Gait & Posture 68 (2019) 305–310

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

Gait initiation and partial body weight unloading for functional improvement in post-stroke individuals

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ARTICLE INFO

Keywords:
Overground body weight support system
Force plate
Center of pressure
Hemiparesis

ABSTRACT

Background: To better understand gait initiation in individuals with stroke and suggest possible training strategies, we compared the gait initiation of individuals with stroke and age-matched controls, and we examined the influence of different amounts of body weight support (BWS) during the execution of gait initiation in individuals with stroke.

Materials and methods: Twelve individuals with stroke and 12 age-matched controls initiated gait after a verbal command at a self-selected and comfortable speed, and individuals with stroke also initiated gait wearing a harness with 0%, 15%, and 30% of BWS. Length and velocity of the first step, distance between heels, and weight bearing in both lower limbs in the initial position were calculated. We also assessed the displacement and average velocity of the center of pressure (CoP) in the medial-lateral (ML) and anterior-posterior (AP) directions in 3 distinct sections during gait initiation, which correspond to the CoP position toward the swing limb, stance limb and progression line, respectively.

Results: Individuals with stroke presented shorter and slower step, shorter and slower CoP-ML and CoP-AP toward swing limb and Cop-ML towards stance limb, and longer and faster CoP-AP toward stance limb compared to their peers. The BWS lead individuals with stroke to decrease step length and to increase CoP-ML displacement and average velocity toward stance limb.

Conclusion: Individuals with stroke present impairments in executing gait initiation mainly during the preparation period and the employment of an overground BWS system promotes a better performance. These results suggest that BWS is a functional strategy that enables individuals with stroke to modulate gait initiation and it could be adopted for gait intervention.

1. Introduction

Gait is one of the most investigated motor skills in individuals with stroke, who usually consider its improvement the main goal in rehabilitation programs [1]. However, besides the knowledge concerning gait after stroke and the mostly therapeutic approaches aimed at its improvement, there is still little known about how individuals with stroke manage gait initiation.

The specificity of gait initiation is such that, contrary to ongoing gait, each lower limb has a distinct function. For instance, the limb performing the first step (swing limb) is used to apply the largest vertical force to lift the foot, whereas the contralateral limb (stance limb) is used initially for supporting the body weight during the first step, and afterward for applying the propulsive force to move the body forward during the second step [2]. Such limb function specificity poses a particularly challenging task for disabled individuals.

Compared to non-disabled individuals, individuals with stroke initiate gait more slowly and with a shorter step length of the swing limb, and they have diminished bilateral forward propulsive force [2,3], among other differences. Yet, individuals with stroke prefer to initiate gait with the paretic limb, enabling the non-paretic limb to support the body weight during the first step and achieving greater propulsive forces and higher speed [2,4].

Among different possible parameters to investigate gait initiation, those from the center of pressure (CoP) calculations have been most commonly considered in both non-disabled individuals [5,6] and in individuals with gait impairments [7,8]. The CoP trajectory during gait initiation can be divided into 3 sections, namely S1, S2, and S3 [9,10]. Thus far, a few studies have observed that individuals with stroke present decreased initial CoP backward displacement toward the swing

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https://doi.org/10.1016/j.gaitpost.2018.12.008
Received 8 March 2018; Received in revised form 4 October 2018; Accepted 5 December 2018
0966-6362/

limb [2,11], which corresponds to S1. However, to our knowledge, no study has investigated the subsequent CoP displacement (i.e., S2 and S3) in individuals with stroke.

Investigating different strategies to initiate gait and the causes of difficulties in individuals with stroke is imperative for several reasons. First, the control of initiating gait is challenging even for an intact system, and the challenges are even more evident in a system with asymmetric function and control, as in the case of individuals with stroke. Second, in daily life, everyone initiates gait countless times, and therefore, it is a fundamental necessity to perform it appropriately to carry out daily activities. It is important to investigate possible strategies to improve the performance of gait initiation in individuals with stroke as previously reported [2,3]. However, before proposing any intervention program, it is also important to identify how stroke can affect gait initiation and if it is possible to alter gait initiation in individuals with stroke based on an external constraint.

One possible strategy to promote an external constraint during locomotion is employing a system that partially unloads the body weight. Partial body weight support (BWS) systems have been widely employed for gait rehabilitation after stroke [12,13]. The rationale for using these systems is that by reducing the load that has to be overcome by the individual, movement of the lower limbs would be facilitated [14]. The system could also improve safety and be in line with the requirements of the regular gait situation. However, thus far, it has not been established how BWS might influence gait initiation in individuals with stroke.

We planned the current study to further understand the performance of gait initiation in individuals with stroke by conducting 2 experiments. The aim of the first experiment was to compare gait initiation of individuals with stroke to age-matched non-disabled controls. We hypothesized that both groups would present different CoP during gait initiation, mainly in the first and second sections of CoP (S1 and S2). The aim of the second experiment was to investigate how different amounts of BWS would influence the gait initiation of individuals with stroke.

2. Methods

2.1. Participants

Twelve individuals with stroke and 12 non-disabled controls participated in experiment 1, and the same individuals with stroke participated in experiment 2. All individuals with stroke presented high motor functions (Table 1), seven used a cane for community ambulation and one wore ankle foot orthesis. All participants signed a written consent form approved by the Institutional Ethics Committee.

Inclusion criteria for the individuals with stroke were presence of hemiparetic gait after an ischemic or hemorrhagic stroke more than 6 months from the stroke event, absence of any orthopedic or pulmonary pathology or other neurologic impairment that could compromise gait, ability to follow verbal commands, and ability to walk independently at least 4 m without interruption. Inclusion criteria for the non-disabled control individuals were the absence of any known orthopedic or neurologic impairment that could compromise gait and no use of any medication that might affect gait and/or balance.

Table 1
General characteristics for individuals with stroke and age-matched non-disabled controls.

Characteristics	Stroke (n = 12)	Control (n = 12)	*p*
Sex (Female/Male)	3/9	9/3	
Age (years)*	62 ± 4.6	62 ± 5.0	0.86
Mass (kg)*	68.2 ± 12.5	61.6 ± 13.2	0.22
Height (m)*	1.61 ± 0.08	1.54 ± 0.05	0.03
Time post-stroke (months)*	72 ± 54	–	–
Type of Lesion (Ischemic/Hemorrhagic)	8/4	–	–
Hemiparesis side (Right/Left)	4/8	–	–
Fulg-Meyer score (max 84)*	73.4 ± 6.0	–	–
Functional independence score (max 91)*	83.4 ± 4.1	–	–
10-m walk test (m/s)*	0.64 ± 0.17	–	–

* Mean ± standard deviation values.

2.2. Procedure

Gait initiation of both experiments was performed on a 7-m walkway equipped with 2 embedded force plates (model 9286BA, Kistler) positioned side by side in the middle of the walkway. A computerized gait analysis system (VICON, Inc.) with 7 infrared cameras was used to acquire data from reflective markers placed on the sacrum, heel, and second metatarsal of both feet.

In experiment 1, all participants were instructed to stand quietly with each foot on a force plate, trying to distribute body weight equally between both feet, looking straight ahead and with arms hanging at the side for approximately 3 s. After a verbal command, the participants were instructed to walk toward the end of the walkway at a comfortable speed with no interruption. Participants were barefoot and the initial stance position was traced on the top of each force plate to keep it consistent throughout data acquisition. Before data acquisition, all participants practiced for 3 trials and the limb that initiate gait predominantly was chosen as the leading limb. Individuals with stroke started walking with the paretic limb, and non-disabled individuals started walking with the right limb.

In experiment 2, only individuals with stroke underwent gait initiation with BWS, and they received the same instructions as in experiment 1. Three different conditions of body weight unloading were employed (0%, 15%, and 30%) in a randomized order. The BWS system (FENIX Tecnologia) used in this experiment has been described previously [13]. At the beginning of each body weight unloading condition, participants performed a few practice trials until they felt comfortable with the BWS apparatus, and at least 3 trials were performed for each experimental condition. Data from the force plates and cameras were sampled at 100 Hz and acquired synchronously. In both experiments, rest periods were provided when necessary to minimize possible fatigue effects.

Individuals with stroke also underwent lower limb recovery and functional independence assessment to characterize their lower extremity impairment level using the Fugl-Meyer scale (FM), the motor functional independence measure (FIM), and the 10-m walk test (Table 1).

2.3. Data analysis

The same procedures were adopted to analyze data from both experiments. All analyses were performed using a customized routine written in Matlab software (MathWorks, Inc.). Automatic identification and visual inspection to guarantee correct identification of heel-off [15] and toe-off of both feet, and heel strike [16] of the swing limb were made based on the trajectories of reflective markers and force plate data. For the CoP trajectories, 3 sections were identified (Fig. 1) from the start of gait initiation to the maximum value of the horizontal AP component of the ground reaction force, which corresponds to the heel-strike of the swing limb [17].

The following measures were calculated: 1) initial weight loading on swing and stance limbs and ML distance between heels, both calculated before the verbal command to start gait initiation; 2) displacement and average velocity in ML and AP directions for each of the 3 sections of CoP trajectories [9]; 3) step length of swing limb, calculated as the distance between the initial position and heel strike of the swing limb along the progression line (determined by the position of the heel marker); and 4) step velocity of swing limb, calculated as the rate between step length and duration.

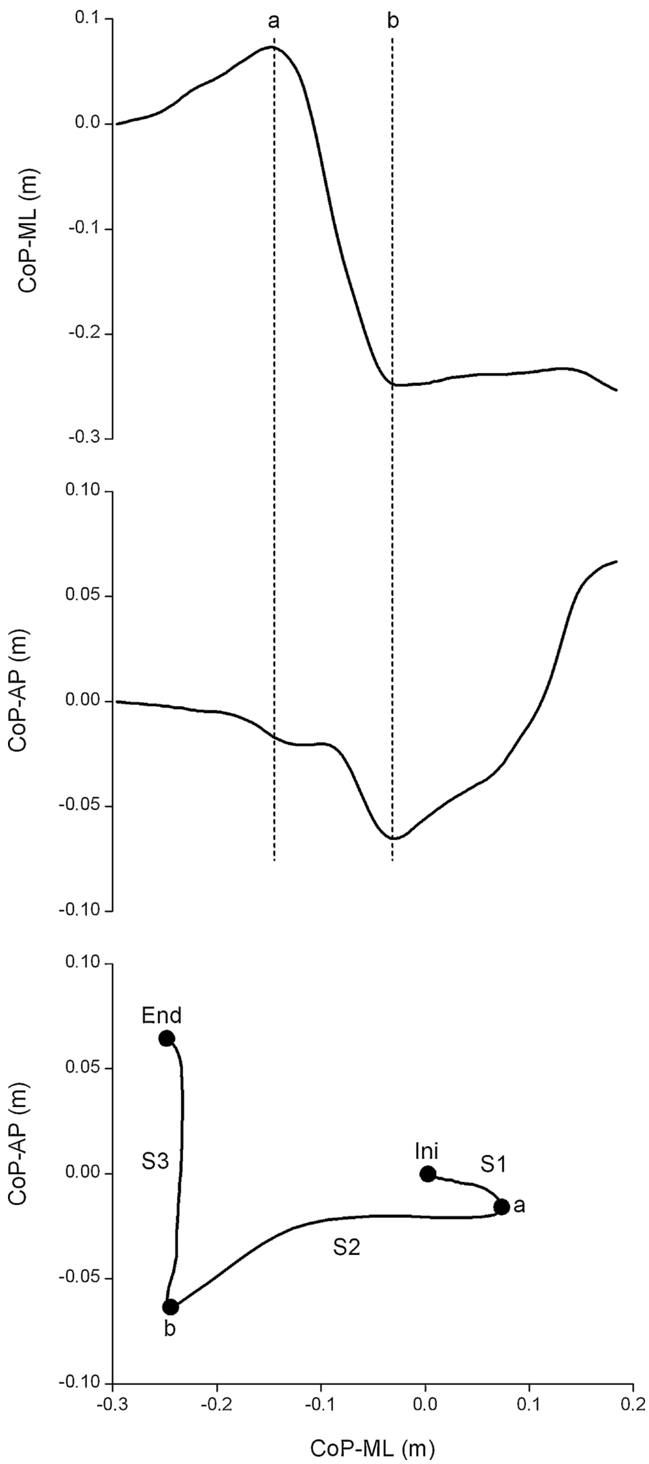

Fig. 1. Center of pressure (CoP) trajectory in the medial-lateral (ML) and anterior-posterior (AP) directions during a single trial of gait initiation with the right limb of an individual with stroke. Section 1 (S1) is from "Ini" (CoP onset) to "a" (most lateral and posterior CoP position toward the swing limb); Section 2 (S2) is from "a" to "b" (most lateral and posterior position of the CoP toward the stance limb); Section 3 (S3) is from "b" to "End" (maximum value of the horizontal AP component of the ground reaction force, and most posterior CoP position toward progression line).

For all variables, data from 3 trials were averaged for each participant and condition. One-way analysis of variance (ANOVA) and multivariate analyses of variance (MANOVA) were employed using as the factor group, stroke and control for the first experiment, and BWS (0%, 15%, 30%) for the second experiment. For both experiments, the dependent variables were distance between heels (ANOVA); initial weight loading on swing and stance limbs; step length and step velocity; CoP displacement in the ML and AP directions for Section 1, Section 2, and Section 3; and CoP average velocity in the ML and AP directions for Section 1, Section 2, and Section 3 (MANOVA). When necessary, univariate tests and pairwise comparisons with Bonferroni adjustments were employed. Alpha level of 0.05 was adopted and analyses were performed using the Statistical Package for Social Sciences software.

3. Results

3.1. Experiment 1

Table 2 depicts results for the initial weight loading on each limb and distance between heels and step length and step velocity of both groups. Individuals with stroke stood with a higher percentage of body weight on the stance limb than non-disabled individuals, both groups presented similar distance between heels during the initial position and individuals with stroke presented a shorter and slower step.

Regarding CoP displacement (Table 3), individuals with stroke presented shorter displacement in both ML and AP directions in S1; shorter displacement in the ML direction and longer displacement in the AP direction in S2 compared to non-disabled individuals, and there was no difference between both groups in S3. For CoP average velocity measures (Table 3), individuals with stroke presented slower velocity in both ML and AP direction in S1; slower average velocity of CoP in the ML direction and a faster average velocity in the AP direction in S2; and slower average velocity of COP in the AP direction in S3 than non-disable individuals.

3.2. Experiment 2

Table 4 depicts results for the initial weight loading on each limb, distance between heels, and step length and step velocity after using 0%, 15%, and 30% of BWS. Individuals with stroke presented similar body weight distribution and maintained similar distance between their heels in the different percentages of BWS. They presented shorter steps with 30% of BWS than with 0% of BWS, and there was no difference for step velocity.

For the CoP displacement (Table 5), there was no BWS effect in S1. In S2 individuals with stroke presented longer CoP displacement in the ML direction with 30% of BWS than with 0% of BWS, and in S3 they presented longer CoP displacement in ML direction with 15% and 30% of BWS than with 0% of BWS. For the CoP average velocity (Table 5), there was no BWS effect in S1 and S2, and in S3 they presented faster average velocity of CoP with 15% of BWS than with 0% of BWS.

4. Discussion

The two experiments proposed in this study were planned to further our understanding of how individuals with stroke initiate gait. Only a few studies have investigated gait initiation in individuals with stroke [18,19], and none of them have investigated the CoP trajectory throughout the whole task of gait initiation and compared it to age-matched controls. Therefore, our results provide new information regarding the CoP dynamics because individuals with stroke have to manage body sides that are functionally asymmetrical to initiate gait.

Individuals with stroke present impairments when transferring body weight onto the paretic limb during the upright position, and consequently they present an asymmetrical weight bearing [20]. An asymmetrical body weight distribution was observed in this study during the initial position before the performance of gait initiation and can be associated with the muscle weakness, spasticity, impaired balance, and sensorial deficits observed in the paretic side of this population [20]. Altogether, these impairments contribute to an increasing dominance of

Table 2
Mean (± SD) and confidence interval (CI) values for the descriptive variables presented by individuals with stroke and age-matched non-disabled controls.

Variables	Stroke (n = 12)		Control (n = 12)		F	*p* value
	Mean ± SD	95% CI	Mean ± SD	95% CI		
Initial loading (% body weight)						
Swing limb	38 ± 7.4	34-41	49 ± 3.1	46-53	23.93	*< 0.001*
Stance limb	62 ± 7.4	59-65	51 ± 3.1	47-54	23.87	*< 0.001*
Distance between heels (m)	0.16 ± 0.03	0.14-0.18	0.18 ± 0.04	0.15-0.19	0.74	0.398
Step Length (m)	0.37 ± 0.09	0.32-0.42	0.51 ± 0.08	0.46-0.56	18.54	*< 0.001*
Step Velocity (m/s)	0.58 ± 0.12	0.49-0.67	0.50 ± 0.67	0.87-1.04	40.41	*< 0.001*

Table 3
Mean (± SD) and 95% confidence interval (IC) values for center of pressure (CoP) displacement and average velocity in the medial-lateral (ML) and anterior-posterior (AP) directions in the Sections 1,2 and 3 (S1, S2 and S3, respectively) for individuals with stroke and non-disabled controls.

Variables	Stroke (n = 12)		Control (n = 12)		F	*p* value
	Mean ± SD	95% CI	Mean ± SD	95% CI		
CoP displacement (m)						
S1						
ML	0.05 ± 0.02	0.04-0.07	0.08 ± 0.03	0.07-0.10	8.53	*0.008*
AP	0.01 ± 0.01	0.00-0.02	0.02 ± 0.01	0.02-0.03	22.37	< 0.001
S2						
ML	0.27 ± 0.05	0.24-0.30	0.38 ± 0.03	0.36-0.41	36.02	*< 0.001*
AP	0.04 ± 0.02	0.03-0.05	0.01 ± 0.01	0.01-0.02	21.52	*< 0.001*
S3						
ML	0.02 ± 0.01	0.01-0.02	0.01 ± 0.01	0.01-0.02	1.62	0.216
AP	0.12 ± 0.02	0.10-0.13	0.11 ± 0.02	0.09-0.12	1.26	0.273
CoP average velocity (m/s)						
S1						
ML	0.20 ± 0.08	0.11-0.28	0.36 ± 0.18	0.27-0.44	7.73	*0.011*
AP	0.03 ± 0.03	0.002-0.06	0.10 ± 0.06	0.07-0.13	14.82	*< 0.001*
S2						
ML	0.56 ± 0.18	0.42-0.70	1.10 ± 0.27	0.96-1.24	31.22	*< 0.001*
AP	0.83 ± 0.05	0.06-0.11	0.04 ± 0.02	0.02-0.06	7.90	*0.010*
S3						
ML	0.03 ± 0.03	0.02-0.04	0.03 ± 0.02	0.02-0.04	0.17	0.686
AP	0.19 ± 0.03	0.17-0.22	0.24 ± 0.06	0.21-0.27	5.63	*0.027*

the non-paretic limb in performing daily activities, including transfer tasks such as gait initiation. Furthermore, these deficits associated with asymmetric weight bearing may contribute to the decreased first step length and velocity during gait initiation in individuals with stroke [18].

Shorter and slower step can also be related to the CoP trajectory in S1, as there is a linear relationship between the initial posterior CoP displacement toward the swing limb and step parameters [21–23]. The differences presented by individuals with stroke compared to non-disabled controls in S1 have also been described in other populations with balance impairments [7,24], having these impairments been associated with centrally mediated anticipatory postural adjustments. The initial movements are important to generate propulsion and minimize the upcoming body disturbance during the first step execution [2,21]. Specifically in individuals with stroke, this difference compared to non-disabled controls has been associated with bilateral failure to modulate the inhibition of the soleus muscle and an inefficient activation of the tibialis anterior muscle of the paretic limb, which results in poor postural stability [11] and increases the risk and incidence of falls. Therefore, intervention protocols should aim to promote transitions between standing still and walking to diminish balance deficit in individuals with stroke.

Shorter and slower CoP trajectory in the ML direction in S2 can also be related to initial asymmetric weight bearing. This asymmetry before gait initiation and the decrease in CoP trajectory in the ML direction in S1 may require the CoP to travel a shorter distance until the stance limb is the only one to fully support the body weight allowing the step execution [8]. In addition, the decrease in CoP trajectory in the ML

Table 4
Mean (± SD) and 95% confidence interval (CI) values for the descriptive variables presented by individuals with stroke using the 3 percentages of body weight support (0%, 15% and 30%).

Variables	0% of BWS		15% of BWS		30% of BWS		F	p-value
	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI		
Initial loading (% body weight)								
Swing limb	38 ± 5.8	34-42	40 ± 6.3	35-44	40 ± 7.2	36-45	1.94	0.167
Stance limb	62 ± 5.8	58-66	60 ± 6.3	56-64	60 ± 7.2	55-64	1.90	0.174
Distance between heels (m)	0.16 ± 0.03	14.2-17.6	0.15 ± 0.03	13.7-17.3	0.16 ± 0.03	13.9-18.2	1.00	0.384
Step length (m)	0.36 ± 0.09[a]	0.30-0.42	0.33 ± 0.07	0.28-0.37	0.32 ± 0.07[a]	0.27-0.36	6.68	*0.005*
Step velocity (m/s)	0.54 ± 0.09	0.48-0.60	0.52 ± 0.09	0.46-0.58	0.51 ± 0.12	0.44-0.59	1.04	0.372

Note: [a] indicates difference between conditions.

Table 5
Mean (± SD) and 95% confidence interval (CI) values for CoP displacement and average velocity in the medial-lateral (ML) and anterior-posterior (AP) directions in the Sections 1,2 and 3 ((S1, S2 and S3, respectively) for individuals with stroke using the 3 percentages of body weight support (0%, 15% and 30%).

Variables	0% of BWS		15% of BWS		30% of BWS		F	*p* value
	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI		
CoP displacement (m)								
S1								
ML	0.06 ± 0.02	0.04-0.07	0.06 ± 0.03	0.04-0.08	0.07 ± 0.03	0.05-0.09	1.39	0.270
AP	0.01 ± 0.01	0.005-0.01	0.01 ± 0.01	0.01-0.02	0.01 ± 0.01	0.01-0.02	1.18	0.325
S2								
ML	0.27 ± 0.4[a]	0.24-0.30	0.30 ± 0.06	0.26-0.34	0.31 ± 0.05[a]	0.28-0.34	8.11	*0.002*
AP	0.03 ± 0.02	0.02-0.05	0.04 ± 0.02	0.03-0.05	0.03 ± 0.02	0.02-0.04	2.30	0.123
S3								
ML	0.01 ± 0.01[a,b]	0.008-0.01	0.02 ± 0.01[a]	0.01-0.02	0.02 ± 0.01[b]	0.01-0.02	5.38	*0.013*
AP	0.12 ± 0.02	0.10-0.13	0.11 ± 0.03	0.09-0.13	0.11 ± 0.02	0.09-0.12	0.54	0.590
CoP average velocity (m/s)								
S1								
ML	0.23 ± 0.11	0.16-0.30	0.27 ± 0.14	0.18-0.35	0.27 ± 0.15	0.18-0.37	0.78	0.471
AP	0.04 ± 0.02	0.02-0.05	0.05 ± 0.04	0.03-0.08	0.05 ± 0.04	0.03-0.08	1.67	0.211
S2								
ML	0.57 ± 0.16	0.46-0.67	0.65 ± 0.25	0.50-0.81	0.66 ± 0.23	0.51-0.80	4.34	*0.026**
AP	0.07 ± 0.05	0.04-0.10	0.08 ± 0.04	0.05-0.11	0.06 ± 0.05	0.04-0.09	1.81	0.19
S3								
ML	0.02 ± 0.01[a]	0.01-0.02	0.03 ± 0.01[a]	0.02-0.03	0.03 ± 0.02	2.02-4.01	4.25	*0.047*
AP	0.17 ± 0.04	0.14-0.19	0.18 ± 0.07	0.14-0.22	0.18 ± 0.04	0.02-0.04	0.59	0.56

Note: [a, b] indicate difference between conditions; * comparisons with Bonferroni adjustments did not reveal any effect.

direction might be related to deficits in hip abductors and adductor muscle activation, which are well characterized in this population [25,26].

Finally, it seems that stroke does not substantially affect CoP trajectory when the body moves forward (S3). This finding can be explained by 2 reasons: (1) the distinct neural mechanisms related to each of the CoP sections described in the literature, (2) the unilateral motor impairments and muscle weakness resulting from the stroke impairments. S1 and the approximately first half of S2 correspond to the postural phase, which is centrally controlled, and the second half of S2 section and the whole of S3 represent the execution phase, which is regulated by the lower level of spinal processes [23].

Experiment 2 was conducted to investigate how different amounts of BWS would influence gait initiation of individuals with stroke. Overall, the results revealed that individuals with stroke could improve their stability in the ML direction, even though the step length of the swing limb was shorter when patients initiated gait with 30% of BWS. Such a result could be due to a movement constraint at the hip joint, as reported in a previous study that investigated individuals with stroke walking with 0%, 15%, and 30% of BWS over the ground [27]. In this case, the BWS system diminished the propulsive force and during gait initiation step length is dependent on propulsive forces at toe lifting of the swing limb [18]. At first, this finding seems negative as the vertical mechanical support may prevent the generation of ground reaction force and, consequently, the propulsion to move the limb forward [28]; however, long-term training using this system could improve lower-limb strength and promote benefits for gait initiation performance in this population.

The use of BWS during gait initiation influenced CoP trajectory only in S2, as individuals with stroke presented longer and faster CoP trajectory in the ML direction. This result can be associated either with the initial position of CoP before initiating gait or to a strategy from the central nervous system to maintain balance due to an external constraint. In addition, this result suggests that individuals with stroke are still able to increase CoP displacement in the ML direction, and more importantly, they can modulate their control according to the task to be performed. If we consider that it is essential to modulate balance and stability according to internal and/or external constraints to avoid falls [29], it seems that the use of an overground BWS system could be very appropriate for improving gait initiation in individuals with stroke.

It is important to note that the use of an overground BWS system during gait initiation can be considered a strategy to improve stability in the ML direction without changing first step velocity, because participants were instructed to initiate gait after a verbal command at a comfortable speed during all conditions. This strategy seems to be important to decrease the risk of falls once a high-level of motor control is necessary for maintaining ML stability compared to AP stability [30]; it is known that instability in the ML direction is associated with increasing risk of falls [29].

Although this study demonstrated promising results, there are some limitations. The variability of the lesion time since stroke onset could influence gait initiation performance and mask possible differences between groups in experiment 1, and between conditions in experiment 2. Only 3 different percentages of BWS were investigated, and these were the same for all participants. Only a short period for adaptation was provided for the participants, and it might not have been enough to reveal some other effects of the BWS system during gait initiation. Finally, it is important to note that we did not match the proportions of male and female participants between groups in the first experiment, and the generalizability should be taking into consideration. In addition, future studies aiming other measurements, such as trunk and lower limb displacement, should be considered.

5. Conclusion

Individuals with stroke initiate gait differently from their age-matched non-disabled controls, and these differences are mainly during the postural phase. However, individuals with stroke are able to improve gait initiation using a strategy with a BWS system over the ground, particularly in terms of ML stability. Considering that gait initiation is a motor task commonly performed by everyone in daily life, therapists and caregivers should consider the importance of rehabilitation of gait initiation for individuals with stroke, primarily because they are able to modulate the CoP trajectory in the ML direction.

Conflict of interest

None

Acknowledgments

The authors acknowledge the financial support of the São Paulo Research Foundation – FAPESP (grant #2009/15003-0; #2010/15218-3; #2013/02322-5 to AMF Barela; and fellowship to GL Gama grant #2013/01050-1 and ML Celestino grant #2015/13100-9).

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