Fleckenstein D[1,4], Ueberschär O[2,3], Wüstenfeld JC[4], Wolfarth B[1,4,5]

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Physiological and Metabolic Reaction to Lower Body Positive Pressure Treadmill Running

Physiologische und metabolische Reaktionen auf dem Anti-Schwerkraft-Laufband

Summary

- **Aim:** The aim of the present study was to investigate the reactions of oxygen consumption ($\dot{V}O_2$), heart rate (HR) and lactate accumulation (La) when running on lower body positive pressure treadmills (LBPPT).
- **Methods:** 15 well-trained male athletes ($\dot{V}O_2$peak: 60.2±3.8ml kg^{-1} min^{-1}) completed in randomized order three analogous maximal incremental treadmill tests, recording spiroergometrical data using breath-by-breath analysis. Two tests were held on a LBPPT, with 80% and 60% body weight (80% BW_{Set} and 60% BW_{Set}), respectively. The third test was completed on a conventional treadmill (100% BW_{Set}).
- **Results:** Average of all running speed stages from 10 to 18km h^{-1}, $\dot{V}O_2$ decreased significantly from 48.1±8.4 via 39.7±6.8 to 33.5±7.3ml kg^{-1} min^{-1} at 100%, 80% and 60% BW_{Set} ($p<0.001$). HR was on average 15 bpm and 27 bpm lower at 80% and 60% BW_{Set} compared to 100% BW_{Set} ($p<0.001$), while La decreased from 2.5±2.3 via 1.5±1.1 to 1.1±0.5 mmol l^{-1} ($p<0.001$).
- **Conclusion:** $\dot{V}O_2$, HR and La are clearly changed by LBPPT running. Furthermore, regression analyses showed that training at a fixed $\dot{V}O_2$ stimulus leads to higher lactate values on the LBPPT compared to the conventional treadmill, which may indicate a change in energy contributions.

Zusammenfassung

- **Zielstellung:** Das Ziel der Studie bestand darin, die physiologischen und metabolischen Anpassungen in Form von Sauerstoffaufnahme ($\dot{V}O_2$), Herzfrequenz (HF) und kapillarer Laktatkonzentration (La) während des Laufens auf einem Anti-Schwerkraft-Laufband (ASL) zu erfassen.
- **Methodik:** 15 trainierte männliche Ausdauerathleten ($\dot{V}O_2$peak: 60,2±3,8ml kg^{-1} min^{-1}) absolvierten drei identische Laufband-Stufentests in randomisierter Reihenfolge, bei denen spiroergometrische Daten sowie kapillare Laktatkonzentrationen erfasst wurden. Zwei Tests fanden auf dem ASL statt, bei 80% bzw. 60% des Körpergewichts (80% KG und 60% KG). Der dritte Test wurde auf einem herkömmlichen Laufband bei gesamtem Körpergewicht absolviert (100% KG).
- **Ergebnisse:** Über die Geschwindigkeiten von 10-18km h^{-1} reduzierte sich die $\dot{V}O_2$ im Mittel signifikant von 48,1±8,4 über 39,7±6,8 auf 33,5±7,3 ml kg^{-1} min^{-1} bei 100%, 80% und 60% KG ($p<0.001$). Die HF sank um 15 (80% KG) bzw. 27 (60% KG) Schläge pro Minute im Vergleich zum Wert bei 100% KG. Die La reduzierte sich von 2,5±2,3 via 1,5±1,1 auf 1,1±0,5mmol l^{-1} ($p<0.001$).
- **Fazit:** $\dot{V}O_2$, HF und La sind während des Laufens auf einem ASL signifikant reduziert. Zudem zeigen Regressionsanalysen, dass bei einer festgelegten Belastung (% $\dot{V}O_2$peak) auf dem ASL höhere La ermittelt werden. Diese Anpassung gilt es bei Trainingsinterventionen zu beachten.

KEY WORDS:
AlterG, Hypogravity, LBPPT, Anti-Gravity, Oxygen Consumption

SCHLÜSSELWÖRTER:
AlterG, Teilschwerelosigkeit, Teilgewichtsentlastung, Sauerstoffaufnahme

1. HUMBOLDT-UNIVERSITY BERLIN, *Department of Sports Science, Berlin, Germany*
2. INSTITUTE FOR APPLIED TRAINING SCIENCE LEIPZIG, *Department of Biomechanics, Leipzig, Germany*
3. MAGDEBURG-STENDAL UNIVERSITY OF APPLIED SCIENCE, *Department of Engineering and Industrial Design, Magdeburg, Germany*
4. INSTITUTE FOR APPLIED TRAINING SCIENCE LEIPZIG, *Department of Sports Medicine, Leipzig, Germany*
5. CHARITÉ - UNIVERSITÄTSMEDIZIN BERLIN, *Department of Sports Medicine, Berlin, Germany*

CORRESPONDING ADDRESS:
M.Sc. Daniel Fleckenstein
Department of Sports Medicine
Institute for Applied Training Science
Marschnerstraße 29
04109 Leipzig, Germany
: fleckenstein@iat.uni-leipzig.de

Introduction

Middle-distance and long-distance running success is influenced by the physiological factors of maximal oxygen uptake ($\dot{V}O_2$max) (16, 29), running economy (RE) (5, 27, 29, 33), utilization of $\dot{V}O_2$max (% $\dot{V}O_2$max) (2, 26) and the running speed at the anaerobic threshold (vAT) (7, 40, 41). To improve those parameters, high training volumes are commonly realized (3, 39).

Inevitably, high training volumes imply increased mechanical stress to the musculoskeletal system. Altogether, 37-56% of all runners incur at least one running-related injury per year, while 1000 hours of training statistically result in 2.5-12.1 injuries (42). To avoid overuse injuries and their repercussions of training reduction or cessation, elite coaches and runners have been seeking and adopting ›

Table 1

General characteristics of participants (n=15) included in the study.

MEASURE	MEAN±SD
Age (y)	30.2±6.8
Height (cm)	180.8±6.0
Body mass (kg)	73.1±5.7
VO2peak (ml kg^{-1} min^{-1})	60.2±3.8
Personal best 10km (min:ss)	34:06±2:26

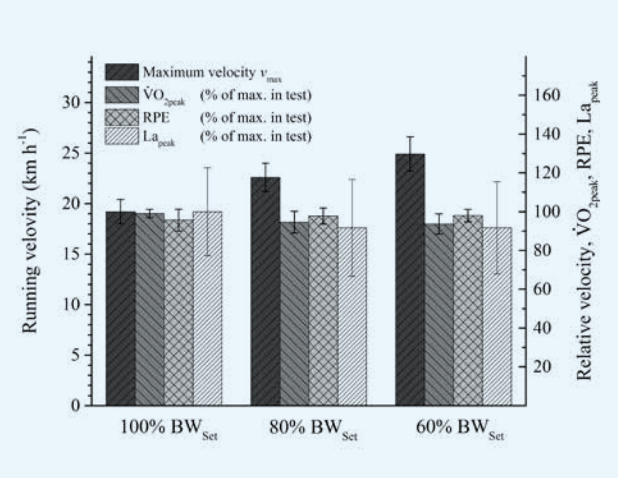

Figure 1

Maximal running speed v_{max} (Mean±SD), peak oxygen consumption VO_2peak (% of max. in test; Mean±SD) perceived exertion RPE (% of max. in test; Mean±SD) and peak lactate accumulation La_{peak} (% of max. in test; Mean±SD) on 100% BW_{Set}, 80% BW_{Set} and 60% BW_{Set}.

new training tools, such as underwater treadmills and lower body positive pressure treadmills (LBPPT). Both technological concepts allow runners to maintain high training volumes, whereas their musculoskeletal load is reduced because of partial body-weight support by static buoyance (water) or lift (air).

With regard to oxygen consumption ($\dot{V}O_2$), previous studies revealed that running on a LBPPT implies a decrease in $\dot{V}O_2$ as compared to running under standard conditions at the same speed (1, 18, 23, 24, 30). Concerning cardiac reactions, maximal heart rate (HRmax) seems to be unaffected from LBPPT running, whereas submaximal heart rate (HR) is reduced.

As for metabolic reactions, the understanding of how LBPPT affects lactate accumulation (La) has been incomplete. To date, only one study has explicitly addressed that question, reporting that peak lactate (La_{peak}) after an incremental treadmill test was lower for running on a LBPPT at 85% BW_{Set} (6.4 ± 1.8 mmol l^{-1}) than on a standard treadmill (7.7±2.2mmol l^{-1}) (9). At 95% BW_{Set} and 90% BW_{Set}, however, no significant differences between LBPPT and standard treadmill running were found.

Because $\dot{V}O_2$, HR and La belong to the most important physiological parameters for exercise monitoring and training control (8, 25, 34, 39), we investigated the simultaneous reactions of those parameters in well-trained runners during an incremental treadmill test on the LBPPT. The explicit aim of the present study was to elucidate $\dot{V}O_2$, HR and La reactions in a combined multifactorial parameter analysis in order to advance and refine practical training implications and recommendations of LBPPT running for sports scientists, physicians and practitioners. To the best of our knowledge, the present study is the first multifactorial approach to combine metabolic and respiratory parameters in a holistic view.

Materials and Methods

Fifteen well-trained male runners and triathletes (Table 1) performed three identical incremental treadmill tests until volitional exhaustion in randomized order. The inclusion criterion was a personal best better than 40:00 min at an official 10km road race. All participants were familiar with treadmill running, performing several sessions every year. The study was approved by the ethics committee (HU Berlin) and is in accordance with high ethical standards (11) and the Declaration of Helsinki. Written consent to participate in the study was given by all participants.

One test was completed on a conventional treadmill h/p/cosmos saturn® 250/100 (100% BW_{Set}; h/p/cosmos sports & medical GmbH, Nußdorf-Traunstein, Germany). The other two tests were performed on a LBPPT AlterG® Anti-Gravity Treadmill® Pro 200 Plus (AlterG®, Fremont, California, USA), with 80% and 60% BW_{Set}, respectively. For each participant, the tests were performed on the same weekday and at the same time of day (±30min) in three consecutive weeks. Prior to each test, body weight and height were measured (Seca Vogel & Halke Hamburg 910, seca GmbH & Co. KG, Hamburg, Germany). Spiroergometrical data were acquired throughout each test using a stationary system with breath-by-breath analysis (Quark CPET, COSMED, Pavona di Albano, Italy). Data processing was completed via the software OMNIA 1.6 (COSMED, Pavona di Albano, Italy). HR measurements were performed using the HRM RunTM system (Garmin Ltd., Canton Schaffhausen, Switzerland). At rest, between the stages and after exhaustion, a sample of 20 µl of arterialized capillary blood was taken from the earlobe, solubilized in a 1000µl hemolysate solution and analyzed using the SUPER GL ambulance system (Dr. Müller Gerätebau GmbH, Freital, Germany). In addition, between the stages and after exhaustion, rating of perceived exertion (RPE) was inquired on the basis of the Borg Scale (4).

For each treadmill condition, the initial running speed was set to 6km h^{-1} and increased by 2km h^{-1} after each completed stage. The individually achieved maximal running speed was that at volitional exhaustion and differed between participants (see below). The maximal running speeds were observed on the LBPPT and reached 28km h^{-1} for some participants. Each stage lasted 3 min, except for the last one at individual volitional exhaustion, which could be stopped earlier. Only complete stages were considered in later data analysis. Between the stages, a rest break of 30s was made for taking blood samples and ask for RPE. All participants performed their tests with the same individual, familiar pair of running shoes, thereby avoiding footwear-related intra-individual distorting effects (13, 36). Furthermore, participants were instructed to replicate a similar pattern of training and nutrition during the last 48h before their tests.

Data Treatment

The first two stages (6km h^{-1} and 8km h^{-1}) of each trial were considered as a standardized warm-up and excluded from data analysis. All participants successfully completed the stages from 10km h^{-1} to 18km h^{-1}, irrespective of BW_{Set} condition. Running at 20km h^{-1}, some participants reached volitional exhaustion before the end of the stage. To maintain data homogeneity for

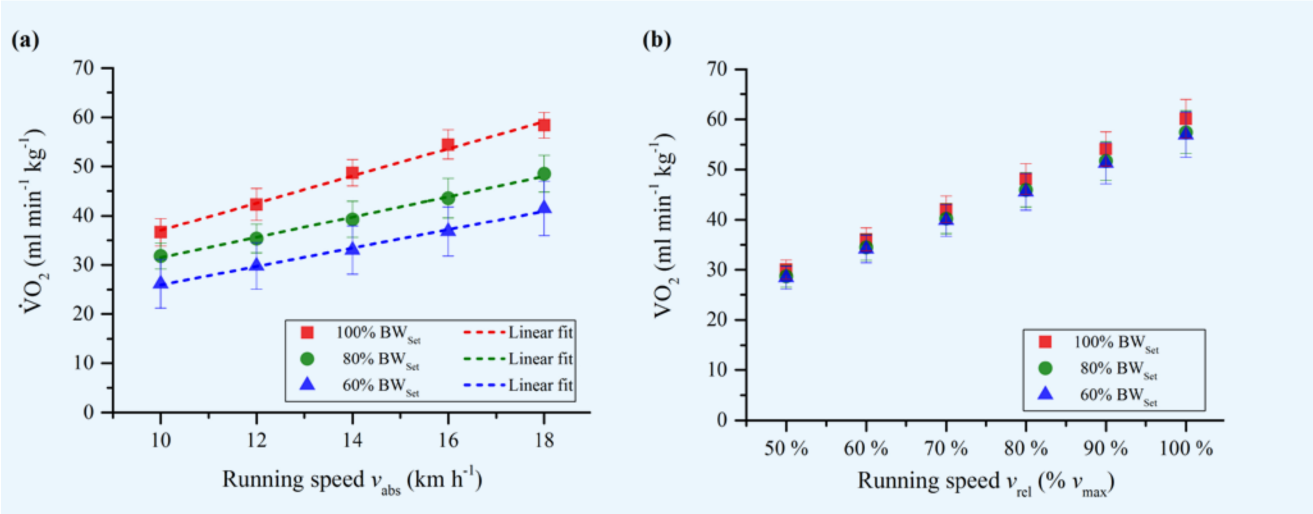

Figure 2

Oxygen consumption VO_2 (Mean±SD) in terms of absolute running speed v_{abs} (10km h^{-1} to 18km h^{-1}; left) and relative running speed v_{rel} (50% v_{max} to 100% v_{max}; right), respectively, as compared for running on 100% BW_{Set}, 80% BW_{Set} and 60% BW_{Set}.

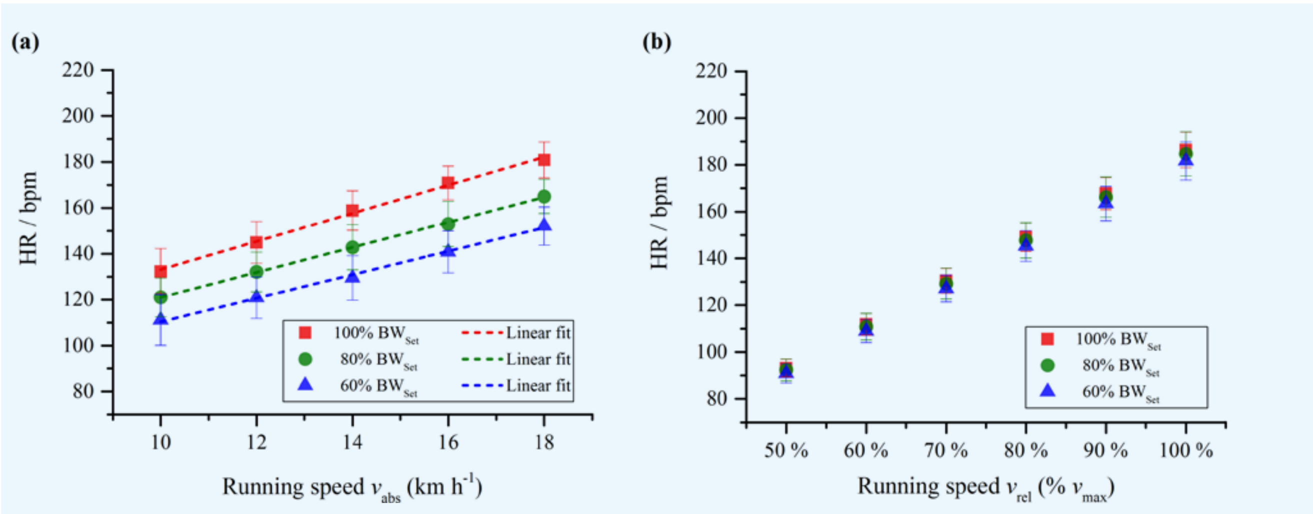

Figure 3

Heart rate HR (Mean±SD) in terms of absolute running speed v_{abs} (10km h^{-1} to 18km h^{-1}; left) and relative running speed v_{rel} (50% v_{max} to 100% v_{max}; right), respectively, as compared for running on 100% BW_{Set}, 80% BW_{Set} and 60% BW_{Set}.

each BW_{Set} condition and participant, those additional stages were disregarded in later data analysis. Hence, for each BW_{Set} condition and running speed, the same number of participants (n=15) was included.

To obtain a precise approximation for the individual maximal running speed (v_{max}) of each participant in each trial, v_{max} was extrapolated linearly from the actually completed stage duration (i.e., ≤3:00min) and the nominal running speed of the last stage, e.g. v_{max}=25km h^{-1} for running 1:30min at 26km h^{-1}. Based on those v_{max} values, an additional normalization of individual absolute running speeds (v_{abs}, in terms of km h^{-1}) with respect to v_{max} was done, yielding relative running speeds v_{rel} in terms of 50-100% v_{max}, i.e. v_{rel}:=v_{abs}/v_{max} x100%. For retrieving $\dot{V}O_2$, HR and La figures at those specific relative running speeds, a linear interpolation of mean measurement values was conducted.

Following recommended procedure, acquired $\dot{V}O_2$ data were averaged over 30s (31), while the last 30s value of each stage was used in later statistical analysis. HR data were manually saved 15s before the end of each stage and directly after exhaustion.

For enabling an easy transfer of our study result into practice, regression equations were computed for $\dot{V}O_2$, HR (linear model) and La (exponential model) as functions of absolute running speed by means of Origin 2017 (OriginLab Corp., Massachusetts, USA), solely using the data of stages from 10-18km h^{-1}. Moreover, a standard low-intensity training stimulus of ≈75% $\dot{V}O_2$peak (14, 15, 39) was selected for comparing responses in running speed, HR and La for running on a LBPPT vs. a standard treadmill, and deducing practical implications therefrom.

Statistics

Data were processed with Microsoft Excel 2016 (Microsoft Corporation, Redmond, USA) and IBM SPSS Statistics 23 (IBM, Armonk, USA). Results are presented as mean±standard deviation. To identify a bias between the three BW_{Set} conditions, three individual cases of a one-way analysis of variance (ANOVA) for the factor BW_{Set} were performed on the dependent variables v_{max}, $\dot{V}O_2$peak and La_{peak}. For RPE, a Friedman Test was ›

Table 2

Regression equations of VO_2, HR and La. VO_2=Oxygen consumption. HR=Heart rate. La=Lactate accumulation. BW_{Set}=Body weight setting; 100% BW_{Set}=regular treadmill; 80% BW_{Set}=80% body weight on lower body positive pressure treadmill; 60% BW_{Set}=60% body weight on lower body positive pressure treadmill; R^2=explained variance/coefficient of determination; v=running speed in km h^{-1}.

	VO_2 [ML KG^{-1} MIN^{-1}]	HR [BPM]	LA [MMOL L^{-1}]
100% BW_{Set}	VO_2=2.6551 v + 11.1734 (R^2=0.9887)	HR=5.9634 v + 74.5322 (R^2=0.9946)	La=0.6544 + 0.0042 exp(v/2.5234) (R^2=0.9999)
80% BW_{Set}	VO_2=2.1785 v + 9.0586 (R^2=0.9976)	HR=5.4623 v + 66.3854 (R^2=0.9991)	La=0.7258 + 0.0045 exp(v/2.9669) (R^2=0.9999)
60% BW_{Set}	VO_2=1.9212*v + 6.4596 (R^2=0.9924)	HR=5.2512 v + 57.1603 (R^2=0.9966)	La=0.7130 + 0.0038 exp(v/3.2749) (R^2=0.9994)

Table 3

Calculated training stimulus at VO_2=45ml kg^{-1} min^{-1} (~75% VO_2peak). VO_2=Oxygen consumption; HR=Heart rate; La=Lactate accumulation; BW_{Set}=Body weight setting; 100% BW_{Set}=regular treadmill; 80% BW_{Set}=80% body weight on lower body positive pressure treadmill; 60% BW_{Set}=60% body weight on lower body positive pressure treadmill.

	[KM H^{-1}]	[BPM]	[MMOL L^{-1}]
100% BW_{Set}	12.7	151	1.31
80% BW_{Set}	16.5	157	1.90
60% BW_{Set}	20.1	163	2.45

conducted, instead. Furthermore, a two-way ANOVA was computed based on the two factors BW_{Set} and v_{abs} (for 10-18km h^{-1}) for the dependent variables $\dot{V}O_2$, HR and La. In consideration of the two mathematically equivalent representations of running speed in terms v_{abs} (km h^{-1}) and v_{rel} (percentage of v_{max}), a second ANOVA was computed for the dependent variables $\dot{V}O_2$, HR and La on the basis of the factors BW_{Set} and v_{rel} (for 50%-100%). Notably, in spite of the mathematical equivalence of running speed representations in terms of v_{abs} and v_{rel}, corresponding statistics for $\dot{V}O_2$, HR and La as functions of v_{abs} and v_{rel} are not equivalent. The reason for this is given by the definition of v_{rel}, by which it not only depends on nominal running speed but also on the individual's maximal running speed v_{max}, which differs from participant to participant. Hence, the v_{rel} representation implicitly covers differences in performance level of the participants, which the v_{abs} representation does not include.

For all ANOVA computations, variance homogeneity was assessed first using Levene's test (p>0.05). Standard level of significance was set to p=0.05. 95% confidence intervals (CI) were calculated. Effect sizes (ES) with partial eta-squared (η^2) values were calculated as following (20): $0.01\geq\eta^2\leq0.09$, small ES; $0.09\geq\eta^2\leq0.25$, medium ES; and $\eta^2\geq0.25$, large ES. Bonferroni correction was used for post hoc multiple comparison of means for main effects and significant interactions.

Results

Maximal Running Speed v_{max}, Peak Oxygen Consumption $\dot{V}O_2$peak, Peak Lactate Accumulation La_{peak} and Perceived Exertion RPE at Exhaustion

With increasing level of unloading and thus decreasing BW_{Set}, the participants achieved significantly higher maximal running speeds v_{max} (p<0.001; Figure 1). In relative terms, v_{max} grew by 18±5% for 80% vs. 100% BW_{Set} and by 30±7% for 60% vs. 100% BW_{Set}. In contrast, $\dot{V}O_2$peak, La_{peak} and RPE at exhaustion were unaffected by BW_{Set}.

Oxygen Consumption ($\dot{V}O_2$)

In terms of absolute running speed v_{abs}, an increase in speed resulted in a higher $\dot{V}O_2$ (p<0.001, η^2 = 0.743) across all BW_{Set} conditions, the changes proving significant for each stage from 10-18km h^{-1} (p<0.05, Figure 2). Conversely, mean $\dot{V}O_2$ significantly decreased with lower BW_{Set}, where mean decreases amounted to 8.4 (CI: 6.9-9.9) and 14.7 (CI: 13.1-16.2) ml kg^{-1} min^{-1} for 80% vs. 100% and 60% vs. 100% BW_{Set}, respectively (p<0.001, η^2=0.720; Figure 2). Expressed in terms of relative running speed v_{rel}, $\dot{V}O_2$ significantly increased with v_{rel} (p<0.001, η^2=0.909) and BW_{Set} (p<0.001, η^2=0.100; Figure 2, right), the latter, however with only medium effect size. On average, the decrease in $\dot{V}O_2$ from 100% to 80% and 60% amounted to 2.0 (CI: 0.8-3.2) and 2.4 (CI: 1.2-3.5) ml kg^{-1} min^{-1}, respectively. No interaction effect of relative running speed and BW_{Set} was observed for $\dot{V}O_2$ (p=0.999, η^2=0.006).

Heart Rate (HR)

In terms of v_{abs}, higher running speeds resulted in significantly increased HR across all unloading conditions (p<0.001, η^2=0.766), with each difference proving significant (p<0.05) from 10-18km h^{-1}. Moreover, HR significantly decreased with decreasing BW_{Set} (p<0.001, η^2=0.612; Figure 3, left), the mean reduction amounting to 15 (CI: 11-18) and 27 (CI: 23-30) bpm for 80% vs. 100% and 60% vs. 100% BW_{Set}, respectively. No interaction effect between absolute running speed and BW_{Set} was found for HR (p=0.661, η^2=0.027). Also in terms of v_{rel}, HR significantly increased with BW_{Set} (p<0.05, η^2=0.053). Regarding the factor BW_{Set}, a significant decrease of 4 bpm (CI: 1-6) was observed only for 100% vs. 60% BW_{Set} (Figure 3, right). No interaction of v_{rel} and BW_{Set} was observed for HR (p=1.000, η^2=0.003).

Lactate Accumulation (La)

Expressed as a function of v_{abs}, higher La values were observed for increasing running speeds (p<0.001, η^2=0.472; Figure 4, left). As for unloading condition, significant reductions from 100% to 80% and from 100% to 60% BW_{Set} were found, amounting to 1.04 (CI: 0.6-1.4) and 1.44 (CI: 1.0-1.8) mmol l^{-1}, respectively. For example, running with 16 km h^{-1} at 100% BW_{Set} led to a La of 3.05±1.48mmol l^{-1}, whereas 80% and 60% BW_{Set} resulted in 1.71±1.01 and 1.21±0.37mmol l^{-1}, respectively (Figure 4, left). In summary of all running speeds, there was a La decrease of 1.04mmol l^{-1} at 80% BW_{Set} and 1.44mmol l^{-1} at 60% BW_{Set}, corresponding to a relative reduction of 29% and 42%, respectively.

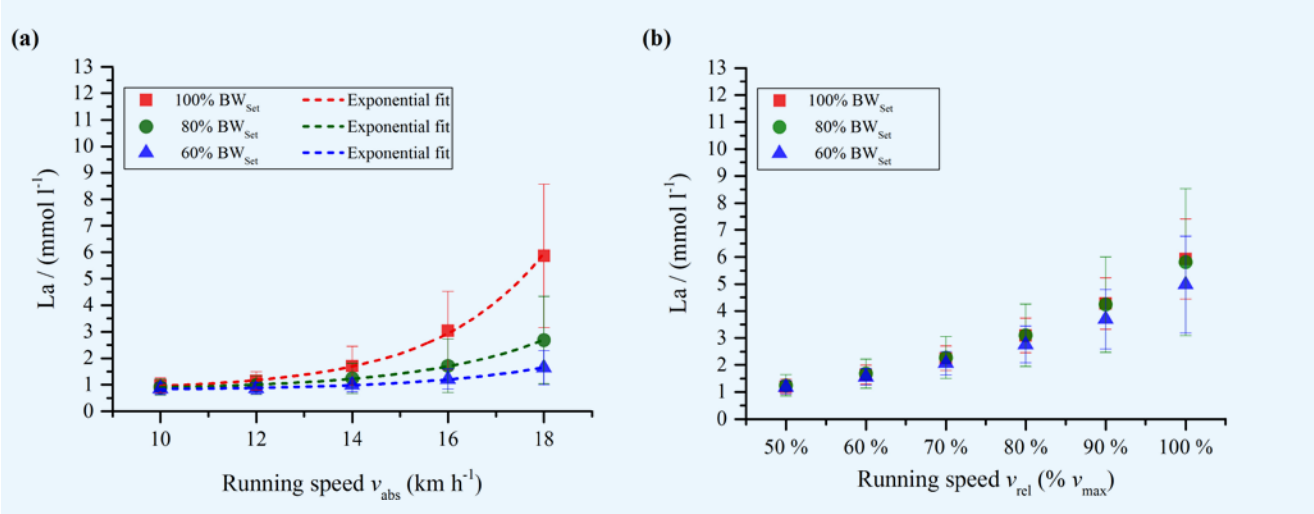

Figure 4

Lactate accumulation La (Mean±SD) in terms of absolute running speed vabs (10km h^{-1} to 18km h^{-1}; left) and relative running speed v_{rel} (50% v_{max} to 100% v_{max}; right), respectively, as compared for running on 100% BW_{Set}, 80% BW_{Set} and 60% BW_{Set}.

In terms of v_{rel}, La significantly increased with BW_{Set}, yet with only a small effect size ($p<0.05$, $\eta^2=0.024$; Figure 4, right). No interaction between v_{rel} and BW_{Set} was found in La ($p=0.932$, $\eta^2=0.017$).

Regression Analyses

Regression analyses of $\dot{V}O_2$, HR and La with respect to BW_{Set} are presented in Table 2, yielding high values for the coefficient of determination $R^2>0.98$ through all BW_{Set} conditions. For achieving a practically relevant training stimulus of $\dot{V}O_2$=45ml kg^{-1} min^{-1} (≈75% $\dot{V}O_2$peak), running speed should be increased by 3.8km h^{-1} at 80% BW_{Set} and by 7.4km h^{-1} at 60% BW_{Set} as compared to 100% BW_{Set}, as our data show. With that increase in running speed, HR elevates by 6 bpm at 80% BW_{Set} and by 12bpm at 60% BW_{Set}. Furthermore, La values raise disproportionally from 1.31 to 1.90 and 2.45mmol l^{-1} at 100%, 80% and 60% BW_{Set}, respectively (Table 3).

Discussion

There is evidence, for instance, that LBPPT running implies lower vertical ground reaction forces and thus reduces biomechanical loading (6, 10, 12, 17, 30). Regardless of that biomechanical unloading, it is essential for elite athletes to account for the changes that BW_{Set} induces in their physiological training load. First findings showed a nearly proportional decrease of $\dot{V}O_2$ with body-weight support for 70%, 80% and 90% BW_{Set} (18). However, beyond that range of body-weight support, i.e. <70% BW_{Set} or >90% BW_{Set}, the relative change in $\dot{V}O_2$ differed from that of BW_{Set} (18). Generally, a $\dot{V}O_2$ decrease on LBPPT has been confirmed in the present study. We obtained decreases of -17% and -30% in $\dot{V}O_2$ from 100% to 80% and 60% BW_{Set}, respectively. Interestingly, data of elite runners showed significantly higher $\dot{V}O_2$ decreases of 34% and 38% at 80% and 60% BW_{Set} (24). As a possible explanation, the authors suspected that 80% BW_{Set} may be an optimal level of horizontal support for the elite runners (24).

Furthermore, HR data from the present study are in accordance with previous studies, reporting a reduction in HR from 123±6bpm to 105±8 and 101±12bpm at 100%, 80% and 60% BW_{Set}, respectively (24). Barnes and Janecke (1) showed a HR

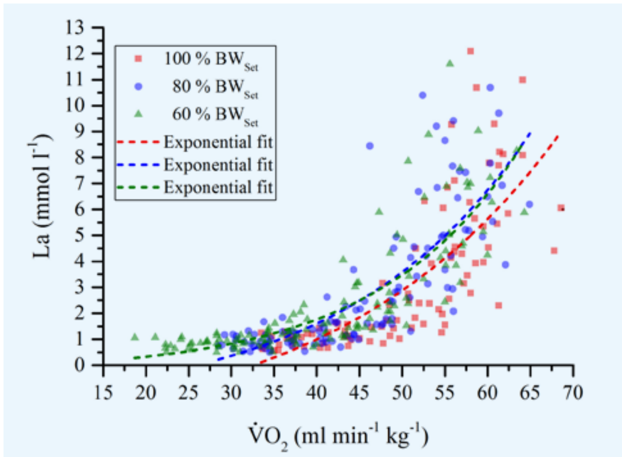

Figure 5

Relationship between oxygen consumption (VO_2) and Lactate accumulation (La), as compared for running on 100% BW_{Set}, 80% BW_{Set} and 60% BWSet.

decrease from 143±5 bpm at 100% BW_{Set} to 126±3 bpm at 80% BW_{Set} (12% reduction). The pertinent result of the present study supports this outcome. In analogy to the $\dot{V}O_2$ reactions, with respect to elite runners, however, the relative reduction proved slightly lower at 80% BW_{Set}. Also for higher running speeds, the results are qualitatively comparable with the findings of the present study: We found changes of -9% for 80% vs. 100% BW_{Set} and -17% for 60% vs. 100% BW_{Set}, while previous studies on elite runners showed a HR decrease of -16% (80% BW_{Set}) and -22% (60% BW_{Set}) (24). In view of the quantitative deviations, it may be hypothesized that highly trained runners benefit "better" from BW_{Set} than well-trained runners do. The variability of the running economy may be one explanation (24). McNeill et al. (24) demonstrated that even elite runners, who had developed an economical stride for several years, showed an increased variability from 100% BW_{Set} to 80% BW_{Set} and even more through 60% BW_{Set}. Furthermore, running economy on LBPPT seems to be higher ("poorer") (38). It seems likely that this variability is more pronounced in recreational or less-trained runners (28). This high variability may lead to a less economical stride and therefore to higher physiological reactions, e.g. heart rate. On the other hand, Stucky et al. (37) showed that stroke volume is increased during steady-state treadmill running on LBPPT. It may be hypothesized that elite runners – provided with an already high stroke volume – benefit in such a way that heart rate can be decreased in a disproportional way. Such presumptions should be substantiated or refuted by future investigations. In addition, it was shown that the LBPPT had no influence on venous return during submaximal running (37). The authors explained that the produced forces of the muscle pump (~90mmHg) during physical stress override the generated forces of the LBPPT (~30mmHg at 60% BW_{Set} and ~15mmHg at 80% BW_{Set}, respectively).

To date, only little has been known about how LBPPT affects submaximal La values. Trying to bridge that gap, the present study revealed that La significantly decreased on LBPPT ($p<0.001$). La at lower running speeds was unaffected by LBPPT, while clear differences were observed for faster running.

In essence, $\dot{V}O_2$, HR and La are clearly changed by LBPPT running. Since those three quantities are often used for monitoring and controlling training (8, 25, 35, 39), it is essential that coaches carefully instruct their athletes on how they should alter their session targets on LBPPT. While some studies show that submaximal intensities of 70-85% $\dot{V}O_2$max seem to be most beneficial to increase $\dot{V}O_2$max, other authors suggest training at higher intensities (90-100% $\dot{V}O_2$max) (25). Based on a mean $\dot{V}O_2$peak of 60.2±3.8ml kg^{-1} min^{-1} in this study, a submaximal training speed of, e.g., 12.7km h^{-1} (≈75% $\dot{V}O_2$peak) at 100% BW_{Set} should be increased to 16.5km h^{-1} at 80% BW_{Set} in order to maintain the same $\dot{V}O_2$ stimulus. In that case, La increases from 1.31mmol l^{-1} at 100% BW_{Set} to 1.90mmol l^{-1} at 80% BW_{Set}, suggesting that anaerobic energy contributions increase. It may be hypothesized that biomechanical changes on the LBPPT (32) as well as altered muscular innervation patterns (21, 22) lead to a less economical stride that goes along with increased La values. The relationship between $\dot{V}O_2$ and La (Figure 5) for the three BW_{Set} conditions supports this assumption. Bearing in mind that elite athletes are used to complete at least 70% of their training at intensities below La levels of 2mmol l^{-1} (19, 25), an increase in running speed on LBPPT should thus be carried out carefully – as long as aerobic adaptations are desired. Despite that, LBPPT running allows to train closer to the race pace at reduced physiological effort.

Farina et al. (6) described that the biomechanical and physiological adaptations appear "to become more exaggerated at body weight settings <70 %". Considering the results of the present study, it seems advisable from a practical training perspective not to fall below this threshold. As described in the results, the running speed to reach the same $\dot{V}O_2$ stimulus has to be increased so much that the lactate values rise significantly. While at 80% BW_{Set} only minor changes in lactate and thus in the anaerobic energy contribution are observed (still being classified as a low intensity training), lactate level at 60% BW_{Set} clearly exceeds the 2mmol l^{-1} threshold. Hence, for low intensity training, we recommend keeping the body weight reductions and associated speed increases low (around 80% BW_{Set}) to prevent the risk of significant adjustments in the aerobic-anaerobic energy contribution.

Regarding previous research, a current review by Farina et al. (6) described that every 10% decrease in BW_{Set} leads to a $\dot{V}O_2$ decrease of 3.4ml kg^{-1} min^{-1} (ranging from 1.79 to 5.36m s^{-1} and LBPPT settings of 50-100% BW_{Set}), which would amount to 6.8ml kg^{-1} min^{-1} for 20% BW_{Set} and 13.6ml kg^{-1} min^{-1} for 40% BW_{Set}. However, the present study with well-trained athletes yielded slightly different adjustments of 8.4ml kg^{-1} min^{-1} (80% BW_{Set}) and 14.7ml kg^{-1} min^{-1} (60% BW_{Set}). The reductions in oxygen uptake found by McNeill et al. (24) for elite runners (at 4.47m s^{-1}) were also clearly different: 14.3ml kg^{-1} min^{-1} (at 80% BW_{Set}) and 17.0ml kg^{-1} min^{-1} (at 60% BW_{Set}). Those results suggest that absolute changes in $\dot{V}O_2$ can be very different, depending on the tested participants. As already discussed above, the reasons might be the higher performance capacity and the associated different running economy. In future, it will be necessary to address the questions of physiological reactions on the LBPPT for different performance levels to be able to deduce more specific training instructions.

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Conflict of Interest
The authors have no conflict of interest.

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