

Walking reeducation with partial relief of body weight in rehabilitation of patients with locomotor disabilities

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Abstract—This study was undertaken to investigate the contribution of a weight-relieving system on the gait of patients with severe locomotor disabilities. Temporal parameters of gait and subjective evaluations of the effect of the system were studied in 24 patients and 6 healthy subjects. Partial weight relief was accomplished through a pneumatic system mounted in the ceiling over a conductive walkway which was placed between parallel bars. Subjects were tested in three walking trials: free walking, walking while harnessed to the system but without weight relief, and walking with relief of 20 percent of their body weight. Temporal measurements indicated a positive effect of the system on duration of the stance and swing phases. The percentage of the stance period of the involved lower limb relative to the uninvolved one increased by 148 percent; at the same time, the swing period of the involved limb relative to the sound one decreased to 68 percent of that value in free ambulation. A substantial increase in gait symmetry and velocity were also noted. Subjective information from the patients and observers also pointed to a facilitative effect of the system on the patients' ambulation. Conversely, natural gait velocity of the healthy subjects was impeded by weight relief through the system.

Key words: *ambulation, gait analysis, locomotor disabilities, rehabilitation, velocity, walking.*

INTRODUCTION

Walking is the most functional and most common of all human movements. Therefore, gait impairments, or the inability to walk, constitute a major challenge to professionals engaged in the rehabilitation of walking disabilities.

Although impairments frequently affect both the swing and the stance phase of gait, the more disabling events occur at the stance phase (5). Regardless of the etiology of the walking impairment, it is frequently associated with the inability of the affected lower extremity (LE) or extremities to accept, bear, and transfer the weight of the body forward. A common adaptation strategy for these disabilities is shortening the stance period of the afflicted LE, while lengthening that of the sound one. This results in an asymmetric gait pattern and in decreased gait velocity (2,3,6).

Walking aids such as walkers, crutches, canes, or another person's arm are frequently used to substitute and/or augment weight transference through the disabled LE. Minimal requirements for the proper utilization of a walking aid include sufficient control over the upper trunk, and at least one intact upper extremity. Additionally, the patient has to be capable of investing a sufficient amount of energy in order to proceed with reasonable velocity. A putative solution for enabling patients who do not meet these demands might be an external system which relieves the affected LE of an adjusted proportion of body weight at the time of stance phase. Such a relief should enable the stance LE to function while bearing less than the weight of the whole body.

This current work constitutes the first phase in an attempt to devise an instrument which fulfills such a weight-relief function. The specific goal of this study is to develop and test a weight-relieving system capable of reducing a controlled predetermined percentage of the patient's weight during ambulation. A survey of the literature revealed only one comparable attempt (1,4).

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METHOD

Subjects

The subjects included 24 patients who were residents of a geriatric rehabilitation institute. Sixteen of them were men; the age range was from 42 to 84 years. Eighteen of the patients were at the beginning of their rehabilitation process. Seventeen of these 18 suffered from hemiplegia of a vascular origin, while one was paraparetic due to a traumatic injury at the C7 level. Three of the hemiplegic patients had a below-knee amputation of the unaffected LE and wore a prosthesis. All of these 18 patients suffered severe walking impairments and were unable to walk outside of the parallel bars, even with the assistance of a walking aid. Six other patients were completely unable to walk. These six patients were residents of a long-term care department and were wheelchair-bound for periods of 6 months to 2 years.

Six healthy volunteers, 3 men and 3 women (ranging in age from 25 to 50), were also tested in order to study the influence of the weight relief system on subjects with no damage to the locomotor system.

Instrument¹

The weight-relieving system (Figure 1, Figure 2, and Figure 3) was pneumatic and mounted in the ceiling over the parallel bars located in the physical therapy department of the rehabilitation institute. Subjects were harnessed to the system by means of an aluminum frame,² which supported the chest and pelvis while leaving the upper and lower extremities free. The frame was connected by an adjustable length strip to a cable of a piston which received air from an external pressure tank. The pressure in the tank was maintained by an external compressor. The piston was connected to a cart which moved on a track above the walkway. To free the subject from the need to drag the cart, the latter was driven by an electric motor whose operation was dependent on, and synchronized to, the periods of walking. The weight of the subject was relieved by closing a pressure regulator located on the pressure tank, which caused a desired amount of air to be compressed into the piston and proportionally shorten the cable. Consequently, the frame supporting the subject was raised, and the weight of the subject on the ground decreased. The tension in the cable did not change as a result of the vertical walking motions because the action of the piston compensated for

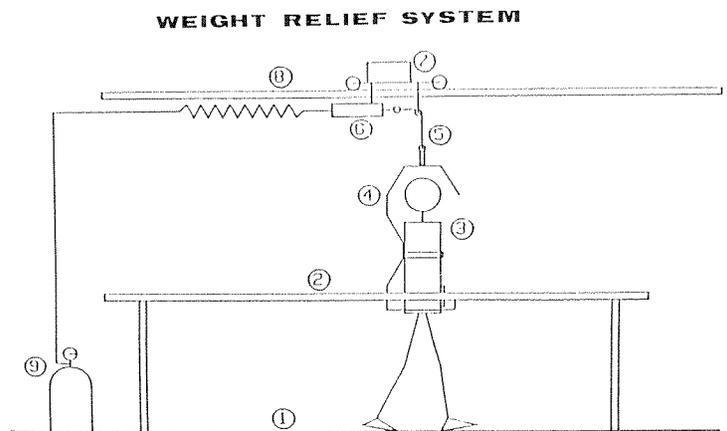


Figure 1.

Schematic drawing of the weight relief system: 1) walkway; 2) parallel bars; 3) walking subject; 4) aluminum frame; 5) adjustable length cable; 6) pneumatic piston; 7) cart; 8) overhead track; and, 9) pressure accumulator.

such movements. The amount of weight in kilograms which was relieved from the subjects could be adjusted in a range of zero to 150 kg. Adjustment was controlled by a digital display mounted on the pressure tank. Validity and reliability of the system were confirmed through pilot measurements on several healthy subjects. Their weight was measured on a calibrated bathroom scale, and compared to the readings obtained by the system first at full body weight on the ground, and then when known proportions of their weight was relieved.

Measurement system and dependent variables

The measurement system was composed of a walkway located between the parallel bars, a computer, and a video camera with a recording system. Metal conducting strips were attached to the walkway and connected to both an oscilloscope and an Apple computer. Conductive aluminum tape was glued to the soles of the shoes of the walking subject; as the subject stepped on the walkway an electrical circuit was closed, which remained closed as long as the subject's foot was in contact with the ground. Consequently, the time periods of stance and swing of each LE were measured. These data were collected, stored, and later analyzed with the aid of the computer. Additional variables, such as gait symmetry and gait velocity, could be calculated from these raw data. Each walking experiment was filmed from the side and retrieved on video cassettes. A frame-by-frame analysis enabled a closer observation of gait parameters that could not be obtained through the walkway. Identification and proper deletion of artifacts

¹Goldman Automation LTD, 30 Harishonim St., Kiryat Haiim, Israel.

²Enraf Balancer, Enraf nonius, Delft, Holland.

(such as apparently exceptional long periods of stance phase that actually resulted from a dropped foot) was accomplished through this analysis.

Data collected in each walking trial were: 1) duration of stance and swing phase of each LE; 2) subject's subjective evaluation of his gait; and, 3) investigator's subjective evaluation of the subject's gait.

Protocol

The experimental protocol was established after the completion of a pilot study which included seven patients.

Data from each of the 18 patients and the 6 healthy subjects were recorded using three types of gait: 1) free ambulation between the parallel bars; 2) ambulation between the bars harnessed to the weight-relieving system, but without any relief of body weight; and, 3) ambulation between the bars harnessed to the weight-relieving system with relief of 20 percent of body weight. Relief of this per-

centage of weight was chosen because it was sufficient enough to facilitate gait in all patients of the pilot group. Patients' fatigue prevented us from testing walking under additional paradigms. For each type of gait, subjects had to walk back and forth at least once between the parallel bars. A minimum of three consecutive strides was used for analysis. The three patients who suffered one LE amputation were tested while wearing their prosthesis. Those six patients who were unable to walk with their full weight on the ground were tested only once, with 20 percent of their weight relieved by the system. In all experiments, subjects were allowed to hold onto the bars with their hands as they wished.

For the healthy controls, the ratio between duration of the stance and the swing periods of one LE to the corresponding periods in the other LE was calculated. For the patients, with the exception of the paraparetic patient, this ratio was calculated for the unaffected versus the

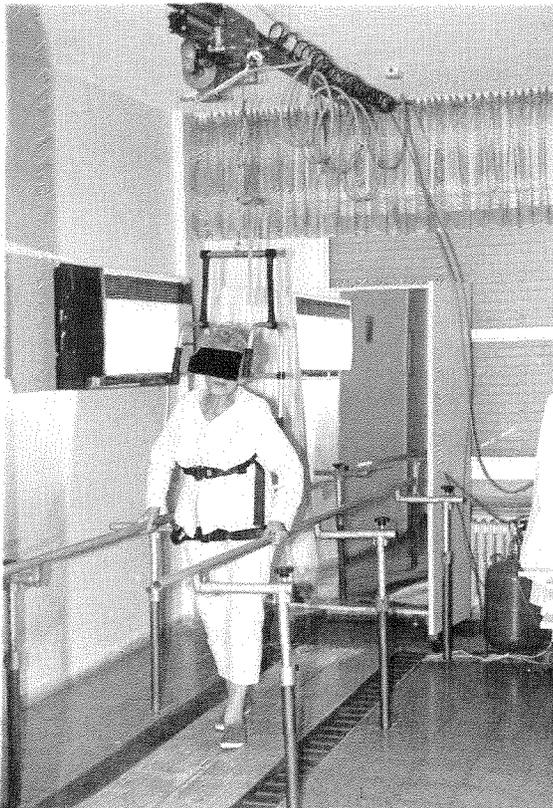


Figure 2.
Subject walks with the aid of the system. Anterior view.



Figure 3.
Subject walks with the aid of the system. Posterior view.

affected LE. Gait velocity (m/sec) was also calculated and the relative change introduced by the system was determined by assigning a value of 1 to velocity at free ambulation (Table 1).

RESULTS

The ratio between the stance and swing periods of the lower extremities changed only in the patients. The ratio between duration of the stance phase of the unaffected to the affected LE decreased, while the corresponding ratio for the swing phase increased. These changes occurred even when the patients were harnessed to the system with no weight relief, and became more pronounced during weight relief (Table 1).

As to gait velocity, an opposite trend was noted in the patients and in the healthy controls: in the patients, walking speed increased only slightly when they were harnessed to the system without weight relief (by a factor of 1.09). However, when weight was relieved, it was associated with an average increase of 1.7 times their gait velocity without the aid of the system. For some subjects, this increase

exceeded three times their normal walking speed. In the healthy subjects, being harnessed to the system caused a 10 percent decrease in gait velocity, while with the 20 percent of weight relief, gait was slowed up to two-thirds of its normal value.

The influence of the weight-relieving system on the ratio between the stance and the swing periods of the two LEs, as well as on gait velocity of the experimental and healthy subjects, is depicted in (Figure 4, Figure 5, and Figure 6).

Twenty-one of the patients felt the system facilitated their walking. This included the six patients who were unable to walk without weight relief. Only three patients stated that the system had not helped them to ambulate more easily. The trend of changes in the measured variables was similar in these three patients to the trend noted in the rest of the patients. Subjective evaluation of patients' gait by the investigators was in accordance with the objective findings. Patients appeared to walk faster and with less effort when their body weight was partially relieved, as compared to unassisted ambulation. Being harnessed without weight relief seemed to have some facilitory effect on ambulation by the mere provision of support and safety.

The healthy subjects shared a common feeling that their normal walking was impeded by the system. Although execution of walking movements seemed to be facilitated during weight relief, forward progression was felt to be partially arrested and had to be overcome by pulling with at least one hand on the bar.

Table 1.
Effect of the weight relief system on temporal variables of gait.*

	Ambulation Type	VI/VO	Swing: TS/TA	Stance: TS/TA
	Free	1.000	0.518 (0.167)	1.602 (0.453)
Right or left hemiplegia (n=17)	Harness 0% B.W.	1.087 (0.171)	0.615 (0.174)	1.256 (0.284)
	Harness 20% B.W.	1.758 (0.443)	0.758 (0.158)	1.118 (0.145)
	Free	1.000	0.999 (0.035)	1.026 (0.036)
Healthy (n=6)	Harness 0% B.W.	0.895 (0.065)	1.012 (0.099)	0.972 (0.061)
	Harness 20% B.W.	0.648 (0.117)	1.066 (0.107)	1.016 (0.051)

*Values given are means and standard deviations.

0% B.W. - Harnessed to the system without relief of body weight.
20% B.W. - Harnessed to the system with relief of 20% body weight.
TS/TA - Period of affected LE.
Vi - Gait velocity with the aid of the system.
Vo - Gait velocity at free ambulation.
TS - Time period of stance or swing of the sound limb.
TA - Time period of stance or swing of the affected limb.

DISCUSSION

The results of this preliminary study point to a substantial contribution of the tested system to the ambulation of motor handicapped patients. It enabled them to walk at a faster pace, reduce stance time on the unaffected LE, and enable longer weightbearing periods on the affected LE. Concomitantly, gait symmetry was improved. With the aid of this system, some patients who were otherwise wheelchair-bound, were able to stand and walk. The device also made a significant contribution to the task of the physical therapist; the security provided by its application enabled the physical therapist to be unencumbered in order to concentrate on guiding and improving the gait pattern of the patient.

The findings of this work agree with, and extend the findings of, Barbeau *et al.*, (1) who tested treadmill locomotion under similar conditions. The system as described appears to be of potential benefit to departments engaged

WALKING VELOCITY RATIO

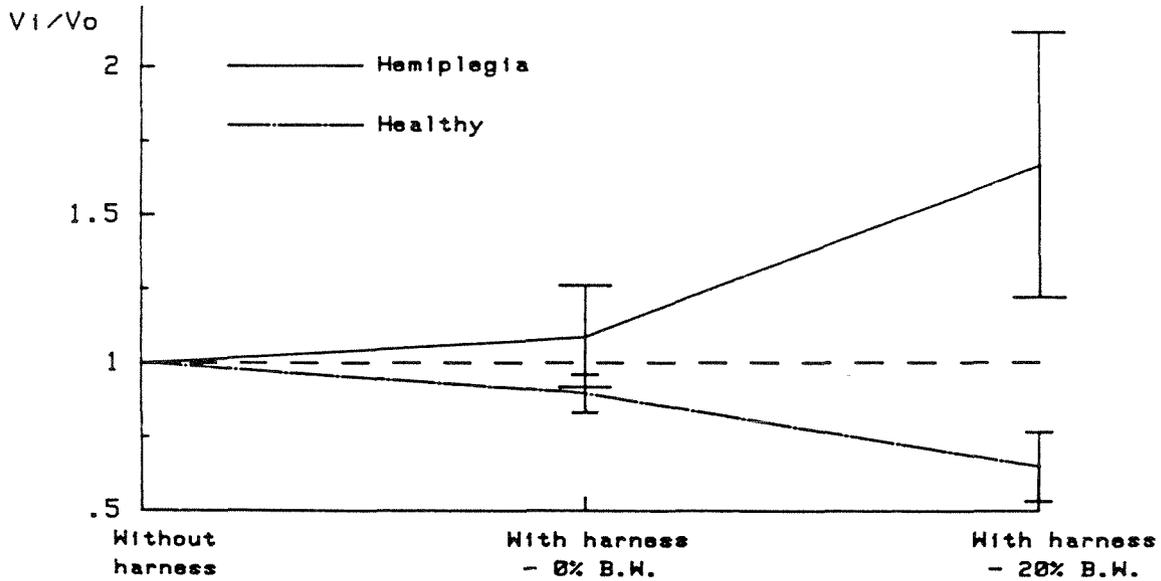


Figure 4. Relative change in walking velocity (V_i/V_o) while walking: a) harnessed to the system without relief of body weight; and, b) with relief of 20 percent of body weight.

STANCE TIME RATIO

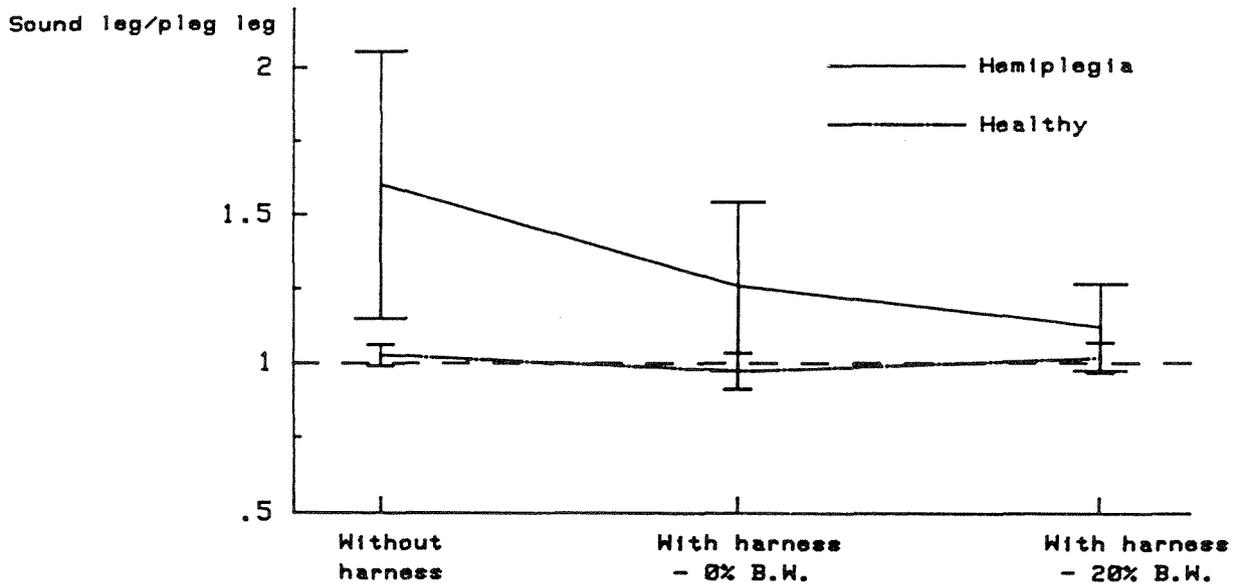


Figure 5. Effect of the weight relief system on the ratio of stance time of the sound LE to the affected LE. (In healthy subjects: Ratio between one LE to the other one.)

SWING TIME RATIO

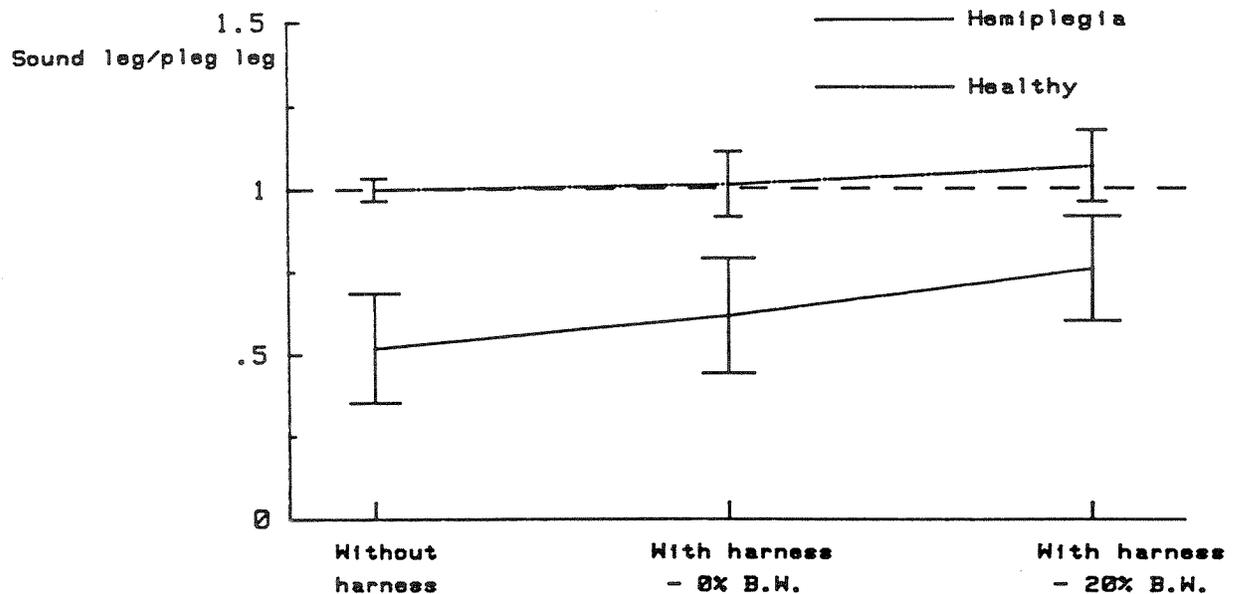


Figure 6.

Effect of the weight relief system on the ratio of swing time of the sound LE to that of the affected LE. (In healthy subjects: Ratio between one LE to the other one.)

in rehabilitation of gait impairments. Potential users are large populations of patients who are temporarily or permanently unable, or restricted from, full weightbearing on one or both lower extremities. Not only is the system useful in gait restoration, it can also be applied for walking reeducation by gradually and progressively loading more weight onto the patient's feet.

Regarding the opposing effect the system had on gait velocity of the patients and the healthy subjects, it must be noted that the walking speed of the latter was on the average 10 times greater than that of the patients. Hence, even after velocity of the healthy subjects decreased by a factor of 0.65, and that of the patients increased by a factor of 1.7, the healthy subjects still walked considerably faster than the patients. The explanation for the decrease in the gait velocity of the healthy subjects lies probably in the restraint the system posed on the forward fall of the head, arms, and trunk (HAT), which characterizes normal gait. Presumably, the relatively slow walking speed of the patients, and their inability to let their HAT accelerate forward, eliminated their awareness of this restriction. Additional planning has to be made in order to overcome this problem in future devices.

On the basis of the preliminary data of this study, several avenues of research become apparent. One of these

should aim to limit the weight-relieving phase to the stance period of the affected LE. Another desired improvement is a system which will assist patients in standing until harnessed. Further modification should be aimed at the construction of a functional weight-relieving device which would operate outside the parallel bars and a more "friendly" frame which would be easier to harness.

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