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# Robot-Assisted Balance Training for Gait Modification

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***Abstract*- Diminished balance control while walking is a main concern for people with stroke. An appropriate training method would help improve their balance during walking. In this study, we examined if a novel robot-assisted balance training (RABT) program could change human gait patterns. Five healthy individuals underwent a RABT program with either stepping or standing movements. An external perturbation using a force field was applied to the lower trunk to alter weight distribution patterns during training. The results showed that people who had a RABT with stepping movements demonstrated a greater change in gait patterns compared to those who had the RABT with standing movements. This suggests that the RABT program with stepping movements can be used as a rehabilitation approach to facilitate an adaptation of a new balance control pattern in human beings.**

*Keywords— balance; stroke; adaptation; rehabilitation*

## I. INTRODUCTION

People with stroke experience difficulty controlling balance during daily activities such as walking and standing from sitting. Although diverse balance training approaches have been introduced to improve balance control following stroke, the advantages of using these methods are limited with regard to regaining symmetrical gait patterns, which is important for balance control during walking [1]. The limited effect on gait symmetry may be due to the fact that the training approaches are mostly performed while standing. However, most falls in people with stroke occurs during transfers in positions or activities [2]. It suggests that balance training in a dynamic environment (e.g., stepping) may be more beneficial to regain walking balance.

Recent evidence suggests that combining robotics with existing training programs enhances functional movements in people with stroke, such as reaching [3, 4] and walking [5-7]. However, to our knowledge, there is no effective training method that directly targets balance control for people with stroke. The robot-assisted balance training (RABT) program that has been developed in our laboratory can apply a dynamic perturbation during standing or stepping movements using a force field to a person's trunk/pelvis to enhance the balance control. In this pilot study, we investigated whether if the RABT program could facilitate an adaptation of new gait patterns in healthy individuals.

## II. BACKGROUND

### A. Balance Training Following Stroke

Balance training following stroke usually consists of standing movements with visual feedback [1, 8, 9]. People with stroke who received balance training with standing movements utilizing real-time visual feedback demonstrated a significantly greater decrease of lateral displacement of postural sway towards the sound side than those who received transitional physical therapy did [9]. Other studies also showed that balance training using a similar paradigm significantly improved standing symmetry [1, 8]. Nonetheless, the benefits of standing balance training using visual feedback on dynamic balance, such as gait symmetry, appear to be limited [10]. Thus, standing balance training may not be sufficient to change dynamic balance control.

Conventional therapy for people with stroke tries to reduce weight distribution errors between the legs by assisting the body movement towards the paretic side. However, the literature suggests that enhancing errors of the body movement, (e.g., forcing weight shifting more towards the sound side) rather than assisting the movement, induces better motor adaptation/learning [11]. Hence, we used the error-enhancing training method in this study.

### B. Robot-Assisted Balance Training

Recent literature shows that rehabilitation using robot technology can be an effective approach to facilitate functional recovery after stroke. Robot-assisted therapy was shown to improve joint excursion [12], muscle strength, and coordination of the upper extremity in people with chronic stroke [13]. Recent studies also showed the benefits of robot-assisted therapy on the recovery of the lower extremity function, such as walking, in people with stroke [5, 6].

The literature indicates that people with stroke have an adaptability of motor control, and robot-assisted training using a force-field constraint facilitates their motor adaptation [14, 15]. Moreover, a recent study showed that a robot-assisted training program combining a force-field constraint with real-time visual feedback could facilitate an adaptation of healthy people's locomotion patterns [16]. Adding somatosensory inputs using a force-field to real-time visual feedback training also appears to enhance the motor adaptation or learning in individuals with stroke [11]. Thus, balance training using such robotic technology may

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be an efficient therapeutic approach for recovery of balance control after stroke. However, the therapeutic approach that applies an external force field perturbation to a part of a human body has been tested mainly with the upper extremity functions (e.g., reaching). Therefore, in this study, we aimed to identify if RABT, combining external force-field application with real-time visual feedback, could enhance the adaptation of a new balance control pattern in healthy individuals**.**

## III. ROBOT-ASSISTED BALANCE TRAINING

### *A. Robot-Assisted Balanced Trainer*

The balance training device, developed in our laboratory, applied an external perturbation using a force field to the trunk/pelvis to facilitate the modification of weight distribution during standing or stepping movements. In the current design (Figure 1), two motors, attached to the corners of a rigid standing frame, were connected via cables to a waist belt on the participant. Using feedback from force sensors attached to the cables, the motors applied a force to the lower trunk of the participant during the experiment. The combined forces from the two servomechanisms allowed a resultant force in a direction in the transverse plane that was constant or updated based on the participants' motions. For the experiments presented here, the force was applied to the participants was constant throughout the training. The force was applied towards the direction opposite to the target side.

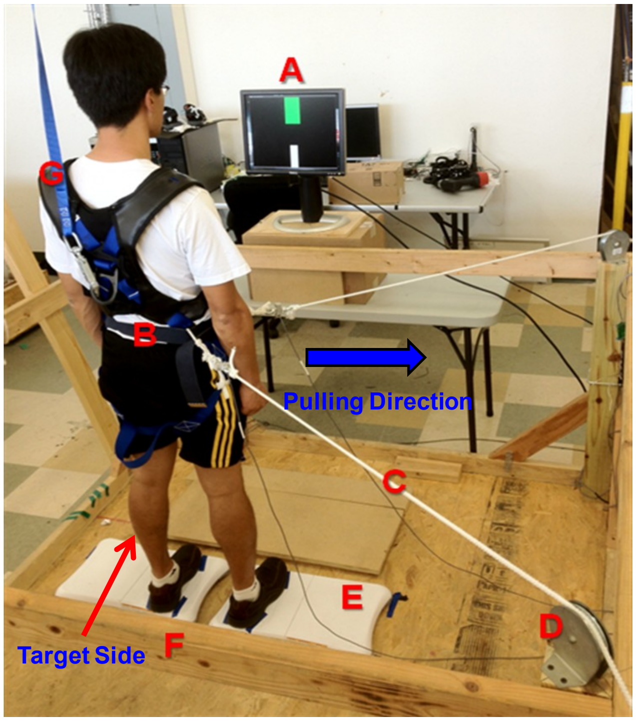

**Figure 1**. A prototype of the robot-assisted balance training device. The participant stands on two Wii Balance Boards and real-time visual feedback of the weight on the target leg is provided on the computer monitor in front of the device. A: Monitor, B: Waist belt, C: Pulling cable, D: Pulley, E: Wii Balance Boards, F: Frame, G: Safety harness

Two Wii Balance Boards (Nintendo, Kyoto, Japan) were used to record weight distribution during testing and to provide real-time visual feedback of weight bearing during training.

The current in each motor was generated by a voltage controlled current source op amp (OPA548) configuration that can supply up to 5A at up to 30V. The two force sensors were attached to the cables near the participant's pelvis and were sampled after a 1st order RC filter with a cutoff frequency of 320Hz was applied. The control loop for the force sensors and motor torque was performed at 1000Hz using a NI PCI-6229 DAQ. The Wii Balance Boards were sampled at 120Hz and were used to provide visual feedback to the participants. The Wii Balance Board has been validated against laboratory-grade force platforms and shows comparable results [17].

Safety was ensured by limiting the maximum force that the motors could apply in several ways. First, the software controller specified a maximum force. Second, the DC motors only have a limited force production capacity. Third, an emergency stop switch was accessible to the experimenter that would halt power to the motors. The maximum tension allowed in each cable was 50N; in the configuration used for this experiment, this corresponds to approximately 80N in the lateral direction. Encoders attached to the motors measured the length of the cable, which determined the position of the participant's pelvis, and the forces in the cable were adjusted accordingly to ensure the desired force and magnitude was applied.

### *B. Training Procedure*

Five healthy young adults participated in this study. Each participant was randomly assigned to one of two groups receiving a RABT program with stepping movements (STEP group, n=3)) or standing movements (STAND group, n=2) (Table 1). The participants underwent a RABT program that consisted of 120 training trials with a 2-3 minute break after every 30 trials. The participants stood comfortably on two Wii Balance Boards prior to stepping or standing movements (Figure 1). There were two vertical bars on the computer monitor that were placed in front of the participants. The higher bar represents 90% of the participant's weight and the lower bar represents the weight distribution on the target leg. The participants showed 2.2% asymmetry in step length at the baseline over-ground walking test. The leg that took a longer step was selected as the target leg. Two metronome beeps, 4 seconds apart, were given to the participants for each trial. The STEP group was asked to make the lower bar reach the higher bar by shifting at least 90% of their weight onto the target leg (i.e., the first peak of the solid red line in Figure 2A) at the first beep and

**Table 1.** Characteristics of Participants

| Group | Gender (m/f) | Age (year) | Height (cm) | Weight (kg) |
|---|---|---|---|---|
| STEP | 2/1 | 22.7 ± 2.5 | 173.2 ± 12.0 | 80.8 ± 21.9 |
| STAND | 1/1 | 23.0 ± 1.4 | 179.1 ± 16.2 | 81.7 ± 12.8 |

then to take a step forward. They returned to their previous position at the second beep. The STAND group was also instructed to start shifting their body-weight towards the target leg to make the lower bar reach the higher bar (i.e., the first peak of the solid red line in Figure 2B) at the first beep and then, to maintain it until the second beep. The participants returned to their previous position at the second beep. To facilitate the modification of weight distribution during training, a constant pulling force was applied to the participant's lower trunk toward the side opposite of the target leg throughout the training. The amount of lateral pulling force was determined based on each participant's submaximal tolerable level and ranged between 40N and 60N.

### C. Testing Procedure

The participants' weight distribution on the target leg during stepping movements was assessed for the baseline (prior to training) and catch trials (immediately after 100 training trials) without applying a pulling force. In particular, the participants were not informed if there was a pulling force during the catch trials by suddenly removing the force immediately before each trial.

The participants' over-ground walking was examined using a GAITRite Walkway System (CIR Systems, Inc., PA) over the two test periods (baseline and post-training). The participants were asked to walk at their comfortable speed along the 26-foot long walkway. The participants had a total of five trials of walking with a 2-minute break between. Symmetry of gait variables (e.g., step length and double support phase) during over-ground walking was assessed before and after training.

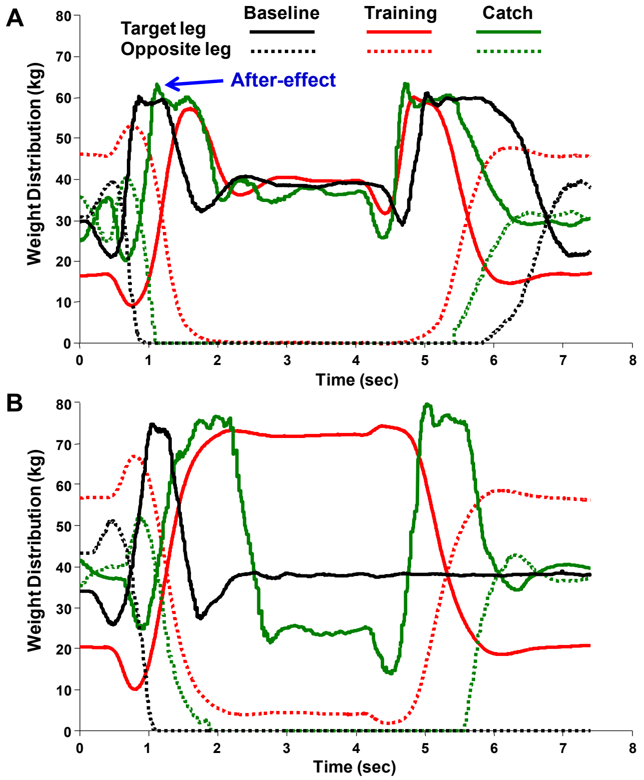

**Figure 2.** Changes in weight distribution on each leg across baseline (black lines), training (red lines), and catch trials (green lines) for a participant in the STEP group (A) and a participant in the STAND group (B). The solid and dotted lines represent the average of weight distribution on the target and opposite legs, respectively. Note that no pulling force was applied for the baseline and catch trials.

### D. Data Processing and Statistical Analysis

Weight distribution on each leg during stepping and standing movements and spatiotemporal gait variables were processed using MATLAB 7.3.0 (the MathWorks, Inc., MA). Symmetry indices of step length ($SL_{sym}$) and double support phase ($DSP_{sym}$) were calculated as follows [18]: $SL_{sym} = [(target\ side - opposite\ side) / 0.5\ (target\ side + opposite\ side)]\ x\ 100$. In this case, a positive value indicates a longer step length of the target side. No statistical analysis was conducted due to a limited number of participants.

## IV. RESULTS AND DISCUSSION

The results of this study indicate that healthy people undergoing a RABT program with stepping movements

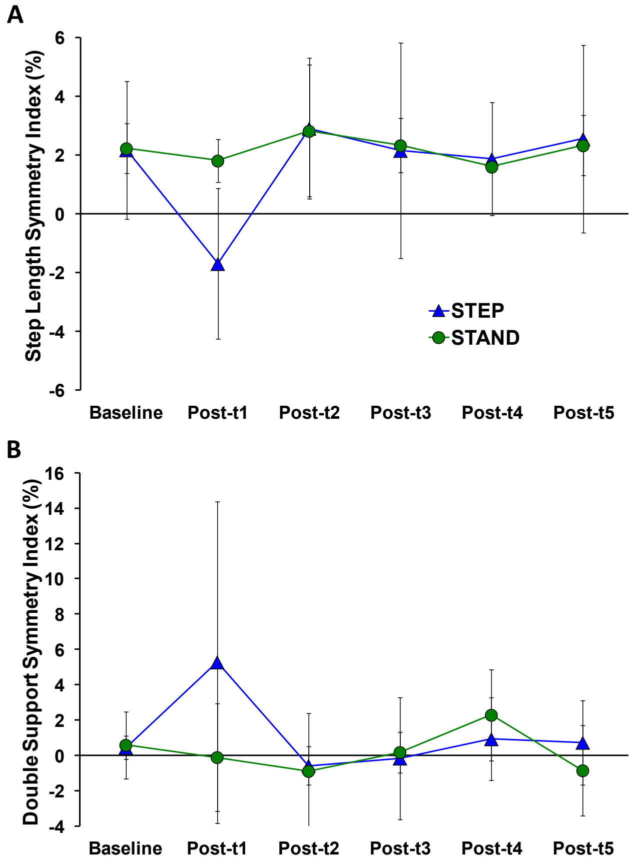

**Figure 3.** Average changes in step length (A) and double support phase symmetries (B) over baseline (prior to training) and post-training tests. STEP and STAND groups: participants who had RABT with stepping and standing movements, respectively; Post-t1-5; post-training test trial 1-5. Error bars represent standard deviations.

showed a greater short-term adaptation of a new balance control pattern compared to people undergoing the training with standing movements. The STEP group (Figure 2A) increased their weight shifted to the target leg more so than the STAND group (Figure 2B) did during catch trials (i.e., after-effect), compared to the baseline trials. The STEP group demonstrated greater changes in spatiotemporal gait variables during over-ground walking after training, compared to the STAND group. The STEP group showed a noticeable change in $SL_{sym}$ (4% difference) immediately after training (Figure 3A). A clear change in $DSP_{sym}$ (5% difference) was also observed in the STEP group following training (Figure 3B). However, the changes were not retained throughout the post-training test. Conversely, changes in $SL_{sym}$ and $DSP_{sym}$ after training were minimal (less than 1% difference) in the STAND group.

The results show that the dynamic movement involved in stepping is more beneficial for changing the gait patterns than the standing movement. It may be simply because the stepping is closer to the actual motion that will be implemented during gait than the standing movement. Nonetheless, the stepping movement alone would not be able to change gait patterns in healthy individuals since the patterns are established based on over twenty years of practice. The findings are consistent with the results of previous studies [19, 20]. In this study, the RABT challenged the participant's error-correction mechanisms during weight shifting movements, utilizing a force field. Error-correction mechanism that we incorporated into the training paradigm might play an important role in modifying the gait patterns. Thus, our results suggest that to modify balance control patterns during walking, rehabilitation training should be performed in a dynamic environment. Moreover, enhancing errors of the participant's weight shifting movement during training could be an effective approach to facilitate an adaptation of a new gait pattern [11].

## V. CONCLUSION AND FUTURE STUDIES

Healthy individuals who underwent a balance training program combined with robotic technology showed a noticeable short-term change in the symmetry of spatiotemporal gait variables. The training effects are more evident in the STEP group. The results indicate that a RABT program using the error-enhancing approach can modify gait patterns even in healthy people. The findings suggest that the RABT training can be used as a potential method to enhance the adaptation of a new gait pattern following stroke. However, further studies with greater number of participants are needed to confirm the results from this study. The effect of the RABT program on gait symmetry in people with stroke also needs to be identified.

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## REFERENCES

[1] C. J. Winstein, E. R. Gardner, D. R. McNeal, P. S. Barto, and D. E. Nicholson, "Standing balance training: effect on balance and locomotion in hemiparetic adults," *Arch Phys Med Rehabil,* vol. 70, pp. 755-62, Oct 1989.

[2] V. Weerdesteyn, M. de Niet, H. J. van Duijnhoven, and A. C. Geurts, "Falls in individuals with stroke," *J Rehabil Res Dev,* vol. 45, pp. 1195-213, 2008.

[3] L. Dipietro, H. I. Krebs, S. E. Fasoli, B. T. Volpe, J. Stein, C. Bever, and N. Hogan, "Changing motor synergies in chronic stroke," *J Neurophysiol,* vol. 98, pp. 757-68, Aug 2007.

[4] B. T. Volpe, H. I. Krebs, and N. Hogan, "Is robot-aided sensorimotor training in stroke rehabilitation a realistic option?," *Curr Opin Neurol,* vol. 14, pp. 745-52, Dec 2001.

[5] S. Hesse and D. Uhlenbrock, "A mechanized gait trainer for restoration of gait," *J Rehabil Res Dev,* vol. 37, pp. 701-8, Nov-Dec 2000.

[6] M. Pohl, C. Werner, M. Holzgraefe, G. Kroczek, J. Mehrholz, I. Wingendorf, G. Hoolig, R. Koch, and S. Hesse, "Repetitive locomotor training and physiotherapy improve walking and basic activities of daily living after stroke: a single-blind, randomized multicentre trial (DEutsche GAngtrainerStudie, DEGAS)," *Clin Rehabil,* vol. 21, pp. 17-27, Jan 2007.

[7] S. K. Banala, S. H. Kim, S. K. Agrawal, and J. P. Scholz, "Robot assisted gait training with active leg exoskeleton (ALEX)," *IEEE Trans Neural Syst Rehabil Eng,* vol. 17, pp. 2-8, Feb 2009.

[8] A. M. Wong, M. Y. Lee, J. K. Kuo, and F. T. Tang, "The development and clinical evaluation of a standing biofeedback trainer," *J Rehabil Res Dev,* vol. 34, pp. 322-7, Jul 1997.

[9] A. Shumway-Cook, D. Anson, and S. Haller, "Postural sway biofeedback: its effect on reestablishing stance stability in hemiplegic patients," *Arch Phys Med Rehabil,* vol. 69, pp. 395-400, Jun 1988.

[10] R. Barclay-Goddard, T. Stevenson, W. Poluha, M. E. Moffatt, and S. P. Taback, "Force platform feedback for standing balance training after stroke," *Cochrane Database Syst Rev,* p. CD004129, 2004.

[11] J. L. Patton, M. E. Stoykov, M. Kovic, and F. A. Mussa-Ivaldi, "Evaluation of robotic training forces that either enhance or reduce error in chronic hemiparetic stroke survivors," *Exp Brain Res,* vol. 168, pp. 368-83, Jan 2006.

[12] L. E. Kahn, M. L. Zygman, W. Z. Rymer, and D. J. Reinkensmeyer, "Robot-assisted reaching exercise promotes arm movement recovery in chronic hemiparetic stroke: a randomized controlled pilot study," *J Neuroengineering Rehabil,* vol. 3, p. 12, 2006.

[13] S. E. Fasoli, H. I. Krebs, J. Stein, W. R. Frontera, and N. Hogan, "Effects of robotic therapy on motor impairment and recovery in chronic stroke," *Arch Phys Med Rehabil,* vol. 84, pp. 477-82, Apr 2003.

[14] J. W. Krakauer, C. Ghez, and M. F. Ghilardi, "Adaptation to visuomotor transformations: consolidation, interference, and forgetting," *J Neurosci,* vol. 25, pp. 473-8, Jan 12 2005.

[15] R. Shadmehr and H. H. Holcomb, "Neural correlates of motor memory consolidation," *Science,* vol. 277, pp. 821-5, Aug 8 1997.

[16] S. H. Kim, S. K. Banala, E. A. Brackbill, S. K. Agrawal, V. Krishnamoorthy, and J. P. Scholz, "Robot-assisted modifications of gait in healthy individuals," *Exp Brain Res,* vol. 202, pp. 809-24, May 2010.

[17] R. A. Clark, A. L. Bryant, Y. Pua, P. McCrory, K. Bennell, and M. Hunt, "Validity and reliability of the Nintendo Wii Balance Board for assessment of standing balance," *Gait Posture,* vol. 31, pp. 307-10, Mar.

[18] R. O. Robinson, W. Herzog, and B. M. Nigg, "Use of force platform variables to quantify the effects of chiropractic manipulation on gait symmetry," *J Manipulative Physiol Ther,* vol. 10, pp. 172-6, Aug 1987.

[19] T. Prokop, W. Berger, W. Zijlstra, and V. Dietz, "Adaptational and learning processes during human split-belt locomotion: interaction between central mechanisms and afferent input," *Exp Brain Res,* vol. 106, pp. 449-56, 1995.

[20] V. Dietz, W. Zijlstra, and J. Duysens, "Human neuronal interlimb coordination during split-belt locomotion," *Exp Brain Res,* vol. 101, pp. 513-20, 1994.