The influence of weight-bearing asymmetry on postural responses to balance perturbations in individuals with stroke

Master thesis

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Ondergetekende,

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“bevestigt hierbij dat de onderhavige verhandeling mag worden geraadpleegd en vrij mag worden gefotokopieerd. Bij het citeren moet steeds de titel en de auteur van de verhandeling worden vermeld.”

Dutch abstract

Introductie. Trainen van balans is een belangrijk doel gedurende de revalidatie na een Cerebrovasculair accident (CVA). Gewichtname asymmetrie, waarbij meer gewicht wordt genomen op het niet aangedane been, is een algemeen voorkomend fenomeen na een CVA. Verbeteren van symmetrie was dan ook een gericht aandachtspunt tijdens trainen van balans. Er werd verondersteld dat herstel van een meer symmetrische gewichtsverdeling is geassocieerd met een betere balans. Verschillende studies suggereren echter dat een geringe gewichtname asymmetrie mogelijk een compensatie strategie is om de balans te vergroten. **Doel.** Het onderzoeken van het effect van een gewichtname asymmetrie op uitkomstmaten van stabiliteit in de chronische fase na CVA: 1) de stapdrempel en 2) de keuze van het stap been na een balansverstoring. **Methode**. Acht personen in de chronische fase na een CVA werden blootgesteld aan balansverstoringen in vier richtingen door middel van een beweegbaar platform. De stapdrempel en de keuze van het stap been werden bepaald voor iedere richting en voor drie verschillende condities van gewichtsverdeling (symmetrische verdeling, 10% en 20% meer gewicht op het niet aangedane been). De stapdrempel was gedefinieerd als de hoogste balansverstoring die kon worden opgevangen zonder te stappen. **Resultaten**. Toename van asymmetrische gewichtsverdeling verhoogde de stapdrempel naar de aangedane zijde *(P* = .065), en verlaagde deze naar de niet aangedane zijde *(P* = .006). De stapdrempel van de voorwaartse en achterwaartse verstoringen werden niet beïnvloed door de mate van gewichtsverdeling (*P* = .078 en *P* = .595). Toename van asymmetrische gewichtsverdeling verhoogde de kans op stappen met het aangedane been (20.8% symmetrie (WBA 0%), 31.3% (WBA 10%), 44.8% (WBA 20%)), echter de aanwezige dominante stap strategie met het niet aangedane been bleef behouden. **Conclusie.** Asymmetrische gewichtsverdeling vergroot mogelijk de mogelijkheid om balansverstoringen op te vangen naar de aangedane zijde. De toegenomen kans op stappen met het aangedane been vergroot mogelijk het risico om te vallen, echter dit effect was vooral zichtbaar bij een asymmetrie van 20%. Een geringe gewichtname asymmetrie zoals vaak waargenomen bij mensen na een CVA, zou als een bruikbare strategie kunnen worden gezien

om de stabiliteit naar de aangedane zijde te vergroten zonder dat daarbij de stap strategie nadelig wordt beïnvloed.

English Abstract

Background: Improvement of postural stability is an important goal during post-stroke rehabilitation. Since weight-bearing asymmetry (WBA) towards the unaffected leg is common, training of weight-bearing symmetry has been a major focus in post-stroke balance rehabilitation. It is assumed that restoration of a more symmetrical weight distribution is associated with improved postural stability. Several studies, however, suggest that a moderate degree of WBA may be used as a compensatory strategy to improve stability. **Objective.** To investigate the effect of WBA on measures of dynamic postural stability in the chronic phase after stroke i.e.: 1) the threshold for compensatory stepping and 2) the choice of the stepping leg after postural perturbations. **Methods.** Eight people in the chronic phase after stroke were exposed to translational balance perturbations in four directions while standing on a moveable platform. The stepping threshold and the choice of the stepping leg were determined in each direction and for three conditions of imposed WBA (symmetric loading, 10%, and 20% extra weight on the unaffected leg). The stepping threshold was defined as the highest perturbation intensity that could be sustained without stepping. **Results.** More WBA tended to increase the stepping threshold for perturbations towards the affected side *(P* = .065), whereas it decreased the stepping threshold towards the unaffected side *(P* = .006). Stepping thresholds for forward and backward perturbations were not influenced by WBA (main effect *P* = .078 and *P* = .595). Increased WBA resulted in an increased likelihood of stepping with the affected leg (20.8% symmetric loading (WBA 0%), 31.3% (WBA 10%), 44.8% (WBA 20%)) however; predominant stepping with the unaffected leg persisted. **Conclusion.** WBA may improve the ability to sustain perturbations towards the affected side. The increased likelihood of stepping with the affected leg may, however, result in a higher fall risk, which was most pronounced when as much as 20% extra body weight was borne on the unaffected leg. Therefore, a moderate WBA after stroke may be regarded

as a useful strategy to improve stability towards the affected side without adversely affecting stepping responses.

Keywords: postural balance, stroke, weight-bearing asymmetry, rehabilitation

Introduction

Stroke is the most important cause of morbidity and long-term disability in Europe. It is therefore a major contributor to the total burden of disease (1). Most patients after stroke experience some degree of functional recovery, however, limitations of mobility and daily activities still remain in the chronic phase (2,3). After stroke postural stability is usually impaired, resulting in reduced mobility and an increased risk of falling with as many as 50% to 70% of the people who return home after rehabilitation experiencing incidents of falls (4). These falls can have severe consequences such as hip fractures and decreased physical activity due to fear of falling (5,6).

Weight-bearing asymmetry

In people after stroke a substantial amount of weight-bearing asymmetry (WBA) in favor of the unaffected leg is commonly observed (7-9). Although asymmetry significantly improves during the first weeks of rehabilitation, some degree of WBA persists (on average 10% more weight being born on the unaffected leg) (10-12). WBA is often regarded as a cause of postural instability. Therefore training of weight-bearing symmetry has been a major focus in post-stroke balance rehabilitation based on motor learning principles (i.e. the Bobath concept and related Neuro-Developmental Treatment (NDT))(13,14). Although WBA is associated with poorer standing balance in cross-sectional studies, it remains unknown whether these two phenomena are causally related (15). The reported associations may have resulted from the dependence of both WBA and postural stability on disease severity (15). Alternatively, WBA after stroke might be regarded as a compensatory strategy for the reduced motor control of the affected leg (16,17). To determine whether a moderate WBA towards the unaffected leg may be beneficial for postural stability, different degrees of WBA should be imposed within the same subjects (15).

Weight-Bearing Asymmetry and the ability to sustain perturbations

Most studies on WBA and postural stability focused on static posturography. In daily life however, we experience countless perturbations in all directions. The capacity to withstand these perturbations is critical to prevent falls (18). Small perturbations can be recovered without stepping (feet-in-place response). For larger perturbations compensatory stepping is necessary to prevent falling (19,20). The largest perturbation that can be sustained without stepping can be defined as the stepping threshold. The stepping threshold is a measure of maximum capacity of feet-in-place responses (21). This threshold can be determined in different directions by applying postural perturbations with a gradually increasing magnitude until the participant needs to make a step (20). The effect of WBA on stepping threshold was assessed during multidirectional stance perturbations on ten young healthy subjects. In these subjects asymmetry in weight bearing increased the stepping threshold (stability improves) towards the unloaded side (unpublished results D. de Kam). In people after stroke, unloading of the affected leg may be an effective strategy to increase the ability to sustain perturbations in that direction.

Whereas weight-bearing asymmetry may be an effective strategy to improve the stepping threshold towards the affected side, it may be unfavourable for perturbations that require compensatory stepping responses. In a cross-sectional study by Mansfield et al. (2012), WBA increased the likelihood of making a compensatory step with the affected leg (21). The impaired motor control of the affected leg probably reduces the ability to make an adequate step in response to a perturbation. Stepping with the affected leg may therefore lead to poorer balance recovery ability, potentially increasing the risk of falls.

To decide whether allowing a moderate WBA might be beneficial for postural stability, more insight in the causal relationship between these two variables is needed. The aim of this pilot study was therefore to investigate the effect of WBA on two measures of dynamic postural stability: 1) the stepping threshold and 2) the choice of stepping leg after postural perturbations in people in the chronic phase after stroke. This effect was determined for different degrees of WBA within the same subjects. We hypothesized that a moderate degree of

WBA would improve the stepping threshold towards the affected side, but it would increase the likelihood of stepping with the affected side.

Methods

A cross-sectional study with a with-in subject design was conducted to investigate the effect of different imposed WBA conditions on postural stability.

Participants

All participants took part in a previous study on postural stability and falls and were familiar with the experimental equipment. Participants of the previous study were recruited from rehabilitation centers in the Netherlands. Inclusion criteria were: 1) Unilateral Supratentorial Stroke > 6 months post stroke according WHO definition (22), 2) 18 years and older, 3) a Mini Mental States Examination score of at least 24 (23) and 4) being able to stand independently (on bare feet) for at least *30* minutes. Participants were excluded if they had any other neurological or musculoskeletal disorder affecting balance or if they used medication that negatively affected balance. The sample size was based on the pilot study on healthy subjects that showed significant effects of WBA on the stepping threshold (unpublished results by D. de Kam).
All participants gave informed consent. Approval was obtained from the Arnhem-Nijmegen medical ethical board.

Demographic and Clinical Measures

Demographic data on age, sex, time after stroke, type of stroke and side of paresis were collected (Table 1). Furthermore a clinimetric assessment was performed in order to quantify disease severity. The Berg Balance Scale (BBS), Functional Ambulation Categories (FAC), Trunk Impairment Scale (TIS) and Brunnstrom-Fugl Meyer scale (BFM) were performed to quantify postural stability, gait capacity, trunk control and motor selectivity of the lower extremity (24-27)
Additionally, participants spontaneous weight distribution was determined from the previous experiment.

Experimental setup

Postural perturbations were delivered by a moveable platform (240 x 174 cm) that could suddenly and unexpectedly translate in each of four directions (forward, backward and both sideways directions), (Baat Medical BV Enschede, the Netherlands), (Figure 1). During the balance assessment, participants stood on the platform barefoot with their arms alongside their trunk. For safety purposes, a rail was mounted around the platform and a safety harness was worn. A brace on the affected ankle was used to prevent distortion. The participants stood with each foot on a separate force plate (AMTI®, Watertown, USA). The vertical ground reaction forces of the force plates were used to provide the participants with online visual feedback about their weight distribution on a screen. Each perturbation consisted of an acceleration phase of 300 milliseconds, followed by a constant velocity period of 500 milliseconds and a subsequent deceleration phase of 300 milliseconds. The magnitude of the acceleration (in m/s^2) represents the perturbation intensity.

Outcome measures of postural stability

The stepping threshold and choice of stepping leg were determined for three conditions of WBA and in four directions. The three weight-bearing conditions that were imposed were symmetric loading (0%) and asymmetric loading (10% and 20% extra weight on the unaffected leg). The order of the WBA conditions was balanced among the subjects. Perturbation direction was varied at random. In this way, participants were not able to preselect their direction specific recovery responses. The participants were instructed to distribute their weight between the two legs according the feedback of the computer screen and to respond to the perturbations without stepping or grabbing the rails. The investigator told them when to expect a perturbation, but the exact timing was unexpected.

The primary outcome measure was the *stepping threshold*, which was defined as the highest perturbation intensity (in m/s^2) at which balance was recovered with a feet in place response (28). The stepping threshold was assessed by gradually increasing the intensity of the perturbation with steps of 0.125 m/s^2. At each intensity three attempts were allowed.

The secondary outcome measure was the *stepping leg* (affected or unaffected) for the three failed trials above the stepping threshold. Two experimenters assessed the stepping leg for each trial. The number of trials that were recovered with a step of the affected leg was reported and could range from 0 (no steps with the affected leg) to 3 (all trials recovered with a step of the affected leg). All trials were captured on videotape and could be checked afterwards in case of disagreement between the experimenters.

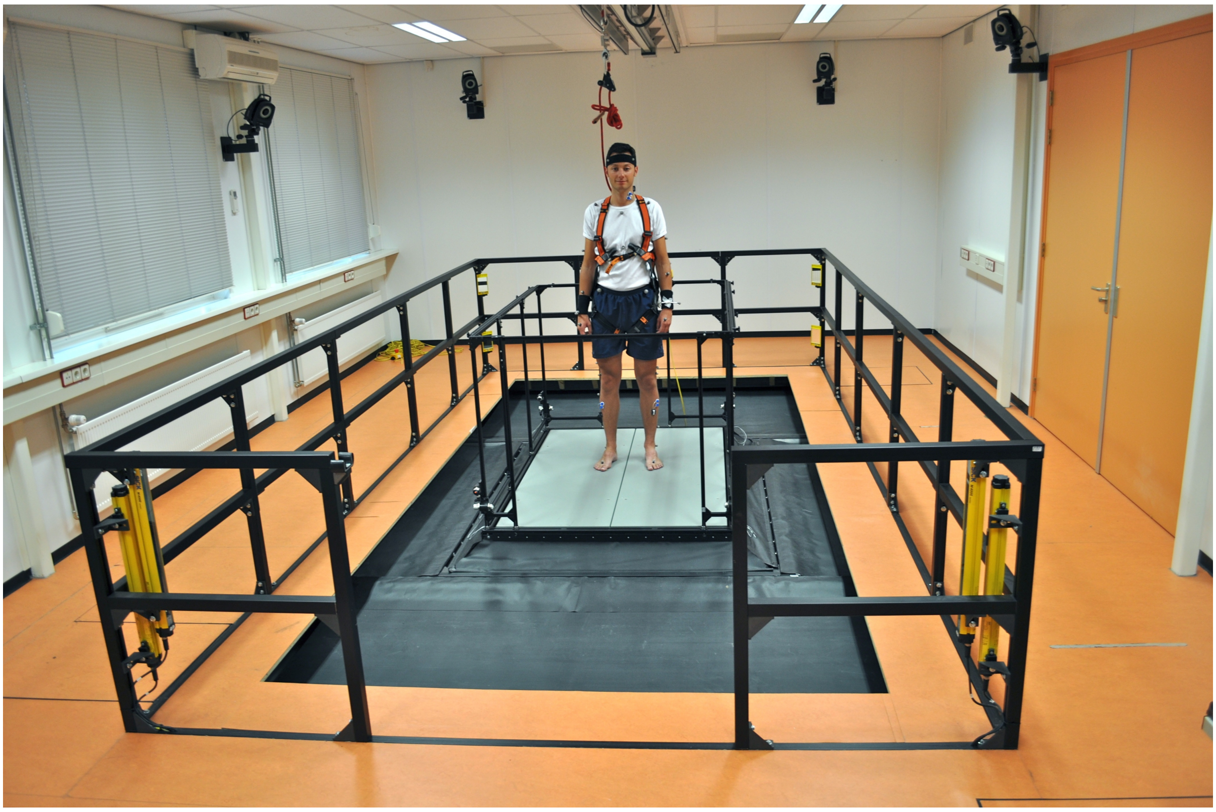

Figure 1. Experimental setup; perturbations were delivered by a moveable platform

Statistical analysis

Descriptive statistics (means and standard deviations) were reported for the baseline and subjects characteristics. To examine the effect of WBA on the stepping threshold, we conducted a general linear model (GLM) for repeated measures with WBA as a within-subjects factor for each perturbation direction separately. To compare choice of step leg among the different WBA conditions a Fisher's Exact test was used for each direction separately. A paired T-test was used to compare stepping thresholds towards the affected and unaffected sides for each condition. All statistical analyses were performed using IBM

SPSS statistics software, versions 21. Significance level of alpha was 0.05 for all tests.

Results

Eight people in the chronic phase after stroke (63.3 ± 7.3 years old, 6.1 ± 5.4 years post stroke) participated in this pilot study. Participant characteristics are shown in Table 1. Reasons for not participating in this study were 1) participating in another study (n=3), 2) no time available to participate (n=14), 3) burden and duration of the study (n=9). On average the eight participants had a spontaneous WBA corresponding with 4.2% extra weight borne on the unaffected leg. Five subjects had a WBA of about 10% extra weight on the unaffected leg whereas three subjects had a symmetric distribution or a slight WBA towards the affected side.

Table 1

Summary of participant characteristics

Participant	Sex	Age	Time since stroke	Type of stroke	Affected hemiside	FAC	BBS	BFM	TIS	Spontaneous weightbearing	SD
1	M	49	29	Ischemic	Left	5	56	28	23	38.0	4.7
2	F	63	52	Ischemic	Left	5	56	29	23	39.8	4.5
3	M	64	46	Ischemic	Right	5	54	23	21	42.6	8.6
4	M	71	94	Ischemic	Right	5	56	24	22	40.2	4.0
5	M	63	136	Ischemic	Left	5	56	29	19	43.9	3.5
6	M	58	8	Hemorrhargic	left	5	55	28	18	54.5	5.2
7	M	72	28	Ischemic	Right	5	56	33	22	53.0	3.3
8	M	66	198	Ischemic	Left	5	56	32	20	54.4	5.9

Time since stroke is expressed in months. Functional Ambulation Categories (FAC) assesses gait independence on a scale from 0 to 5. The Berg Balance Scale (BBS) assesses static and dynamic balance on a scale from 0 to 56. The Brunnstrom-Fugl Meyer scale (BFM) assesses motor selectivity of the lower extremity on a scale from 0 to 34 and the Trunk Impairment Scale (TIS) assesses trunk control on a scale from 0 to 23. Spontaneous weight-bearing and standard deviation (SD) is expressed in percentage weight borne on the affected leg.

Effects of weight-bearing asymmetry on postural stability

I. Effects of weight-bearing asymmetry on the stepping threshold

The effects of WBA on the stepping thresholds of all eight participants for the different conditions are shown in Figure 2 and Table 2. The GLM revealed a significant main effect of WBA on the stepping threshold towards the unaffected side *(P* = .006) with larger WBA (i.e. more weight on the unaffected leg) resulting in reduced stepping thresholds. For the affected side the main effect of WBA was not significant *(P* = .065), but there was a clear tendency of greater WBA (i.e. unloading of the affected leg) resulting in increased stepping thresholds. For forward and backward perturbations no effect of WBA was found on the stepping threshold (main effect *P* = .078 and *P* = .595 respectively) Table 2). For the symmetric loading condition (WBA 0%), there was no significant difference between stepping thresholds to the affected and unaffected side (0.203 m/s^2; *P* = .741). When standing asymmetrically, the stepping threshold is larger for perturbations towards the affected versus the unaffected side (WBA 20%; *P* = .02, WBA 10%; *P* = .041).

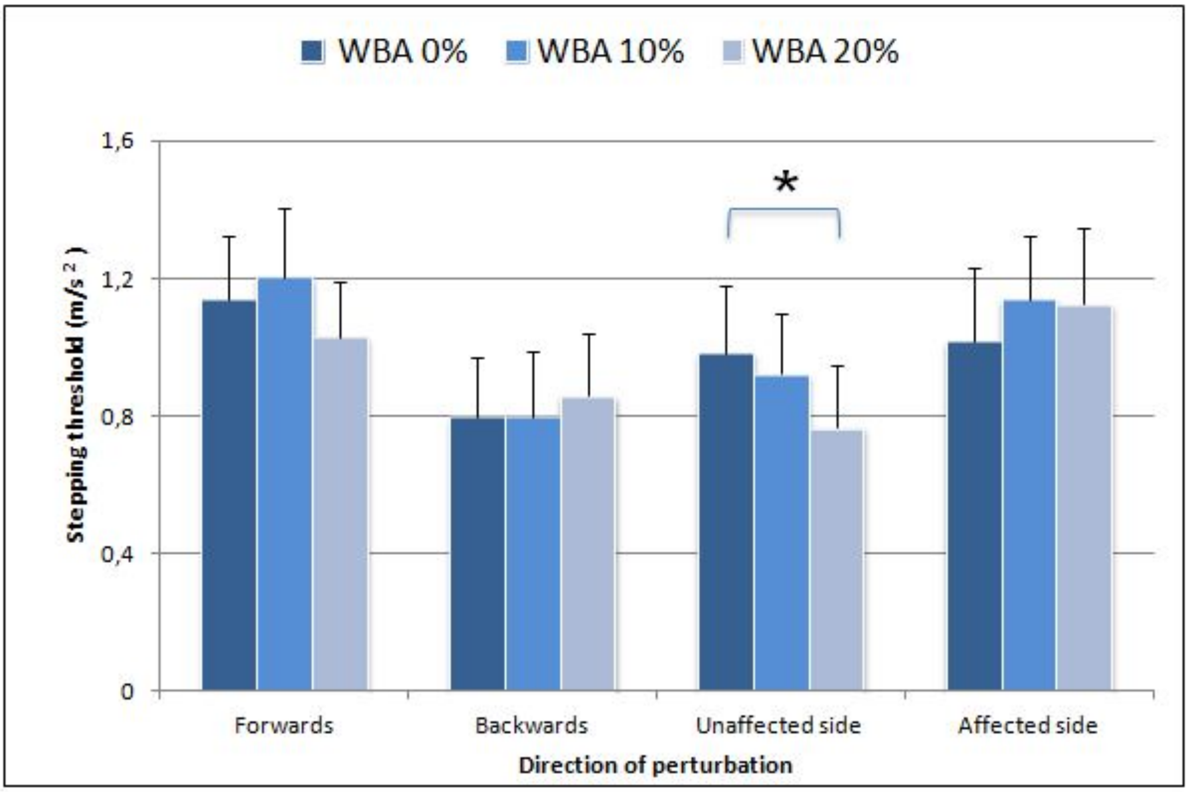

Figure 2. Effects of weight-bearing asymmetry on the stepping threshold (n=8) for three conditions of WBA (symmetric loading (0%) and asymmetric loading (10% and 20% extra weight on the unaffected leg)). Significant effects are marked with an asterisk. (α = .05).

Table 2

Main effects of weight-bearing asymmetry on the stepping threshold

Direction of perturbation	$F_{1,8}$ value	P value
Forwards	3.085	0.078
Backwards	0.538	0.595
Unaffected side	7.378	0.006 *
Affected side	3.353	0.065

Significant effects are marked with an asterisk. ($\alpha = .05$)

II. Effects of weight-bearing asymmetry on the choice of stepping leg

The effects of WBA on the choice of stepping leg are shown in Figure 3. The general trend was that more WBA increased the likelihood of stepping with the affected leg (20.8% symmetric loading (WBA 0%), 31.3% (WBA 10%), 44.8% (WBA 20%). However, predominant stepping with the unaffected leg persisted. This trend was observed in all perturbation directions (Figure 3). The Fisher's Exact test only revealed significant differences between the WBA conditions 0% and 20% for the forward and backward directions ($P = .02$, $P = .018$ respectively). No significant results were found for perturbations towards the affected side ($P = .055$) and for perturbations towards the non-affected side ($P = .27$). Overall participants had a preference for stepping with the unaffected leg (68% of all trials). This preference was most pronounced for perturbations towards the affected side (98.6% of all trials).

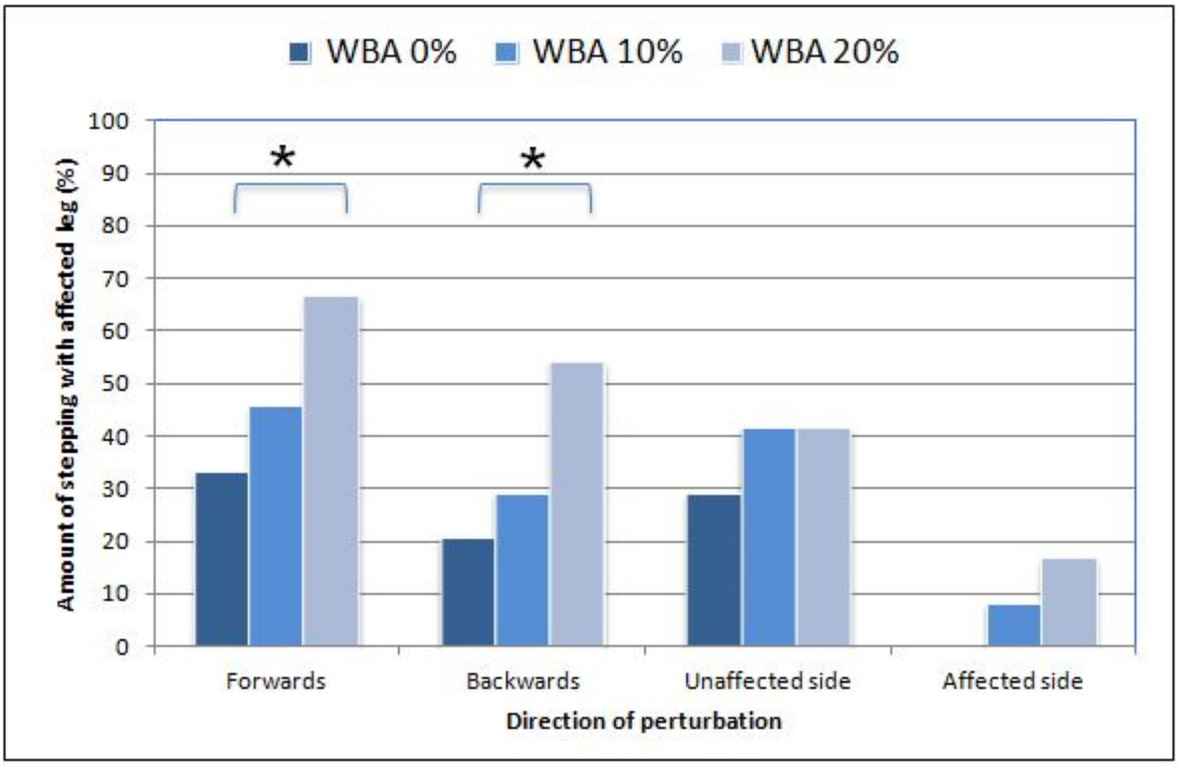

Figure 3. Effects of weight-bearing asymmetry on the choice of stepping leg for three conditions of WBA (symmetric loading (0%) and asymmetric loading (10% and 20% extra weight on the unaffected leg)). The overall percentage of steps with the affected leg for the total of 24 trials is shown for each direction of perturbation separately. Significant effects are marked with an asterisk. ($\alpha = .05$).

Discussion

It was found that WBA tended to improve the stepping threshold for perturbations towards the affected side, whereas the stepping threshold towards the unaffected side was decreased by WBA. However, WBA resulted in an increased likelihood of stepping with the affected leg, which may result in a poorer stepping response. Nevertheless, a preference for stepping with the unaffected leg remained.

I. Weight-Bearing Asymmetry and stepping threshold

In the present study it was found that WBA tends to improve the ability to sustain perturbations towards the affected side. By this mechanism WBA could be regarded as a compensatory mechanism to improve stability towards the affected side. Although several cross-sectional studies reported a negative association between spontaneous WBA and postural stability during quiet stance, these associations could be influenced by the dependence of both WBA and postural stability on disease severity and do not necessarily reflect a causal relationship (15,29,30). In fact some findings in these cross-sectional studies suggest that WBA could be regarded as a compensatory strategy to improve postural stability (15-17). First, it was found that the dynamic contribution of the affected leg to postural control in terms of both amplitude (16,17) and timing (11) of corrective torques was considerably impaired even in patients with good functional recovery. In these patients the contribution of the affected leg to postural control is considerably smaller (10-20%) than its contribution to weight bearing (40-45%) (16), indicating that bearing more weight on the affected leg does not simply improve regulatory activity. Second, the effect of different degrees of imposed WBA on the timing and amplitude of postural reflexes was investigated by Marigold et al. (2004) (31). In contrast to healthy controls, people after stroke showed largely absent load modulation of postural reflexes in the affected leg. These findings suggest that WBA is not the primary cause of the reduced postural stability after stroke.

If WBA would be a compensatory strategy for the reduced stability towards the affected side, one would expect a lower stepping threshold towards that side while standing symmetrically. In contrast we found comparable stepping thresholds for the affected and unaffected sides for the symmetric stance condition. These results may have been driven by the well-recovered patients who preferred a symmetric loading or even more weighting the affected leg. This preference was also observed by Mansfield et al. (2013) (32). Regarding our findings, indeed only 63% of the participants had an asymmetric loading towards the unaffected side when they were allowed to self-select their weight distribution. Therefore stepping thresholds for the affected and unaffected side may be different during symmetric standing when only those participants would be considered. This was also suggested in the study by Pereira et al. (2010) were subgroup differences were found for the individuals bearing more weight on the unaffected leg (33). Yet, further research is needed to confirm this notion.

II. Weight-bearing asymmetry and the choice of stepping leg

WBA resulted in an increased likelihood of stepping with the affected leg. These results were in accordance with the results of a cross-sectional study by Mansfield et al. (2012) who found that WBA was associated with a higher possibility of stepping with the affected leg after forward perturbations (28). In the present study it was found that the effect of WBA on stepping leg was found for the backward direction as well. Although unloading of the affected leg increased the likelihood of stepping with the affected leg, the overall preference for compensatory stepping with the unaffected leg remained. This may indicate that participants are aware of their limited ability to make an adequate step with the affected leg. The ability to make an adequate step in response to perturbations is essential to prevent falling in daily life circumstances and requires sophisticated control of movements (19,34). Effective stepping responses are characterized by extremely rapid onset and movement speed. Also amplitude and trajectory have to be scaled to the degree of instability in order to be effective (18,35-37). Although there is not much evidence on the quality of stepping with the affected versus the unaffected leg, it is likely that steps with the affected leg are less adequate due to sensorimotor impairments and thereby increases the risk of falling.

For perturbations in the frontal plane, participants can choose between either a cross step strategy or a side step strategy. The cross step strategy has been associated with an increased likelihood of falling (36). However, a side step strategy requires quick unloading of the leg that is passively loaded by the perturbation (19,35). Quick push-off forces of the stance limb are needed to allow this quick unloading. In this study, cross stepping with the unaffected leg remained the preferred strategy (98.6%) for perturbations towards the affected side. This predominant cross stepping indicates that the affected leg may have been unable to generate those push-off forces. When recovering from perturbations towards the unaffected side, sidestep strategies with the unaffected leg were most common (~70% of the trials), but WBA tended to increase the likelihood of making a cross step with the affected leg. This is probably associated with a poor balance recovery since 1) the cross step is associated with increased likelihood of falling and 2) stepping with the affected leg is probably less adequate.

Clinical implications

A moderate WBA towards the unaffected side may help to improve the ability to sustain perturbations towards that side. This is important because falls towards the affected side are associated with an increased fracture risk of the affected hip (6,38). Although WBA increases the likelihood of stepping with the affected leg, the effects were most pronounced when as much as 20% extra weight was borne on the unaffected leg. Therefore, this study provides preliminary evidence that allowing a moderate WBA during rehabilitation may improve stability towards the affected side without adversely affecting compensatory stepping.

Limitations

The first limitation of the present study was the limited sample size. It was therefore not possible to assess the influence of important covariates, such as spontaneous weight distribution and disease severity, on the relation between WBA and postural stability. Nevertheless, the results of this pilot study provide an indication that WBA influences both the stepping threshold and the choice of stepping leg.

The instruction to the participant to stand in a certain WBA condition and prevent stepping or grabbing, may influence the choice of stepping leg. However, our findings are in line with the findings of Mansfield et al (2012), where patients were not instructed to prevent stepping (39).

The quality of the stepping responses was not examined in this study. We can therefore not directly conclude that steps with the affected leg are less adequate. However, it is likely that the sensorimotor impairments in this leg result in a poorer quality of the stepping responses (38,40).

Conclusion

Weight-bearing asymmetry tended to improve the capacity to sustain perturbations towards the affected side, which may decrease the risk of falling in that direction. WBA resulted in an increased likelihood of stepping with the affected leg, although this was most pronounced when as much as 20% extra body weight was borne on the unaffected leg. Therefore, a moderate WBA after stroke may be regarded as a useful strategy to improve stability towards the affected side without adversely affecting stepping responses.

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