Experimental Brain Research (2019) 237:1699–1707
https://doi.org/10.1007/s00221-019-05541-y

RESEARCH ARTICLE

Unique controlling mechanisms underlying walking with two handheld poles in contrast to those of conventional walking as revealed by split-belt locomotor adaptation

Hiroki Obata[1] · Tetsuya Ogawa[2] · Kimitaka Nakazawa[2]

Received: 29 January 2019 / Accepted: 15 April 2019 / Published online: 17 April 2019

Abstract
Pole walking (PW), a form of locomotion in which a person holds a pole in each hand, enhances the involvement of alternating upper-limb movement. While this quadruped-like walking increases postural stability for bipedal conventional walking (CW), in terms of the neural controlling mechanisms underlying the two locomotion forms (PW and CW), the similarities and differences remain unknown. The purpose of this study was to compare the neural control of PW and CW from the perspective of locomotor adaptation to a novel environment on a split-belt treadmill. We measured the anterior component of the ground reaction (braking) force during and after split-belt treadmill walking in 12 healthy subjects. The results demonstrated that (1) PW delayed locomotor adaptation when compared with CW; (2) the degrees of transfer of the acquired movement pattern to CW and PW were not different, regardless of whether the novel movement pattern was learned in CW or PW; and (3) the movement pattern learned in CW was washed out by subsequent execution in PW, whereas the movement pattern learned in PW was not completely washed out by subsequent execution in CW. These results suggest that the neural control mechanisms of PW and CW are not independent, and it is possible that PW could be a locomotor behavior built upon a basic locomotor pattern of CW.

Keywords Walking adaptation · Locomotion · Motor learning · Pole walking

Introduction

The use of a pole in each hand while walking (pole walking: PW) has been recognized as an assistive tool for locomotion for individuals with poor physical fitness or balance impairment (Figard-Fabre et al. 2010; Parkatti et al. 2012; Kang et al. 2016; Monteiro et al. 2017). Indeed, the use of this intervention was demonstrated to increase the base of support and stabilize gait posture while walking (Zoffoli et al. 2017). In light of its potential effect, recent studies have proposed the usefulness of this PW paradigm as an intervention for gait rehabilitation in patients with gait disorders, such as hemiplegia (Obata et al. 2017) and osteoarthritis (Fukusaki et al. 2018). The use of PW is, therefore, expected to play a significant role not only as an assistive tool but also for restoring conventional walking (CW) through repetitive use of the underlying neural mechanism (i.e., use-dependent plasticity).

In using PW for gait rehabilitation, a potential issue arises from the perspective of the specificity of locomotion-related adaptation that is dependent on given locomotive tasks and contexts (Choi and Bastian 2007; Vasudevan and Bastian 2010; Ogawa et al. 2012, 2015, 2018). The present study addressed this issue by using a split-belt adaptation paradigm. When first walking on a split-belt treadmill in which two belts (one under each foot) are driven at different speeds, subjects initially experience a pronounced limp with perceived asymmetry in their leg movements, which is subsequently reduced over the course of the adaptation period lasting for about 10 min (Reisman et al. 2005; Ogawa

Hiroki Obata and Tetsuya Ogawa contributed equally to this work.

✉ Hiroki Obata
obata@dhs.kyutech.ac.jp

1 Department of Humanities and Social Sciences, Institute of Liberal Arts, Kyushu Institute of Technology, 1-1 Sensui-cho, Tobata-ku, Kitakyushu, Fukuoka 804-8550, Japan

2 Department of Life Sciences, Graduate School of Arts and Sciences, The University of Tokyo, 3-8-1, Komaba, Meguro-ku, Tokyo, Japan

et al. 2012, 2014, 2015). With the subjects fully adapted to walk with this physical constraint, subsequent exposure to a normal belt condition (two belts moving at same speed) leads to the emergence of a robust aftereffect in which subjects experience limping, despite the normal walking condition. The course of adaptation in this split-belt paradigm has been well characterized in extant literature along with other locomotor adaptation paradigms, such as those using a force field imposed by a robotic exoskeleton (Lam et al. 2006) and elastic rubber band (Blanchette and Bouyer 2009). The changes in gait have been well established with parameters such as spatiotemporal adjustments (step length and double support time) (Reisman et al. 2005) and the braking component of the ground reaction force (GRF) (Ogawa et al. 2012, 2014, 2015). In the anterior braking component of the GRF, particularly, subjects learn to step asymmetrically during the adaptation periods, and the emergence of an aftereffect upon walking on a normal belt is observed as a prominent difference in the magnitude of this force component between two limbs (Ogawa et al. 2012, 2014, 2015).

Even provided that there is a task or context dependency in the locomotor adaptation that takes place regardless of the similarities in the joints and muscles involved, PW intervention does not necessarily lead to a restoration of CW. With the previous results suggesting that CW can actually be classified as a quadrupedal action (Zehr et al. 2016; Dietz 2002; Meyns et al. 2013) on the basis of electrophysiological considerations, it is not known how these aspects would be apparent for the difference in the behavioral aspect between CW and PW and particularly for adaptation. Therefore, the present study tested how the adaptations that took place in both PW and CW would affect each other using the locomotor adaptation paradigm on a split-belt treadmill. Adaptation in one locomotor task that either transferred to or was washed out by the subsequent execution of the other to a large degree denoted similarity in the neural mechanisms underlying the two locomotor tasks and, therefore, the usefulness of PW intervention for the restoration of CW. On the other hand, partial transfer or washout of adaptation between the tasks suggested that the use of PW is rarely useful as an intervention for gait rehabilitation and plays a role as an assistive tool. Knowledge from this study provides a rationale for the purpose of using PW (i.e., assistance or restoration of CW) and gives clues for developing a new intervention for gait rehabilitation.

Methods

Subjects

Twelve able-bodied male subjects (age: 26.7 ± 3.2 years old; height: 174.4 ± 5.0 cm; weight: 67.7 ± 9.1 kg; mean ± SD) with no known history of neurological disorders participated in this study. Each subject was tested in two of four experimental protocols (Fig. 1). The gait

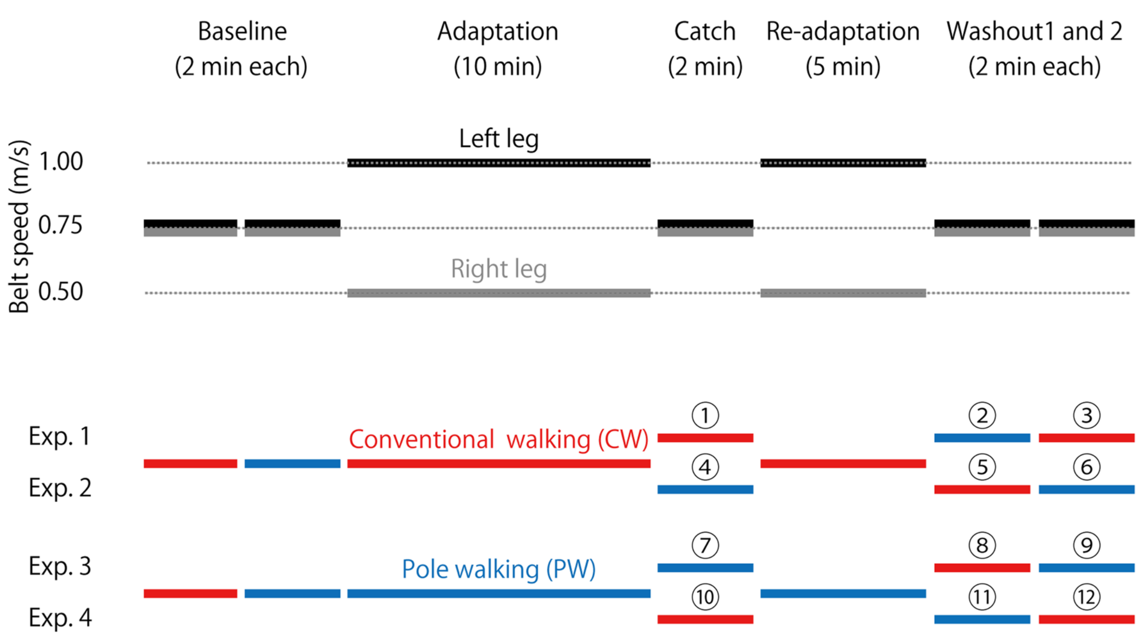

Fig. 1 Time course of the experimental protocols. Subjects were given a split-belt walking-adaptation task of either conventional walking (CW) (Exps. 1 and 2) or pole walking (PW) (Exps. 3 and 4). The adaptation and re-adaptation periods were 10 and 5 min, respectively, on an asymmetrically driven treadmill (the left belt was set to 1.00 m/s and the right to 0.50 m/s). The baseline (Baseline), catch (Catch), and washout periods (Washout1 and Washout2) were 2 min each on a symmetrically driven treadmill (at 0.75 m/s)

modes (CW and PW) in each period and their combinations were different among these protocols to minimize potential order effects. Six subjects participated in Experiments 1 and 3, while the other six participated in Experiments 2 and 4. The order of participation in these experiments was randomized across subjects. All participants gave informed written consent prior to participating in the study. The experimental procedures were conducted in accordance with the Declaration of Helsinki and were approved by the human ethics committee of the University of Tokyo, Japan.

Experimental protocols

We studied the characteristics of walking adaptation and de-adaptation using a split-belt treadmill (Bertec, Columbus, OH, USA). The treadmill is composed of two separate belts that can be controlled independently. In this study, the treadmill belts were driven at the same velocity (i.e., tied belt) and at different velocities (i.e., split belt). Subjects were positioned to step on each belt with each foot; they were asked to walk with a pair of Nordic walking poles (i.e., PW) and without poles (i.e., CW), depending on the experiments and their protocols. Subjects were instructed to walk naturally and to refrain from looking down at the treadmill belts to avoid receiving any visual information about velocity. During PW, subjects were asked to put one of the Nordic poles vertically on either split belt with the contralateral lower-limb heel contact at each stride. The length of the poles was adjusted so that the elbow joint angles were approximately 90° when subjects stood upright with the poles and kept them naturally in front of them.

Participants first underwent baseline periods of CW and PW (Baseline; 2 min each, tied belt at 0.75 m/s) and then the adaptation period (Adaptation; 10 min, split belt); the velocity of the left belt was set to 1.00 m/s and the right to 0.50 m/s under the conditions of CW or PW, depending on the experiment. After the adaptation period, they were exposed to the catch period (Catch; 2 min, tied belt at 0.75 m/s) and then to the re-adaptation period (Re-adaptation; 5 min, split belt); the velocity of the left belt was set to 1.00 m/s and the right to 0.50 m/s under the conditions of CW or PW, depending on the experiment. Subsequently, they were exposed to the washout periods (Washout1 and Washout2; 2 min each, tied belt at 0.75 m/s) under the conditions of CW and PW, depending on the experiment.

The velocities of separate belts were changed in each period. For safety, subjects were asked to stand outside the belts before these changes and step onto the belts using their left foot first after achieving the required belt velocity.

Data recordings and analysis

Triaxial GRFs were measured using two force plates mounted beneath each treadmill belt. The force data were digitized at a sampling frequency of 1 kHz using an analog-to-digital converter and low-pass filtered at 8 Hz (PowerLab, AD Instruments, Sydney, Australia).

Stride cycles were determined by detecting the moment of foot contact at which the vertical ground reaction forces were more than 2.5 N. Peak absolute values in the anterior (horizontal braking) component of the GRF were calculated for each stride cycle because the braking component has been found to exhibit a prominent difference between the limbs after split-belt adaptation in both walking and running (Ogawa et al. 2012). Next, differences in the peak forces between the left and right strides (the degree of asymmetry) were calculated for this component. The data for the first stride cycle of each period were excluded from later analysis, since gaits were remarkably perturbed when subjects started walking on the moving belts. The data were averaged over stride cycles in 10-s bins for the de-adaptation periods (i.e., Catch, Washout1, and Washout2) and in 1-min bins for the adaptation periods, since the number of steps is different between gait modes and between subjects (Ogawa et al. 2015).

To address the rates of adaptation, the number of stride cycles required to adapt and de-adapt was calculated by fitting the exponential function on the basis of a previous study (Lam et al. 2006). The time course of the stride-to-stride values for the degree of asymmetry (for Adaptation, Catch, and Washout1) was fitted with the following equation:

$$f(x) = \alpha + \beta \times \exp^{-\frac{x}{\tau}},$$

where x is the number of stride cycles, α represents the offset, β is the gain, and τ is the time constant, representing the number of steps it would take to obtain 63.2% of total adaptation and de-adaptation. Washout2 was not fitted by the function because clear de-adaptation was not observed except in Exp. 3.

Statistical analysis

Statistical analyses were performed for the degree of asymmetry in peak braking forces using a commercially available software package (SPSS 21.0, SPSS, Chicago, IL, USA).

To confirm that contact of the poles on the treadmill surface did not affect the GRF measurements, a paired Student's t test was performed to compare the average braking force of the first ten strides during baseline periods (CW vs. PW in Exps. 1 and 2) on the left and right sides.

To compare the degree of adaptation (i.e., adaptation period), a two-way analysis of variance (ANOVA) with repeated measures (factors: acquired movement pattern (CW or PW) and time points (average of the first or last ten strides) was performed. For the number of stride cycles required to adapt, a paired Student's *t* test was performed for the time-constant adaptation (i.e., τ) to compare the differences between CW and PW.

To compare the degree of transfer of the acquired movement pattern (i.e., ①+⑤, ②+④, ⑦+⑪, and ⑧+⑩ in Fig. 1), a three-way ANOVA with repeated measures (factors: acquired movement pattern (CW or PW), gait mode of de-adaptation (CW or PW), and time points (average of the first or last ten strides) was performed. To determine the number of stride cycles required to de-adapt, a two-way ANOVA with repeated measures [factors: acquired movement pattern (CW or PW) and gait mode of de-adaptation (CW or PW)] was performed for the time-constant adaptation.

To compare the degree of washout (i.e., ③ and ⑨ in Fig. 1), a two-way ANOVA with repeated measures (factors: stored movement pattern (CW or PW) and time points (average of the first or last ten strides) was performed.

When the two-way ANOVA gave significant interactions, Tukey's post hoc comparisons were performed to test for differences between gait modes. Data are presented as the mean and standard error (mean ± SEM). The time-constant adaptation is presented as the mean and standard deviation (mean ± SD). Statistical differences were accepted as significant when $P < 0.05$.

Results

A typical example of a stride-to-stride profile of the peak braking force for both left and right sides is shown in Fig. 2. During the baseline, where the belt conditions were tied, the differences in the peaks between the left and right sides were small. With exposure to split-belt conditions (i.e., Adaptation), the difference was prominent for the first few minutes. It is notable that it took more time to achieve a plateau value with PW (Exps. 3 and 4) than with CW (Exps. 1 and 2). With a return to the tied-belt condition (i.e., Catch and Washout1), the difference between the left and right sides was prominent for the first minute, whereas the differences among the experiments were not clear. After the washout of a stored movement pattern (i.e., Washout2), the difference between the left and right sides still existed in Exp. 3 but not in Exps. 1, 2, or 4. In the following section, the statistical results of group data are described.

To confirm that contact of the poles on the treadmill surface did not affect the GRF measurements, the peak braking forces during baseline periods were compared between CW and PW. Figure 3a shows representative waveforms of the anterior–posterior GRF for both left and right sides. In Fig. 3b, the averages of the peak braking forces of the first ten strides during baseline periods were compared between CW and PW. A paired Student's *t* test showed no statistical difference between CW and PW in either side, indicating that braking force contributions from the poles were negligible compared to the forces applied by the body.

During the split-belt adaptation, more time was needed to adapt to the split treadmill in PW than in CW, whereas the initial and final values of the degrees of asymmetry during the adaptation period were not different between CW and PW. Figure 4 depicts the comparison of the mean data of the degree of adaptation between CW and PW. In Fig. 4a, the averages of the peak braking forces of the initial (the first ten strides) and final time points (the last ten strides) during adaptation were compared between CW and PW. A two-way repeated-measure ANOVA showed no significant interaction between the time points and gait, whereas the main effect of the time points was found ($F_{(1, 11)} = 111.843$, $P < 0.01$). On the other hand, the time constant, which was calculated from the stride-to-stride values, was significantly greater in PW than in CW ($P < 0.01$) (Fig. 4b).

The degrees of transfer to PW and CW were not different, regardless of whether a new movement pattern was acquired in PW or CW. Figure 5 compares the mean data related to the degree of transfer of the acquired movement pattern across CW and PW. In Fig. 5a, b, the averages of the peak braking forces of the initial and final time points were compared. A three-way repeated-measure ANOVA showed the main effect of the time points ($F_{(1, 11)} = 123.696$, $P < 0.01$), whereas no other main effects or interactions were found. Note that these results are presented in Fig. 5a, b for the reader's convenience. Figure 5c shows the time constant of de-adaptation among conditions [acquired movement pattern (CW or PW) × gait pattern of de-adaptation (CW or PW)]. A two-way repeated-measure ANOVA did not show the main effects, and interactions indicating the conditions did not affect the rate of de-adaptation.

Gait mode in which a new movement patter was stored affected the washout of the stored motor pattern by another gait mode. Figure 6 compares the peak braking forces between the initial and final time points in the degree of washout. A two-way repeated-measure ANOVA showed the main effects of gaits ($F_{(1, 5)} = 7.027$, $P < 0.05$) and time points ($F_{(1, 5)} = 7.253$, $P < 0.05$) as well as the interaction between time points and gaits ($F_{(1, 5)} = 7.064$, $P < 0.05$). Post hoc testing revealed that the degree of asymmetry during the initial time points was significantly smaller than that during the final time points in PW (after washout by CW) but not in CW (after washout by PW) ($P < 0.05$). This result indicates that the stored motor pattern of PW could not be completely washed out by CW.

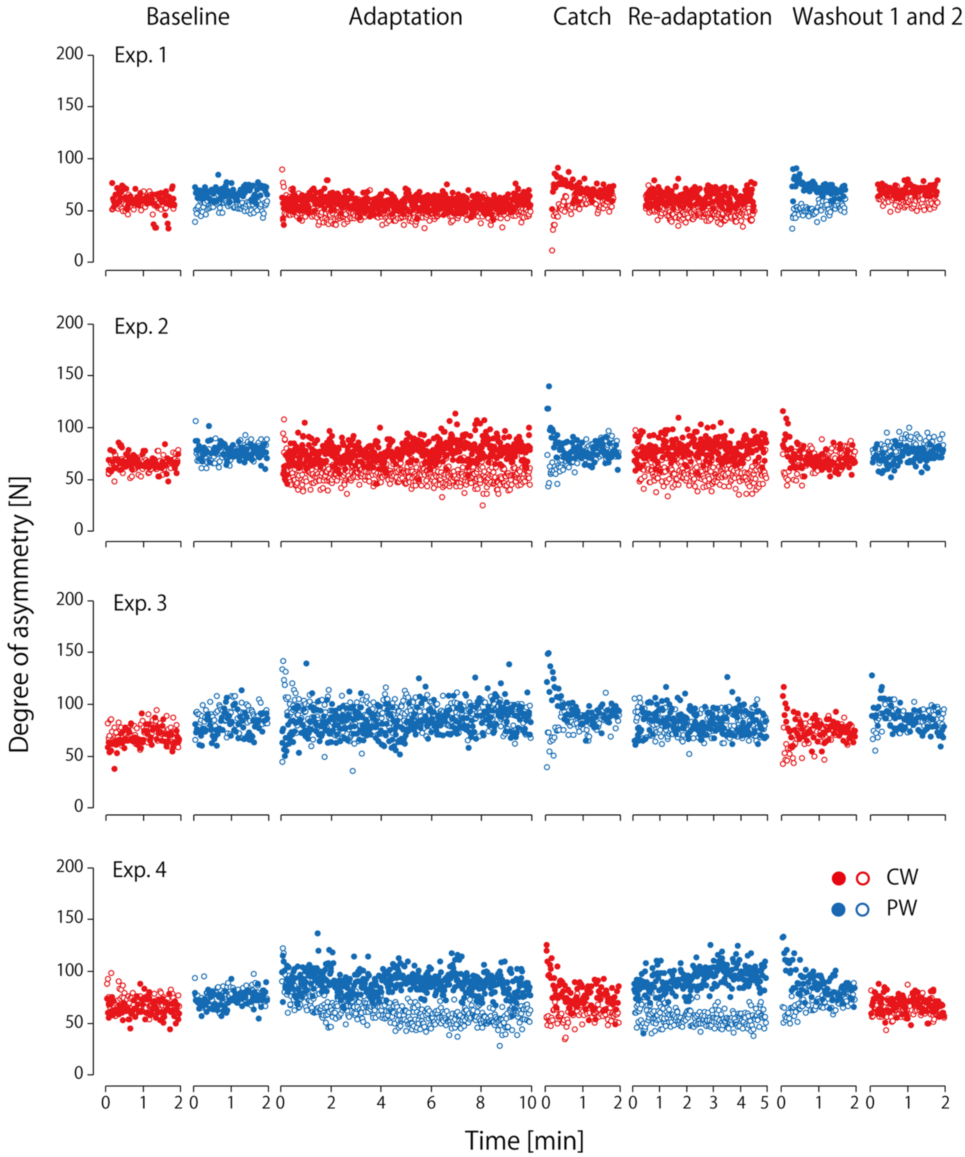

Fig. 2 Typical examples of the degree of asymmetry in the peak braking force over the time course of each experiment. Stride-to-stride profiles of the peak anterior braking force for both left (fast) and right (slow) sides. Filled circles and open circles represent the left and right sides, respectively. Red circles and blue circles represent CW and PW, respectively. These plots were obtained from the same single subject in Exps. 1 and 3 and in Exps. 2 and 4, respectively

Discussion

The purpose of this study was to investigate the difference in the neural control mechanism between PW and CW from the perspective locomotor adaptation in a novel environment. The present results demonstrated that (1) PW delayed locomotor adaptation when compared with CW; (2) the degrees of transfer of the acquired movement pattern to CW and PW were not different, regardless of whether the novel movement pattern (i.e., walking on an asymmetrically driven treadmill) was learned in CW or PW; and (3) the movement pattern learned in CW was washed out by subsequent execution in PW, whereas the movement pattern learned in PW was not completely washed out by subsequent execution in CW. These results suggest unique controlling mechanisms underlying PW in contrast to those of CW.

Locomotor adaptation

Adaptations are the trial-and-error process of adjusting movements to new demands and recalibrating the motor output (Bastian 2008). Split-belt walking is one of these adaptations, and it is a process for recalibrating motor output to adjust lower-limb movements for walking on a split treadmill. For this process, the cerebellum's involvement has been suggested by pathophysiological (Morton and Bastian 2006) and neurophysiological studies (Jayaram et al. 2011, 2012). Jayaram et al. (2012) demonstrated that cerebellar transcranial direct current stimulation (tDCS) affects the adaptation rate of split-belt walking. They listed changes in the behavior of Purkinje cells, such as the population and dynamic range of cells involved in the adaptation, as possible mechanisms to explain their result.

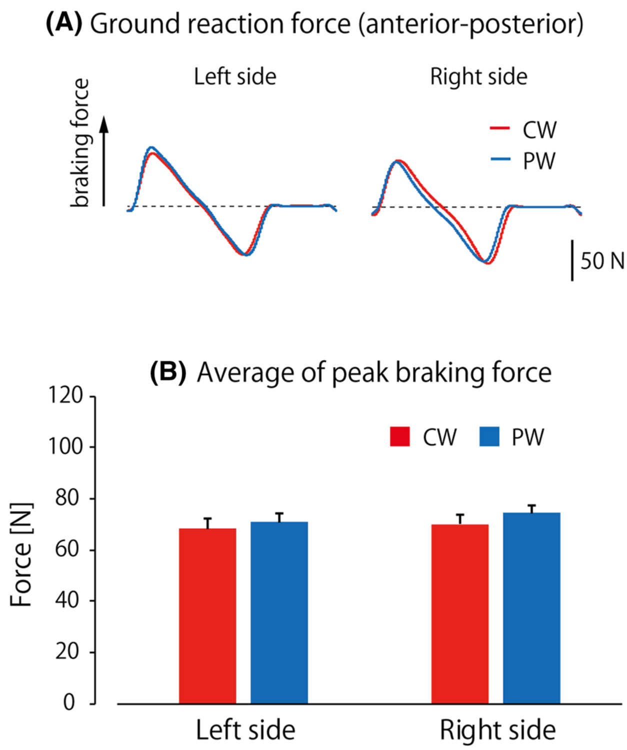

Fig. 3 Comparison of the braking force between CW and PW during baseline periods. **a** Representative waveforms of the braking force in the left and right sides. Each waveform was the average of the first ten strides obtained from the single subjects in Exp. 1. **b** Average of peak braking force of the first ten strides during baseline periods (Exps. 1 and 2) of CW (red bars) and PW (blue bars) in the left and right sides

Long-term depression (LTD) in Purkinje cells is known to be associated with sensorimotor calibration in animal studies (Medina 2011). Therefore, the present result of slow adaptation during PW indicates that the use of poles may affect the recalibration process in the cerebellum during adaptation.

PW has features that are not found in bipedal walking. Based on the following features, we expected that PW would facilitate locomotor adaptation in newly applied environments. First, the use of a pole in each hand increases the base of support and improves balance during walking (Zoffoli et al. 2017). Improved stability would additionally benefit the neural control of walking. In general, the central nervous system must control walking balance and movement simultaneously in the lower limbs. The use of poles can reduce the neural resources required for balance control during walking. Second, upper-limb movements would be emphasized during PW. Arm swing is a very important factor in stabilizing locomotion, not only in biomechanics (offsetting the rotational torque produced by the lower limbs) (Elftman 1939), but also in neural control (Ferris et al. 2006). Recent studies have revealed possible interactions between the upper and lower extremities, and rhythmic arm movement has been shown to facilitate locomotor-related functional networks in the lower limbs (Kaupp et al. 2018). However, our result showed the opposite, and PW delayed split-belt adaptation.

Task difficulty resulting from pole use may contribute to the results. PW during split-belt walking requires subjects to complete adaptations in both the upper and lower limbs, which involves the coordination and integration of processing mechanisms between those limbs. In a normal split-belt walking (i.e., CW) study, MacLellan et al. (2013) demonstrated that the motion of both upper limbs follows the motion of the lower limbs on the faster moving belt, suggesting that symmetrical upper-limb movements were maintained during a split-belt adaptation. On the other hand, the use of poles during the walking adaptation would enhance asymmetric upper-limb movements, since the poles were

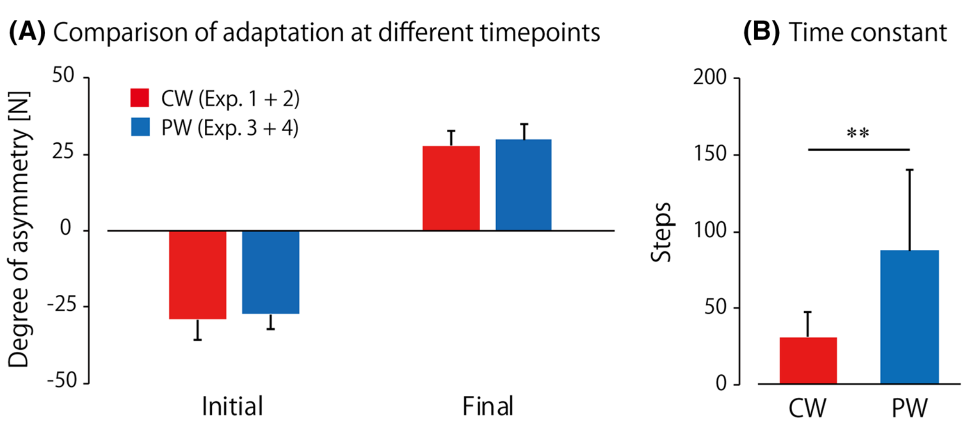

Fig. 4 Degree of adaptation in an acquired movement pattern between CW and PW. **a** Average of peak braking force differences over the first ten strides (initial) or last ten strides (final) during adaptation to CW (adaptation periods in Exps. 1 and 2, red bars) and PW (adaptation periods in Exps. 3 and 4, blue bars). Error bars represent the standard error of the mean. **b** Comparison of the time constants (i.e., number of steps to obtain 63.2% of total adaptation) required to adapt to the novel environment between CW and PW. An asterisk indicates a significant difference between CW and PW (**$P < 0.01$)

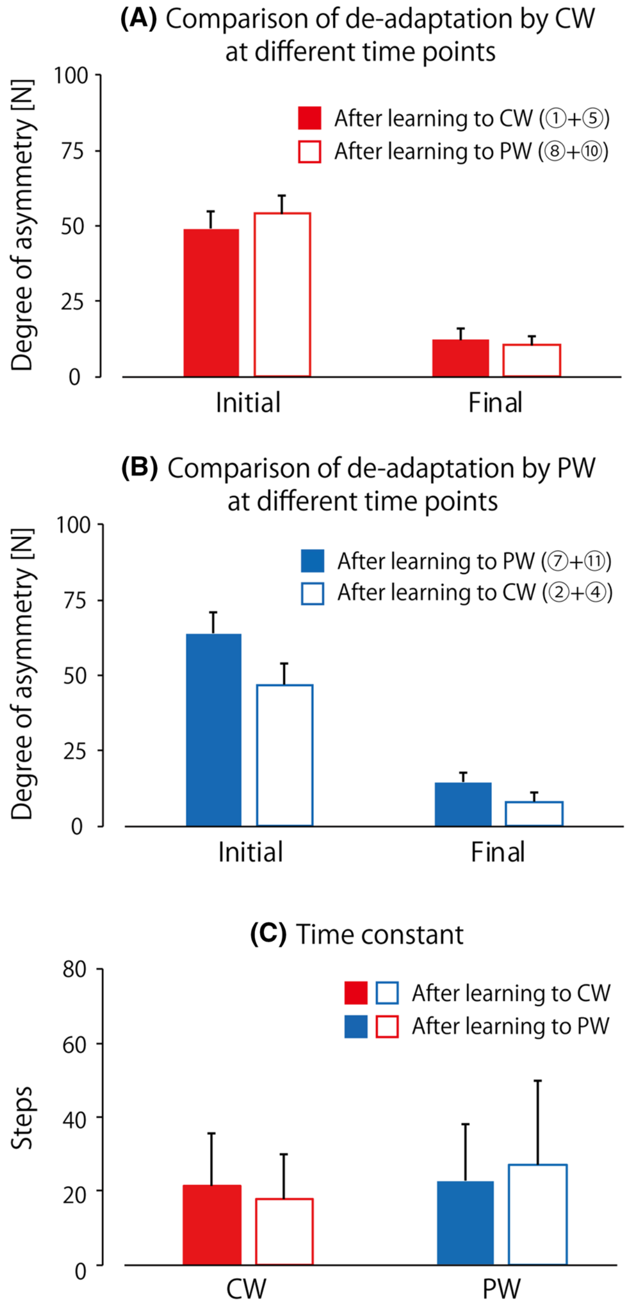

Fig. 5 Degree of transfer of the acquired movement pattern across CW and PW. **a** Average of peak braking force differences over the first ten strides (initial) or last ten strides (final) during de-adaptation from CW after adaptation to CW (Catch in Exp. 1 (①) and Washout1 in Exp. 2 (⑤), filled red bars) and after adaptation to PW (Washout1 in Exp. 3 (⑧) and Catch in Exp. 4 (⑩), open red bars). **b** Average of peak braking force differences over the first ten strides (initial) or last ten strides (final) during de-adaptation from PW after adaptation to PW (Catch in Exp. 3 (⑦) and Washout1 in Exp. 4 (⑪), filled blue bars) and after adaptation to CW (Washout1 in Exp. 1 (②) and Catch in Exp. 2 (④), open blue bars). Error bars represent the standard error of the mean. **b** Comparison of the time constants (i.e., number of steps to obtain 63.2% of total adaptation) required to wash out the acquired movement pattern between CW and PW

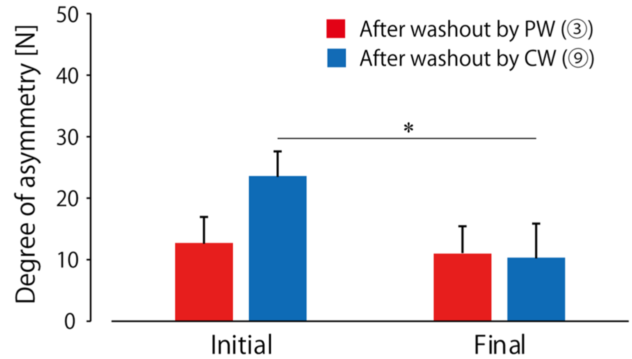

Fig. 6 Degree of washout in the stored motor pattern between CW and PW. Average of peak braking force differences over the first ten strides (initial) or last ten strides (final) during CW after washout by PW (Washout2 in Exp. 1 (③), red bars) and PW after washout by CW (Washout2 in Exp. 3 (⑨), blue bars). Error bars represent the standard error of the mean. An asterisk indicates a significant difference between Initial and Final (*$P < 0.05$)

alternately placed on the asymmetrically driven split belts during adaptation periods. Thus, in a split-belt adaptation during PW, the central nervous system has to learn not only lower-limb asymmetrical movements but also upper-limb asymmetrical movements. The conflict and complexity of motor coordination between upper and lower limbs could delay adaptation during PW.

In a few previous studies, it was reported that a secondary task impairs motor adaptation. In a reaching task to adapt force perturbations, Taylor and Thoroughman (2007) reported that an additional auditory-discrimination task reduced adapted reaching movement and suggested that the secondary task affects the recalibration of motor output. For a split-belt walking adaptation, consistent with the present results, Malone and Bastian (2010) demonstrated that a group who counted the number of times a particular word was spoken on a television program showed slower adaptation than a control group given no specific task. It is possible that PW is a dual task, consisting of CW and the use of poles. Distraction from the split-belt walking adaptation by the pole movements in the upper limbs could explain the slower learning rate as compared with CW.

Neural mechanisms underlying pole walking

Previous studies have demonstrated the independence of neural control between forward and backward walking (Choi and Bastian 2007), between walking and running (Ogawa et al. 2012, 2015), and among various walking (Vasudevan and Bastian 2010) and running (Ogawa et al. 2018) speeds. Limited transfer or washout of newly acquired movement patterns has been accepted as indirect evidence of independent neural control in human studies (Ogawa et al. 2012). For the neural mechanisms underlying CW and PW, some

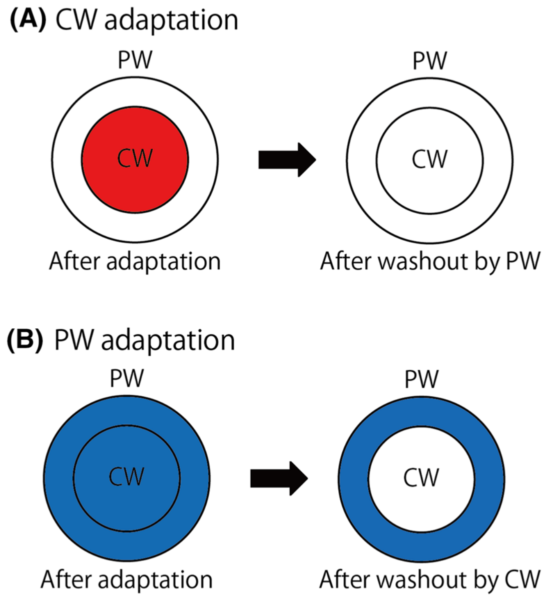

Fig. 7 A conceptual model that explains the present results of asymmetrical transfer and washout of the acquired movement pattern between PW and CW. The circles indicate the storage of movement patterns. This model predicts that CW adaptation trials should partially transfer to PW movement, and PW washout trials after CW adaptation should completely wash out CW adaptation (**a**). It also predicts that PW adaptation trials should completely transfer to CW movement, and CW washout trials after PW adaptation should not completely wash out CW adaptation (**b**)

previous results would argue that CW can actually be classified as a quadrupedal action (Zehr et al. 2016; Dietz 2002; Meyns et al. 2013) on the basis of action in the spinal reflex circuit. With these results, however, it is not known how these aspects would be evident for the difference in the behavioral aspect between CW and PW and particularly for adaptation. Our result showed that the movement pattern acquired in CW was washed out by subsequent execution in PW, whereas the movement pattern learned in PW was not completely washed out by subsequent execution in CW. This suggests that the neural control mechanisms of PW and CW are not independent.

With regard to the asymmetrical washout of the stored movement pattern between CW and PW (Fig. 7), based on previous studies which support the idea that adaptive locomotor tasks are built upon a basic locomotor pattern (McFadyen and Winter 1991; Ivanenko et al. 2005), it is possible that PW is a locomotor behavior built upon a basic locomotor pattern of CW. This model predicts that CW adaptation trials should partially transfer to PW movement, and PW washout trials after CW adaptation should completely wash out CW adaptation (Fig. 7a). It also predicts that PW adaptation trials should completely transfer to CW movement, and CW washout trials after PW adaptation should not completely wash out CW adaptation (Fig. 7b). CW can be considered as a fundamental movement, whereas PW is an extended movement of CW. Some studies hypothesize that the dorsolateral prefrontal cortex is responsible for coordinating and allocating resources in these dual tasks, thus enabling multitasking (Schubert and Szameitat 2003; Collette et al. 2005). Functional networks, consisting of the brain area and neural mechanism in normal split-belt walking adaptation, such as the cerebellum (Reisman et al. 2010), and its involvement over the course of adaptation may explain the different neural process constructions of CW and PW.

Clinical significance

The degree of transfer of the acquired movement pattern to CW was the same, irrespective of whether the novel movement pattern was learned in CW or PW. This finding is valuable from a clinical perspective. The use of walking poles has been adopted both as an intervention for gait rehabilitation and as an assistive tool for social locomotion in patients with a variety of diseases, including those affecting neurological functions (Monteiro et al. 2017; Bombieri et al. 2017; Obata et al. 2017). Our results suggest the possibility that repeated gait rehabilitation using poles may have an effect on regaining a normal walking pattern (without poles). In addition, the fact that subjects in this study were novice pole walkers suggests that it would be easy to introduce PW as a gait rehabilitation program for neurologically impaired patients.

Conclusion

In conclusion, the present adaptation results demonstrate that the use of poles (i.e., PW) slows split-belt walking adaptation as compared with the adaptation in CW. The present results of asymmetrical transfer of split-belt walking adaptation suggest that the neural control mechanisms of PW and CW are not independent, and it is possible that PW could be a locomotor behavior built upon a basic locomotor pattern of CW. The present results have important implications for the construction of training strategies using walking aids in gait rehabilitation processes.

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