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Suitability of Body-Weight Supported Treadmill Therapy in Increasing Sports Performance

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Abstract

Background: The high demands on the performance of professional athletes can lead to overloading of the joints of the lower limbs, the occurrence of stress fractures and other associated musculoskeletal problems. Due to the great pressure from sponsors and the environment, it is desirable to speed up post-injury rehabilitation as much as possible. This can lead to re-overloading and re-injury which continues to hold the athlete back from improving their athletic performance.

Methodology: Two hundred and twenty-five experimental body-weight supported treadmill exercises were performed on 15 healthy athletes with the primary aim of evaluating the dependence of the device settings on the physical training difficulty. The relationship between burned calories and the level of weight support/the speed set during the exercise was statistically analyzed and its strength was evaluated using the Pearson correlation coefficient. A simple conversion table between the speeds on a regular treadmill and a body-weight supported treadmill resulting in burning the same amount of calories was proposed.

Results: At low walking speeds, a statistically insignificant relationship between body-weight support level and burned calories was demonstrated. At speeds above 8 km/h, a statistically significant effect of body-weight support was proven, but its strength was evaluated as low. In contrast, the strength of the relationship between speed settings and burned calories was evaluated as high and statistically significant across all body-weight support settings.

Conclusion: Body-weight supported treadmill represents a suitable tool for sports performance enhancement with preserved running difficulty. It brings benefits not only for athletes returning from injury but also for professional athletes who want to increase their performance and at the same time protect the musculoskeletal system from overloading.

Keywords: Antigravity treadmill; Sports training; Athletes; Lower body positive pressure; Heart rate

Introduction

It is assumed that people's sports performance cannot progress indefinitely, which is why sports performances have stagnated in recent years [1]. Achieving records and pushing limits is becoming more and more difficult, which leads to increasing pressure on athletes, their performance and their training methods. Increasing physical and mental stress can lead not only to an improvement in physical performance but also to the emergence of overtraining syndrome, stress fractures and joint overloading associated with other musculoskeletal problems [2]. Generally, among athletes of different sport disciplines, around 6.5%-9.7% is dealing with a stress fracture [3] of which approximately 21.5% is recurrent and 20.7% is associated with the off-season-ending [4]. Such an injury requires several weeks of treatment during which the athlete cannot train fully, which affects his physical condition. An untreated stress fracture can lead to a complete fracture requiring surgical fixation and, in the long term, can promote the development of osteoporosis [4].

Any necessary sports break hinders the athlete's development, prevents his participation in competitive events and significantly affects his career. Therefore, the goal of sports physiotherapists is to speed up recovery and enable the athlete to include physical activities in the rehabilitation program that allows maintaining or even increasing physical condition. Body-Weight Supported Treadmill (BWST) therapy enables rehabilitation with the simultaneous involvement of the patient in the training process. The system provides weight support to the patient during walking or running and thus prevents the overloading of the injured area. Similarly, in healthy athletes, it contributes to reducing the load on the lower limbs and preventing joint and musculoskeletal system overusing. Despite these indisputable advantages, the influence of body weight support on the difficulty of therapy and sports performance remains questionable. Gojanovic aimed at distance runners and the speed at which they can achieve maximum oxygen uptake. It has been found that athletes can reach higher speeds at Body-Weight Support (BWS) level of 85%-95% than with unsupported weight [5]. Grabowski, et al., investigated the effect of BWS on ground reaction forces and metabolic power. The study concluded that even though peak vertical ground reaction forces are reduced when running with weight support at high speeds, the aerobic stimulus is maintained [6]. Similar to Gojanovic and Kline, et al., focused on comparing the metabolic rate and speed achieved while running on a regular treadmill and a BWS treadmill. The output of his research is a conversion table comparing over ground speed with the speed achieved at different BWS levels. These charts represent a promising tool for designing an appropriate rehabilitation and training protocol for elite athletes [7].

Existing studies suggest that an increasing BWS level leads to a reduction in the intensity of running activity. However, it is not clear how strong this dependence is and whether it changes at different speeds and weight loads. The goal of the present research is to evaluate the strength of the dependence between BWS and burned calories and compare it with the dependence of burned calories on speed across the entire spectrum of BWS and speed levels. This will determine the suitability of BWST therapy to improve physical performance. As a secondary outcome measure, a simple conversion table will be made between the speeds on a regular treadmill and a BWST with different BWS settings that burn the same amount of calories.

Materials and Methods

The research was conducted in an independent sports medicine center between April and May 2023.

Subjects

Adult healthy participants who are regularly intensively engaged in running and were willing to confirm their interest by signing an informed consent were included. Those who suffered from any health limitation which might have a direct impact on their performance were excluded. The 1975 Declaration of Helsinki ethical guidelines adopted by the General Assembly of the World Medical Association (1997-2000) and by the Convention on Human Rights and Biomedicine of the Council of Europe (1997) were followed [8].

Protocol

Participants underwent training on a BWST with different speed and weight support settings. The experimental session consisted of introducing the subject to the BWST device, warming up for a maximum of 5 minutes, during which the participant experienced different degrees of weight support and the subsequent experiment itself. This consisted of running at different levels of weight support and measuring heart rate using a BTL ECG-08 Holter device (BTL Industries, Ltd.). An experiment was performed at one speed within one session. Another session was scheduled for another speed setting. During the first session, the subject started at the highest level of unweighting 80% and gradually reached the level of 0%. The second session was performed with an unweighting change in the opposite direction - from 0% to 80%. The last, third measurement, started at a setting of 40% and after a gradual reduction to 0%, an increase to 60% and 80% was initiated. Each subject was randomly assigned to one of the exercise groups. While the first group underwent exercise on a BWST with speed settings of 2, 8 and 16 km/h, the second group underwent walking/running at speeds of 5, 12 and 20 km/h. Participants were not aware of which group they were assigned to, nor were they informed of setting changes during the session.

Body-Weight supported treadmill

The experiment was performed using a BWST device (BTL Industries, Ltd.) intended for gait retraining in patients recovering from musculoskeletal or neurological disorders. This special treadmill enables patients with limited mobility, stability or load-bearing capacity of the lower limb to incorporate walking or running activities into their treatment program at an early rehabilitation stage.

The participant was asked to wear special shorts containing a half-zipper allowing attachment to an inflatable bag. This connection enables sealing the system and creating positive pressure, which subsequently provides the patient with weight support. After the subject is zipped in the inflatable bag surrounding the lower half of his body, the bag is inflated and the system is calibrated to the subject's weight. Subsequently, the operator adjusts the settings (unweighting, inclination and BWS) and the treadmill under the bag starts running.

Data processing

Data processing and statistical analysis took place in the Matlab programming environment using a custom written script (MatLab R2010b, Mathworks, Inc., Narick, MA, USA). When designing the methodology, previous research with a similar focus was taken into account [5-7]. Burned calories were calculated based on equations experimentally designed by Keytel, et al., [9].

For women:

- $$C = \frac{t \cdot (0.4472 \cdot HR - 0.1263 \cdot m + 0.074 \cdot a - 20.4022)}{4.184}$$

- Where “t” represents the activity duration in min, “m” stands for the patient’s weight in kg and “a” is the patient’s age in years. In our case, we calculated with the value t=1 min.

For men:

- $$C = \frac{t \cdot (0.6309 \cdot HR + 0.1988 \cdot m + 0.2017 \cdot a - 55.0969)}{4.184}$$

- Where “t” represents the activity duration in min, “m” stands for the patient’s weight in kg and “a” is the patient’s age in years. In our case, we calculated with the value t=1 min.

For the purpose of calculating the relationship between the BWS and the speed settings and the calculated burned calories, the Pearson correlation coefficient was used. The strength of the relationship between burned calories and the respective setting was evaluated based on the absolute value of the magnitude of the correlation coefficient [10]:

- 0.9-1.0 very high correlation
- 0.7-0.9 high correlation
- 0.5-0.7 moderate correlation
- 0.3-0.5 low correlation
- < 0.3 little if any correlation

A level of p<0.05 was considered statistically significant.

Linear regression was used to fit the calculated data with curves and to design equations describing trend lines for individual BWS settings. Based on these equations, a conversion table was designed to track the difference in speeds needed to burn the same amount of calories on a regular treadmill and a treadmill with different BWS settings.

Results

A total of 15 regular healthy recreational runners were recruited. All were able to complete the entire experimental measurement and none of them experienced any health limitations during the study course. See **Table 1** for group demographics.

Table 1: Participants demographics.

No. of participants	15
Height (cm)	178.53 ± 7.36
Weight (kg)	78.10 ± 9.74
Age (years)	29.20 ± 5.52
Sex (male/female)	12/3

The measured heartbeat values are summarized in **Table 2**. It can be seen that while the heartbeat decreases with increasing BWS value, it increases with increasing speed setting. The same trend can be observed in the effect on calculated burned calories **(Table 3)**.

Table 2: Summary of recorded heartbeat for respective body-weight supported treadmill settings. Data are displayed as mean ± standard deviation.

Heart rate (bpm)	**BWS (%)**				
Speed (km/h)	**0**	**20**	**40**	**60**	**80**
2	87.6 ± 12.88	86 ± 12.61	82.6 ± 13.24	82.4 ± 13.46	78.6 ± 8.76
5	107 ± 13.15	105.4 ± 14.22	100.8 ± 12.30	97.4 ± 12.66	93.4 ± 9.91
8	144.25 ± 16.79	132.38 ± 19.24	123 ± 17.93	111.5 ± 16.42	105.88 ± 16.08
12	169.15 ± 17.48	154.69 ± 20.12	138.54 ± 18.35	123.92 ± 13.94	115.15 ± 11.01
16	182.29 ± 6.18	169 ± 11.90	156.71 ± 15.26	146 ± 14.62	139 ± 13.03
20	178.25 ± 19.28	185.5 ± 14.85	175.33 ± 8.08	167.5 ± 5.8	150 ± 10.42

Table 3: Summary of calculated burned calories for respective body-weight supported treadmill settings. Data are displayed as mean ± standard deviation.

Burned calories	**BWS (%)**				
Speed (km/h)	**0**	**20**	**40**	**60**	**80**
2	3.64 ± 1.30	3.45 ± 1.24	3.04 ± 1.50	3.05 ± 1.67	2.58 ± 0.78
5	6.52 ± 3.22	6.27 ± 3.17	5.71 ± 2.86	5.25 ± 2.62	4.82 ± 2.59
8	12.42 ± 2.97	10.77 ± 3.31	9.51 ± 3.26	7.91 ± 2.99	7.13 ± 2.83

12	15.96 ± 2.54	13.91 ± 2.72	11.69 ± 2.73	9.65 ± 2.01	8.51 ± 2.17
16	19.50 ± 0.90	17.49 ± 1.62	15.64 ± 2.18	14.02 ± 2.17	12.97 ± 1.91
20	18.92 ± 2.62	19.76 ± 1.83	18.28 ± 1.22	17.25 ± 1.15	14.53 ± 1.73

The effect of BWST settings on burned calories is graphically displayed in **Figure 1**. It can be seen that the effect of BWS is significantly lower at walking speeds of 2 and 5 km/h than at running speeds of 8 km/h and higher. This trend is confirmed by statistical analysis, which for walking speeds of 2 and 5 km/h did not show a statistically significant dependence of burned calories on the BWS settings **(Table 4)**. At higher speeds, this relationship reached statistical significance, but its strength was evaluated as low.

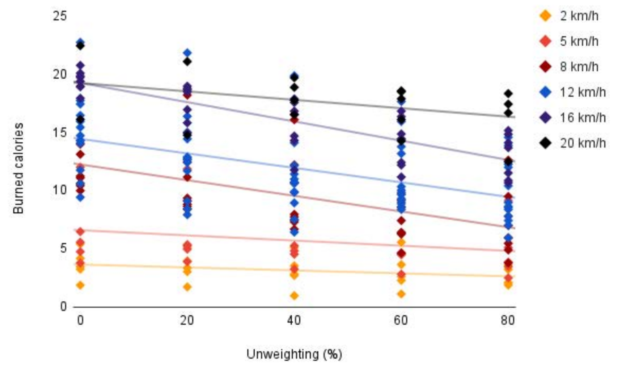

Figure 1: Dependence of the calculated values of burned calories on the body-weight support setting. For better clarity, the data is interspersed with trendlines correspond-ing to respective speed settings.

The dependence of burned calories on the speed setting, as expected, turned out to be stronger and more significant across all BWS settings **(Figure 2)**. The graph shows a lower physical load when using a BWST than when utilizing a regular treadmill. The difficulty of running decreases further as the percentage of BWS increases.

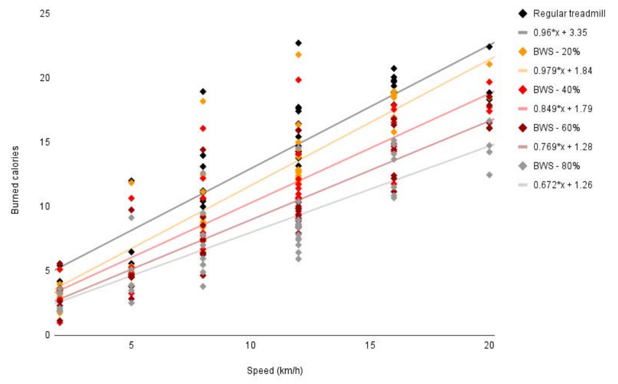

Figure 2: Dependence of the calculated values of burned calories on the speed setting. For better clarity, the data is interspersed with trend lines corresponding to respective body-weight support settings labeled by trend line equation.

The strong relationship between speed settings and calories burned was also confirmed by statistical analysis, which evaluated the correlation as statistically significant and high across all BWS settings **(Table 4).**

Table 4: Statistical analysis of the correlation between burned calories and body-weight support exercise settings. The Unweighting section summarizes the effect of body-weight support level on burned calories at individual speed settings. The Speed section summarizes the effect of speed settings on burned calories at individual body-weight support settings. P values<0.05 are meeting statistical significance.

	Pearson	**Relationship**	**P<0.05**
Unweighting			
Speed=2 km/h	-0.307	low negative	0.164
Speed=5 km/h	-0.333	low negative	0.261
Speed=8 km/h	-0.348	low negative	<0.001
Speed=12 km/h	-0.341	low negative	<0.001
Speed=16 km/h	-0.336	low negative	<0.001
Speed=20 km/h	-0.315	low negative	0.003

Speed			
BWS=0%	0.875	high positive	<0.001
BWS=20%	0.886	high positive	<0.001
BWS=40%	0.871	high positive	<0.001
BWS=60%	0.882	high positive	<0.001
BWS=80%	0.857	high positive	<0.001

Based on the relationship between speed and burned calories at different BWS levels, a conversion table was created **(Table 5)**. When running on a BWST, as the BWS setting increases, the difference between the amounts of calories burned compared to a regular treadmill also increases. Therefore, training requires a higher speed setting.

Table 5: Conversion table between BWS level and the speed needed to burn the same amount of calories per minute as on a regular treadmill. Values are displayed as a percentage increase.

0% BWS (Regular treadmill)	20% BWS	40% BWS	60% BWS	80% BWS
2 km/h	75.18%	104.95%	159.43%	198.36%
5 km/h	28.91%	49.82%	78.67%	105.06%
8 km/h	17.34%	36.04%	58.49%	81.73%
12 km/h	10.91%	28.39%	47.27%	68.77%
16 km/h	7.70%	24.56%	41.66%	62.30%
20 km/h	5.77%	22.26%	38.30%	58.41%

Discussion

The current study demonstrated that treadmill speed settings have a significantly greater effect on burned calories than the level of BWS. The influence of BWS was evaluated as statistically insignificant at walking speeds of 2 km/h and 5 km/h and as statistically significant at speeds above 8 km/h. The strength of this relationship was evaluated as low across the entire speed spectrum. This finding is consistent with the conclusion of Hoffman, et al., who found that to maintain a given metabolic demand, increasing levels of BWS require much greater increases in speed with running than with walking [11]. The negligible effect of BWS on burned calories when walking at a low speed can be considered a promise especially in the rehabilitation of patients immediately after surgery of the musculoskeletal system, whose condition does not allow a full weight load. These patients do not have many opportunities to burn calories during exercise and at the same time, if they are elite athletes, they want to stay in shape. Although this is beyond the scope of this study, a low-speed walking program might be promising in the rehabilitation of neurological patients who need to maintain metabolic output.

Although statistically significant, the low dependence between BWS and burned calories makes exercise a suitable tool for building physical condition in athletes. Running remains physically demanding and the small difference between a regular and a BWST can be compensated by setting a higher speed, which, on the contrary, has shown a high effect on the burned calories. For this purpose, a conversion table was designed to compensate for the physical demands of training at a higher BWS setting by increasing the speed setting.

Such findings are in line with existing clinical evidence, which lacks an evaluation of the magnitude of the correlation, but the trend of dependence and possible compensation of physical demands with increased speed corresponds to current research [5-7]. This fact encourages the use of BWST therapy for speed training of athletes, allowing them to run at higher speeds with lower metabolic demand.

The above mentioned findings and the mechanism of action make the BWST a suitable tool for running training for athletes. As a result of the reduction of the weight load during exercise, there is a decrease in ground reaction forces and thus also the elimination of the risk of musculoskeletal system overloading [6]. Athletes can thus devote themselves to intensive physical training without the risk of a stress fracture, joint overloading and other musculoskeletal problems resulting from overtraining.

Some limitations of this study must be mentioned. Participants had no set limit determining their level of physical fitness, which would be part of the inclusion criteria. For this reason, the physical fitness of the subjects varied quite a bit. To reduce the influence of their different physical abilities, the participants were randomly divided into two groups that completed running or walking at three different speeds. In the future, however, it will be more appropriate to set a physical performance limit (*e.g.* time for 1 km) and have the subjects complete all speed tests. For the greater relevance of the findings, it would be appropriate to repeat the experiment with non-athletes or with athletes in a different phase of rehabilitation after musculoskeletal surgery. Possible extensions of the existing experiment will be left as a research option to other future trials.

Conclusion

The study showed that despite the relief of the musculoskeletal system during running, the physical demands of sports training on a BWST is maintained. In case of walking at speeds lower than 5 km/h, no statistically significant dependence between BWS and burned calories was demonstrated. At higher speeds, this dependence reached significance but was evaluated as low. BWST represents a suitable tool for sports performance enhancement. It brings benefits not only for athletes returning from injury but also for professional athletes who want to increase their performance and at the same time protect the musculoskeletal system from overloading.

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