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Original Research

Training on a Lower Body Positive Pressure Treadmill with Body Weight Support does not Improve Aerobic Capacity

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ABSTRACT

International Journal of Exercise Science 14(7): 829-839, 2021. This study examined the physiological changes resulting from training on a lower body positive pressure treadmill (LBPPT) at three different levels of body weight support (BWS). Thirty-three healthy college aged students (22.3 ± 3.1 years) completed the study. Participants performed a graded exercise test (GXT) to exhaustion and were placed into one of three experimental groups corresponding to 100%, 75%, and 50% of their normal BW. Participants trained at their experimental BW levels for eight-weeks. Training speed was monitored by heart rate (HR) and speed was adjusted to elicit approximately 60% of participant's peak oxygen uptake ($\dot{V}O_{2peak}$) at normal BW prior to including body weight support (BWS). One-way analysis of variance (ANOVA) was used to compare the change in aerobic capacity. The 100% BW group improved their relative $\dot{V}O_{2peak}$ (1.42 ± 1.52 ml $\cdot$ min^{-1} $\cdot$ kg^{-1}) when compared to the 50% BW group (-0.87 ± 2.20 ml $\cdot$ min^{-1} $\cdot$ kg^{-1} [p = .022]) but not the 75% BW group (-0.16 ± 1.92 ml $\cdot$ min^{-1} $\cdot$ kg^{-1}, [p = .14]). Furthermore, no statistical differences in $\dot{V}O_{2peak}$ were observed between the 75% and 50% BW groups (p = .66). Based on this study, training at 75% and 50% of normal BW on a LBPPT does not improve aerobic capacity compared to training with no BWS when using training speeds derived from a GXT with full BW. The outcome of this study may help to prescribe training speeds while utilizing a LBPPT to maintain or improve aerobic capacity.

KEY WORDS: Anti-gravity, running, injury, performance

INTRODUCTION

In any calendar year, up to 70% of all runners experience an overuse running injury (32). Overuse injuries result from repeated application of stresses below the absolute failure threshold of a tissue, but with insufficient recovery time between applications (6, 27, 30). While too high an amount or too frequent an application of stress can lead to injury, certain amounts are required for muscle, tendon, ligament, and bone adaptation (5, 16). Aerobic training associated with running can also enhance functions of the cardiorespiratory system and the oxidative capacity of skeletal muscle (19). In efforts to obtain these musculoskeletal adaptations, while improving aerobic capacity and avoiding injury, a possible supplemental training program which presents repeated stress below the mechanical limits of a structure could be incorporated. One method for reducing repetitive stress while walking or running is the use of body weight support (BWS) training devices and methods. Examples of such devices include: the harness system (14), deep water running (1), and the lower body positive pressure treadmill (LBPPT) (9).

Harness systems and deep water running have been shown to be effective in reducing BW during exercise and popular in rehabilitation populations (1, 9, 17), because it provides a means of safety for individuals, however, they do have limitations (2, 15, 20). The harness systems become uncomfortable with increasing support and after long time durations (13). Grabowski and Kram also stated harness systems can impede circulation, and therefore may be inadequate for certain populations (13). In deep water running, it may not be safe for individuals with open wounds or surgical incisions during post-operative periods since it can increase risk of infection (3). Further, muscle recruitment when running on land is different than deep water running (11).

An alternative to harness systems and deep water running is the LBPPT. The LBPPT uses differential air pressure technology to regulate the amount support applied to a person as they use the device. When using a LBPPT, individuals wear a specific pair of compression shorts which zip into a plastic bubble surrounding the treadmill. By manipulating the air pressure inside the bubble, the LBPPT applies an upward directed force on the pelvis which effectively allows one to walk or run on the treadmill with BWS. A variety of populations ranging from clients in rehabilitation to highly trained athletes utilize LBPPTs (18). Previous studies have shown the LBPPT can lower the magnitude of impact forces as well as reduce energy expenditure and oxygen consumption while walking and running compared to over ground running, (9, 10, 13, 14, 27). Compared to no support conditions, Hoffman et al. found that reducing BW using a LBPPT also results in lower HR, blood pressure during exercise. (18). They concluded speed must be increased to match $\dot{V}O_2$ of 100% BW when running at reduced BW (18).

To date, most physiology studies using the LBPPT have examined acute changes and little is known regarding the physiological adaptations from training with reduced BW on the LBPPT. Understanding the physiological adaptations to chronic training on a LBPPT would clarify the role of this tool for improving fitness and athletic performance while reducing load and injury risk, or for maintaining fitness while rehabilitating following an injury. Therefore, the purpose of this study was to examine the effects of an eight-week training program on a LBPPT utilizing different levels of BW. Based on the literature of the acute LBPPT studies (9, 10, 27), it was hypothesized that there would be a difference in aerobic capacity observed at all percentages of BW following the eight-week training period.

METHODS

Participants

An a priori power analysis was performed using the G*Power software (8), and it was determined that thirty-three participants would be needed to power this study for detection of a medium effect size with an alpha of 0.05, and a power of 0.80. To account for possibility of drop out, forty-two college aged students were recruited to participate. All participants completed a written informed consent, a health-history questionnaire, and were classified as "low-risk" by American College of Sports Medicine (ACSM) criteria (26) prior to participation. Protocols for this study were approved by the University's institutional review board for the protection of human participants. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (25).

Protocol

Body height and mass were measured using a stadiometer (Seca stadiometer, Chino, CA, USA) and scale (Mettler Toledo, Model 8510100 Pomona, CA, USA), after which a graded exercise test (GXT) was performed by each participant. Graded exercise tests were performed on a Trackmaster TMX425 treadmill (Full-Vision, Newton, KS, USA) utilizing a Parvo Medics TrueOne® 2400 automatic metabolic measurement system (Parvo Medics, Sandy, Utah, USA). Heart rate (HR) was monitored using a Polar® Electro H1 Heart Rate Monitor (Polar Electro Inc., Lake Success, NY, USA) which was strapped around participant's chest. For our GXT, a modified Åstrand treadmill protocol was used. The protocol for the GXT consisted of three minutes of sitting at rest followed by a five minute warm-up at a speed of 4.03 km · hr^{-1}. Participants then ran at 8.86 km · hr^{-1} with the grade of the treadmill increasing 2.5% every two minutes. The GXT continued to volitional fatigue and concluded when the participants signaled they could no longer continue. The highest $\dot{V}O_2$ from the GXT was determined as their $\dot{V}O_{2peak}$. After the GXT, participants proceeded to cool-down at 4.03 km · hr^{-1} for at least five minutes. Following the GXT, participants who were deemed to have a "very-poor" fitness level based on their age and $\dot{V}O_{2peak}$, according to the ACSM guidelines, were excluded from the study (26).

Participants were placed into one of the three experimental groups by training status (trained or untrained) based upon initial $\dot{V}O_{2peak}$ values. To account for differences in the initial fitness levels and to balance the groups, participants were placed into their group based upon the results of the GXT. At least two days after the GXT, participants completed a familiarization session on the LBPPT (AlterG®, Fremont, CA, USA) running at their prescribed training speed at each of the three experimental bodyweight (BW) levels: 100%, 75%, and 50% of their normal BW. Even though participants only trained at one level of BW for their training sessions, familiarization trials were conducted at all three levels due to a biomechanical study being conducted in parallel with this one. Since $\dot{V}O_2$ was not measured during the familiarization and training sessions, a HR that corresponded to 60% of their $\dot{V}O2_{peak}$ was used to help determine the initial target speed for each training session. This has been found to be the minimum level required to improve aerobic capacity at least three training sessions per week (29). The familiarization session consisted of five minutes of standing, five minutes of warm-up at 4.03 km · hr^{-1} at 100% BW, and ten minutes of running at each experimental BW condition starting at 100%, 75%, and finally 50% at their prescribed training speed. Participants finished with a five-minute cool-down at the same speed as the warm-up at 100% BW. The 100%BW group, with no additional support, still completed their training sessions on the LBPPTs. Since $\dot{V}O_2$ was not measured during the familiarization or training sessions, the first two training sessions were used to establish the target HR by averaging the HR obtained from the two training sessions while running at the prescribed level of BW.

At least two days after the familiarization session, participants began an eight-week training program on the LBPPT at their assigned BW level. Participants trained three times per week and heart rate was continuously recorded during the training sessions. In addition, participants reported their rating of perceived exertion (RPE) every three minutes of exercise on a Borg 6-20 scale. If a participant was unable to run on a scheduled day, they made up the missed session by running on consecutive days, but no more than two days at a time. A training session consisted of five minutes of standing in the LBPPT, a five minute warm-up of 4.03 km $\cdot$ hr^{-1} at 100% BW, thirty minutes of running at their prescribed training speed, and finally a cool-down at the same speed as their warm-up at 100% BW. In total, twenty-four training sessions were completed in eight weeks. A progressive training protocol was used whereby training speed was increased across the eight weeks when training HR dropped below 5 b $\cdot$ min^{-1} of their target HR in consecutive training sessions. Once the eight-week training session was complete, participants completed another GXT to exhaustion no more than a week following their last training day. Participants were instructed to refrain from exercise outside the study's training sessions, avoid consuming meals two hours prior to exercise/training, stay hydrated before and during exercise/training sessions, and not to consume caffeine-containing products for a minimum of twelve hours before exercise/training sessions.

Statistical Analysis
A one-way analysis of variance (ANOVA) was used to evaluate differences between the experimental BW groups for the average HR, RPE, and training speed across the entire training sessions. In addition, one-way ANOVAs were used to compare differences in pre-training variables and changes from pre- to post-training across groups. Pre-training variables included: age, height, body mass, relative $\dot{V}O_{2peak}$ and HR_{peak}. A repeated measures ANOVA was used to compare the training sessions within the 100%, 75%, and 50% BW groups for HR, RPE, and training speed. Where a significant omnibus result was obtained, post hoc comparisons between experimental groups were evaluated using the Bonferroni correction. When the assumption of sphericity was violated, a Greenhouse-Geiser correction was made to correct the F-value. For all statistical evaluations, an alpha of less than .05 was used to indicate statistical significance. If a statistical significance was observed, an effect size (ES) was calculated using Cohen's d (d) or Steiger's psi (Ψ) for one-way ANOVA. All statistical analysis was performed using Statistical Package for the Social Sciences (SPSS Statistics Version 22, SPSS, Chicago, IL.).

RESULTS

In total, thirty-three participants (eleven participants in each experimental BW group) completed all phases of the experiment (14 males and 19 females, age: 22.3 ± 3.1 years, 44.4 ± 8.36 ml $\cdot$ min^{-1} $\cdot$ kg^{-1}). Nine participants were excluded due to a poor $\dot{V}O_{2peak}$ for their age category, injuries sustained outside the study, or not being able to adhere to the training schedule due to personal time constraints. There were no differences among groups with regard to pre-training age, height, weight, relative $\dot{V}O_{2peak}$, or HR_{peak} ($p > .05$).

Physiological Data

There were no differences HR_{peak}, absolute $\dot{V}O_{2peak}$, $\dot{V}_E$, RER, and time of exercise test (Table 1) from pre- to post-training. There was a significant difference between the experimental groups when observing the changes in relative $\dot{V}O_{2peak}$ from pre- to post-training (p = .025, Ψ = .65). The 100% BW group demonstrated an increased change in relative $\dot{V}O_{2peak}$ (+1.42 ± 1.52 ml ·min^{-1} ·kg^{-1}) compared to the 50% BW group (-0.87 ± 2.20 ml ·min^{-1} ·kg^{-1}, p = .022, d = 1.21) but not the 75% BW group (-0.16 ± 1.92 ml ·min^{-1} ·kg^{-1}, p = .14, d = .91). Changes experienced by the 75% and 50% BW groups were not different (p = .66, d = .34).

Table 1. Physiological variables measured before and after training on the LBPPTs at three different BW levels. All statistical values were determined by measuring the change scores.

	100% BW		75% BW		50% BW		
	Pre-	Post-	Pre-	Post-	Pre-	Post-	P - value
HR_{peak} (b · min^{-1})	193 ± 8.79	194 ± 7.94	191 ± 8.97	190 ± 6.37	193 ± 8.58	197 ± 6.38	.47
Absolute $\dot{V}O_{2\,peak}$ (l · min^{-1})	3.28 ± 1.09	3.37 ± 1.06	3.28 ± 0.96	3.28 ± 0.88	2.89 ± 0.69	2.86 ± 0.66	.09
Relative $\dot{V}O_{2\,peak}$ (ml · min^{-1} · kg^{-1})	46.0 ± 9.35	47.4 ± 8.40	44.6 ± 8.46	44.5 ± 7.59	42.6 ± 7.62	41.7 ± 7.35	.025*
Ventilation (l · min^{-1})	117 ± 31.8	119 ± 35.2	115 ± 31.3	114 ± 29.3	107 ± 18.5	109 ± 21.8	.74
RER	1.21 ± 0.06	1.19 ± 0.08	1.17 ± 0.04	1.16 ± 0.06	1.19 ± 0.06	1.21 ± 0.06	.19
Time of Exercise Test (minutes)	9.87 ± 3.40	10.3 ± 2.94	9.61 ± 2.60	9.71 ± 2.59	8.79 ± 2.75	8.80 ± 2.80	.58

Values are expressed as mean ± SD. P-values are based on one-way ANOVAs. * = significant on p < .05.

Training Data

The average of the total eight-week training HR data showed that the 100% BW group had the highest average $\%HR_{peak}$ among the three groups (80.9 ± 4.66%), followed by the 75% (72.6 ± 6.2%) and 50% BW group (68.2 ± 6.8%; Table 2; Figure 1). The training HR% for the 100% BW group was statistically higher than the 75% and 50% BW groups (p = .001, d = 1.51 and p < .001, d = 2.18 respectively), but no difference in average training HR% was observed between the 75% and 50% BW groups (p = .054, d = .68). Additionally, there was a significant main effect for sessions (p < .001) where session 9 (72.7 ± 8.7%) was significantly lower in HR compared to session 1 (76.2 ± 8.4%; p = .001, d = .41).

Table 2. Average % of peak heart rate (HR), rating or perceived exertion (RPE), and training speed for all participants throughout the 24 training sessions.

	100% BW	75% BW	50% BW	P - value
HR (%) of peak	80.9 ± 4.66	72.6 ± 6.15*	68.2 ± 6.83*	< .001
RPE	11.0 ± 1.30	9.56 ± 1.04*	9.35 ± 1.13*	< .001
Training speed (km · hr^{-1})	8.68 ± 1.15	9.0 ± 1.08	9.29 ± 1.30	.415

Values are expressed as mean ± SD. P-values are based on one-way ANOVAs. * = significant difference from 100% BW (p < .05).

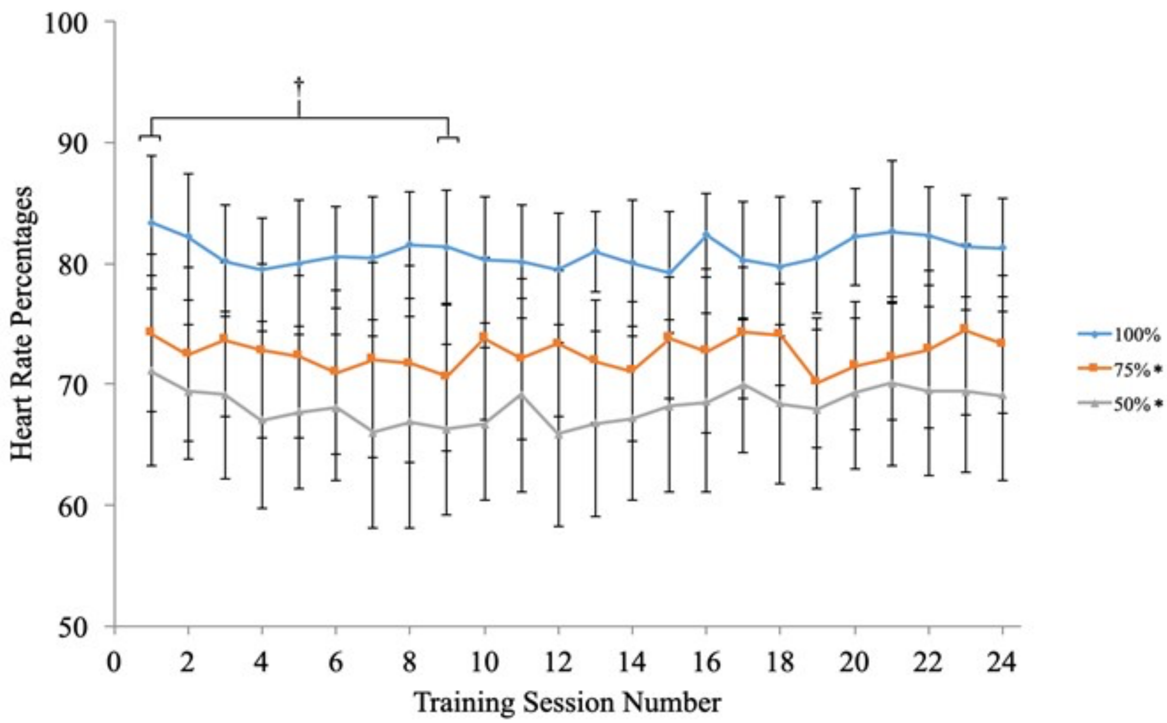

Figure 1. Shows the HR percentages for each experimental group throughout all the training sessions. Heart rate percentages are based on HR_{peak} found during the GXT. Values are expressed as mean ± SD. *Denotes difference from 100% BW, $p < .05$. † Denotes difference from session 1, $p < .05$.

The average training speed was also recorded for the three BW groups (Table 2, Figure 2). All three BW groups started at approximately the same training speed for the first training session, but were adjusted accordingly based on a drop in average training HR in consecutive training sessions. No statistical difference in average training speed was observed between groups (p = .415), however there was both a significant main effect of session (p < .001) and interaction effect between group and session speed (p < .001). Session speed was significantly faster starting at session 10 compared to session 1 and continuing until the final training session (p < .01). The effect size (d) for training sessions 10 to 24 compared to session 1 were as follows: .48, .56, .65,

.70, .86 .94, .94, .97, .97, 1.03, 1.08, 1.16, 1.17, 1.15, and 1.15. Furthermore, the training speed was significantly faster for the 50% BW group compared to 100% BW but not the 75% BW group starting at session 19 also continuing to the final training session ($p < .05$). The effect size (Cohen's d) for session 19 to 24 were as follows: 1.04, 1.16, 1.11, 1.02, 1.05, and 1.05. There were no differences in speed between the 50% and 75% BW groups across sessions ($p > .05$).

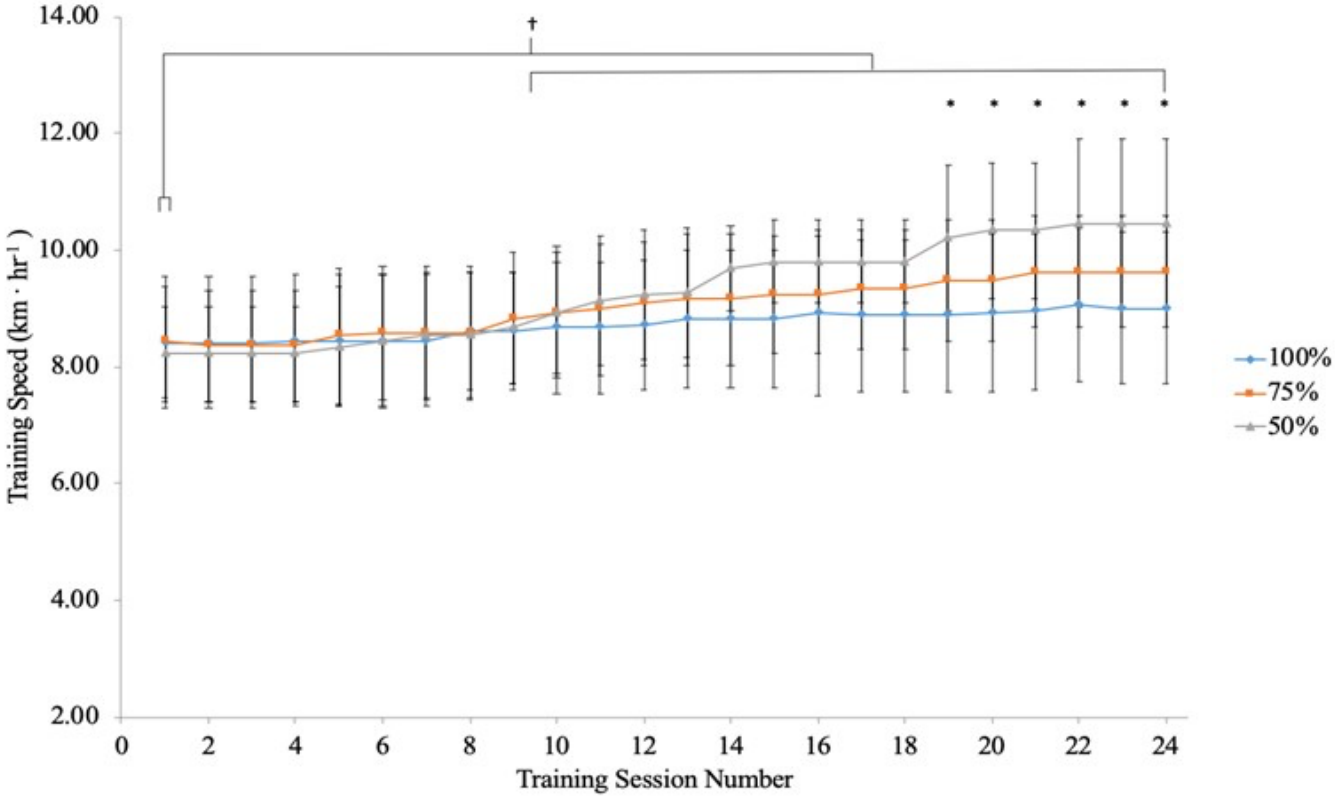

Figure 2. Shows the average training speed for each experimental group throughout all the training sessions. Values are expressed as mean ± SD. There was no statistical difference in the starting training or average training speeds between the three experimental groups. * Denotes difference between 50% and 100% BW groups, $p < .05$. † Denotes difference from session 1, $p < .05$.

The average RPE recorded during the training sessions of the 100% BW group (11.0 ± 1.3) was higher than the 75% BW (9.56 ± 1.04, $p = .001$, $d = 1.22$) and the 50% BW (9.35 ± 1.13, $p < .001$, $d = 1.35$) groups. No statistical difference was observed between the 75% and 50% BW groups ($p = .84$, $d = .19$).

DISCUSSION

This study examined the effects of training eight-weeks on an LBPPT at different percentages of BW using a prescribed speed corresponding to 60% VO_{2peak} from a GXT. With the increasing prevalence of LBPPTs in rehabilitation clinics and to supplement training for athletes, it is important to understand how using different percentages of BW may influence physiological adaptations to training. The main outcome from this study is that running at approximately 60% $\dot{V}O_{2peak}$ at 100% of normal BW increases aerobic capacity after 8 weeks of training but not at 75%

or 50% of normal BW on a LBPPT. Furthermore, the results from the training data agree with previous studies showing a decline in HR during steady state running with reduced BW (18, 12). It is therefore concluded that prescribed running speeds derived from a GXT at normal BW are inadequate for increasing aerobic capacity while training at 75% and 50% of one's BW on a LBPPT. Even though aerobic capacity did not improve in the 75% BW group, no change was observed in $\dot{V}O_{2peak}$ after eight-weeks of training. Therefore, this could be a positive benefit to clients trying to maintain aerobic capacity for a period of time, while trying to recover from or prevent an injury. However, further investigation would need to be done in order to assess this potential benefit to running on an LBPPT at 75% BW at a moderate intensity.

For all groups, the intensity of the training protocol was set to 60% of the participant's $\dot{V}O_{2peak}$ observed at 100% BW as this is the minimum intensity needed to elicit an improvement in aerobic capacity (29). Acute studies have shown that if running speed is constant during an exercise session, HR and $\dot{V}O_2$ decrease linearly with reduced BW (18, 27). We decided to incorporate a progressive training program that increased treadmill speed throughout the training period to maintain the desired training HR of each participant. This allowed for the maintenance of the average training HR% for all groups to be greater than the ACSM recommended range of 64%-76% of max HR to be considered moderate intensity aerobic exercise, and should have been enough to elicit improvements in aerobic capacity for all groups (26). Yet this was not the case, as there were no improvements in aerobic capacity for the 75% and 50% BW groups.

Modifications of treadmill speed were implemented to maintain desired target HR's. Across all groups, average session speed started increasing at session 10 with the greatest overall increase in speed occurring in the 50% BW group (23.31%) and diminishing speed increases with the 75% (14.24%) and 100% (7.65%) BW groups. Despite the greater adjustments to speed in the groups using lower percentages of BW, aerobic capacity failed to improve after the 24 sessions. Hunter and colleagues (2014) derived an equation to predict the change in running speed required to elicit similar metabolic costs when reducing BW. Based on the initial speeds of 8.64 $km \cdot hr^{-1}$ at normal BW, similar metabolic costs could be achieved by increasing speed 27% and 55% when running at 75% and 50% of normal BW, respectively (21). Farina and colleague derived similar equations, suggesting that to achieve the same metabolic cost when running at 9.0 $km \cdot hr^{-1}$ at 100% BW, speeds of 13.68 $km \cdot hr^{-1}$ and 18 $km \cdot hr^{-1}$ would be needed while running at 75% and 50% of normal BW, respectively (7). Since the previous studies had yet to be publisheds prior to data collection in our study, it was not possible to take these equations into account when establishing our methodology. These increases in speed are substantially more than those used in the current study. The initial running speed of participants in the current study was selected to correspond with 60% $\dot{V}O_{2peak}$ gathered from the baseline GXT performed at 100% BW. The reasoning behind this approach is due to the likelihood that users of LBPPTs may attempt to choose training speeds in relation to performance at full BW. Identifying the target speed and HR while measuring gas exchange during GXTs performed at reduced BW on a LBBPT would likely have resulted in the usage of higher speeds possibly resulting in improved aerobic capacity.

Mechanistically, the lack of improvements in aerobic capacity in the 75% and 50% BW groups can be explained by the metabolic cost of generating force hypothesis. Originally proposed by Taylor and colleagues in 1980, the hypothesis states that the metabolic cost of running can be determined based on the average vertical force applied to the ground and the rate at which this force must be applied (31). Running on an LBPPT may influence both parameters. As percent BW decreases, the average vertical force applied to the ground decreases. The effects on contact time are more variable, with studies showing increases (14), decreases (27), and no difference in contact time with unloading (28). Even if contact time does not change, reducing the vertical force required while running with body weight support would reduce the overall metabolic cost, and thus reduce any potential training effect.

Kipp and colleagues recently updated the cost of generating force hypothesis to show that across a wide range of velocities, the rate of force generation and the volume of active skeletal muscle accounts for 98% of the metabolic costs (22). Numerous studies have reported that muscle activity in major muscle groups decreases with decreasing percentages of BW (21, 23, 24, 28). Thus, the combined effects of less active skeletal muscle and the reduced vertical forces needed with higher body weight support likely explain the lack of improvements in aerobic capacity at 75% and 50% BW conditions. Determining which element is most responsible requires further research but would be essential for optimizing training protocols on LBPPTs.

Another possible explanation for the lack of improvement in the 75% and 50% BW groups could be the positioning of the participants in the LBPPT cockpit. Chang and Kram have shown that in addition to vertical forces, the horizontal forces produced are also important for running economy (4). Grabowski and Kram reported that LBPPT devices can apply horizontal assistance forces which reduced the metabolic costs of running (14). In the current study the position of the runner in the LBPPT was not controlled so it is possible they may have been running at higher speeds, and with a HR that should have elicited an improvement in aerobic adaptations, however with a lower metabolic cost due to horizontal assistance. This effect should be considered in future training studies involving LBPPTs.

Based on the current study, training speeds derived from a GXT at normal BW for usage during training sessions on a LBPPT at 75% and 50% of normal BW show that with increasing support, HR and RPE concomitantly drop. When support was applied in the form of differential air pressure from the LBPPT, the effects of training are reduced and therefore an improvement in aerobic capacity was not observed when compared to running at 100% BW. In conclusion, contrary to our hypothesis, training on a LBPPT at 75% or 50% of normal BW does not improve aerobic capacity when compared to running at 100% of normal BW at a moderate intensity. These results have implications for improving methods for designing exercise prescriptions using LBPPTs. Specifically, it is recommended to be cautious when designing exercise prescriptions on LBPPTs derived from a GXT with full BW as intensity may be insufficient to increase aerobic capacity when training with reduced BW.

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