DOI: 10.2478/rjom-2024-0004

Original papers

Study on plantar pressure in overground gait rehabilitation system that may facilitate return to work

Doina Ioana Badea[1], Ileana Ciobanu[2], Agripina Rașcu[1,3], Petre Lucian Seiciu[4], Mihai Berteanu[2,3]

[1] Colentina Clinical Hospital, Bucharest, Romania
[2] Elias University Emergency Hospital, Bucharest, Romania
[3] Carol Davila University of Medicine and Pharmacy, Bucharest, Romania
[4] Department of Machine Elements and Tribology, Politehnica University of Bucharest, Romania

Corresponding author
Doina Ioana Badea
dr.doina.badea@gmail.com

Abstract

Background: This study is focused on the investigation of advanced technology with potential involvement in the process of rehabilitation of working–age patients with orthopedic and neurologic disabilities. The main advantages of the use of advanced technology are related to decrease in recovery time and increase in return-to-work rate. This study addresses the biomechanics of walking and compares different gait sessions with RELIVE system. The purpose is to highlight the effect on the plantar pressure changes the system has during these sessions.

Methods: The study was realized on 15 healthy, disability-free subjects tested in 6 walking sessions. All the selected sessions were characterized by one particular characteristic, walking with hands on the handrail, and each participant had to perform three walks during each session. The F-Scan device from Tekscan (research software version), attached to the participants' belt was used to record the plantar pressure for each of the 18 walks.

Results: When walking with hands on the handrail, with 20% body weight offload, the average pressure values were lower with the alternator turned on compared to the seasons with the alternator turned off. Additionally, the body weight offloading of the participants determined by the body weight support subsystem resulted in decreased average pressure values with each percentage of unloaded body weight.

Conclusion: The unloading of the participants' weight was obtained by the body weight support subsystem. In all gait sessions studied, a drawback is represented by the interferences between the alternator and the body weight support subsystem. Therefore, is mandatory to find a solution for the interference between these two systems to assure a better gait training. Thus, a good alternative for conventional rehabilitation of working-age patients could be RELIVE system.

Keywords: *plantar pressure, gait rehabilitation, overground system, pelvic mechanism, return-to-work*

Introduction

Physical health is a fundamental necessity for independent living. The first World Disability Report, published more than a decade ago by World Health Organization and World Bank, states that 200 million people have functional disabilities and the prevalence is increasing [1]. It is estimated that 12.6% of the adult population has a functional disability, the most common types being visual and walking disorders [2]. The inability or disability to walk has a major physical and psychological impact on both patients and their families. The activities of daily living are affected when lower limb disability occurs, the patient requiring specialized help permanently [3,4].

Retirement age has increased in Europe [5,6], secondary to increased average life expectancy [7]. Working-age patients must cope with different health conditions and disabilities in order to continue working [8]. Return-to-work (RTW) has benefits for the patients (income and improved mental well-being), while employers benefit from less disability and more workforce [9]. The disabilities of working-age patients have an important economic and financial effect on society as a whole by two major ways: loss of productivity and reliance on government-funded income supplements [10], [11].

The number of employees who undergo hip and total knee arthroscopy is rising rapidly[6]. It is expected that by 2030 over 50% of these surgeries will be performed for working-age patients [12]. However, it can take up to 17 weeks after surgery to RTW [13,14], this being influenced by the working environment, occupational class, socioeconomic status [6].

With increased incidence of osteoporosis, the number of fragility hip fractures will become greater in the following years [15–17]. 40-60% of patients could resume previous level of ambulation after a fragility hip fracture, approximatively one third remaining totally dependent [18,19]. Independent ambulation can be delayed or impacted by factors such as preoperative hypoalbuminemia and postoperative complications [20].

Most patients with limb amputation choose a prosthetic device in order to regain some physical function [21–23], however in the long term, disablement is a serious concern [24,25]. The rates of RTW after amputation vary between 43-70% [26,27].

The incidence of stroke in younger people has the tendency to increase in the following years, approximately 30% of the survivors being under the age of 65, in their income-earning years [28,29]. It is very important for patients who had a stroke, to be able to RTW. It increases their general health, self-esteem, psychosocial comfort and life satisfaction and decreases the mortality rates [30,31]. The occupational physician must understand the limitations this type of patients have (motor, cognitive, verbal disabilities and fatigue) and must find the most effective interventions in order to accommodate the patient in the workplace [32]. Rehabilitation programs don't meet the needs of young stroke survivors wishing to RTW, being perceived as insufficient in terms of duration and aim to prepare them for work [33,34]. Furthermore, the published evidence on the effectiveness of these interventions is limited [28].

The most common recommendations at workplace for people with functional disabilities are changes to individual workstations, changes to worksites being less common. Among these accommodations are computer based technologies, alternative communication devices and assistive devices, which require little assistance for installing and can be implemented quickly [35]. For people with ambulatory disabilities, wheelchairs can help achieve mobility in daily living [36] and facilitate work performance [37,38].

Taking all these into consideration, we did a study with the aim to assist and investigate the development of advanced technology that has the potential to help the process of rehabilitation of working-age patients with various disabilities (orthopedic, neurologic). Using advanced technology may help decrease recovery time and increase RTW rates. Gait rehabilitation technology is growing rapidly, as regaining functional gait is very important for all aspects of independent living [39].

This study investigates RELIVE system, which is an assistive overground gait training system developed for rehabilitation of patients with disorders that generate walking disabilities. It was conceived and implemented within the project PN II – Partnerships in priority areas – contract 190/2012: „Sistem mecatronic de realitate 3D pentru recuperarea ambientală a pacienților cu afecțiuni neurologice centrale – RELIVE” (CNDI–UEFISCDI PN-II-PT-PCCA-2011-3.2-0053). The system was designed and built by a multidisciplinary team composed of specialists (mechatronics specialists, engineers, rehabilitation medicine specialists and psychologists) from Politehnica University Bucharest, Elias University Emergency Hospital Bucharest, S.C. Tehnomet S.A. Buzău, S.C. Corner Prod S.R.L. Câmpina and S.C. SIS S.A. Bucharest [40].

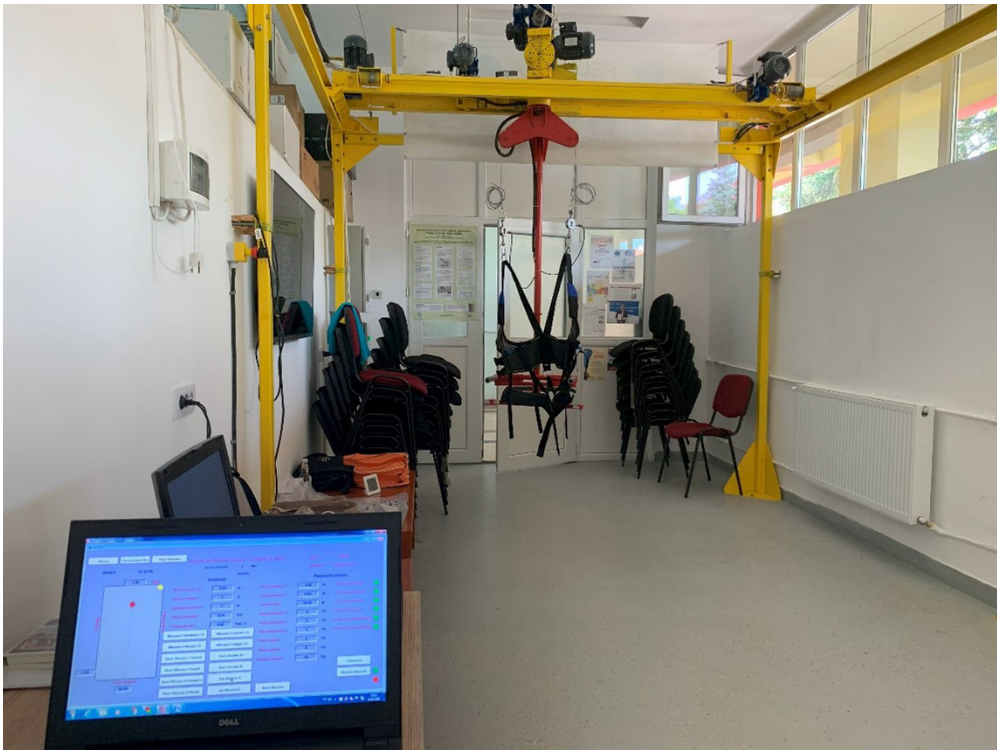
The system was primarily designed to assist patients with central neurological disorders (e.g. stroke), but the intention is to allow gait training in case of a wider range of pathologies (e.g. traumatic, degenerative, cardiovascular and respiratory). RELIVE system can have a significant impact on the health system, by reducing the expenses involved in caring for people with major gait disabilities.

The development of such a complex system required interdisciplinary collaboration between specialists in rehabilitation medicine, psychologists, mechatronic specialists and engineers [40]. The system is in TRL5 stage and its functioning as a whole must be investigated, under relevant conditions, in preclinical studies using subjects without known pathologies.

RELIVE system (Figure 1) consists of a) an assembly of supporting poles and fixed beams, which enclose the therapeutic space; b) a mobile beam on which the body weight support (BWS) subsystem and the vertical oscillation mechatronic subsystem (alternator) are placed. The novelty of the system is given by the alternator, which allows anterior translation and rotation (oblicity) movements of the pelvis [41], considering that the pelvis mechanism that permits natural pelvis movements necessary for physiological gait patterns is an underdeveloped component [42]. A more detailed description of the system and other studies were previously published [43–46].

In this study, we studied the biomechanics of walking, by comparing several gait sessions with RELIVE system, in order to understand if and how plantar pressure changes according to certain particularities of these sessions.

Figure 1. RELIVE system



Material and methods

This study is based on a series of cases and is an experimental pilot study as part of a more complex research focused on RELIVE system. Other experimental results have already been published in previous papers [44,46]. The research was approved by the Ethics Committee of Elias Emergency University Hospital (6364/13.09.2021) and took place in the Physical Medicine and Rehabilitation Department of Elias Emergency University Hospital during 2021-2022. The participants were selected from the clinic staff and they signed an informed consent form.

The study included 15 healthy, disability-free subjects, both men and women, without a history of lower limb pain or neurological pathologies.

The 6 walking sessions selected to study the biomechanics of walking have all in common the following characteristic: walking with hands on the handrail (HH) (Table 1). During each session, each participant had to perform three walks. Plantar pressure data was recorded for each of the 18 walks using the F-Scan device from Tekscan (research software version), attached to the participants' belt.

To obtain relevant data for this study, the peak/stance average function was applied resulting, for each walk, the average distribution of pressure values for each foot. The first and the last recorded step were deleted with the purpose to investigate only complete stance phases. This is a method to eliminate the inaccuracies which occur during initiation and termination of gait [44]. In the end, by averaging the pressure values for each foot, for the three walks, within the same gait session, we obtained the 24 average pressure values (AVP) for each foot and 48 APV for each gait session. This methodology is detailed in a previously published article [45].

For statistical analysis, IBM SPSS Statistics v28 tool was used. Because we have less than 2000 records the Shapiro-Wilk test was applied to verify if a variable is normally distributed. The p-value significance threshold was 0.05. The data were considered normally distributed if p-value was above 0.05. The corresponding non-parametric test was used if one of the two variables compared was non-normally distributed.

Table 1. RELIVE system

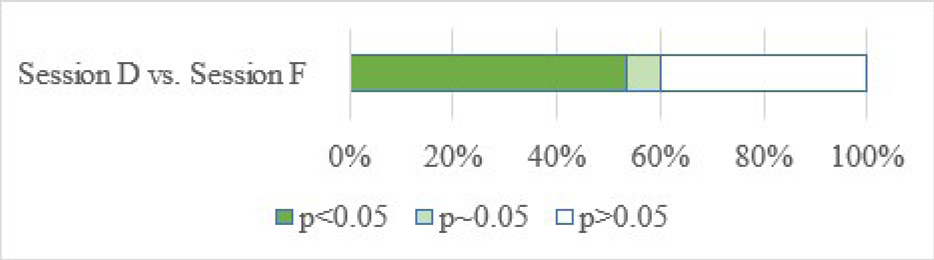
	Body weight offload (BWO)	Alternator
D	0%	turned off
F	0%	turned on
H	10%	turned off
J	10%	turned on
L	20%	turned off
N	20%	turned on

Results

Sessions D vs. F

Participant 1: from an average of 81.2500 in session D to one of 72.2292 in session F, the difference is not considered statistically significant: p-value = 0.172.
Participant 2: from an average of 77.4375 in session D to one of 73.3125 in session F, the difference is not considered statistically significant: p-value = 0.381.
Participant 3: from an average of 83.8333 in session D to one of 68.6875 in session F, the difference is considered statistically significant: p-value < 0.001.
Participant 4: from a mean of 80.3750 in session D to one of 67.7917 in session F, the difference is considered statistically significant: p-value = 0.002.
Participant 5: from an average of 81.5208 in session D to one of 66.8958 in session F, the difference is considered statistically significant: p-value = 0.002.
Participant 6: from a mean of 73.0208 in session D to one of 71.4375 in session F, the difference is not considered statistically significant: p-value = 0.963.
Participant 7: from a mean of 81.3542 in session D to one of 70.9792 in session F, the difference is considered statistically significant: p-value = 0.029.
Participant 8: from a mean of 76.0417 in session D to one of 70.7292 in session F, the difference is not considered statistically significant: p-value = 0.470.
Participant 9: from an average of 75.9375 in session D to one of 64.7708 in session F, the difference is considered statistically significant: p-value = 0.015.
Participant 10: from a mean of 82.3125 in session D to one of 71.6667 in session F, the difference is considered statistically significant: p-value = 0.001.
Participant 11: from a mean of 78.0208 in session D to one of 70.0625 in session F, the difference is not considered statistically significant, although close to the significance threshold of 0.005: p-value = 0.069.
Participant 12: from a mean of 84.3333 in session D to one of 72.0417 in session F, the difference is considered statistically significant: p-value = 0.026.
Participant 13: from an average of 79.9792 in session D to one of 70.0208 in session F, the difference is considered statistically significant: p-value = 0.045.
Participant 14: from a mean of 76.3958 in session D to one of 72.4167 in session F, the difference is not considered statistically significant: p-value = 0.415.
Participant 15: from an average of 72.2500 in session D to one of 62.2708 in session F, the difference is not considered statistically significant: p-value = 0.163.

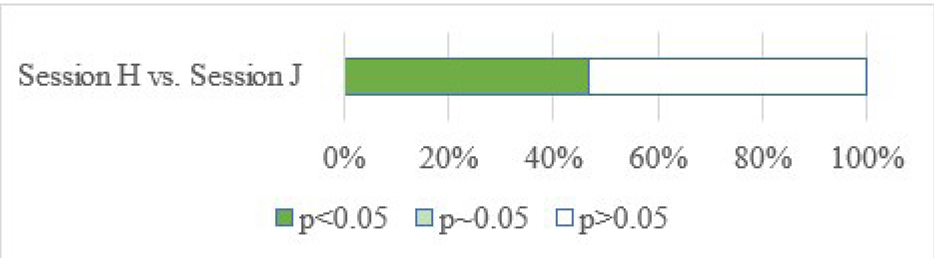
Figure 2. Session D versus Session F



Sessions H vs. J

Participant 1: from an average of 59.5208 in session H to one of 48.8333 in session J, the difference is considered statistically significant: p-value < 0.001. *Participant 2:* from an average of 54.9583 in session H to one of 51.0208 in session J, the difference is not considered statistically significant: p-value = 0.267. *Participant 3:* from a mean of 58.7708 in session H to one of 52.5438 in session J, the difference is considered statistically significant: p-value < 0.001. *Participant 4:* from a mean of 53.0208 in session H to one of 45.5625 in session J, the difference is considered statistically significant: p-value = 0.013. *Participant 5:* from an average of 46.5833 in session H to one of 47.4167 in session J, the difference is not considered statistically significant: p-value = 0.712. *Participant 6:* from a mean of 47.3750 in session H to one of 48.6842 in session J, the difference is not considered statistically significant: p-value = 0.851. *Participant 7:* from an average of 45.2708 in session H to one of 49.2500 in session J, the difference is not considered statistically significant: p-value = 0.152. *Participant 8:* from a mean of 50.2917 in session H to one of 47.6250 in session J, the difference is not considered statistically significant: p-value = 0.274. *Participant 9:* from a mean of 48.4792 in session H to one of 47.6250 in session J, the difference is not considered statistically significant: p-value = 0.488. *Participant 10:* from an average of 58.7083 in session H to one of 50.5000 in session J, the difference is considered statistically significant: p-value = 0.010. *Participant 11:* from a mean of 56.8333 in session H to one of 47.2292 in session J, the difference is considered statistically significant: p-value = 0.010. *Participant 12:* from a mean of 58.6875 in session H to one of 50.5417 in session J, the difference is considered statistically significant: p-value = 0.004. *Participant 13:* from a mean of 55.1875 in session H to one of 57.5208 in session J, the difference is considered statistically significant: p-value < 0.001. *Participant 14:* from a mean of 58.9167 in session H to one of 43.4583 in session J, the difference is considered statistically significant: p-value < 0.001. *Participant 15:* from a mean of 47.7917 in session H to one of 50.3750 in session J, the difference is considered statistically significant: p-value < 0.001.

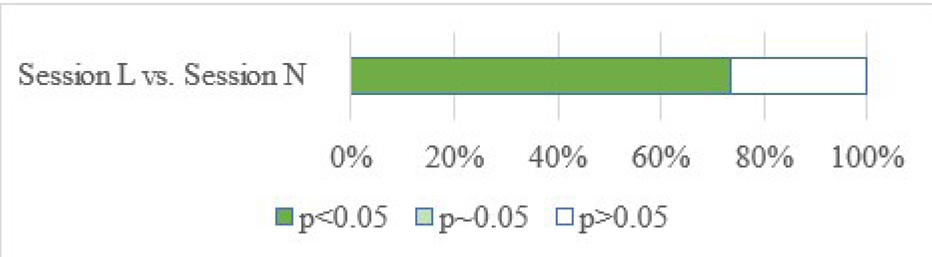
Figure 3. Session H versus Session J



Sessions L vs. N

Participant 1: from a mean of 43.9792 in session L to one of 32.2917 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 2:* from a mean of 39.5833 in session L to one of 31.5625 in session N, the difference is considered statistically significant: p-value = 0.009. *Participant 3:* from a mean of 43.2708 in session L to one of 34.9375 in session N, the difference is considered statistically significant: p-value = 0.001. *Participant 4:* from a mean of 40.8542 in session L to one of 34.2917 in session N, the difference is considered statistically significant: p-value = 0.004. *Participant 5:* from a mean of 38.3958 in session L to one of 34.7708 in session N, the difference is not considered statistically significant: p-value = 0.091. *Participant 6:* from a mean of 40.7292 in session L to one of 32.2292 in session N, the difference is considered statistically significant: p-value = 0.023. *Participant 7*: from an average of 37.3750 in session L to one of 35.5000 in session N, the difference is not considered statistically significant: p-value = 0.300. *Participant 8:* from a mean of 38.2917 in session L to one of 33.2083 in session N, the difference is not considered statistically significant: p-value = 0.082. *Participant 9*: from a mean of 35.1042 in session L to one of 32.7292 in session N, the difference is not considered statistically significant: p-value = 0.456. *Participant 10:* from an average of 43.4375 in session L to one of 31.0208 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 11:* from a mean of 40.6042 in session L to one of 30.9792 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 12:* from an average of 43.7917 in session L to one of 31.2292 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 13:* from a mean of 49.0625 in session L to one of 36.9792 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 14:* from a mean of 38.9167 in session L to one of 32.7083 in session N, the difference is considered statistically significant: p-value = 0.021. *Participant 15:* from a mean of 37.9167 in session L to one of 25.9167 in session N, the difference is considered statistically significant: p-value < 0.001.

Figure 4. Session L versus Session N



Sessions F vs. J

Participant 1: from an average of 72.2292 in session F to one of 48.8333 in session J, the difference is considered statistically significant: p-value < 0.001. *Participant 2:* from an average of 73.3125 in session F to one of 51.0208 in session J, the difference is considered statistically significant: p-value < 0.001. *Participant 3:* from a mean of 68.6875 in session F to one of 52.54378 in session J, the difference is considered statistically significant: p-value < 0.001. *Participant 4:* from an average of 67.7917 in session F to one of 45.5625 in session J, the difference is considered statistically significant: p-value < 0.001. *Participant 5:* from an average of 66.8958 in session F to one of 47.4167 in session J, the difference is considered statistically significant: p-value < 0.001. *Participant 6:* from a mean of 71.4375 in session F to one of 48.6042 in session J, the difference is considered statistically significant: p-value < 0.001. *Participant 7:* from an average of 70.9792 in session F to one of 49.25 in session J, the difference is considered statistically significant: p-value < 0.001. *Participant 8:* from an average of 70.7292 in session F to one of 47.625 in session J, the difference is considered statistically significant: p-value < 0.001. *Participant 9:* from an average of 64.7708 in session F to one of 47.625 in session J, the difference is considered statistically significant: p-value < 0.001. *Participant 10:* from an average of 71.6667 in session F to one of 50.5000 in session J, the difference is considered statistically significant: p-value < 0.001. *Participant 11:* from an average of 70.0625 in session F to one of 47.2292 in session J, the difference is considered statistically significant: p-value < 0.001. *Participant 12:* from an average of 72.0417 in session F to one of 50.5417 in session J, the difference is considered statistically significant: p-value < 0.001.

Participant 13: from a mean of 70.0208 in session F to one of 57.5208 in session J, the difference is considered statistically significant: p-value = 0.011. *Participant 14:* from an average of 72.4167 in session F to one of 43.4583 in session J, the difference is considered statistically significant: p-value < 0.001. *Participant 15:* from a mean of 62.2708 in session F to one of 50.3750 in session J, the difference is considered statistically significant: p-value = 0.037.

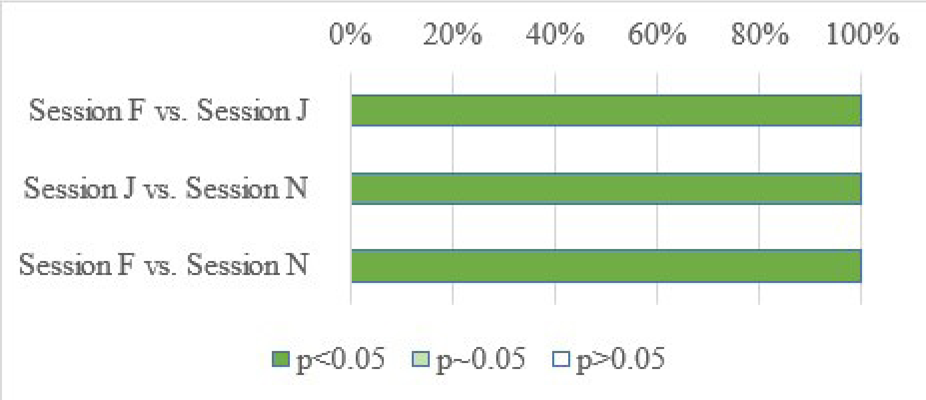
Sessions F vs. N

Participant 1: from an average of 72.2292 in session F to one of 32.2917 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 2:* from a mean of 73.3125 in session F to one of 31.5625 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 3:* from a mean of 68.6875 in session F to one of 34.9375 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 4:* from a mean of 67.7917 in session F to one of 34.2917 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 5:* from a mean of 66.8958 in session F to one of 34.7708 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 6:* from a mean of 71.4375 in session F to one of 32.2292 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 7:* from a mean of 70.9792 in session F to a mean of 35.5 in session N, the difference is considered statistically significant: p-value < 0.001.
Participant 8: from a mean of 70.7292 in session F to one of 33.2083 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 9:* from a mean of 64.7708 in session F to one of 32.7292 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 10:* from an average of 71.6667 in session F to one of 31.0208 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 11:* from a mean of 70.0625 in session F to one of 30.9702 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 12:* from an average of 72.0417 in session F to one of 31.2292 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 13:* from a mean of 70.0208 in session F to one of 36.9792 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 14:* from a mean of 72.4167 in session F to one of 32.7083 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 15:* from a mean of 62.2708 in session F to one of 25.9167 in session N, the difference is considered statistically significant: p-value < 0.001.

Sessions J vs. N

Participant 1: from an average of 48.8333 in session J to one of 32.2917 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 2:* from an average of 51.0208 in session J to one of 31.5625 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 3:* from an average of 52.54378 in session J to one of 34.9375 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 4:* from an average of 52.54378 in session J to one of 34.2917 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 5:* from an average of 47.4167 in session J to one of 34.7708 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 6:* from a mean of 48.6042 in session J to one of 32.2292 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 7:* from an average of 49.25 in session J to one of 35.5 in session N, the difference is considered statistically significant: p-value < 0.001.
Participant 8: from an average of 47.625 in session J to one of 33.2083 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 9:* from an average of 47.625 in session J to one of 32.7292 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 10:* from an average of 50.5000 in session J to one of 31.0208 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 11:* from an average of 47.2292 in session J to one of 30.9792 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 12:* from a mean of 50.5417 in session J to one of 31.2292 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 13:* from a mean of 57.5208 in session J to one of 36.9792 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 14:* from a mean of 43.4583 in session J to one of 32.7083 in session N, the difference is considered statistically significant: p-value < 0.001. *Participant 15:* from a mean of 50.3750 in session J to one of 25.9167 in session N, the difference is considered statistically significant: p-value < 0.001.

Figure 5. Session F versus Session J versus Session N



Discussions

When comparing Session D to Session F (Fig. 2), for 8 out of 15 participants, there were statistically significant differences ($p<0.05$) in APV values. When walking with HH, without BWO and with the alternator turned on, the APV values were lower than those in the case of walking with HH, without BWO and with the alternator turned off. The result is similar to the one obtained in the case of walking with hands alongside the body (HB)[45], but it is statistically significant only for half of the participants, and therefore we cannot say for certain that the alternator has an influence on the participant's BWO, when walking with HH.

When comparing Session H to Session J (Fig. 3.), for 7 out of 15 participants, there were statistically significant differences in APV values. When walking with HH, with 10% BWO and with the alternator turned on, the APV values were lower than those in the case of walking with HH, with 10% BWO and with the alternator turned off. The result is similar to the one obtained in the case of walking with HB [45], but it is statistically significant only for half of the participants, and therefore we cannot say for certain that the alternator has an influence on the participant's BWO, when walking with HH at 10% BWO.

When comparing Session L to Session N (Fig. 4.), for 11 out of 15 participants, there were statistically significant differences in APV values. When walking with HH, with 20% BWO and with the alternator turned on, the APV values were lower than those in the case of walking with HH, with 20% BWO and with the alternator turned off. The result is similar to the one obtained in the case of walking with HB with 20% BWO [45] and supports the claim that at 20% BWO, the alternator influences the participant's BWO.

When comparing Session F to Session J and Session N (Fig. 5.), the differences between all sessions were statistically significant. This result implies that the BWS subsystem determines the BWO of the participants, which leads to decreased values of APV with each percentage of BWO. The alternator interferes by increasing the offload, not by reducing it.

These comparisons showed that, for each participant, when walking with HH and with alternator switched on, the BWS subsystem gradually determines BWO, corresponding to the degree of BWO ordered by the operator. This was demonstrated by the APV values which decreased with each percentage of BWO. Also, the alternator subsystem interferes with the BWS subsystem, by increasing the degree of BWO when it is turned on, during sessions with 20% BWO when the participant walks with HH. This has been proven by decreased APV values during these sessions.

The study has some limitations, in terms of number and age of participants, inclusion criteria, type of footwear worn, the sensitivity of the sensor for detecting pressure, and the positioning of the handrail.

For some comparisons, the results are inconclusive. In order to be able to clearly say whether or not there are statistically significant differences for these comparisons, the number of participants must be increased. In older-age patients plantar pressure changes [47]. The enrolled participants were between the ages of 24 and 52 and were not divided into age groups.

One of the inclusion criteria referred to the lack of a history of foot pain, but no clinical examinations were performed to invalidate certain hidden/ unknown pathologies or deformities (hallux valgus, pes cavus, leg planus etc.), which are known to affect the distribution of plantar pressure [48],[49].

The construction of the shoe influences the load characteristics of the foot [48]. For the study, closed shoes were worn, so that the sensors were secured inside, against displacement (slipping), but the type and characteristics of the shoes were not evaluated.

The position of the handrail was not changed according to the height of the participant.

Conclusions

The study showed changes in the APV during gait sessions with the alternator turned on versus gait sessions with the alternator turned off, under the same conditions. Based on the results obtained, several conclusions can be drawn:

1) The BWS subsystem unloads the weight of the participants.

When the alternator subsystem is switched on, the APV values gradually decrease with the increase of the degree of BWO, for each participant, regardless of the position of the hands (HH or HB). The BWS subsystem represents an advantage for the gait recovery of people with ambulatory disabilities. BWO improves gait pattern by decreasing the effort and reducing the energy cost for executing steps, which leads, in the case of neurological patients, to a decrease in tonic reflexes and spasticity.

In addition, the BWS subsystem is also necessary for transfer training from sitting to standing position and vice versa, for obstacle training or in case of disturbances. It also has a role in preventing falls and it ensures comfort from a psychological point of view, the patient feeling safe and willing to practice more. A disadvantage could be the inhibition of posture reflexes in the trunk and more difficult balance training. In patients without neurological involvement, the BWS subsystem provides BWO in order to avoid further pain or injury to the affected area, allowing patients to focus on dynamic aspects and gait pattern symmetry.

2) The alternator subsystem interferes with the BWS subsystem in all gait sessions studied.

The alternator, when switched on, decreases the APV values and therefore, increases the degree of BWO, compared to the percentage set in advance, regardless of the position of the hands (HH or HB); The explanation for the occurrence of this change in APV could be the fact that the two subsystems (alternator and BWS) are not completely mechanically separated from each other, which can lead to one influencing the other or both influencing themselves. As this leads to a further increase in the degree of BWO, it can lead to an overly high degree of BWO, which could change the gait pattern by decreasing the force necessary for propulsion, generated by the posterior muscles of the lower limb at the end of the stance phase. With the increase of the BWO the ground reaction force also decreases causing the walking speed to decrease. However, essential in post-stroke rehabilitation is the increase in walking speed.

3) Finding a solution for the interference of the two systems is mandatory for better gait training. RELIVE system can be a good alternative for conventional rehabilitation of working-age patients. The new generations of employees are more technology oriented and using advanced technology for this category of patients might raise their compliance to the treatment, achieving higher recovery and RTW rates. Also, RELIVE system can reduce the expenses necessary for the care of the people with major gait disabilities, including working–age persons, thus having a major impact on the health system and economy.

Conflicts of interest

Nothing to declare.

Acknowledgement

This work was supported by a grant of the Romanian National Authority for Scientific Research, CNDI–UEFISCDI PN-II-PT-PCCA-2011-3.2-0053, project number 190/2012 and is part of the first author's PhD (doctoral) thesis at Carol Davila University of Medicine and Pharmacy in Bucharest.

References

1.World Report on Disability. Geneva: World Health Organization & World Bank; 2011.

2. Mitra S, Yap J. The Disability Data Report. New York: Disability Data Initiative. Fordham Research Consortium on Disability; 2021.

3. Wang C, Liu Q, Ye J, Chen G, Shen Y, Shang W, et al. Mechanism Design of a Novel Multi - Functional Assistant Robot for Rehabilitation Training. 2018 IEEE Int. Conf. Real-Time Comput. Robot. RCAR, 2018, p. 526–31. https://doi.org/10.1109/RCAR.2018.8621710.

4. Song Z, Chen W, Wang W, Zhang G. Dynamic Modeling and Simulation of a Body Weight Support System. J Healthc Eng 2020;2020:e2802574. https://doi.org/10.1155/2020/2802574.

5. Hess M. Rising Preferred Retirement Age in Europe: Are Europe's Future Pensioners Adapting to Pension System Reforms? J Aging Soc Policy 2017;29:245–61. https://doi.org/10.1080/08959420.2016.1255082.

6. Kamp T, Gademan MGJ, Zon SKR van, Nelissen RGHH, Vlieland TPMV, Stevens M, et al. Time to return to work by occupational class after total hip or knee arthroplasty. Bone Jt J 2023;105-B:977–84. https://doi.org/10.1302/0301-620X.105B9.BJJ-2023-0190.R1.

7. Khavinson V, Popovich I, Mikhailova O. Towards realization of longer life. Acta Bio-Medica Atenei Parm 2020;91:e2020054. https://doi.org/10.23750/abm.v91i3.10079.

8. Vooijs M, Leensen MCJ, Hoving JL, Wind H, Frings-Dresen MHW. Perspectives of People with a Chronic Disease on Participating in Work: A Focus Group Study. J Occup Rehabil 2017;27:593–600. https://doi.org/10.1007/s10926-016-9694-6.

9. Correlation of return to work with patient satisfaction after surgery for lumbar spondylolisthesis: an analysis of the Quality Outcomes Database in: Neurosurgical Focus Volume 48 Issue 5 (2020) Journals n.d. https://thejns.org/focus/view/journals/neurosurg-focus/48/5/article-pE5.xml (accessed September 30, 2024).

10. Singh S, Ailon T, McIntosh G, Dea N, Paquet J, Abraham E, et al. Time to return to work after elective lumbar spine surgery 2021. https://doi.org/10.3171/2021.2.SPINE202051.

11. Ghatnekar O, Persson U, Glader E-L, Terént A. Cost of stroke in Sweden: An incidence estimate. Int J Technol Assess Health Care 2004;20:375–80. https://doi.org/10.1017/S0266462304001217.

12. Kurtz SM, Lau E, Ong K, Zhao K, Kelly M, Bozic KJ. Future Young Patient Demand for Primary and Revision Joint Replacement: National Projections from 2010 to 2030. Clin Orthop Relat Res 2009;467:2606. https://doi.org/10.1007/s11999-009-0834-6.

13. Leemput DV, Neirynck J, Berger P, Vandenneucker H. Return to Work after Primary Total Knee Arthroplasty under the Age of 65 Years: A Systematic Review. J Knee Surg 2021;35:1249–59. https://doi.org/10.1055/s-0040-1722626.

14. Hoorntje A, Janssen KY, Bolder SBT, Koenraadt KLM, Daams JG, Blankevoort L, et al. The Effect of Total Hip Arthroplasty on Sports and Work Participation: A Systematic Review and Meta-Analysis. Sports Med 2018;48:1695–726. https://doi.org/10.1007/s40279-018-0924-2.

15. Marks R. Hip fracture epidemiological trends, outcomes, and risk factors, 1970-2009. Int J Gen Med 2010;3:1–17.

16. Dong Y, Zhang Y, Song K, Kang H, Ye D, Li F. What was the Epidemiology and Global Burden of Disease of Hip Fractures From 1990 to 2019? Results From and Additional Analysis of the Global Burden of Disease Study 2019. Clin Orthop Relat Res 2023;481:1209. https://doi.org/10.1097/CORR.0000000000002465.

17. Global Epidemiology of Hip Fractures: Secular Trends in Incidence Rate, Post- Fracture Treatment, and All- Cause Mortality | Journal of Bone and Mineral Research | Oxford Academic n.d. https://academic.oup.com/jbmr/article/38/8/1064/7610444?login=false (accessed September 30, 2024).

18. Dyer SM, Crotty M, Fairhall N, Magaziner J, Beaupre LA, Cameron ID, et al. A critical review of the long-term disability outcomes following hip fracture. BMC Geriatr 2016;16:158. https://doi.org/10.1186/s12877-016-0332-0.

19. Schattner A. The burden of hip fractures—why aren't we better at prevention? QJM Int J Med 2018;111:765–7. https://doi.org/10.1093/qjmed/hcx216.

20. Chanthanapodi P, Tammata N, Laoruengthana A, Jarusriwanna A. Independent Walking Disability After Fragility Hip Fractures: A Prognostic Factors Analysis. Geriatr Orthop Surg Rehabil 2024;15:21514593241278964. https://doi.org/10.1177/21514593241278963.

21. McFarland LV, Winkler SLH, Heinemann AW, Jones M, Esquenazi A. Unilateral upper-limb loss: Satisfaction and prosthetic-device use in veterans and servicemembers from Vietnam and OIF/OEF conflicts. J Rehabil Res Dev 2010;47:299. https://doi.org/10.1682/JRRD.2009.03.0027.

22. van Velzen JM, van Bennekom CA, Polomski W, Slootman JR, van der Woude LH, Houdijk H. Physical capacity and walking ability after lower limb amputation: a systematic review. Clin Rehabil 2006;20:999–1016. https://doi.org/10.1177/0269215506070700.

23. Raichle KA. Prosthesis use in persons with lower- and upper-limb amputation. J Rehabil Res Dev 2008;45:961–72. https://doi.org/10.1682/JRRD.2007.09.0151.

24. Darter BJ, Hawley CE, Armstrong AJ, Avellone L, Wehman P. Factors Influencing Functional Outcomes and Return-to-Work After Amputation: A Review of the Literature. J Occup Rehabil 2018;28:656–65. https://doi.org/10.1007/s10926-018-9757-y.

25. MacKenzie EJ, Bosse MJ, Kellam JF, Pollak AN, Webb LX, Swiontkowski MF, et al. Early Predictors of Long-Term Work Disability After Major Limb Trauma. J Trauma Acute Care Surg 2006;61:688. https://doi.org/10.1097/01.ta.0000195985.56153.68.

26. Burger H, Marinček Č. Return to work after lower limb amputation. Disabil Rehabil 2007;29:1323–9. https://doi.org/10.1080/09638280701320797.

27. Penn-Barwell JG. Outcomes in lower limb amputation following trauma: A systematic review and meta-analysis. Injury 2011;42:1474–9. https://doi.org/10.1016/j.injury.2011.07.005.

28. Interventions to Facilitate Return to Work after Stroke: A Systematic Review n.d. https://www.mdpi.com/1660-4601/20/15/6469 (accessed September 30, 2024).

29. Prevalence of Cardiovascular Risk Factors and Strokes in Younger Adults | Cerebrovascular Disease | JAMA Neurology | JAMA Network n.d. https://jamanetwork.com/journals/jamaneurology/fullarticle/2617268 (accessed September 30, 2024).

30. Brannigan C, Galvin R, Walsh ME, Loughnane C, Morrissey E-J, Macey C, et al. Barriers and facilitators associated with return to work after stroke: a qualitative meta-synthesis. Disabil Rehabil 2017;39:211–22. https://doi.org/10.3109/09638288.2016.1141242

31. Return to work after young stroke: A systematic review - Jodi D. Edwards, Arunima Kapoor, Elizabeth Linkewich, Richard H. Swartz, 2018 n.d. https://journals.sagepub.com/doi/10.1177/1747493017743059 (accessed September 30, 2024).

32. Torre GL, Lia L, Francavilla F, Chiappetta M, Sio SD. Factors that facilitate and hinder the return to work after stroke: an overview of systematic reviews. Med Lav Work Environ Health 2022;113:e2022029–e2022029. https://doi.org/10.23749/mdl.v113i3.13238.

33. Lock S, Jordan * L, Bryan K, Maxim J. Work after stroke: focusing on barriers and enablers. Disabil Soc 2005;20:33–47. https://doi.org/10.1080/0968759042000283629.

34. Röding J, Lindström B, Malm J, Öhman A. Frustrated and invisible–younger stroke patients' experiences of the rehabilitation process. Disabil Rehabil 2003;25:867–74. https://doi.org/10.1080/0963828031000122276.

35. Sabata D, Williams MD, Milchus K, Baker PMA, Sanford JA. A Retrospective Analysis of Recommendations for Workplace Accommodations for Persons With Mobility and Sensory Limitations. Assist Technol 2008;20:28–35. https://doi.org/10.1080/10400435.2008.10131929.

36. DeLisa's Physical Medicine and Rehabilitation: Principles and Practice. https://shop.lww.com/DeLisa-s-Physical-Medicine-and-Rehabilitation--Principles-and-Practice/p/9781496374967 (accessed

September 30, 2024).
37. Stenberg G, Henje C, Levi R, Lindström M. Living with an electric wheelchair – the user perspective. Disabil Rehabil Assist Technol 2016;11:385–94. https://doi.org/10.3109/17483107.2014.968811.
38. Community integration of wheelchair-bound athletes: a comparison before and after onset of disability - Saskia MF Pluym, Tessa JA Keur, Johan Gerritsen, Marcel WM Post, 1997 n.d. https://journals.sagepub.com/doi/10.1177/026921559701100306 (accessed September 30, 2024).
39. Mikolajczyk T, Ciobanu I, Badea DI, Iliescu A, Pizzamiglio S, Schauer T, et al. Advanced technology for gait rehabilitation: An overview. Adv Mech Eng 2018;10:1687814018783627. https://doi.org/10.1177/1687814018783627.
40. RELIVE-Sist Mecatronic Realitate 3D Pentru Recuperarea Ambient Pacientilor Cu Afectiuni Neurol UEFISCDI PN II- Parteneriate Domen Prioritare Contract 1902012 n.d. http://www.omtr.pub.ro/cesit/granturi/RELIVE/index.html.
41. Ciobanu I. Sistem mecatronic complex de reabilitarea mersului la pacienții cu afecțiuni neurologice dizabilitante. Teza de doctorat. Coordonator Științific: Prof. Dr. Mihai Berteanu. Universitatea de medicina si farmacie Carol Davila Bucuresti, 2016.
42. Pelvis mobility control solutions for gait rehabilitation systems: a review – Health, Sports & Rehabilitation Medicine n.d. https://jhsrm.org/health-sports-rehabilitation-medicine-vol-22-no-1-january-march-2021/pelvis-mobility-control-solutions-for-gait-rehabilitation-systems-a-review/ (accessed February 26, 2023).
43. Seiciu PL, Popescu AM, Ciobanu I, Iliescu AN, Berteanu M. HIP VERTICAL MOVEMENT MECHATRONIC SYSTEM FOR GAIT REHABILITATION n.d.
44. Badea DI, Ciobanu I, Iliescu A, Paduraru GI, Alexe MA, Prisecaru DA, et al. Changes in Plantar Pressure Distribution Induced by RELIVE Overground Gait Rehabilitation System. 2022 E-Health Bioeng. Conf. EHB, 2022, p. 1–4. https://doi.org/10.1109/EHB55594.2022.9991432.
45. Badea DI, Ciobanu I, Popa R, Seiciu PL, Berteanu M. Modifications in plantar pressure in overground assisted gait training. Health Sports Rehabil Med 2023;24:54–60. https://doi.org/10.26659/pm3.2023.24.2.54.
46. Badea DI, Ciobanu I, Iliescu A, Paduraru GI, Stoica CR, Alexe MA, et al. Changes in Pelvic Biomechanics Induced by RELIVE Overground Gait Rehabilitation System. 2021 Int. Conf. E-Health Bioeng. EHB, 2021, p. 1–4. https://doi.org/10.1109/EHB52898.2021.9657647.
47. Hessert MJ, Vyas M, Leach J, Hu K, Lipsitz LA, Novak V. Foot pressure distribution during walking in young and old adults. BMC Geriatr 2005;5:8. https://doi.org/10.1186/1471-2318-5-8.
48. Rosenbaum D, Becker H-P. Plantar pressure distribution measurements. Technical background and clinical applications. Foot Ankle Surg 1997;3:1–14. https://doi.org/10.1046/j.1460-9584.1997.00043.x.
49. Elftman H. A cinematic study of the distribution of pressure in the human foot. Anat Rec 1934;59:481–91. https://doi.org/10.1002/ar.1090590409.