Influencing kinetic energy using ankle-foot orthoses to help improve walking after stroke: a pilot study

（脳卒中後の歩行改善のための短下肢装具の使用は運動エネルギーに影響を与える：試験的研究）

木村　和夏

Corrigendum

Influencing kinetic energy using ankle-foot orthoses to help improve walking after stroke: A pilot study: Corrigendum

In the article mentioned above,[1] the author has requested the following corrections:

1. Another inclusion criteria has been added to the paragraph under Methods on page 514. The sentence is in bold and included below.

Participants were included if they were first-ever unilateral hemiparetic stroke and were able to walk independently without an AFO and assistance. Also, they usually walked with wearing an AFO-OD when walking outdoors and without any orthosis indoors. Excluded were the presence of any other orthopedic, neurological diseases, dementia, and if they were unable to walk without an AFO.

2. At the end of the legend of Figure 3 ($*P > 0.05$) should be ($*P < 0.05$).

Reference

1. Kimura N, Ohata K, Kawasaki S, et al. Influencing kinetic energy using ankle-foot orthoses to help improve walking after stroke: a pilot study. *Prosthet Orthot Int* 2021; 45: 513–520.

※These corrections were made on page 5 and 16 in this boolet.

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Influencing Kinetic Energy Using Ankle-Foot Orthoses To Help Improve Walking After Stroke: A Pilot Study.

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Declarations of Conflicting Interests

The authors declare that there is no conflict of interest.

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ABSTRACT

Study Design: Observational study within-subject.

Background: An ankle-foot orthosis with an oil damper(AFO-OD) may improve kinetics and kinematics for efficient walking after stroke. Yet it is unknown whether hemiplegic walking behaves like “inverted-pendulum“ gait and how it is modulated by using AFO-ODs for efficiency.

Objectives: This study examined whether the use of AFO-ODs improves the kinetics of total vertical ground reaction force(vGRF) and kinematics of vertical pelvic displacement in different walking phases, and gait speed following stroke. Also, the relationship between those gait parameters was examined to assess efficient walking.

Methods: Eight participants with hemiplegia walked at self-selected speed without and with AFO-ODs over the walkway and gait speed was measured. Force plates were used to measure total vGRF during the double-limb support phase with the paretic leading limb(DSPL) and with the paretic trailing limb(DSPT). The vertical pelvic displacement in the paretic and non-paretic stance phases was measured by a three-dimensional motion analysis system.

Results: Without AFO-ODs, reduced total vGRF during DSPT was related to greater vertical pelvic displacement in the subsequent non-paretic stance. Using AFO-ODs significantly increased gait speed and total vGRF during DSPL and during DSPT, which were significantly correlated. Vertical pelvic displacement in the non-paretic stance was higher than the paretic stance in both conditions.

Conclusions: Decreased total vGRF during DSPT was compensated by excessive vertical pelvic displacement in the non-paretic stance phase without AFO-ODs, indicating inefficient walking. However, the use of AFO-ODs improved the kinetic energy of total vGRF during the double-limb support phase, contributing to efficient walking.

Word count: 250 words

Clinical Relevance statement: The AFO-ODs can be utilised to improve kinetic energy and to modulate functions in the weight transition during the double-limb support phase, with faster walking speed. Thus, AFO-ODs can be considered to be therapeutic AFOs to acquire efficient walking performance in post-stroke rehabilitation.

Word count: 43 words

Keywords: Ankle-foot orthosis; Hemiplegic walking; Ground reaction force; Inverted pendulum theory

Background

The ability to walk independently is a primary therapeutic goal of post-stroke rehabilitation. Prior reports have established that gait impairment is a common comorbidity in approximately 25 percent of stroke survivors,[1] and that limited activity in daily life is compromised in a high proportion of stroke survivors.[2.] Thus, it is essential to attain stable and efficient walking performance after stroke.

Gait speed is commonly utilised as an indicator of gait function in stroke survivors.[2-4.] Slower gait speed commonly presents with an asymmetrical gait pattern due to reduced function of the paretic limb and compensation by the non-paretic limb.[5-6.] This asymmetric pattern between the paretic and non-paretic limbs would increase the metabolic energetic cost of walking and decrease movement efficiency, contributing to decreased physical activity.[7-8.] Thus, faster walking speed and symmetric walking pattern between limbs would contribute to the decrease in the metabolic energy cost following stroke.[7]

The inverted pendulum theory of walking is thought to reduce the metabolic energetic expense of normal gait.[9-13.] According to this theory, during the gait cycle, mechanical energy from the body's centre of mass (CoM) is converted to kinetic energy during the double-limb support phase, which is subsequently converted to gravitational potential energy during the single-limb support phase.[9,13.] The exchange between kinetic and potential energies sustainably maintains mechanical energy. The CoM moves at the lowest vertical position with downward acceleration during the double-limb support phase and reaches the highest vertical position with deceleration during the single-limb support phase. The redirection of the CoM upward during the double-limb support phase requires a total of the vertical component of ground reaction force (vGRF) generated by both limbs which exceed body weight.[11, 13] In this study, the total vGRF is defined as the peak force of the vGRF generated by both the paretic and non-paretic limbs during the double-limb support phase. The increasing kinetic energy of total vGRF would help to move the CoM upward efficiently. A previous study suggested that the vGRF during the paretic stance was lower than the non-paretic stance during gait after stroke.[14] Another previous study showed that vertical CoM displacement was reduced in the paretic mid-stance phase compared to the non-paretic side and healthy adults.[15] These findings may suggest that the reduced kinetic energy of the vGRF could be related to the reduced potential energy of the vertical CoM displacement in the hemiplegic gait pattern. However, total vGRF generated by both limbs during the double-limb support phase has not been examined, and the relationship between the vertical displacement of the CoM and total vGRF has not been clarified after stroke.

An ankle-foot orthosis (AFO) is often worn on the paretic limb to improve walking performance in post-stroke rehabilitation.[16] AFOs can increase the load on the paretic limb, with increasing the vGRF in the paretic stance phase,[16.] which would help to move the CoM upward during the double-limb support phase. Especially, an AFO with an oil damper (AFO-OD; Gait Solution Design, Kawamura Gishi, Japan) provides functional movement by generating resistive ankle plantarflexion moment during the paretic loading response phase (The details are represented in Figure 1).[17-18.] Previous work showed that the use of AFO-ODs improved heel rocker and ankle rocker functions[17-18], which correspond to the double-limb support phase with the paretic leading limb (DSPL) and the paretic stance phase, respectively. However, the effect of forefoot rocker function that occurs during the double-limb support phase with the paretic trailing limb (DSPT) has not been identified when using AFO-ODs. If using AFO-ODs can improve total vGRF during the DSPL and the DSPT, it may help to achieve efficient walking after stroke.

The primary purpose of the study was to investigate whether the use of AFO-ODs improves total vGRF during the double-limb support phase, vertical pelvic displacement in the stance phase, and gait speed following stroke. These were examined by comparing the difference between condition (without and with an AFO-OD) and gait phase (DSPL and DSPT) on total vGRF, and between condition (without and with an AFO-OD) and stance phase (paretic and the non-paretic stance phases) on vertical pelvic displacement. The secondary purpose was to examine the relationship between total vGRF and resultant vertical pelvic displacement based on the inverted pendulum theory of walking. Also, the relationship between total vGRF during the DSPL, DSPT, and gait speed was analysed to assess efficient walking. We hypothesised that the use of AFO-ODs would increase total vGRF during the double-limb support phase, especially during the DSPL, due to heel rocker function. We also hypothesised that total vGRF would be related to vertical pelvic displacement in the subsequent stance phase. Additionally, there would be relationships between total vGRFs during the DSPL, DSPT, and gait speed.

Methods

Participants

Eight subjects with chronic hemiplegia post-stroke were recruited from community-dwelling adults by using convenience sampling. Participants were included if they were first-ever unilateral hemiparetic stroke and were able to walk independently without an AFO and assistance. Also, they usually walked with wearing an AFO-OD when walking outdoors and without any orthosis indoors. Excluded were the presence of any other orthopaedic, neurological diseases, dementia, and if they were unable to walk without an AFO. Before the data collection, the Fugl-Meyer Assessment Scale for the motor function of lower extremity[19], the Modified Ashworth Scale[20], the Barthel Index[21], the Short Form Berg Balance Scale[22], the passive range of motion in the paretic ankle dorsiflexion, and the percent maximum voluntary muscle force in the paretic and non-paretic lower limb joints were evaluated to identify the characteristic of participants (Table 1). All participants signed a written informed consent form and the protocol was approved by the Ethics Committee Graduate School of Medicine and Faculty of Medicine Kyoto University.

Experimental Procedure

Participants were instructed to walk at a self-selected speed on a 5-metre walkway under the following conditions: 1) without an AFO (footwear only) and 2) wearing the AFO-OD with footwear. Two force plates (KISTLER, Switzerland; Sampling frequency 200 Hz) were used to determine three-dimensional GRF during the double-limb support phases. The force plates were placed lengthways along the 5-metre walkway and were embedded at the middle of the walkway (Figure 2, A.B). This system was reported as high reliability and validity.[23.] Also, a three-dimensional motion analysis system (National Institute of Advanced Industrial Science and Technology; Sampling frequency 30 Hz) with a video camera was used to measure pelvic displacement in the stance phases. In this system, the reference marker, as a calibration point, was set 637 mm from the ground at the end of the walkway to calculate the coordinates. The three body markers were attached to the pelvis and each thigh. The pelvis marker trajectory was assessed as an alternative outcome to the CoM. The intraclass correlation coefficient for test-retest reliability was evaluated in each variable, which all data showed between good and excellent reliability.

Prior to gait data acquisition, each participant's body weight was recorded for 5 seconds to normalise the vGRF data. During gait data acquisition, simultaneous full paretic and non-paretic foot placements within the two force plates were measured during the DSPL and the DSPT for each experimental condition (Figure 2, A.B), and two trials in each condition were conducted. Two experienced physiotherapists observed the trials to ensure adequate foot contacts within the two force plates and to record the identification of the DSPL and the DSPT phases. Two participants failed to make sufficient foot contacts with both force plates simultaneously, so were performed an additional trial. The time while walking on the 3-metre in the middle of the 5-metre walkway was measured to calculate gait speed. Participants were first asked to perform the task without AFO-ODs and were subsequently asked to perform the task with AFO-ODs to compare the primary outcome of gait performance.[4.] A 1-minute resting time was provided between tasks. In order to ensure the participants' safety, an experienced physiotherapist supervised the task, walking alongside the participants.

Data Processing and Analysis

The raw data were filtered with a fourth-order zero-phase Butterworth low-pass filter with a cut-off frequency of 6 Hz by using TRIAS II software (DKH Co., Ltd, Japan) for kinetics of force plates data and by using MATLAB programs (MathWorks, Natick, Massachusetts) for kinematics of pelvic displacement. Total vGRF was analysed to assess the total force acting on the body. A total of four variables for total vGRF was assessed, including total vGRF during the double-limb support phase with the paretic leading limb (DSPL; corresponding to the paretic loading response phase; Figure 2, A), and total vGRF during the double-limb support phase with the paretic trailing limb (DSPT; corresponding to the paretic pre-swing phase; Figure 2, B) in each condition without and with AFO-ODs. The identification of those phases was referred to the record during the data acquisition. In order to determine the peak force of total vGRFs during the DSPT and the DSPL, the GRF in three-dimension and the centre of pressure (CoP) in two-dimension measured by the force plates were plotted. Firstly, the double-limb support phase was determined by referring to the mediolateral CoP that changed remarkably from the ipsilateral to the contralateral legs. Secondly, remarkable peak force during the double-limb support phase was identified as total vGRF (Figure 2, C). Total vGRF was normalised as the percent change from body weight, which was considered the total vGRF of static standing, and was averaged across two trials.

The vertical pelvic displacement (vPD) was determined as the difference between the lowest and the highest vertical positions during the paretic stance phase (vPD_p) and during the non-paretic stance phase (vPD_{np}). A total of four variables was evaluated including the vPD_p and the vPD_{np} in each condition without and with AFO-ODs. In order to identify the lowest and highest positions, pelvic displacement was also plotted, which exhibited the highest position during the mid-stance phase and the lowest position during the double-limb support phase.[15] The vPD_p was calculated as the difference between the minimal position during the DSPL and the maximal position during the paretic single-stance phase. The vPD_{np} was calculated as the difference between the minimal position during the DSPT and the maximal position during the non-paretic single-stance phase (Figure 2, D).

The vPD_p and the vPD_{np} were averaged from two trials and normalised to the individual's body height. Self-selected gait speed was calculated by the 3-metre distance divided by the time that each participant took, and those were averaged over two trials.

Statistical Analysis

The statistical analysis was performed by IBM SPSS Statistics version 25 software. A two-way repeated measures analysis of variance (RM-ANOVA) was conducted to examine the difference between: 1) condition (without and with an AFO-OD) and gait phase (DSPL and DSPT) in the kinetics of total vGRFs, and 2) condition (without and with an AFO-OD) and stance phase (vPD_p and the vPD_{np}) in the kinematics of the vPDs. The post-hoc test was adjusted by using the Bonferroni correction. Furthermore, the paired t-test was applied to assess the changes in gait speed between the AFO-OD conditions. Pearson product-moment correlation coefficient was performed to investigate the relationship between total vGRF during the DSPL and vPD_p, and between total vGRF during the DSPT and vPD_{np} in conditions with or without AFO-ODs. These were analysed based on the inverted pendulum theory of walking for efficiency. Additionally, the relationship between total vGRF during the DSPL and the DSPT, and total vGRF during the DSPL/DSPT and gait speed in conditions with or without AFO-ODs was assessed. These were analysed since faster and more symmetric walking was considered to be minimising metabolic energy.[7] Statistical significance was set at $p<0.05$.

Results

Comparison of Gait Parameters

Gait speed was significantly increased when using AFO-ODs compared to without AFO-ODs (t=-2.382, p=0.049).

As for total vGRF, a two-way RM-ANOVA showed a significant main effect of the AFO-OD condition (F(1, 7)=7.41, p=0.03, Partial Eta squared=0.51; Figure 3,A. Table 2). However, there was no interaction (F(1, 7)=2.11, p=0.19) nor main effect of the gait phase (DSPL and DSPT; F(1, 7)=0.01, p=0.93). The Bonferroni post-hoc test showed that total vGRF was significantly increased in the condition with AFO-ODs compared to without AFO-ODs, irrespective of the gait phase (p=0.03).

In the vPD, a two-way RM-ANOVA showed a significant main effect of the stance phase (vPD_p and vPD_{np}; F(1, 7)=20.59, p=0.003, Partial Eta squared=0.75; Figure 3, B. Table 2). However, neither interaction (F(1, 7)=0.28, *p*=0.62) nor main effect of the AFO-OD condition (F(1, 7)=0.15, *p*=0.71) was found. Further, the post-hoc test showed that the vPD_{np} was significantly higher than the vPD_p, irrespective of the AFO-OD condition (*p*=0.003).

Relationship Between Kinetic and Kinematic Gait Parameters

In the condition without AFO-ODs, total vGRF during the DSPT was significantly negatively related with the vPD_{np} (r=-0.712, *p*=0.048; Table 3), while total vGRF during the DSPL was not significantly related with the vPD_p.

In the condition with AFO-ODs, there were significant relationships between total vGRF during the DSPL and the DSPT (r=0.779, *p*=0.023), between total vGRF during the DSPL and gait speed (r=0.89, *p*=0.003), and between total vGRF during the DSPT and gait speed (r=0.87, *p*=0.005; Table 3).

Discussion

Interaction Between Kinetics and Kinematics During Gait Without AFO-OD

Assessment of vertical pelvic displacement revealed a significant increase in the non-paretic stance phase compared to the paretic stance phase without AFO-ODs, consistent with a previous study.[14] Furthermore, contrary to our hypothesis, diminished total vGRF during the DSPT was related to greater vertical pelvic displacement in the subsequent non-paretic stance phase. Prior studies suggested that the vGRF during the paretic late stance phase, corresponding to the DSPT, was decreased compared to the non-paretic side after stroke[5.14.], and these pathologies are considered common comorbidities in stroke survivors. A feasible explanation for the unexpected findings is that excessive vertical pelvic movement in the non-paretic stance phase could be a compensation strategy for the preceding phase of the diminished total vGRF during the DSPT. In general, the kinetic energy of the vGRF plays an important role in redirecting the CoM upward against its downward acceleration during the double-limb support phase[11.], which is achieved by extension moment at lower leg joints.[24-25.] Our findings of reduced total vGRF during the DSPT might indicate the difficulty in moving the CoM upward with flexed lower limbs. Subsequently, it might require more muscle forces with flexed legs and the compensation to move the CoM upward in the non-paretic stance phase, leading to the increased metabolic cost of walking.[26-27.] These findings indicated that reduced total vGRF during the DSPT would result in higher metabolic energy cost and inefficient walking performance.[28-30.]

Kinetics and Kinematics of Gait Pattern With AFO-OD

Gait speed was significantly increased by wearing AFO-ODs compared to without AFO-ODs, consistent with a prior study.[31.] Moreover, our findings revealed that total vGRF was increased during the DSPL and the DSPT when wearing AFO-ODs compared to without AFO-ODs. In contrast, prior studies demonstrated that the use of AFO-ODs only modified heel rocker and ankle rocker functions, but not forefoot rocker function during the DSPT.[17-18,31.] A plausible explanation for the increased total vGRF during the DSPT could be a consequence of increased gait speed by wearing AFO-ODs. The primary function of AFO-ODs is to provide plantarflexion braking force and heel rocker function during the paretic loading response phase (corresponding to the DSPL), facilitating faster gait speed.[31.] The increase in walking speed would result in greater total vGRF during the DSPT. In fact, our findings suggested strong relationships between gait speed, total vGRF during the DSPL, and total vGRF during the DSPT when using AFO-ODs, despite the lack of a relationship in the absence of AFO-ODs. Awad et al.[7.] suggested that faster and more symmetric walking would decrease in metabolic energy cost of walking after stroke. Thus, the use of AFO-ODs can enhance gait speed and kinetic energy of total vGRF during the double-limb support phases, contributing to efficient gait performance after stroke.

Vertical pelvic displacement in the paretic stance phase was significantly lower than in the non-paretic stance phase in both without and with AFO-ODs. Whilst findings from Kobayashi et al.[32.] revealed that the peak vertical CoM position was higher with AFOs than without AFOs during walking. This is because they assessed the peak vertical CoM position, not vertical displacement, during the stance phase. The vertical CoM position can be predominantly dependent on step length since shorter step length raises the CoM position during the double-limb support phase[13,33] Thus, different methods to calculate vertical CoM motion might affect these inconsistent results. Overall, individuals with post-stroke appeared to have difficulty in moving the CoM upward to gain potential energy by the paretic leg during the paretic stance phase even when wearing AFO-ODs.

Interaction Between Kinetics and Kinematics During Gait With AFO-OD

According to the inverted pendulum model, the kinetic energy produced during the double-limb support phase is theoretically converted to potential energy during the single-limb support phase. However, our findings revealed that increased total vGRF during the DSPL and the DSPT did not influence vertical pelvic displacement in the subsequent stance phase when using AFO-ODs, resulting in no relationship between them. Nevertheless, increased total vGRF generated by both limbs during the double-limb support phases when wearing AFO-ODs could help to achieve efficient walking after stroke. This is because mechanical energy requires the most energy to redirect the CoM upward during the double-limb support phase, which accounts for approximately two-thirds of the metabolic energy cost of walking.[7, 34.] Therefore, improvement of total vGRF during the double-limb support phase when using AFO-ODs would contribute to the reduced metabolic energy cost of walking.

The most clinically significant finding in the present study was that using AFO-ODs increased total vGRF during the double-limb support phase with faster walking speeds after stroke. Hence, the use of AFO-ODs can significantly enhance weight transition during the double-limb support phase, leading to the decreased metabolic cost of walking in post-stroke rehabilitation.

Limitations

The study has some limitations that should be acknowledged to avoid its overinterpretation. Firstly, this study measured total vGRF generated by both limbs, which the precise extent to which the paretic and non-paretic limbs affected total vGRF could not be determined. Secondly, this study did not examine the kinematics of lower limb joints so that we could not explore to discuss our findings concerning pathological gait. Thirdly, the sample size was small and was limited to chronic post-stroke, Additionally, participants included were only those who were able to walk independently without AFOs, which might not be applicable to severe hemiplegic subjects. Fourthly, the order of tasks conducted was fixed with the condition without AFO-ODs followed by with AFO-ODs since the aftereffects of AFO-ODs were reported[4.] which might affect the results. Further, more research is needed to improve methodology to include a wide range of stages and severity and to identify the relative contributions of the paretic and non-paretic limbs to total vGRF both without and with AFO-ODs conditions after stroke. Fifthly, the application of one theory from the inverted pendulum theory of walking remained unresolved to fully explain the mechanical feature of hemiplegic gait so that exploring other theories may offer a different view or the other underlying mechanism in hemiplegic gait. Finally, we could not grasp the justification of AFO-ODs prescription in each participant since participants were recruited from community-dwelling post-stroke individuals after discharge from hospitals. Thus, it was difficult to interpret the details of the efficacy of AFO-ODs in each individual from our findings.

Conclusion

The findings revealed that diminished total vGRF during the DSPT without AFO-ODs was related to the excessive vertical pelvic displacement in the non-paretic stance phase, increasing the metabolic cost of walking. The use of AFO-ODs can significantly increase walking speed and improve the kinetic energy of total vGRF generated by both limbs in the weight transition during the double-limb support phase of gait in individuals with post-stroke.

Word count: 3000 words

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Figure 1: Ankle-Foot Orthosis With An Oil Damper (AFO-OD; Gait Solution Design, Kawamura Gishi, Japan; Pacific Supply. GAITSOLUTION Design R1 Manual[35]). The AFO-OD was developed to facilitate functional movement during walking. It provides the ankle plantarflexion braking force and allows to move ankle dorsiflexion freely during the stance phase (A). Also, the use of the AFO-OD improves toe clearance during the paretic swing phase. AFO-ODs are commonly prescribed to individuals with drop foot, mild to moderate plantarflexor spasticity, reduced paretic loading, lack of ankle rocker motion during stance phase, or extension thrust knee. While cases that are not applicable are serious buckling knee or extension thrust knee, or serious foot deformity and contracture. The ankle joint of the device is made of a hydraulic damper that can apply braking force in response to ankle plantarflexion movement during walking (B). The plantarflexion braking force of the hydraulic damper can be modulated by rotating the adjustment shaft to set proper plantarflexion braking force in four-grade from weak to strong (C). Its adjustment for each user is set by each user's walking pattern. For instance, if the plantarflexion braking force is too weak, it causes rapid ankle plantarflexion movement, leading to extension thrust knee pattern from heel contact to foot flat phases of walking. While if the plantarflexion braking force is too strong, it causes difficulty in moving ankle plantarflexion during those phases, leading to knee bending. The shank vertical angle of the AFO-OD can be set at 0 or 5 degrees dorsiflexion by replacing different thicknesses of the rod caps (D). It was set at 0 degrees for all participants in this study. The AFO-OD is a half-readymade with three different sizes (e.g., medium size; height of the device 345 mm, footplate length 200 mm: see their website for more details including the size selection of the device[35]). The frame of the device is made of titanium (2.5 mm thickness). The straps provide a three-point force system to fix the limb within the device when wearing a shoe. The plantar foot plastic plate of the device is thin and minimised which allows users to wear various types of their own shoes over the AFO-OD (B).

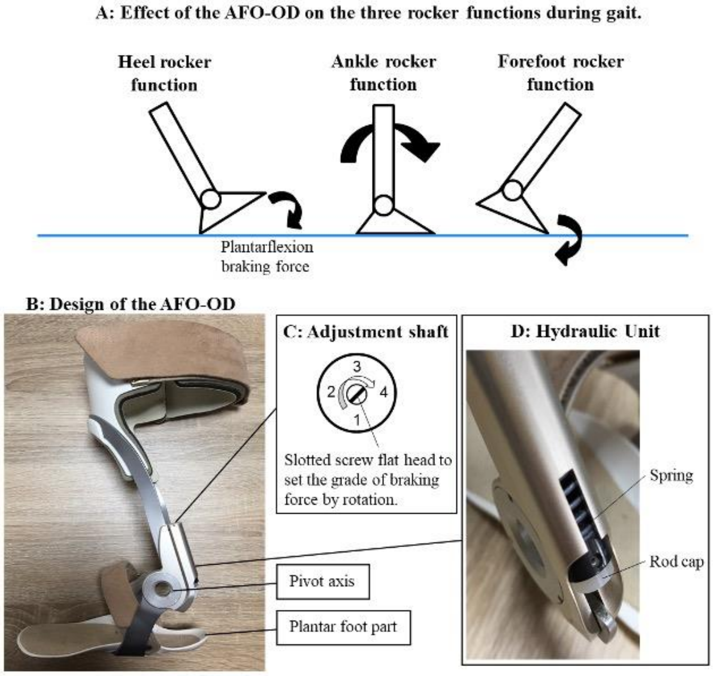

Figure 2: Setup And An Experimental Data Of A Participant. Two force plates (black rectangular) were placed lengthways along the walkway to assess the total of the vertical component of the ground reaction force (vGRF) generated by both legs during the double-limb support phase with the paretic leading limb (DSPL; A) and during the double-limb support phase with the paretic trailing limb (DSPT; B). A lower limb with horizontal stripes represents the paretic side and the other lower limb with a white blank represents the non-paretic side. (C) The bold line represents the total vGRF generated by the paretic and non-paretic limbs without an AFO-OD. The auxiliary lines for solid and dashed lines are accounted for the paretic and non-paretic stance phases, respectively. The peak values of the total vGRF are indicated as a black circle during the DSPL and a white circle during the DSPT. (D) represents the trajectory of vertical pelvic displacement. The vertical pelvic displacement in the paretic stance phase (vPD$_{\text{p}}$; dotted allow) was defined as the difference between the maximum value in the paretic stance phase and the minimum value during the DSPL. The vertical pelvic displacement in the non-paretic stance phase (vPD$_{\text{np}}$; allow with diagonal stripes) was defined as the difference between the maximum value in the non-paretic stance phase and the minimum value during the DSPT. Abbreviations: vGRF, vertical component of the ground reaction force; DSPL, double-limb support phase with the paretic leading limb; DSPT, double-limb support phase with the paretic trailing limb; vPD$_{\text{p}}$, vertical pelvic displacement in the paretic stance phase; vPD$_{\text{np,}}$ vertical pelvic displacement in the non-paretic stance phase.

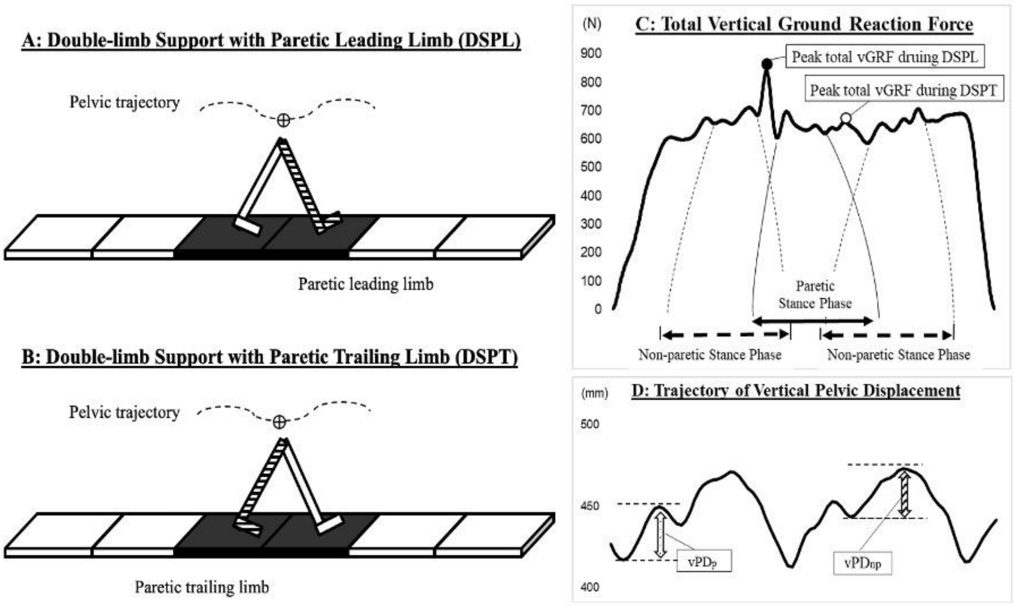

Figure 3: Comparison Of Gait Parameters. The bar graphs and error bars show the average and standard error for each variable, respectively. (A) The average of total vGRF (A) was compared between the AFO-OD condition (i.e. without and with the AFO-OD) and gait phase (i.e. double-limb support phase with the paretic leading limb (DSPL) and with the paretic trailing limb (DSPT)). (B) The average vertical pelvic displacement (vPD; B) was compared between the AFO-OD condition (i.e. without and with the AFO-OD) and stance phase (i.e. paretic stance phase and non-paretic stance phase). Abbreviations: vGRF, vertical ground reaction force; AFO-OD, ankle-foot orthosis with an oil damper; DSPL, double-limb support with the paretic leading limb; DSPT, double-limb support with the paretic trailing limb; vPD, vertical pelvic displacement (*$p < 0.05$).

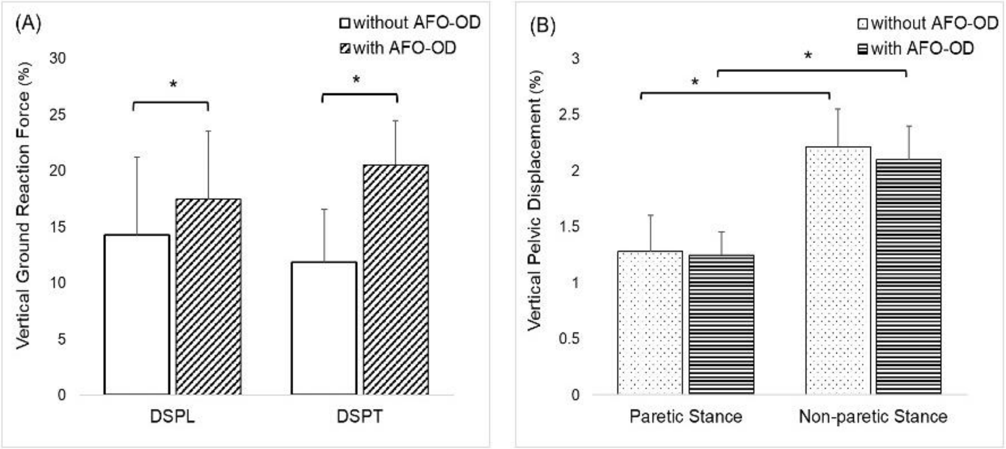

Table 1: Profile Of Participants

Participant	Age (year)	Sex	Type of stroke	Paretic side	Height (cm)	Body weight (kg)	Onset of stroke (year)	FMA for LE	Modified Ashworth Scale		Passive ROM of paretic ankle dorsiflexion (degree)	BI	SFBBS	Hip flexion (Nm/kg)		Hip extension (Nm/kg)		Knee flexion (Nm/kg)		Knee extension (Nm/kg)		Ankle dorsiflexion (Nm/kg)		Ankle plantarflexion (Nm/kg)	
									Ankle dorsi-flexors	Ankle plantar-flexors				P	NP	P	NP	P	NP	P	NP	P	NP	P	NP
1	28	M	I	L	176	68	0.5	19	0	1+	15	100	24	0.73	0.95	0.44	1.16	0.40	1.07	1.44	1.79	0.28	0.68	0.50	1.07
2	45	M	H	R	168	58	7.8	22	0	1+	10	95	22	1.27	1.33	0.96	1.45	0.41	1.00	0.92	1.49	0.36	0.67	0.41	1.32
3	49	F	H	R	170.5	68.5	1.3	21	0	1	15	100	22	1.04	1.15	0.54	1.18	0.73	0.78	1.30	1.09	0.24	0.58	0.36	1.12
4	60	M	H	L	163	58	1.6	23	0	0	15	100	24	1.11	1.27	1.16	1.48	0.80	1.01	1.81	1.72	0.35	0.82	0.68	1.54
5	52	M	I	R	170	65	6.9	24	0	1	15	95	20	0.79	1.18	0.61	0.97	0.49	0.91	0.79	1.42	0.40	0.84	0.37	0.95
6	55	F	H	R	157	50	1.0	24	N/A	N/A	15	90	26	0.55	0.81	0.37	0.85	0.31	0.76	0.89	1.07	0.19	0.56	0.19	1.02
7	48	F	H	L	162	52	12.6	22	0	1+	25	100	24	0.69	0.96	0.49	1.11	0.42	0.83	1.37	1.26	0.31	0.70	0.32	0.98
8	55	F	I	L	164	56	1.5	25	0	1	0	95	22	0.81	1.03	0.65	0.80	0.60	0.92	1.00	0.87	0.28	0.61	0.47	0.88

Abbreviations: M, male; F, female; I, Ischemic; H, haemorrhagic; R, right; L, left; FMA for LE, Fugl-Meyer Assessment scale for motor function of lower extremity; RoM, range of motion; BI, Barthel Index; SFBBS, Short Form Berg Balance Scale; P, paretic side; NP, non-paretic side.

Table 2: Comparison Of Variables Under The Conditions Without And With AFO-OD. The *p*-values for total vGRFs and the vPDs indicate statistically significant results of main effects from a two-way repeated measures ANOVA. There was no interaction (p=0.19) nor main effect of gait phase (DSPL and DSPT; p=0.93) in total vGRF, and no interaction (p=0.62) nor main effect of the ADO-OD condition (p=0.71) in the vPD.

Conditions	Variables	Mean ± SD	*p*-value
without AFO-OD	Total vGRF in DSPL (%)	14.24 ± 13.84	0.03*
with AFO-OD	Total vGRF in DSPL (%)	17.45 ± 12.08	
without AFO-OD	Total vGRF in DSPT (%)	11.81 ± 9.53	0.03*
with AFO-OD	Total vGRF in DSPT (%)	20.49 ± 8.0	
without AFO-OD	vPD_p (%)	1.28 ± 0.64	0.003*
	vPD_{np} (%)	2.21 ± 0.69	
with AFO-OD	vPD_p (%)	1.25 ± 0.42	0.003*
	vPD_{np} (%)	2.1 ± 0.61	
without AFO-OD	Gait Velocity (m/s)	0.34 ± 0.14	0.049*
with AFO-OD	Gait Velocity (m/s)	0.42 ± 0.16	

Notes: Abbreviations : AFO-OD, ankle-foot orthosis with an oil damper; vGRF, vertical ground reaction force; DSPL, double-limb support phase with paretic leading limb; DSPT, double-limb support phase with paretic trailing limb; vPD_p, vertical pelvic displacement in the paretic stance phase; vPD_{np}, vertical pelvic displacement in the non-paretic stance phase.

* Significant at $p < 0.05$.

Table 3: Correlation Between Gait Parameters

Conditions	Variables	vPD_p	vPD_{np}	Gait Velocity
without AFO-OD	Total vGRF in DSPL	-0.08	-0.12	0.64
	Total vGRF in DSPT	-0.51	-0.71*	0.47
with AFO-OD	Total vGRF in DSPL	0.02	-0.05	0.89**
	Total vGRF in DSPT	-0.32	-0.15	0.87**

Abbreviations: vGRF, vertical ground reaction force; DSPL, double-limb support phase with paretic leading limb; DSPT, double-limb support phase with paretic trailing limb; vPD_p, Vertical pelvic displacement in the paretic stance phase; vPD_{np}, Vertical pelvic displacement in the non-paretic stance phase.

Correlation is significant at *p<0.05. **p<0.01.