CHAPTER 5

BALANCE SUPPORT AFTER STROKE

The effect of balance support on the energy cost of walking after stroke

*Ijmker T, Houdijk H, Lamoth CJ, Jarbandhan AV, Rijntjes D, Beek PJ, van der Woude LH.

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ABSTRACT

The objective of this study was to examine the influence of balance support on the energy cost of treadmill and overground walking in ambulatory patients with stroke. Patients with stroke depending on a walking aid in daily life (n=12; walking aid dependent ambulators) and walking aid independent ambulators (n=12), all able to walk for at least 5 minutes participated in this experiment. Energy cost (J·kg⁻¹·m⁻¹) and temporal gait parameters (walking speed, mean and coefficient of variation of stride time, and symmetry index) were obtained during 4 walking trials at preferred walking speed: overground with and without a cane and on a treadmill with and without handrail support. On the treadmill, handrail support resulted in a significant decrease in energy cost of 16%, independent of the group. Although walking aid dependent ambulators had on average a larger reduction in energy cost than walking aid independent ambulators (19% vs. 14%), this interaction did not reach statistical significance (p=.11). Interestingly, overground walking with support resulted in an 8% reduction in energy cost for walking aid dependent ambulators, but a 6% increase for walking aid independent ambulators. The reduction in energy cost with support was accompanied by changes in temporal gait parameters, most notably an increase in stride time and symmetry and a decrease in stride time variability. Balance support can result in a significant reduction in the energy cost of walking in stroke patients, the magnitude of which depends on walking ability and the walking task. Impaired balance control should not be overlooked as a contributing factor to the increased energy cost of walking in patients with stroke, and improving or assisting balance control should be considered to reduce the energy cost of hemiplegic gait.
INTRODUCTION

Stroke is one of the leading causes of death and disability in the western world for people older than 65 years\(^{1,2}\). It can result in various physical and neuropsychological impairments that limit performance of activities of daily living and participation in society. Two major physical problems that often arise in this population are post-stroke fatigue and difficulties with maintaining balance\(^{13}\).

Poststroke fatigue is thought to be a multidimensional concept involving physical as well as neuropsychological factors\(^{13-14}\). Physiologically fatigue can be seen as the consequence of an imbalance between physical capacity, or energy resources, and energy demands\(^{13}\). In patients with stroke physical capacity is often decreased due to deconditioning\(^{15-16}\), while the energy demand of activities of daily life is frequently increased. For instance, patients with stroke often have an energy cost of walking (in J·kg\(^{-1}\)·m\(^{-1}\)) of up to twice the cost of healthy counterparts walking at the same speed\(^{21,117}\).

The nature of this increase in the energy cost of walking is not fully understood. Increased muscle work due to stroke related impairments, such as increased muscle tone and spasticity, and compensatory strategies, such as increased displacement of the center of mass, hip hiking, and circumduction of the paretic leg, have all been related to this increase\(^{1,39,117-118}\). However, in these analyses the potential metabolic effort for maintaining balance and ensuring a stable gait pattern is often overlooked.

Literature has shown that maintaining balance during gait involves a metabolic energy cost even in healthy subjects\(^{47-49}\). Moreover, previous research suggests that balance problems, which are often seen in stroke survivors, can result in an increased metabolic effort for balance maintenance. It has been shown that balance perturbations during upright standing, for instance standing on foam, lead to an increase in energy expenditure which is up to twice as high for patients with stroke than for healthy controls\(^{52}\). If perturbing balance in patients with stroke elicits an extra metabolic demand, supporting balance, by contrast, could lead to a decrease in energy cost. This should especially be true for stroke survivors with more residual deficits affecting balance control, such as those relying on a walking aid, and for more challenging walking conditions.
Therefore, the purpose of this study was to investigate the effect of balance support on the energy cost of walking in walking aid independent and walking aid dependent ambulatory patients with stroke, and whether this effect was similar for treadmill and overground walking. We hypothesized that providing support would decrease the energy cost of walking in patients with stroke, and that this decrease would be larger for patients depending on a walking aid in daily life than for independent ambulators. For patients with stroke the energy cost of walking is generally higher on the treadmill than overground\textsuperscript{22}, and treadmill walking is claimed to be more challenging to balance control for these patients due to altered visual and proprioceptive input, the moving support surface, and the constant beltspeed. We thus hypothesized that for patients with stroke the effect of support would be larger on the treadmill than overground.

**METHODS**

**Participants**

Subjects were recruited from the stroke unit at the rehabilitation center Heliomare (Wijk aan Zee, the Netherlands). From the total number of stroke patients admitted to the rehabilitation center during the time of the measurements (n=88 over 2.5 months), twenty-four patients (age 52±15.9 years; 14 men; 10 women) who fulfilled the inclusion criteria and were available for measurements, agreed to participate. All patients were able to walk for at least 3 minutes without, and 5 minutes with support of an assistive device overground and on a treadmill, and achieved a score of 4 or higher on the Functional Ambulatory Category (FAC)\textsuperscript{119}. Prior to the experiment, all subjects had walked on the treadmill at least once during regular physical therapy sessions. Exclusion criteria were vestibular disease, cardiovascular or pulmonary comorbidities contra-indicating moderate exercise, visual impairments, cognitive and communicative disorders that could interfere with the protocol, and medication use and/or non-stroke related sensory/motor impairments that could interfere with balance control.

Subjects were classified as either dependent or independent ambulators based on their dependence on walking aids in daily life. Of the 24 subjects, 12 subjects used a
walking aid in daily life (dependent ambulators), whereas the other 12 did not (independent ambulators). Based on previous studies on the energy cost for balance control we estimated the effect size in this group to be $0.4^{47,54}$. With this effect size, an alpha of .05 and a beta power of .8, 12 subjects per group were deemed appropriate to detect statistically significant differences in energy cost between groups and conditions. Balance and walking ability were characterized by the FAC score, Berg Balance Score $1^{20}$ (BBS) and score on a 10 meter timed walk test (TMWT)$^{121}$. The scores were obtained from a standard clinical assessment by a physical therapist, no longer than 1 month prior to participation. Descriptive characteristics did not differ significantly between the groups except for walking speed on the TMWT and BBS, with lower scores for dependent ambulators (Table 4).

Prior to giving their written informed consent, all participants were fully informed about the content and purpose of the study. This study was approved by the local medical ethics committee.

Table 4: Descriptive characteristics of study population

<table>
<thead>
<tr>
<th></th>
<th>All</th>
<th>Independent</th>
<th>Dependent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>51.8 (15.9)</td>
<td>46.9 (17.3)</td>
<td>57.1 (13.0)</td>
</tr>
<tr>
<td>Gender (male/female)</td>
<td>15/9</td>
<td>8/4</td>
<td>7/5</td>
</tr>
<tr>
<td>Time since stroke onset (days)</td>
<td>79.0 (50.4)</td>
<td>64.8 (48.4)</td>
<td>94.5 (48.4)</td>
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<tr>
<td>BMI$^a$</td>
<td>25.5 (3.0)</td>
<td>26.8 (2.6)</td>
<td>24.1 (2.9)</td>
</tr>
<tr>
<td>FAC (score 4/5)</td>
<td>6/17</td>
<td>2/10</td>
<td>4/7</td>
</tr>
<tr>
<td>BBS</td>
<td>52.5 (4.5)</td>
<td>54.9 (1.3)</td>
<td>49.9 (5.5)*</td>
</tr>
<tr>
<td>TMWT (km·h$^{-1}$)</td>
<td>3.5 (1.3)</td>
<td>4.3 (1.1)</td>
<td>2.7 (1.0)*</td>
</tr>
</tbody>
</table>

Values are mean (±SD) except for FAC (number of subjects with score 4/ number of subjects with score 5); * indicates significant difference from independent group (p<.05); $^a$=Body Mass Index;

Experimental protocol

The experiment consisted of two support conditions (with and without support), which were performed overground and on a treadmill (task conditions), resulting in four walking trials which all lasted 5 minutes. Trials were separated by a resting period of approximately 5 minutes. Subjects were randomly assigned to start on the treadmill or overground, and supported and unsupported trials were then performed
in random sequence. Prior to the walking trials resting metabolism was measured in a seated position for 5 minutes, after a 10 minute resting period.

Support was provided by a standard height-adjustable cane on the non-paretic side during overground walking, and by handrail support on the non-paretic side during treadmill walking. For some patients treadmill walking without support for five minutes can be very challenging; therefore balance support was allowed if necessary during the first 2 minutes of the unsupported treadmill trial. The last 3 minutes were performed without support to ensure steady state oxygen consumption during the final 2 minutes of the trial from which energy consumption was calculated. To avoid excessive weightbearing on the handrail and cane, subjects were given the instruction to use the support to maintain balance without leaning on it. Post-hoc analysis on force platform data from the instrumented treadmill revealed that weightbearing on the handrail was on average no more than 5% of the subject’s body weight.

All walking trials were performed at preferred speed. Prior to the first treadmill trial, preferred walking speed with and without support was determined by having subjects walk on the treadmill at a low beltspeed (0.4 km·h⁻¹), and increasing beltspeed gradually with 0.2 km·h⁻¹ every 10 seconds until the subject subjectively identified his/her preferred walking speed. This speed was maintained for approximately 30 seconds after which the subjects were asked to re-evaluate; if necessary beltspeed was adjusted. This was repeated until the subjects preferred walking speed was established. This process concurrently served as a habituation period for treadmill walking. If necessary this habituation period was extended until the subject reported feeling comfortable walking on the treadmill. During overground trials subjects walked at a comfortable speed back and forth on a 20m indoor path set between two cones. During each lap, the duration to walk the middle 10 meters of the path was timed with a stopwatch. During turns, subjects were supported at the waist by one of the investigators to minimize the possible additional metabolic cost of turning.
**Instrumentation**

Breath by breath oxygen consumption was obtained from a pulmonary gas exchange system. Oxygen consumption data from the final two minutes of each trial were analysed to ensure steady state energy expenditure. During all walking trials trunk accelerations were measured using a tri-axial ambulant accelerometer fixed with an elastic belt near the level of the third lumbar spine segment (sampling frequency 100Hz). Treadmill trials were executed on an instrumented treadmill equipped with a forceplate (1.5 by 1m, sampling frequency 300 Hz) from which vertical ground reaction force was derived to calculate weightbearing on the handrail.

**Data-analysis**

Steady state energy expenditure (J·kg⁻¹·min⁻¹) was calculated from oxygen uptake ($\dot{V}O_2$, ml·kg⁻¹·min⁻¹) and respiratory exchange ratio (RER) obtained during the final two minutes of each trial. Gross metabolic energy expenditure ($E_{gross}$) was calculated using:

$$E_{gross} = (4.960 \cdot RER + 16.040) \cdot \dot{V}O_2.$$  

Net energy expenditure was calculated by subtracting resting metabolism from $E_{gross}$. Net metabolic cost (J·kg⁻¹·m⁻¹) was obtained by normalizing for body weight and walking speed. Oxygen data for one subject (dependent ambulator) did not show prolonged periods of steady state oxygen consumption, therefore this subject was removed from all analyses.

Walking speed was determined from the beltspeed during treadmill walking, and for overground walking from the average time to walk the middle 10 meters of the path over all laps walked during the final 2 minutes of a trial.

The accelerometer data were used to calculate the following gait parameters: mean and variability of stride time, and symmetry index (SI). The accelerometer data were first low-pass filtered with a third order zero-lag Butterworth filter with a cut-off frequency of 20 Hz. Subsequently moments of foot contact were determined from anterior-posterior trunk accelerations based on the method by Zijlstra et al. These moments of foot contact were used to calculate step time. Outliers in the step time data during overground trials caused by turning were removed from the data using a
median filter which removed data points more than 3 SD’s away from the median. Step time was quantified as the time interval (in seconds) between foot contact of the contralateral limb and the next foot contact of the ipsilateral limb. Stride time was calculated by adding left and right consecutive step times. Variability of stride times was quantified by the coefficient of variation (CV) of the stride times of individual participants within a trial. SI was calculated as the ratio between the shorter and longer step time, with perfect symmetry resulting in an SI of 1.0 and smaller values corresponding to larger asymmetry.

Statistical Analysis

Level of significance for all statistical analyses was set at $p<0.05$. Data were tested for normality using the Kolmogorov-Smirnov and Shapiro-Wilk tests which revealed that the majority of the outcome measures were not normally distributed. Therefore non-parametric tests were used.

Main effects of support condition (unsupported vs. supported) and task condition (overground vs. treadmill) were tested using the Wilcoxon signed rank test. Main group effects (independent vs. dependent) were investigated using the Mann-Whitney test. Group × Support condition interaction was tested using the Mann-Whitney test on difference scores (unsupported–supported) between groups. Task condition × Support condition interaction was investigated using a Wilcoxon signed rank test on difference scores (unsupported–supported) for overground and treadmill walking.

RESULTS

Effect of support on the treadmill

A significant main effect of support on energy cost was found for treadmill walking. Supported walking resulted in a significant decrease in energy cost of 16.2% ($0.99 \text{ J} \cdot \text{kg}^{-1} \cdot \text{m}^{-1}$) on average ($p<.001$). Although the reduction in energy cost with support was on average larger for dependent (19%) than independent ambulators (14%), no significant Group × Support condition interaction effect was found ($p=.107$). A significant main effect of group showed that independent of support condition,
dependent ambulators had a significantly higher energy cost of walking than independent ambulators \((p < .01; \text{Figure 18; Table 5}).\)

![Figure 18: Effect of support on energy cost for the independent and dependent ambulators separately for treadmill (A) and overground walking (B). Error-bars represent standard deviations.](image)

The effect of support on gait parameters for treadmill walking are shown in Figure 19A-D and Table 5. No significant main effect of support was found for walking speed, but results did show a significant Group × Support condition interaction \((p < .05)\). Further analysis showed that for independent ambulators walking speed did not change due to support, whereas dependent ambulators showed a trend towards an increased speed with support \((p = .058)\). A significant main effect of support for mean stride time showed that during walking with support stride time increased significantly \((p < .01)\). No significant effect of support on CV of stride time was found. A significant Group × Support condition interaction on step time symmetry was found \((p < .05)\); further analysis showed that step time symmetry improved (became more symmetrical) for dependent ambulators only \((p < .05)\).
Figure 19: Effect of support on gait parameters during treadmill walking for independent and dependent ambulators separately. Error-bars represent standard deviations.

Effect of support overground

No significant main effect of support condition was found for overground walking. A main effect of group revealed that dependent of support condition, dependent ambulators had a significantly higher energy cost than independent ambulators \( (p<.01, \text{Figure 18B}; \text{Table 5}) \). Furthermore, a significant Group × Support condition interaction was found \( (p<.05) \); dependent ambulators showed a significant decrease in energy cost due to support \( (8.4\%, p<.05) \), whereas independent ambulators showed a significant increase in energy cost due to support \( (6.1\%, p<.05) \).

The effect of support on gait parameters for overground walking are shown Figure 20A-D and Table 5. Similar to treadmill walking no significant main effect of support was found for walking speed, but a significant Group × Support condition interaction for speed \( (p<.05) \) revealed that independent ambulators decreased their walking speed significantly with support \( (p<.05) \), whereas no change in speed was found for dependent ambulators. Stride time increased significantly during supported walking \( (p<.01) \). No significant main effect of support on CV of stride time was found, but a significant Group × Support condition interaction effect on CV of stride time showed that supported walking resulted in a significantly reduced CV of stride time for
dependent ambulators only \( (p<.01) \). No significant effect on step time symmetry was found.

![Bar charts showing effects of support on gait parameters during overground walking for independent and dependent ambulators separately. Error-bars represent standard deviations.]

**Figure 20:** Effect of support on gait parameters during overground walking for independent and dependent ambulators separately. Error-bars represent standard deviations.

*Treadmill vs. overground walking*

Treadmill walking resulted in a significantly higher energy cost than overground walking both with (15\%) and without (38\%) support \( (p<.01) \). Furthermore the effect of support on energy cost was significantly larger on the treadmill than during overground walking \( (p<.05) \).

Regarding gait parameters, walking speed was significantly lower on the treadmill compared to overground \( (p<.01) \). No significant Support condition × Task condition interaction was found for any of the gait parameters.
In this study we hypothesized that walking with support would decrease the metabolic effort to maintain balance and would therefore decrease the energy cost of walking. Moreover we expected that this effect would be stronger in dependent ambulators than in independent ambulators, and higher for treadmill walking compared to for overground walking. Support significantly reduced the energy cost of walking on the treadmill, with a reduction in energy cost of 16% on average, corresponding to a decrease of 0.99 J·kg⁻¹·m⁻¹. For overground walking the effect of support was smaller and significant only for dependent ambulators (8.4%). These results demonstrate that providing support can result in a substantial and clinically relevant reduction of the energy cost of walking in patients with stroke.

The effect of support appears to be mediated by the individual’s walking ability; dependent ambulators showed a higher energy cost of walking in general, and a larger effect of support than independent ambulators. In addition, the effect of support appears to be mediated by the walking task. We expected larger effects of support on the treadmill, since we assumed treadmill walking to be more challenging for balance control. Indeed, energy cost was higher, and the reduction in cost due to...
support was considerably larger on the treadmill than overground. During overground walking independent ambulators even experienced a disadvantage of support. However, this difference in effect of support on the treadmill and overground might also be affected by the type of support on the treadmill (handrail) and overground (cane). While cane-assisted walking can provide a biomechanical and somatosensory advantage for balance control, it also represents a dual task and may lead to an increase in energy cost due to handling and carrying the cane. In healthy subjects an increase in cost of 30% in cane-assisted walking has been reported. Similarly, these metabolic demands of cane-assisted walking would be encountered by patients with stroke, negating positive effects of cane support due to facilitation of balance control. Nonetheless, the extra metabolic cost of cane-assisted walking in independent ambulators (6.1%), who were less accustomed to using a cane and showed a more normal gait pattern, was far less than what has been reported for healthy subjects. Moreover, dependent ambulators even showed a reduction in energy cost with support, implying that the benefit of facilitating balance control outweighs disadvantages of cane-assisted walking in this group.

Although many factors could influence energy cost, the manipulation that was used in this study was aimed to primarily alter balance control. Furthermore, the reduction in energy cost with support was accompanied by changes in temporal gait parameters, most notably an increase in stride time, a decrease in stride time variability and an increase in gait symmetry. Previous studies have found that people reduce stride time when gait stability is challenged. Also, lower stride time variability and improved symmetry is often seen as an indicator of a more stable gait pattern. Together these changes can be regarded as evidence that providing support during walking as imposed in this study indeed facilitates balance control, thereby reducing the strain on the balance control system and reducing metabolic cost. Note, however, that providing support does not necessarily reduce the energy cost to normal values (especially not in the dependent ambulators). With balance support the energy cost of walking in stroke patients might still be higher compared to able-bodied subjects, due to other stroke-related problems, such as impairments in leg swing and propulsion.
The mechanisms underlying the energetic requirement of balance control are currently not well understood, but might be related to the selection of energetically less optimal gait parameters such as step frequency or walking speed, or increased muscle co-contraction, to improve stability despite a penalty on energetic cost. In addition, part of the changes in energy cost when walking with support could be related to changes in walking speed, as energy cost is known to depend on walking speed by a U-shaped function. For instance, on the treadmill dependent ambulators showed a trend towards a small increase in speed accompanied by a reduction in energy cost with support. Possibly, walking with support enables these patients to walk at an energetically more optimal walking speed. In future studies, a more elaborate investigation of gait parameters related to gait stability might shed more light on the underlying changes related to the decrease in energy cost due to support.

Study limitations

It can be questioned whether treadmill walking, as used in this study to demonstrate the effect of support in a challenging situation, is relevant in the context of daily functioning. However, the same could be said for the overground walking task in a perturbation free environment, which can be seen as a simplification of real life walking in which perturbations continuously occur. While both conditions can thus be considered somewhat artificial, they do provide an indication of the magnitude of the effect of support that could occur in daily life.

Another limitation of the current study is the relatively young age, and good ambulatory ability of the study population, even in the group of dependent ambulators, due to the inclusion criteria necessary to be able to complete the protocol (FAC>3 and able to walk without support on a treadmill). Therefore this study may actually underestimate the effect of support in patients with more limited ambulatory capacity.

And lastly, the group sizes in this study were relatively small (n=12 for both groups), especially given the large variation in individual impairments in patients with stroke, which may have reduced the statistical power of this study. However, despite the small sample sizes and the heterogenous population we were able to
detect statistically significant results, suggesting that the obtained results reflect
more generic principles regarding the metabolic effort for balance control.

CONCLUSIONS

In conclusion, balance support can result in a significantly reduced energy cost of
walking in patients with stroke, providing further evidence for the notion that
balance control exacts a metabolic demand during walking, particularly in balance
impaired populations. The effect of balance support on the energy cost of walking is
dependent on both ambulatory capacity and the walking task itself, with larger
reductions for subjects depending on a walking aid in daily life and during
challenging tasks, such as walking on a treadmill. Based on these results it can be
argued that, besides other stroke related problems, the increased cost of walking in
patients with stroke partly originates from an increased metabolic effort for balance
control. Improving or assisting balance control during rehabilitation could lead to a
decreased metabolic effort for balance control and a reduced cost of walking in
patients with stroke.