Robot-Assisted Gait Training in Stroke Rehabilitation: A Multidisciplinary Overview on Lokomat Features

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Abstract

Stroke is a significant cause of death and disability worldwide. With the increasing lifespan, the risk of stroke has risen by 50% in the last 20 years, and currently, one in four individuals is at risk of experiencing a stroke. In the early stages of stroke rehabilitation, an interdisciplinary approach is essential to increase independence and ensure patients are discharged from the hospital in a shorter time. This approach involves physicians, physiotherapists, nurses, psychologists, and other healthcare professionals. This review examines the effects of session-specific parameters of the robot-assisted gait training device, Lokomat, used in stroke rehabilitation. Studies have shown that high guidance force levels (100%) decrease sensorimotor cortex engagement, while lower guidance force levels (30-50%) enhance muscle activation and support motor learning. Additionally, adjusting body weight support between 30% and 50% has been found to yield the most effective results. Increasing walking speed has also been observed to enhance muscle activation.

Keywords: Augmented performance feedback, body weight support, stroke.

Rehabilitasyonunda Robot Destekli Yürüme Eğitimi: Lokomat Özelliklerine Multidisipliner Bir Bakış

Öz

İnme, dünya genelinde önemli bir ölüm ve sakatlık kaynağıdır. Artan yaşam süresi ile birlikte son 20 yılda inme riski %50 oranında artmış ve şu anda her dört kişiden biri inme geçirme riski taşımaktadır. İnme rehabilitasyonunun erken aşamalarında, bağımsızlığı artırmak ve hastaların hastaneden kısa sürede taburcu olmasını sağlamak için disiplinlerarası bir yaklaşım gereklidir. Bu yaklaşım, hekimler, fizyoterapistler, hemşireler, psikologlar ve diğer sağlık profesyonellerinden oluşur. Bu derleme, inme rehabilitasyonunda kullanılan Lokomat adlı robot destekli yürüyüş eğitimi cihazının seans odaklı parametrelerinin etkilerini incelemektedir. Yapılan çalışmalar, yüksek kılavuz kuvvet seviyelerinin (%100) sensorimotor korteks etkinliğini azalttığını, daha düşük kılavuz kuvvet seviyelerinin (%30-50) kas aktivasyonunu artırarak motor öğrenmeyi desteklediğini göstermektedir. Ayrıca, vücut ağırlığı desteği %30-50 arasında ayarlandığında en etkili sonuçlar elde edilmiştir. Yürüyüş hızının artırılması ise kas aktivasyonunu güçlendirmiştir.

Anahtar Sözcükler: Arttırılmış performans geri bildirimi, vücut ağırlık desteği, inme.

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Introduction

Stroke is a significant cause of mortality and disability worldwide. Although stroke risk factors are now better understood and managed, the increasing human lifespan has led to a 50% rise in stroke risk over the last two decades, with one in four individuals currently at risk of experiencing a stroke[1]. In the early stages of stroke rehabilitation, a holistic, comprehensive, and interactive approach by an interdisciplinary team is essential to maximize independence, reduce caregiving burdens, and facilitate discharge within increasingly shorter hospital stays. This rehabilitation team typically includes physicians, physiotherapists, rehabilitation nurses, psychologists, and others. While physicians are the primary decision-makers in rehabilitation practices, physiotherapists are responsible for implementing rehabilitation programs and exercises. Nurses play a crucial role as they are the healthcare professionals who interact most directly with stroke patients and their caregivers. They also play an important role in implementing management techniques developed by other team members. Therefore, it is vital for nurses to be familiar with the services and procedures offered by other disciplines in the stroke rehabilitation team[2,3]. And many other professionals are also involved in rehabilitation according to the needs of patients.

This integration enhances the quality of patient care and adds value to the healthcare system through a multidisciplinary approach[4].

Loss of walking ability or difficulty in walking are among the most disabling consequences of stroke, and the restoration of walking is often a primary goal of rehabilitation[5]. A study conducted in 2008 showed that approximately 50% of stroke patients were discharged from the hospital in a wheelchair, 15% could walk indoors without assistive devices, 10% could walk outdoors, and 5% were able to climb stairs[6]. However, research has also reported that about one-third of individuals who suffer a stroke do not regain the ability to walk independently. For those who do recover their walking ability, the gait is often characterized by an asymmetric pattern, reduced walking speed, increased step width, and prolonged double support phase[7].

Regaining walking ability, one of the most important motor and functional losses after a stroke, plays a decisive role in an individual's level of independence and quality of life. In line with this goal, several contemporary treatment approaches have been developed[8]. The American Heart Association/American Stroke Association recommends the following for stroke-related mobility rehabilitation: Intensive-repetitive mobility-task training, Ankle Foot Orthosis, Group therapy with circuit training, Practice walking with either a treadmill or overground walking exercise training, Robot-Assisted Gait Training (RAGT) and Mechanically assisted walking. It should be noted that RAGT is recommended in conjunction with conventional physiotherapy[5].

Robotic devices have emerged as one of the most significant technological innovations in rehabilitation in recent years. These devices support motor learning by promoting intense, repetitive, task-oriented activities and encouraging active participation. Additionally, robotic devices can be adapted to the needs of patients and provide therapists with more objective evaluations of performance, enabling the development of

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individualized treatment approaches[7]. With these features, robotic devices can be effectively utilized in clinical applications for the treatment of individuals who have experienced a stroke[5].

There are various robotic devices, classified as "Exoskeleton" and "End-Effector" based on the movements they apply to the patient's body. Exoskeleton systems support joint movements along the extremity, while end-effector systems indirectly direct movement from a distal point. The Lokomat is an exoskeleton-type walking robot[9]. Existing literature shows that RAGT with the Lokomat has positive effects on gait symmetry[10], walking speed, balance[11], cardiovascular endurance[12], cognitive functions[13], and quality of life[14] in stroke rehabilitation. However, the fact that sessions vary in many ways raises an important discussion. Among these differences are the number of sessions, duration, intensity, other concurrent treatments, and the specific adjustments made to the Lokomat features during sessions. This review focuses on in-session factors, without considering off-session factors such as the number, duration, intensity of sessions and accompanying treatments, and evaluates their rehabilitative effects. When developing specific training protocols for the Lokomat, it is important to understand how exoskeletons modify locomotor task demands and how the nature and magnitude of these modifications vary according to training parameters. The aim of this review is to describe the use of in-session factors with potential effects on the treatment process of the Lokomat, such as guidance force, body weight support, walking speed, augmented performance feedback, and pelvic lateral movement.

Lokomat a Robot Assisted Gait Training Device

The Lokomat is a robotic device that provides safe and customizable walking training, supporting a physiological walking model. It includes a treadmill, a suspension system that provides body weight support, robotic orthoses, and two computers. One computer performs security and control tasks, while the other provides a graphical user interface for physiotherapists. The interface offers feedback on the quality of training. The device has four degrees of freedom. Joint angles are measured with precise potentiometers, and a physiological walking model is performed. The upper and lower leg support devices conform to the patient's legs[15]. In the studies by Mayr et al., it was reported that to use the Lokomat more effectively, the parameters of reduction of body weight support, increase in walking duration, increase in walking velocity, and reduction of guidance force on the hemiparetic leg should be adjusted[16]. In this review, in addition to these features of the Lokomat, augmented performance feedback and pelvic lateral movement features are also examined.

Lokomat Features

Guidance Force (GF) is one of the adjustable key parameters during walking with the Lokomat and determines how much assistance the patient receives in performing the walking movement[10]. It allows patients to partially influence the timing and spatial pattern of their movements during robot-assisted walking training. While maintaining the physiological accuracy of the movements, it provides patients with the opportunity to make and correct movement errors. By providing flexibility within a virtual tunnel, it

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allows for deviations in movements and increases the patients' active participation. Additionally, by modulating the patients' muscle activity with supporting torques, the effort required can be reduced. Guidance Force supports the development of a more natural and active walking model by providing timing freedom and a controlled spatial range of motion[17].

In their study, van Kammen et al. reported that changes in GF had little effect on muscle activity. They noted that in 100%-50% GF conditions, the activity of the gluteus medius on the unaffected side increased[10]. Knaepen et al. conducted a study evaluating cortical activity at different GF levels (30%, 60%, and 100%) and found that as the GF level increased, cortical activity decreased. High GF levels, such as 100%, should be avoided as they result in less active participation. They also reported that reducing GF optimized greater involvement of the sensorimotor cortex, which is crucial for motor learning[18]. In their study with healthy individuals, Swinnen et al. evaluated thoracic and pelvic movements at different GF levels (30%, 60%, and 100%) and found no change in thoracic and pelvic movements, attributing this to the effects of the robotic device and suspension limitations[19]. Cherni et al. compared muscle activity at different GF levels (30%, 50%, and 70%) in Lokomat with treadmill walking and found that the effects of GF were not insignificant. Although the structure and complexity of motor output were largely preserved, some changes in synergies were detected during Lokomat walking[20]. Lee et al. reported that at a walking speed of 1.4 km/h, changes in GF (100%, 80%, and 60%) did not affect oxygen consumption, but at a speed of 1.8 km/h, GF changes affected oxygen consumption[21]. In a study by Moreno et al., with healthy subjects walking on the Lokomat with a fixed Body Weight Support (BWS) and speed, no changes in walking patterns were observed at different GF levels (20%, 40%, 70%, and 100%)[22]. Lin et al. found that as the GF level decreased (70% and 40%), muscle activity increased. Their research concluded that GF, BWS, and walking speed should be considered in treatment plans[23]. The studies related to guidance force are presented in Table 1.

The current literature indicates that GF levels should be carefully adjusted with consideration to BWS and walking speed. Specifically, high GF levels (e.g., 100%) may lead to reduced participation of the sensorimotor cortex, negatively affecting the motor learning process. These levels optimize muscle activity while supporting the motor learning process and contributing to increased cortical activation. Additionally, low GF levels (e.g., 30%) may trigger more muscle activity and ensure more effective participation of the sensorimotor cortex. Therefore, it may be advisable to target a GF level in the range of 30%-50%, but these levels should be personalized according to the patient's recovery status and specific rehabilitation goals.

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Table 1. The effects of guidance force levels

Study	Guidance Force Level	Effect
van Kammen et al.[10]	%100 - %50	As GF levels decrease, Unaffected side Gluteus Medius muscle activity increases.
Knappen et al.[18]	%30 - %60 - %100	Cortical activity decreases with high GF conditions.
Swinnen et al.[19]	%30 - %60 - %100	The GF levels have no effect on thoracic and pelvic movement
Cherni et al.[20]	%30 - %50 - %70	The effects of GF were not insignificant. But the effects of GF are modest compared to the effect of the Lokomat itself.
Lee et al.[21]	%100 - %80 - %60	At walking speed 1.4 km/h GF levels did not affect oxygen consumption. But at a speed of 1.8 km/h GF levels change oxygen consumption.
Moreno et al.[22]	%20 - %40 - %70 - %100	With a fixed speed and BWS conditions GF levels did not affect walking pattern in healthy subjects.
Lin et al.[23]	%70 - %40	As GF levels decrease, muscle activity increases.

Body Weight Support (BWS) is one of the adjustable key parameters during walking with the Lokomat[10]. The BWS system helps support the patient's body weight, allowing the patient's body weight to be compensated and enabling early walking rehabilitation before the patient can fully bear their body weight[19]. Various BWS developments have been made during the development of the Lokomat. These include "Counterweight BWS", "Mechatronic BWS (Lokolift)" and "Advanced Passive BWS (Levi)". The BWS system provides support for up to 60 kg with an error of less than 1 kg at walking speeds of up to 3.2 km/h. This feature allows not only for constant body weight support but also for precise adjustments in support force during the walking cycle with high accuracy[24].

Krewer et al., in their study compared oxygen consumption at 1 km/h and 2 km/h speeds under 100% and 30% BWS conditions and found that oxygen consumption increased as BWS decreased. They reported that factors influencing oxygen consumption were related to the body weight carried and the duration of weight bearing[25]. In a study by van Kammen et al., they found that under 0% BWS conditions, the muscle activity of the healthy side Vastus Lateralis was higher compared to the 50% BWS condition[10]. Cherni et al., in their research, assessed muscle activity at different BWS levels (30%, 50%, and 100%) and observed that muscle activation decreased as BWS increased, as expected[20].

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Lin et al. found that as the BWS level decreased (50% and 30%), muscle activity increased[23]. These results highlight the potential of BWS to modulate muscle activation.

In research by van Kammen et al., they noted that walking without guidance force altered step timing and neuromuscular control of walking. However, the nature and magnitude of these effects were dependent on complex interactions between walking speed and BWS. When normal neuromuscular control of walking is targeted, it is recommended to avoid very low speeds and high BWS levels and instead use high speeds with low BWS[10]. The studies related to body weight support are presented in Table 2.

The current literature indicates that the target levels of BWS should be determined in conjunction with walking speed and GF, based on the patient's individual needs and treatment goals. Studies on oxygen consumption and muscle activity suggest that adjusting the BWS level between 30% and 50% can increase muscle activation while optimizing oxygen consumption. Therefore, the target BWS level should typically fall between 30% and 50%, but these levels should be personalized according to the patient's recovery status and specific rehabilitation goals.

Table 2. The effects of body weight support levels

Study	**Guidance Force Level**	**Effect**
van Kammen et al.[10]	%0 - %50	Vastus medialis muscle activity in unaffected side is higher at %0 BWS condition.
Cherni et al.[20]	%30 - %50 - %100	Muscle activity increases while BWS levels decrease.
Krewer et al.[25]	%30 - %100	Oxygen consumption was related to the body weight carried and its duration.

Walking speed can be controlled by adjusting the speed of the treadmill during walking training with the Lokomat, and this speed is one of the key parameters of the treatment[10]. The primary determinants of walking speed have been identified as stride length and cadence[26]. A study conducted on healthy female individuals reported that a 10% reduction in stride length decreased the hip flexion angle and significantly altered the hip and knee moments[27]. During walking training with the Lokomat, hip and knee flexion angles can be modified, and in this way, stride length can be adjusted during walking. Additionally, cadence can also be adjusted with the orthosis speed parameter.

Krewer et al., in their study, compared oxygen consumption at walking speeds of 1 km/h and 2 km/h with 100% and 30% BWS and found no change in oxygen consumption[25]. This result might suggest that walking speed does not affect oxygen consumption. However, van Kammen et al. evaluated short-term muscle activity at walking speeds of 1 km/h and 2 km/h and found that increasing speed led to greater muscle activation in the

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hemiplegic side (Biceps Femoris, Medial Gastrocnemius, and Tibialis Anterior) as well as in all muscles on the unaffected side[10]. This indicates that walking speed is a parameter that directly affects muscle activation, and as speed increases, muscles become more active. Moreno et al. found that in healthy participants using the Lokomat with fixed BWS and GF, walking patterns did not change at different walking speeds (1.5, 2, and 2.5 km/h)[22]. The studies related to walking speed are presented in Table 3.

According to this literature, we can say that walking speed is an effective factor on muscle activation and oxygen consumption, although the effect may be limited within certain speed ranges. While changes in muscle activation and motor control are observed as walking speed increases, further research is needed to explore the interactions between walking speed and BWS. Additionally, there is a gap in the literature regarding changes in step length and cadence during Lokomat training. Future studies could focus on these areas.

Table 3. The effects of walking speed levels

Study	Guidance Force Level	Effect
van Kammen et al.[10]	1 km/h - 2 km/h	Increasing speed leads to greater muscle activity in hemiplegic side.
Moreno et al.[22]	1.5 km/h - 2 km/h - 2.5km/h	Walking speed did not change walking patterns in healthy subjects.
Krewer et al.[25]	1 km/h - 2 km/h	Walking speed did not change oxygen consumption.

Augmented Performance Feedback (APF) offers game-like exercises that increase patients' motivation and participation. Patients who score points through active participation are more motivated to improve the quality of their movements. There are various games available on the Lokomat, each containing different goals. These are categorized under the headings "Activity Timing," "Endurance," "Movement Pattern," "Symmetry," and "Attention and Motivation"[28].

Prideaux et al. reported that the effects of different types of APF on cardiovascular system were similar. However, participants perceived a higher breathing effort during the "*Faster*" APF activity. In this study, participants' motivation was not influenced by the type of APF, but they found the "*Graph*" APF more enjoyable[12]. Akıncı et al. examined the effects of different types of APF on balance and gait. Their findings indicated that Attention and Motivation games ("*Smile, Gabarello"*), Endurance games ("*Faster*"), and Activity Timing games ("*High Flyer, Treasures, Curve Pursuit*") had significant effects on balance parameters, while Endurance games were superior to all others in improving walking speed[29]. These findings suggest that APF can be diversified to target different goals in rehabilitation processes. When considering the studies by Prideaux et al.[12] and Akıncı et al.[14] together, it can be concluded that endurance-based applications like Faster

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APF have the potential to enhance breathing effort and walking speed, while more enjoyable applications like Graph APF can increase motivation. Additionally, Manuli et al. reported that APF applications can provide effective cognitive feedback[13]. Their findings highlight that such systems have the potential not only to improve physical abilities but also to enhance cognitive engagement. Furthermore, it was noted that participant intention is a critical factor, as it can increase or decrease muscle activity[30]. The ability of APF to influence patient intention underscores its importance in rehabilitation settings.

Pelvis Lateral Movement (FreeD) is an innovation integrated into the Lokomat device with the FreeD module, introduced in October 2014. This module allows the pelvis to move laterally up to 4 cm in the frontal plane and provides pelvic rotation up to 4° in both directions in the transverse plane[31]. FreeD is an optional module for the Lokomat, which guides lateral pelvic movements and transverse rotation. During RAGT, it helps with weight transfer. This feature enables the patient to perform pelvic movements, which are important in normal human gait, with the support of the Lokomat, thus improving trunk kinematics. The FreeD module optimizes trunk movements, reduces compensatory movements, and offers a more natural walking experience[32].

Aurich-Schuler et al. examined the effects of the FreeD on trunk kinematics and hip and trunk muscle activity in healthy individuals. The study found that walking with FreeD resulted in significantly higher lateral pelvic displacement and lower lateral chest displacement compared to walking with a fixed pelvis[32]. The relative reduction in chest movements may reflect a decrease in compensatory trunk movements associated with improved weight shifting facilitated by the FreeD. In another study, Aurich-Schuler et al. investigated whether the timing of the FreeD could better align pelvic movements with physiological gait patterns. They found that manual timing adjustments made by therapists improved the pelvic kinematics produced by the FreeD, making them more similar to physiological overground walking[33]. Furthermore, Manuli et al., in a retrospective case-control study, reported that RAGT with the FreeD not only led to functional improvements in elderly stroke patients but also enhanced mood and walking performance[13]. These findings suggest that RAGT, particularly with the FreeD, can be an effective treatment method for elderly and neurologically impaired patients. The FreeD has the potential to promote more physiologically appropriate pelvic movements and achieve clinically significant improvements.

Conclusions

Robot-assisted gait training for stroke rehabilitation involves session-specific adjustments, including GF, BWS, walking speed, APF, and FreeD. Optimizing these parameters enhances muscle activation, oxygen consumption, motor learning, and overall rehabilitation outcomes. Beyond technical adjustments, patient motivation is crucial. A multidisciplinary approach enhances treatment outcomes, with physicians prescribing appropriate robotic training, nurses fostering participation through communication, and physiotherapists making individualized adjustments. This personalized strategy maximizes functional recovery and rehabilitation success.

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