REVIEW

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The Potential of Split-Belt Treadmill Walking as a Therapeutic Tool in Parkinson's Disease: a Narrative Review

Das Potenzial des Split-Belt Treadmill Walking als therapeutisches Mittel bei Morbus Parkinson: eine Übersichtsarbeit

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Summary

- **Exercise** has become increasingly relevant in the treatment of people with Parkinson's Disease (PD), especially for gait and balance impairments where pharmacological and surgical therapy does not fully alleviate symptoms. Split-belt treadmill (SBT) is a tool which can introduce artificial asymmetry and motor switches through belts running at different velocities and has been used to study motor control or as exercise intervention. This narrative review summarizes the current literature of SBT as a therapeutic tool for people with PD.
- **Studies have shown** that walking on an SBT is safe and feasible for people with PD and results suggest that training should best be carried out under antiparkinsonian medication. Compared to healthy adults, people with PD adapt their gait in a similar manner during and after SBT walking, but effects are smaller. One session of SBT training improved gait adaptation as well as gait during dual tasking, with results being partially retained for 24 hours. With regard to endurance, tendencies are visible that SBT training has generic health benefits similiar to aerobic exercise.
- **Further studies** are ongoing investigating long term training interventions of SBT in people with PD, including the study of retention effects. However, the clinical relevance of the above-mentioned benefits remains unclear. Finally, the aerobic benefit of the training and the potential for alleviation of fall risk in the PD population need to be investigated.

Zusammenfassung

- **Bewegung und Sport** sind ein wichtiger Bestandteil der symptombezogenen Therapie von Personen mit M. Parkinson , vor allem in Bezug auf Gang- und Gleichgewichtsstörungen, welche häufig nicht vollständig durch medikamentöse oder invasive Verfahren gelindert werden können. Bei einem Split-Belt-Laufband können die zwei Bandseiten mit unterschiedlicher Geschwindigkeit gesteuert werden und somit eine künstliche Asymmetrie und einen Wechsel zwischen motorischen Programmen provozieren. Ziel dieses narrativen Reviews ist es, die bisherigen Erkenntnisse bezüglich der Anwendung von Split-Belt-Laufband bei Personen mit M. Parkinson zusammenzufassen.
- **Unter Beachtung** notwendiger Sicherheitsvorkehrungen ist das Gehen auf dem Split-Belt-Laufband für Personen mit M. Parkinson sicher durchführbar. Bisherige Studien haben gezeigt, dass Personen mit M. Parkinson ihr Gangbild währenddessen und danach nach ähnlichen Mustern, aber geringfügiger anpassen im Vergleich zu gesunden Älteren. Eine einzelne Trainingseinheit auf dem Split-Belt-Laufband verbesserte die Gangadaptation sowie das Gangbild bei gleichzeitiger kognitiver Aufgabe und die Effekte hielten zum Teil bis 24h an. Hinsichtlich Ausdauer sind Tendenzen sichtbar, dass Split-Belt-Laufbandtraining ähnlich positive Effekte wie aerobe Ausdauertrainingsformen aufweist.
- **Die Effekte** von längerfristigem Split-Belt-Laufbandtraining werden derzeit in einer aktuellen Studie erforscht. Die klinische Relevanz der beschriebenen vielversprechenden Ergebnisse muss zukünftig erforscht werden. Des Weiteren sollten die Effekte auf die Ausdauerfähigkeit sowie ein potenzieller Einfluss auf das Sturzrisiko bei Personen mit M. Parkinson in zukünftigen Studien adressiert werden.

KEY WORDS:
Rehabilitation, Gait Disorder, Neurological Disease, Exercise Therapy

SCHLÜSSELWÖRTER:
Rehabilitation, Gangstörung, neurologische Erkrankung, Bewegungstherapie

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Introduction

Parkinson's Disease (PD) is a neurodegenerative disorder, which is associated with a loss of dopamine in various parts of the brain, resulting in motor and non-motor symptoms (13, 19). Motor symptoms include tremor, rigor, bradykinesia as well as gait and balance impairments (20). The domains of gait that are compromised in people with PD include pace, rhythmicity and asymmetry (15) and present through reduced gait speed and step length (32), increased gait variability (1) as well as gait asymmetry (1, 36). The mentioned impairments can be summarized as continuous gait impairments. On top of that a subgroup of people with PD experiences Freezing of Gait (FOG), which is an episodic gait impairment, characterized by the brief inability to generate effective

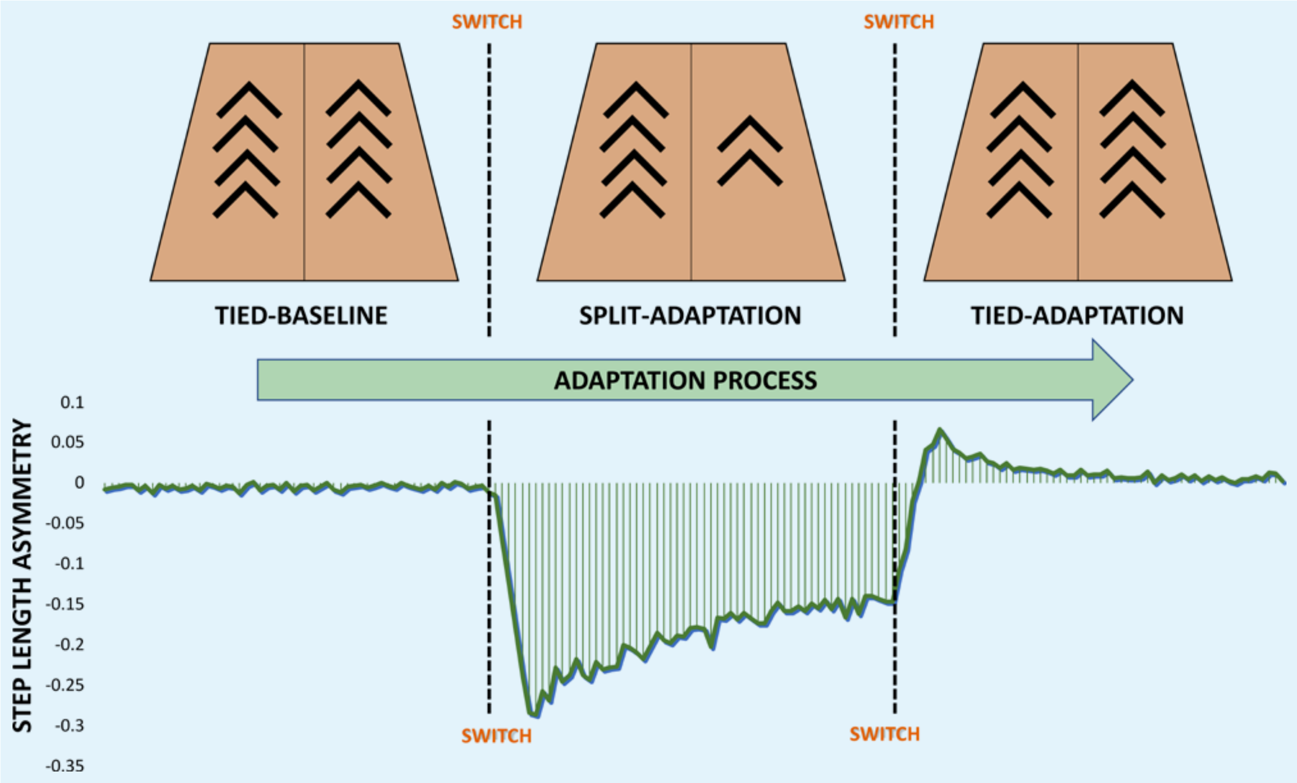

Figure 1

Phases of an exemplary SBT protocol and schematic visualization of how step length asymmetry adapts during each phase. Tied-baseline: both belts at equal speed, normal gait; split-adaptation: belts run at different speeds, gait needs to be adapted in response to the imposed asymmetry; tied-adaptation: belts return to equal speed, aftereffects present initially after the switch and diminish later on when gait returns to baseline state.

stepping (11). Some continuous gait impairments are additionally more affected in people with PD and FOG (PD+FOG), such as gait asymmetry or variability (18).

Symptoms of Parkinson's disease are usually treated with antiparkinsonian medication, via surgical treatment such as Deep Brain Stimulation (DBS) or with exercise. As some gait and balance problems are only partially responsive to medication or DBS (4, 9, 27), exercise has gained importance to alleviate these symptoms. Exercise therapy has been studied more extensively in the past decades, as it provides a cost-efficient alternative to standard therapy with additional health benefits. Physiotherapy was shown to have benefits for people with PD (33) as well as home-based aerobic exercise training (34) which attenuated off-state motor signs. Furthermore, treadmill training has been studied more extensively and was found to have positive effects with clinically relevant changes in gait speed in people with PD (14). There is also some preliminary evidence that high intensity treadmill training might have a positive effect on motor symptoms in people with recently diagnosed PD (26). An alternative form of treadmill training which has been the focus of multiple investigations in various neurological populations (e.g. PD, stroke, cerebral palsy) is the split-belt treadmill (SBT). It has two individual belts which can run at different speeds thereby inducing an artificial asymmetric motor pattern as well as motor switches. SBT has been used to study human motor control and motor learning as well as a therapeutic tool in neurological disease where asymmetry plays a role such as stroke (22). It offers a large number of settings as you can choose between different contrasts, which side to apply it to and how long to apply it. To date there is hardly any research on how the brain controls this unusual gait situation and especially on how this neural control differs e.g. in people with PD. Hinton and colleagues provided some data on brain activation during SBT walking in young adults using positron emission tomography (12). They showed that several brain areas (e.g. supplementary motor area and cerebellum) are more active during SBT walking compared to normal treadmill walking and propose that those areas are part of a "fine-tuning network".

SBT therapy is not yet established in the rehabilitation of people with PD. This is due to the lack of long-term studies looking into the benefits of this method. This narrative review will first give an introduction of SBT paradigms and explain the potential of the method based on the mechanisms that play a role in the PD population. Subsequently, the existing findings on SBT walking in people with PD regarding safety and feasibility, adaptation during SBT walking and training effects will be summarized. Finally, future prospects for this field will be proposed.

SBT Paradigms and Relevance for People with PD

Usually, an SBT protocol starts with a period where both belts run at the same speed (tied-baseline). When one belt is decelerated or accelerated the split-adaptation starts, where gait needs to be adapted (split-adaptation). Finally, when belts return to the same speed aftereffects can be seen right after the switch and following a washout period, gait returns back to its initial state (tied-adaptation). This common procedure is visualized in figure 1. Depending on the aim of training the SBT protocol can focus more on asymmetry or more on adaptation, ›

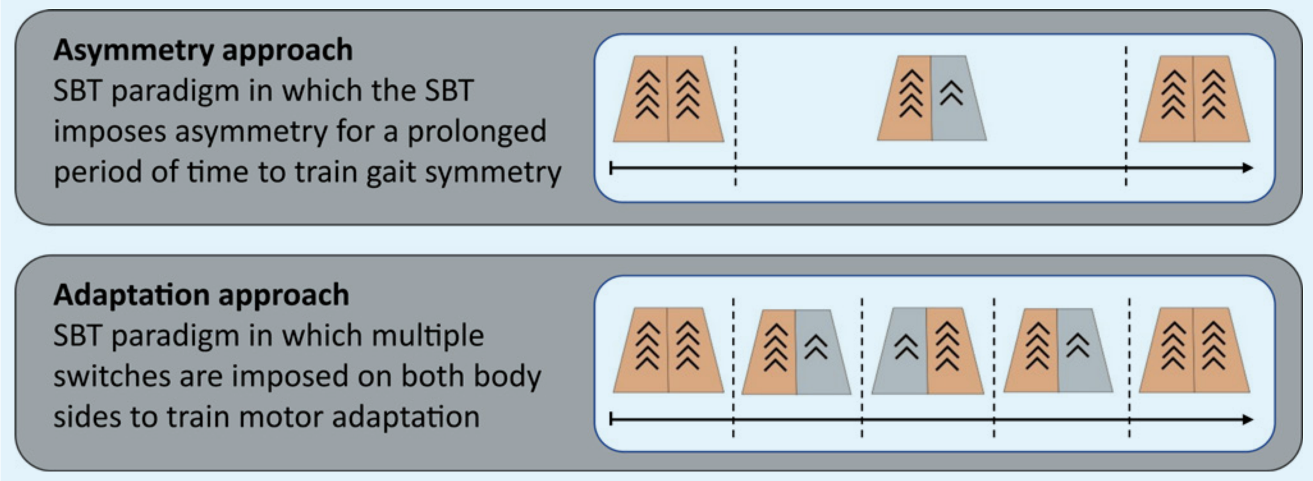

Figure 2

Different approaches for the application of SBT.

although both components always play a role (see figure 2).

Designing a protocol with a prolonged period with different belt speeds and a fixed side which is decelerated or accelerated, will shift the focus mainly on asymmetry. Asymmetric gait has been observed in people with PD previously (36), especially in the subgroup with FOG (18). This is of great relevance as gait asymmetry is in some way related to FOG, although the specific cause-effect-relationship is still unknown. The SBT can create an artificial asymmetry. By running the two belts at different speeds, gait becomes more asymmetric initially and reduces again throughout the SBT bout. This asymmetry is transferred to the tied condition as in aftereffects. In people post-stroke SBT was previously successfully used to reduce their inherent gait asymmetry (21).

In contrast implementing more switches and also applying the asymmetry to both sides is a way of putting the focus on challenging the adaptation. People with PD can have difficulty with adapting their gait to new or changing conditions (7, 16). In individuals with FOG this is further aggravated (16, 31). As SBT training imposes switches of belt speed it gives an opportunity to train adaptation, which could be beneficial in everyday situations, when the gait pattern needs to be altered to accommodate a novel or changing situation.

Safety and Feasibility of SBT Walking in People with PD

Several studies have investigated SBT walking in people with PD and indicated that this tool can be safely and feasibly used in this population (2, 5, 7, 8, 16, 17, 23, 24, 29). None of these studies reported adverse events or injuries, however only 2 studies explicitly stated this in their results (5, 29). To ensure the safe conduction of a training or test protocol on the SBT with people with PD, certain requirements and circumstances need to be provided. Generally, it is recommended that testing and training is conducted in a well-medicated state. This is mainly because medication intake usually improves overall motor function and therefore reduces the risk of falls. Additionally, some evidence has been provided that aftereffects were better retained when participants were ON-medication (23). Another important precaution to prevent injuries is the use of a safety harness, which catches the participant in case of falling or tripping. This was used in the majority of studies (2, 5, 16, 17, 23, 29). Handrails can also increase safety and help people with PD when walking on the SBT for the first time. However, it has been shown that the use of handrails impacts gait performance (3). It has to be noted, that most studies using SBT in the PD population applied deceleration on one belt in contrast to acceleration to further increase safety. The use of SBT is also safe for the subgroup with PD+FOG. There have been reports about some individuals that experienced festination or FOG when the belts changed to the split-condition (16, 29) but this did not result in any adverse events as safety precautions were effective. Hence there are no concerns to conduct SBT walking with people with PD+FOG as long as they can tolerate the different belt speeds.

Adaptation of Gait Characteristics during SBT Walking

The first study that investigated SBT walking in people with PD had its main focus on the muscle activation (7). It was found that already during tied-baseline and split-adaptation people with PD had reduced gastrocnemius activation and increased co-activation of antagonistic muscles compared to healthy controls. According to the authors the increased co-activation is most likely a strategy to maintain gait stability, which suggests that SBT walking is challenging for people with PD. Furthermore, during the split-adaptation the amplitude and modulation of the leg extensor was reduced. This finding is in line with the restricted stride range, which was found as well.

The adaptation of spatial and temporal gait parameters has been investigated in multiple studies in people with PD. Mostly researchers have used asymmetry variables to quantify the adaptation process (2, 8, 16, 17, 23, 24, 29), but also variability (8, 17) and bilateral coordination of gait (17) have been used. Regarding spatial gait parameters step length asymmetry has been most often investigated. Studies have shown that people with PD adapt step length asymmetry in a similar manner compared to healthy subjects, however they often present a higher amount of initial asymmetry and the magnitude of adaptation is smaller compared to healthy elderly (29). Asymmetry increases right after the switch to the split-adaptation and then reduces during that adaptation process, approximating symmetry (23, 24). After switching to the tied-adaptation usually asymmetry increases in the other direction before reaching symmetry again, which is an aftereffect (see Figure 1). Gait variability and gait coordination adapt equally in people with PD compared to healthy elderly (29). When taking a closer look into the subgroup of people with PD+FOG, there is evidence that their adaptation is different from those individuals without FOG. They adapt slower and their adaptation performance is also linked to the symptom severity (8, 16). This deficit is proposed to be related to connectivity alterations in the cerebellum (17), which have been observed in people with PD+FOG previously (10, 35), however other contributors cannot be ruled out.

Effects of SBT Training on Gait and Cognition

The majority of studies have looked into the adaptation process happening during short SBT walking bouts in people with PD. Only few studies exist having investigated the effects of a prolonged SBT walking bout. Our group examined the effects of a single training session (total of 30 min) including 3 different SBT trainings compared to regular treadmill walking on a gait adaptation task (29). First, there was an overall benefit of SBT training vs. regular treadmill training for the performance in the adaptation task in step length asymmetry (29). Second, we found that imposing a larger amount of switches of belt speed differences led to the best adaptation, as this group showed the largest effect size from Pre to Post (Cohen's d=1.14) (29). Furthermore, improvements were retained 24 hours after the training session (29). In this study the outcome of interest was closely related to the design of the training. However, another analysis of the same participants has looked into the transfer of effects to dual task (DT) performance (5). Straight overground walking and turning in place both with and without an auditory stroop dual task (DT) were investigated. An overall increase in DT gait speed for all groups, which was strongest in the SBT group with the largest contrast between belt speeds (Cohen's d=2.67) and also the one with a large number of switches was found (Cohen's d=1.49). Furthermore, DT turning speed and Stroop response time while walking showed significant improvements only for the SBT groups (5).

Those results have revealed the promising potential of SBT therapy for people with PD. Not only does it improve their ability to adapt their gait pattern, but those improvements are also retained for an adequate amount of time considering that only one training session was conducted. Furthermore, this was investigated in participants that additionally experienced FOG. This subgroups' locomotor pathway is known to be more affected, which strengthens the results even more (29). The effects on DT performance are likewise very promising as participants were able to perform better after the SBT training, possibly through reduced cortical demands for the control of gait (5). Although it was not shown in the study, it can be speculated that a better performance during complex gait (e.g. DT gait) could reduce the risk for falls in people with PD (5).

Effects of SBT Training on Aerobic Capacity

In the previous paragraphs the different mechanism and adaptation processes of SBT walking in people with PD have been highlighted. Furthermore, the short-term effects of one SBT training session were summarized. However, one of the main strengths of SBT has not received much consideration in the literature. On top of generating an adaptation process, SBT training is also a form of aerobic exercise. Aerobic exercise is known to have general health benefits, including better cardiovascular and bone health and reduced mortality in people with PD (28). Furthermore, a meta-analysis by Shu et al. (30) has shown that aerobic exercise can immediately improve motor action, balance and gait in people with PD. Even motor symptoms could be attenuated through aerobic exercise (28). Although the perceived effort and energy cost of SBT have not been investigated in people with PD in detail, D'Cruz et al. showed that the subjective physical fatigue post training was similar in SBT groups compared to the conventional treadmill group (5). A study with young individuals has found equal levels of perceived exertion and heart rate when participants walked on a SBT compared to normal treadmill walking (treadmill speed as fast as the fast belt during SBT) (25). Those are promising findings regarding the intensity of the aerobic component of SBT training.

Conclusion and Future Perspective

SBT is safe and feasible for people with PD and results suggest that training should best be carried out in an ON state of medication. People with PD adapt their gait in a similar manner during and after SBT walking, but effects are smaller compared to healthy adults. One session of SBT training improved dual task performance and results suggest reduced cortical control of gait after SBT training.

Future studies are ongoing to investigate long term training interventions of SBT in people with PD, including the study of retention effects. As brain alterations are visible after exercise in people with PD, SBT could also give a great opportunity to investigate how their brain networks are activated during SBT walking by using methods such as EEG or fNIRS. Furthermore, the clinical relevance of the above-mentioned benefits still remains unclear and needs to be confirmed. Therefore, clinical scales with a minimally clinically important difference need to be included in those studies. Future studies should also investigate whether SBT training has similar aerobic benefits as regular treadmill training to strengthen its value for rehabilitation through generic health benefits. Finally, the potential of SBT to have a positive effect on mobility and fall risk in people with PD needs to be explored further by including measurements of gait during everyday activities with wearable sensors.

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Conflict of Interest
The authors have no conflict of interest.

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