mean upper limb loads for both the one-third and two-thirds target loads in the leftward and rightward body weight-shifting. The light and dark grey bars represent the left and right upper limbs, respectively.
6.4 Discussion

6.4.1 Reciprocal Interlimb Weight-Adjustment

In the condition of one-third target load in leftward shift (Figure 13a), the overshooting in CE/w increased as the positive Z-transformed correlation coefficient between the starting (right) lower limb and the left upper limb increased. Given that the load at the starting lower limb were necessarily decreasing during body weight-shifting, the positive Z-transformed correlation coefficient between them also indicates that the load at the left upper limb should decreased during body weight-shifting. This therefore implies that the decrease in load at the left upper limb may be a primary factor causing an overshooting in CE/w. In practical meanings, this should indicate a worse effect in the early stage of recovery.

In the condition of two-thirds target load in leftward shift (Figures 13b and 13c), both the negative Z-transformed correlation coefficients (indicating the left half of the horizontal axis of Figure 13b) between the destination lower limb and the right upper limb and the positive Z-transformed correlation coefficients (indicating the right half of the horizontal axis of Figure 13c) between the starting lower limb and the right upper limb, showed a clear undershooting in CE/w. In both situations, the load at the right upper limb necessarily decreased, given that the load at the destination lower limb necessarily increased, and vice versa for the starting lower limb, in a trade-off manner between the starting and destination lower limbs. This implies that a more decreased load at the right upper limb may enlarge undershooting errors in CE/w at the target (left) lower limb.

At the rightward shift for both the one- and two-thirds target load (Figures 13d and 13e), an increase of the reciprocal interlimb weight-adjustment (i.e., the negative Z-transformed correlation coefficient) between the two lower limbs enhanced overshooting in CE/w, whereas the decrease in such reciprocal interlimb weight-adjustment caused undershooting in CE/w. The
increase of reciprocal interlimb weight-adjustment between the two lower limbs implies a decreased contribution of upper limbs in body weight-shifting, and vice versa. Therefore, these results indicated that an increase of the use of upper limbs (i.e., the decreased reciprocal interlimb weight-adjustment between the two lower limbs) enhanced undershooting in CE/w, while the decreased use of upper limbs resulted in overshooting. This suggests that the use of upper limbs may be crucial in causing either undershooting or overshooting in body weight-shifting to the right lower limb, irrespective of one- and two-thirds target load conditions. For practical meanings, the use of upper limbs should provide a beneficial effect (i.e., undershooting) on body weight-shifting in the light (one-third) target load conditions in the early stage of recovery, whereas the use of the upper limbs should result in worse effect (i.e., undershooting) in the heavy (two-thirds) target load conditions used in the late stage of recovery.

6.4.2 Central Tendency Effects

The result of CE/w (Figure 14) showed a ‘relative’ central tendency effect in terms of z-scores of CE/w, indicating that the central tendency effects appeared in all conditions examined in Experiments 1, 2, and 3. It was clear that the central tendency effects correlated with the degree of reciprocal interlimb weight-adjustment (see 6.4.1). The central tendency effects which showed as the fundamental feature in lateral body weight-shifting in all Experiments were affected the support by upper limbs and those one or some pairs of interlimb weight-adjustment between the lower and upper limbs.
6.4.3 Upper Limb Loads

The mean upper limb loads (Figure 18) showed lateral differences for the two-thirds target load condition. At the leftward shift, the mean load on the left upper limb was smaller than that on the right upper limb, whereas at the rightward shift, the mean load on the right upper limb was smaller than that on the left upper limb. This indicated that the mean upper limb load was smaller for the side of destination lower limb than that for the starting side in the two-thirds target load. That is, participants may increase the upper limb loads on the side of starting lower limb, while increasing the load on the destination lower limb in the condition of two-thirds target load. Such adjustment with the use of upper limbs seemed to stabilize upright posture against asymmetric posture which necessarily resulted from lateral body weight-shifting.
Chapter 7  General Discussion

7.1  Central Tendency Effects of Different Amounts of Target Loads on Accuracy of Lateral Body Weight-Shifting

The central tendency effect appeared in Experiments 1, 2, and 3, which showed relative overshooting at the one-third target load, and relative undershooting at the two-thirds target load. Several previous studies (Li et al., 2001; Hirota et al., 2003; Ebert et al., 2008) which examined the accuracy of lateral body weight-shifting in patients showed similar findings of the central tendency effects. The results of central tendency effects in Experiments 1 to 3 were consistent with the findings of these previous studies. Central tendency effects generally (but perhaps more typically for patients than that for normal people) occur with lateral body weight-shifting regardless of the healthy and medical conditions of individuals.

The central tendency effect occurred as a fundamental feature in common to both the patients with orthopedic complaints and healthy participants. Particularly, this effect occurred for the conditions of with the support by upper limbs alone. The reason for this seemed that postural stability due to the use of upper limbs may affect the appearance of central tendency effects. Some previous studies (Jeka et al., 1994; Ashton-Miller et al., 1996) indicated that the support by upper limbs reduced postural sway and thus increased postural stability. Bateni et al. (2004) however showed, examining healthy participants, that the use of upper limbs with a cane and/or a walker caused smaller lateral step lengths for the condition of with a cane and/or walker than that for the condition of without the devices. This suggests that the use of assistance devices may give rise to worse effect on lateral stepping reactions. Participants in the present study undershot the target load when using the support by upper limbs, particularly in the condition of two-thirds target load. This might be because the participants used upper limbs in lateral body weight-shifting and this impaired task performance, as in the findings of Bateni et
al. According to Bateni et al. findings, the support by upper limbs would affect lateral stepping reactions to be performed with a small step length. Therefore, the use of the support by upper limbs in lateral body weight-shifting may cause a large undershooting (in terms of a small step length in the lateral direction) in the two-thirds target load condition, which is usually used in the late recovery stage.

### 7.2 Lateral Difference of Performance Accuracy

In Experiments 1 and 2, lateral differences appeared in the both patients with orthopedic complaints and healthy participants. In the patients with orthopedic complaints, large RMSE/w scores (Figure 4a) appeared when they loaded a relatively heavy, rather than light target load on the affected lower limb. The pattern of VE/w (Figure 3a), rather than CE/w, among the four conditions was similar to the pattern of RMSE/w. Therefore, lateral differences between the affected and unaffected lower limbs may be influenced by variability (i.e., VE/w) of performance. The RMSE mathematically consists of CE and VE, specifically in terms of the equation of \( \text{RMSE}^2 = \text{CE}^2 + \text{VE}^2 \) (Henry, 1975). The results of RMSE/w in the present study may have been affected by VE/w more than CE/w. This suggests that the patients with orthopedic complaints may have difficulties in steadily performing this task when they loaded a relatively heavy target load on the affected lower limb.

In the healthy participants, the RMSE/w scores (Figure 9) indicated significant lateral differences only for the condition of with support by upper limbs, which differed from those in the patients with orthopedic complaints. That is, the RMSE/w score was significantly smaller for the rightward shift than that for the leftward shift in the condition of two-thirds target load, whereas in the one-third target load the RMSE/w score was smaller for the leftward shift. Lateral differences have often been observed in some other tasks, such as quiet standing.
(Murray et al., 1973; Dickstein et al., 1984; Sackley et al., 1991; Hart et al., 1997; Gutnik et al., 2008) and gait (Singh, 1970; Hamill et al., 1984; Maupas et al., 1999), although the specific feature of lateral differences was equivocal in various tasks. The results of RMSE/w in the present study also indicated lateral differences: the resultant feature of lateral differences differed (in an opposite pattern) for the direction of weight-shifting with the use of upper limbs, whereas no lateral differences occurred in the condition of without the support of upper limbs. Therefore, it seems that the use of upper limbs may lead to producing lateral differences, although the reason for this is far from clear in the present study.

7.3 Effects of the Support by Upper Limbs and Reciprocal Interlimb Weight-Adjustment on Performance Accuracy in a Lateral Body Weight-Shifting

The present study clearly showed that the support by upper limbs had both positive and negative effects on performance accuracy of lateral body weight-shifting. The negative effects of the use of upper limbs occurred as a large undershooting of the target load on the target lower limb, indicating a feature of central tendency effects (Figure 7). The support by upper limbs reduced the load on the target lower limb, particularly in the condition of two-thirds target load, which is usually used in the late recovery stage in rehabilitation. Patients in the late recovery stage need to shift a heavy (e.g., two third or three fourth of the body weight) target load toward the affected lower limb to regain normal standing and gait (e.g., Sugawara et al., 1993; Pai et al., 1994). Therefore, the support by upper limbs in the late recovery stage, in which a heavy target load is used, may impede sufficient recovery. For the condition if one-third target load, however, the support by upper limbs contributed to preventing from loading an excess load on the target lower limb and this may benefit patients in the early recovery stage. This suggests that the negative effects of the use of upper limbs on task performance of lateral body weight-shifting may occur only in the condition of a heavy target load in the late stage of
recovery.

The positive effects of the use of upper limbs appeared as a stable task performance of lateral body weight-shifting. This was underpinned by the results of CV for the condition of with support by upper limbs, in which the CV was smaller than that of the condition of without support by upper limbs (Figure 10). Such effects were consistent with the findings of some previous studies (e.g., Ashton-Miller et al., 1996; Kuan et al., 1999), which examined the effects of the use of a cane in patients with peripheral neuropathy or hemiparesis, showing that the use of a cane improved postural stability. Jeka et al. (1994) also showed that support by only fingertip contact (i.e., light-touch support) was effective in postural stability. The results of the present study also showed that the support by upper limbs placed on horizontal parallel bars benefited performance stability in lateral body weight-shifting.

Experiment 3 showed that the extent of reciprocal interlimb weight-adjustment correlated with the degree of overshooting and undershooting in CE/w scores. For the leftward shift, reciprocal weight-adjustment between the upper and lower limbs correlated with overshooting at the condition of one-third target load, whereas this correlated with undershooting at the condition of two-thirds target load. In contrast, for the rightward shift, a large reciprocal weight-adjustment between the left and right lower limbs correlated with the degree of overshooting at the condition of one-third target load, whereas a small reciprocal weight-adjustment between the upper and lower limbs correlated with the degree of undershooting at the two-thirds target load.

These results therefore indicated that the reciprocal interlimb weight-adjustments differed for the leftward and rightward shifts. Participants may have used interlimb weight-adjustment between a pair of upper and lower limbs in the leftward shift, whereas in the rightward shift participants primarily used reciprocal weight-adjustment between the two lower
limbs. The weight-adjustment between a pair of upper and lower limbs seemed to result from an adjustment of trunk tilting and/or pelvic movements. In the leftward shift, participants adjusted the shift of a target load on the target lower limb with both the reciprocal weight-adjustment between upper and lower limbs and the postural control of the trunk and pelvic movements. This might be because participants (all right-handed and -footed) may have difficulties in shifting the body weight to the left, non-dominant lower limb and, therefore, they needed to use additional control by the upper limbs. In contrast, for the rightward shift, participants may be relatively easy to shift a target load to the right, dominant lower limb and thus adjusted the target load between the two lower limbs without any additional use of the upper limbs, although this should be further examined in the future study.

7.4  Practical Implications for Rehabilitation

The results of the present study clarified some fundamental feature in the lateral body weight-shifting task, which may provide several practical implications for rehabilitation. First, the central tendency effect should be considered when using a lateral body weight-shifting task. For the early stages of rehabilitation, in which a relatively light target load (e.g., one third of body weight) should be used in a body weight-shifting task, patients would most likely overshoot a light target load, and this could cause further damage to the affected lower limb. In the late stages of rehabilitation, a relatively heavy target load is used, and may result in undershooting. This would lead to a lack of sufficient loading in the affected limb, causing a lack of sufficient effects on regaining normal/original strength and the ability to shift body weight.

Second, lateral differences in performing lateral body weight-shifting may occur when upper limbs are used. The fundamental feature of lateral differences may differ in the early and
late stages of recovery. Body-weight shifting of a light target load, as during the early stages of rehabilitation, tend to be inaccurate and inconsistent for rightward but not leftward shifting. This effect appears to be reversed for the two-thirds target load, as would generally be used in the late stages of rehabilitation. Therefore, whether a patient with orthopedic complaints or hemiparesis suffered from left- or right-sided would be expected to affect the performance accuracy of this task. In the early stages of rehabilitation, the performance of this task should more inaccurate in patients with right side disorder than in those with left side disorder. In contrast, in the late stages of rehabilitation, patients with left side disorder should have greater difficulty performing this task accurately.

Finally, the use of reciprocal interlimb weight-adjustment between the upper and lower limbs may deteriorate performance accuracy of lateral body weight-shifting. The reciprocal interlimb weight-adjustment also seemed to result from a slight tilt of the trunk and pelvic movements.

### 7.5 Limitations of this study

Experiment 1 examined the respective features of lateral body weight-shifting for both the patients with orthopedic complaints and healthy participants. Experiments 2 and 3 examined the fundamental feature of the task in healthy participants, whose feature should be fundamental, general, and independent of the effects of any injury. However, there should be some limitations as follows.

First, the present study did not examine the effects of the central tendency, lateral differences, and the support by upper limbs on the processes of recovery from injury in patients. Therefore, fundamental feature of this task in healthy participants would generally be applied to performance in patients, this could also change depending on the feature of individual injury of
Second, the present study did not examine the practical features of lateral body weight-shifting in the patients of early/late stage of recovery. Therefore, this study cannot immediately provide therapists (and/or patients) with practical information, such as appropriate instructions to be used for patients who are performing a lateral body weight-shifting task. Nevertheless, the findings of this study may well contribute to future studies conducted in attempting to elucidate the practical feature of this task in rehabilitation.

Finally, the present study did not clarify effective strategies of interlimb weight-adjustment or support by upper limbs during the lateral body weight-shifting task in healthy participants, whereas the findings of this study indicated correlation between reciprocal interlimb weight-adjustment and performance accuracy. Effective strategies for the lateral body weight-shifting should be verified on the basis of the correlation in future studies.
Chapter 8  Conclusions

The aim of this study was to clarify the effects of fundamental features, such as central tendency effects, lateral differences, and light touch support by the upper limbs on performance accuracy in a lateral body weight-shifting task. In Experiment 1, the features of lateral body weight-shifting were examined for patients with orthopedic complaints compared with age-matched elderly healthy participants. Experiment 2 examined the effects of the fundamental feature of central tendency effects, lateral differences, and light touch support by the upper limbs for performance accuracy of lateral body weight-shifting in healthy participants. Experiment 3 examined the feature of the use of the support by the upper limbs in healthy participants.

Results of Experiments 1 to 3 showed several behavioral features in terms of the fundamental feature of central tendency effects and lateral differences, and also the effects of the support by upper limbs with reciprocal interlimb weight-adjustment on performance accuracy of the task. First, the central tendency effects, which showed (relative) overshooting for the light target and (relative) undershooting for the heavy target, generally occur in the lateral body weight-shifting task irrespective of patients and healthy people. The central tendency effects appeared in the lateral body weight-shifting task, and this was consistent with other perceptual and motor performance (e.g., Jenkins, 1946; Ito et al., 1984; Stelmach et al., 1970; Chez et al., 1989; Crawford et al., 2000; see Chapter 2).

Second, lateral differences appeared in both the patients with orthopedic complaints and the healthy participants. The patients with orthopedic complaints had difficulties in accurately (steadily) performing the task when they loaded a relatively heavy target load on the affected lower limb. In the healthy participants, lateral difference occurred in the condition of the support by upper limbs. Therefore, the use of the support by upper limbs seemed to produce
lateral differences in lateral body weight-shifting.

Finally, the support by upper limbs had both a positive effect, such as an increase of performance stability, and a negative effect, such as an enhancement of undershooting in central tendency effects, on lateral body weight-shifting. Furthermore, Reciprocal interlimb weight-adjustment between the upper and lower limbs correlated with biasing errors, namely, the degree of overshooting and undershooting.

Results of this study regarding the fundamental features of central tendency effects, lateral differences, the effects of the support by upper limbs, and reciprocal interlimb weight-adjustment on performance accuracy of the lateral body weight-shifting task had some practical implications for rehabilitation. The findings of this study may well help therapists conduct rehabilitation for patients, particularly in the use of upper limbs and its effects on biasing error (i.e., undershooting and overshooting) in a lateral body weight-shifting task.
REFERENCES


