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Original Article

Does cardio-respiratory response underlie the gait transition phenomenon?

VLADIMIR ILIC[1], IGOR RANISAVLJEV[2], VLADIMIR MRDAKOVIC[3]
[1,2,3,]Faculty of Sport and Physical Education, University of Belgrade, SERBIA

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Abstract

Gait reorganization is multifactorial phenomenon influenced by biomechanical, energetic, mechanical and perceptual factors. **Problem Statement:** Despite the existence of several studies on this topic, it is not clear exactly how cardiorespiratory loading and metabolic demands influence the initiation of gait reorganization. **Purpose:** The purpose of this study was to define the cardiorespiratory response during walking and running at speeds corresponding to PTS. **Approach:** The sample included 26 male subjects, homogenized with respect to age and anthropometric dimensions. Cardiovascular and respiratory variables were measured during walking and running at five previously determined speeds above and below preferred transition speed (PTS). **Results:** Heart rate (HR), oxygen uptake (VO_2) and carbon dioxide production (VCO_2) increased linearly with acceleration, during both forms of locomotion. Post-hoc analysis revealed a significant difference ($p<0.01$) between all adjacent speeds during walking and running. At PTS and speeds above the PTS, breathing frequency (BF) was higher during walking and significance was obtained at a speed of 8.8 km/h ($\Delta=8.89$ bpm, $p=0.002$). Increase in walking speed significantly influenced increase in BF ($p<0.001$, $ή^2=0.817$) and ventilation ($p<0.001$, $ή^2=0.913$), while at the same time didn't affect the changes in ventilator equivalents. The main finding of this study is that walking at speeds above PTS, require significantly higher exertion of cardiovascular and respiration system in compare to running. Also, running below the PTS is energetically and functionally inefficient locomotion pattern, due to significantly higher oxygen consumption, ventilation and oxygen pulse. Thus, the most significant functional capacity variables as HR, V_E and VO_2 had lower values during walking below and running above PTS which implies the influence of cardio-respiratory variables in gait reorganization. **Conclusion:** This study showed that transition from walking to running leads to a significant decrease in cardiovascular and respiratory systems loading. Thus, we can conclude that physiological underlying mechanisms of human gait transition are relevant for PTS phenomenon.

Key words: movement reorganization, walking, running, heart rate, oxygen uptake, ventilation

Introduction

Functional abilities of the cardiorespiratory system during different loading conditions, has been broadly investigated in the field of sport and medical science. To maintain body homeostasis during different exercise types and intensities, the cardio-respiratory system mainly adapts by increasing heart rate (HR), ventilation (V_E) and oxygen uptake (VO_2). Monitoring of these variables enables objective evaluation of the work intensity during different movement activities (walking, running, jumping, cycling, etc.) (Chen et al., 2016; Barbieri et al., 2019).

Human terrestrial locomotion is possible within a broad range of speeds, which causes diverse physiological responses. Likewise, linear relationship has been established between cardiorespiratory variables and oxygen uptake within a range of locomotion speeds typical for walking (speeds up to 6 km/h) and running (above 8 km/h) (Swain & Brawner, 2014). However, inter-individual variability in cardiorespiratory variables is very large between 6 and 8 km/h (Monteiro, Farinatti, de Oliveira, & Araújo, 2011). Within the range of these two speeds, humans tend to spontaneously switch from walk to run and reverse. This phenomenon of preferred transition speed (PTS), has been excessively researched from the stand point of mechanisms underlying gait reorganization (Ranisavljev et al. 2014a, 2014b; Dobrijevic et al. 2020). It has been shown that muscle contractions provide the mechanical energy required for the mechanical changes and the mechanical changes are correlated with metabolic energy (Sparrow and Newell, 1998), so muscle function affects metabolic changes in human locomotion. Based on this, it can be assumed that people with different levels of physical activity and diverse levels of muscle function may have the influence on the inter-individual variability in metabolic energy response during walking or running on similar speeds (Monteiro et al., 2017).

Individuals modify their gaits mechanically during the transitions in order to adapt to changing environmental conditions and return to proper homeostasis (Diedrich & Warren, 1995). However, it is not clear how physiological strain influence the initiation of gait reorganization. The studies that examined the cardio-respiratory loading during locomotion at the speeds close to PTS, generally showed that humans tend to make

Corresponding Author: VLADIMIR ILIC, E-mail: vladimir.ilic@fsfv.bg.ac.rs

gait transition in order to minimize the physiological response and exertion (Farinatti & Monteiro, 2010; Mercier et al., 1994; Monteiro & Araújo, 2009; Ziv & Rotstein, 2009). Furthermore, small variations in gait velocity within 6 and 8 km/h, cause quite diverse physiological responses to the effort (Monteiro & Araújo, 2009). These authors demonstrated that just 15% of variation in the gait velocity resulted in individual differences of up to 50% in the O_2 consumption, and 25 bpm in HR between the running and walking at the same velocity. Two recent studies shown that 30-min running at PTS induce higher cardiorespiratory response (heart rate, VO_2, VCO_2, ventilation) compare to walking due to the fact that running elicits greater muscle recruitment than walking (Freire et al., 2017; Monteiro et al., 2017). Moreover, at speeds above PTS Fung et al. (2017) has shown greater muscle activation at the same absolute workload during walking compared to running. They found that the metabolic cost increased with increasing walking speed; while, the metabolic cost decreased when running speed increased. This leads to lower mechanical efficiency during walking above PTS and inability to maintain a common walking pattern. In addition, Ganley et al. (2011) showed that walking at speeds above PTS require higher consumption of net energy in compare to running at the same speed. The outcome is a disproportional increase of the functional loading, muscle fatigue and the rate of perceived exertion (Mercier et al., 1994; Monteiro & Araújo, 2009; Ziv & Rotstein, 2009). Considering that higher energy consumption is related with higher cardiorespiratory strain, it implies that cardiorespiratory variables might have significant influence in the gait transition, if they start to enhance with increase in walking speed, or decline after transition to running.

Therefore, the aim of this study was to define the cardiorespiratory response during walking and running at speeds corresponding to PTS, in homogenized sample of young, physically active males. We hypothesized that walking at speeds above PTS would significantly increase cardiorespiratory loading in compare to running.

Material and Methods

Prior to participation, all subjects have signed an informed consent containing detailed information's related to the study goals, all measurement procedures and potential risks. The Institutional Ethics Committee approved study in agreement with Helsinki declaration

Subjects

The subjects included in the study were male adults between 19 and 23 years of age, voluntary recruited among the students of the Faculty of Sport and Physical Education. To create a homogeneous group, all potential candidates (N=137) filled out the questionnaire about the type of exercise regularly performed, volume and intensity of weekly physical activity according to American College of Sports Medicine (Swain & Brawner, 2014). All potential candidates who did not meet the minimal recommendations of moderate or vigorous intensity exercise per week were excluded (13.8% or 19 subjects).

To reduce the influence of anthropometry, the selected sample was homogenized for body height, body weight, and the leg and thigh length. Additionally, subjects with body mass index (BMI) higher than 25 kg/m^2, body fat (BF %) higher than 20% and VO_2max less than 40 $mlO_2/kg/min$ were also excluded from the study. Any surgical procedure conducted in the past on the lower extremities, or use of medication that might affect the study outcomes were also the exclusion criteria for participation. At the testing time, all candidates were physically healthy and without any cardiorespiratory, metabolic or muscle-skeletal disorders which may influence the data.

The final sample included 26 subjects (age 20.8±0.9 years) who met the required criterions. During period of testing subjects were excluded from any vigorous physical activity. They completed 4 separate measurement sessions. The rest period between two consecutive sessions was between 2 and 4 days. The anthropometric data and VO_2 max were recorded in the first session. Individual transition speed from walk-to-run (WRT) and run-to-walk (RWT) was assessed in the second session. During the third and the fourth session, the cardio-respiratory data were collected during walking and running at five different speeds PTS-1, PTS-0.5, PTS, PTS + 0.5 and PTS + 1km/h.

Anthropometric and VO_2 max measurements

All measurements were taken in accordance with International Biological Program. Body height, leg and thigh length were measured with Martin's anthropometer with 0.1 cm accuracy, while body composition variables were collected using multi-frequency BIA device InBody 720 (Seoul, Korea).

After initial anthropometric measurements, all subjects performed at least 15 minutes familiarization with treadmill walking and running according to current recommendation (Simoni et al., 2020). Maximal multistage exercise test on the motorized treadmill (T170, COSMED, Rome, Italy) was performed to determine individual VO_2max. According to ACSM guidelines (Swain & Brawner, 2014) the test was conducted in a closed and ventilated laboratory with constant microclimatic conditions (19-23°C and 50-60% humidity). The device was connected to the computer and data were numerically and graphically displayed in a real-time on computer monitor.

Mobile gas analyzer (Oxycon Mobile, VIASYS Healthcare, Hoechberg, Germany) was used for continuous measurement of oxygen consumption (VO_2) and carbon dioxide elimination (VCO_2). Gases were analyzed by computer every 10 seconds using standard "breath-by-breath" method. All data were processed by PC software (JLAB, CareFusion 234 GmbH, Hoechberg, Germany). The gas analyzer was calibrated before and after each test using ambient air and standard gas mixture: O_2=16.25%, CO_2=4.13%, rest N_2.

Each subject started the test by standing on a treadmill for two minutes while the cardiorespiratory parameters were recorded. The protocol was continued by walking at 4 km/h, and constant 3% gradient. Treadmill speed was continuously increased by 1 km/h every minute with progressively increasing load to failure unless reaching limiting factors or any contraindication. During the test, the monitoring of cardiac function was performed using a 12-channel electrocardiogram, and heart rate (HR) was monitored continuously using the Polar Heart Rate Monitor ™ (Accurex 2, Polar Electro, Finland).

PTS determination protocol

After 10 minutes of warm-up and stretching routine, the increment protocol on a motorized treadmill described in detail by Hreljac and coworkers (2007), was used for determination of individual WRT and RWT. PTS was estimated as the mean between WRT and RWT.

Cardiovascular and respiratory data assessment

During the third and the fourth session cardiovascular and respiratory variables were collected during walking and running at five previously defined speeds around PTS (PTS-1, PTS-0.5, PTS, PTS+0.5, and PTS+1 km/h). At each speed, the subjects were walking or running for 7 minutes in order to reach steady state, where data from the last three minutes were used for further analysis. Confirmation that the participants were at the steady-state during that period was performed by visual inspection of VO_2 and HR. Breathing frequency (BF), breading reserve (BR), ventilation (V_E), VO_2 and VCO_2 were examined by Jaeger gas analyzer. Oxygen pulse was calculated as VO_2/HR, while the oxygen and carbon dioxide ventilator equivalents (EqO_2 and $EqCO_2$) were determined as V_E/VO_2 and V_E/VCO_2, respectively.

Statistical analysis

All statistical analyses were performed by SPSS 21.0 (IBM Corporation). The normality of the data was confirmed by Kolomogorov-Smirnov test. The results are presented as means ± standard deviation (SD) and the coefficient of variance (CV) was assessed to check the homogeneity of the sample. The repeated measure 2-way ANOVA was used to compare differences among the cardio-respiratory variables recorded during walking and running at five determined speeds (PTS-1, PTS-0.5, PTS, PTS+0.5 and PTS+1 km/h), while Bonferroni post-hoc test was used to test the differences between two adjacent speeds. The differences between walking and running for the variables collected at the same speeds were evaluate by the dependent T-test. Statistical significance was set at $p<0.05$.

Results

General physical characteristics of the subjects are presented in table 1. As can be seen, the subjects were of normal weight with a relatively low percent fat and quite homogenous regarding their anthropometric and functional characteristics (CV < 0.1).

Table 1. Anthropometric and functional characteristics of subjects

Variable	Mean ± SD	Range	CV (%)
Body height (cm)	181.93±1.81	180.0-185.5	0.99
Body weight (kg)	78.51±3.06	75.1-83.4	3.90
BMI (kg/m^2)	23.72±0.84	22.2-25.0	3.54
Fat free mass (kg)	69.92±3.24	63.8-74.0	4.63
Body fat mass (%)	11.01±2.29	7.6-13.3	20.71
Leg length (cm)	91.34±1.01	89.4-92.8	1.11
Thigh length (cm)	45.83±0.73	44.9-47.0	1.59
VO_2max (ml/kg/min)	48.42±3.31	43.4-55.4	6.83

The mean WRT and RWT were 7.91±0.19 km/h and 7.74±0.17 km/h, respectively. Although we found small hysteresis of 0.17 km/h, there was significant difference (t=-4.122, p=0.01) between WRT and RWT. Based on the average value expressed as PTS (7.81±0.15 km/h) we determined two speeds above and below PTS: 8.3 and 8.8 km/h and 6.8 and 7.3 km/h, respectively.

Table 2 presents changes in cardiovascular and gas exchange variables during walking and running.

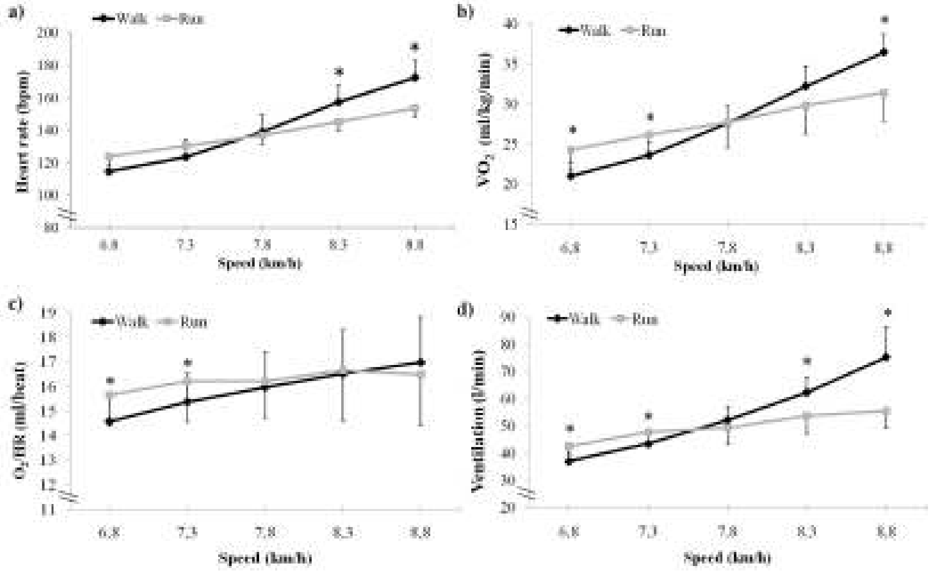
Table 2. Cardiovascular and gas exchange variables during walking and running within the range of speeds normalized to PTS

	Speed (km/h)	HR (bpm)	O_2/HR (ml/beat)	VO_2 (ml/min/kg)	VCO_2 (ml/min/kg)
WALKING	6.8	114.80±10.41	14.58±1.15	20.98±1.65	18.15±1.20
	7.3	123.53±11.63**	15.37±1.17*	23.62±1.65**	21.10±1.73**
	7.8	139.15±14.26**	15.96±1.42*	27.54±2.19**	25.06±2.43**
	8.3	157.29±15.79**	16.52±1.77	32.18±2.51**	29.60±2.45**
	8.8	172.55±15.16**	16.97±1.86	36.43±2.29**	34.11±2.49**
RUNNING	6.8	124.01±10.95	15.66±1.28	24.28±2.36	21.00±1.59
	7.3	130.58±12.29**	16.21±1.65	26.17±2.97**	23.45±2.28**
	7.8	136.84±12.14**	16.20±1.50	27.67±3.18**	24.53±2.13**
	8.3	145.19±14.93**	16.66±2.04	29.77±3.54**	26.69±2.81**
	8.8	153.71±12.91*	16.49±2.08	31.35±3.49**	28.08±2.77**

**p<0.05; **p<0.01 Significant differences between two adjacent speeds*

Heart rate, as well as, VO_2 and VCO_2 increased linearly with acceleration during both forms of locomotion (size effect expressed as partial eta square (ή^2) was higher than 0.9; for walking 0.988 and for running 0.923). Post-hoc analysis revealed a significant difference ($p<0.01$) between all adjacent speeds in both forms of locomotion. As can be seen in Figure 1a, HR was significantly higher during walking at both speeds above PTS. VO_2 was higher during walking at speed 8.8 km/h (Δ=5.08 ml/min/kg, $p<0.001$). During running at speeds below PTS, VO_2 was higher at both speeds (Figure 1b). The increase in walking speed resulted in a significant increase in O_2/HR ($p<0.01$, ή^2=0.48) while increase in running speed remained O_2/HR relatively constant (p=0.084, ή^2=0.20) Post-hoc analysis revealed significant increase only during walking at speeds up to PTS. T-test showed that oxygen pulse was higher during running under PTS, in compare to walking (Figure 1c).

Figure 1. Cardiorespiratory variables during walking and running across the range of speeds normalized to PTS (Mean ± SD)



* Significant difference between walking and running at the same speed ($p < 0.05$).

Respiratory variables during walking and running are presented in Table 3. ANOVA showed that increase in walking speed significantly influenced increase in BF ($p<0.001$, ή^2=0.817) and V_E ($p<0.001$, ή^2=0.913). At PTS and speeds above the PTS, BF was higher during walking and significance was obtained at a speed of 8.8 km/h (Δ=8.89 bpm, p=0.002). Acceleration also leads to a significant rise in V_E with increase in running speed ($p<0.001$, ή^2=0.815). V_E was higher during running at speeds below PTS (Δ=5.49 l/min, p=0.003 for 6.8 km/h and Δ=4.30 l/min, p=0.048 for 7.3 km/h), while at speeds above the PTS, V_E was higher during walking (Δ=8.57 l/min, p=0.049 for 8.3 km/h and Δ=19.78 l/min, $p<0.001$ for 8.8 km/h) (Figure 1d). Increase in V_E was accompanied by inverse decrease in BR.

Table 3. Respiratory variables during walking and running within the range of speeds normalized to PTS

	Speed (km/h)	**BF** (brpm)	V_E (l)	**BR** (l)	EqO_2	$EqCO_2$
WALKING	6.8	20.83±4.51	37.11±3.17	77.09±1.90	22.34±1.85	26.13±2.15
	7.3	22.96±4.86	43.51±4.10**	73.12±2.47**	23.09±2.15	26.39±2.61
	7.8	26.55±4.69**	52.18±4.97**	67.82±3.07**	23.71±2.32	26.68±2.71
	8.3	30.31±3.78**	62.32±5.63**	61.43±3.94**	24.25±2.25	26.93±2.56
	8.8	33.73±4.34*	75.27±11.08**	53.68±6.60**	25.97±3.97	28.20±4.15
RUNNING	6.8	22.18±5.32	42.60±3.29	73.75±1.92	22.20±2.58	26.01±2.89
	7.3	23.03±6.76	47.81±5.69**	70.45±3.53**	22.86±2.97	26.14±3.33
	7.8	23.74±6.21	49.37±6.04	69.56±3.63	22.56±3.54	25.83±3.89
	8.3	25.04±6.14	53.75±6.57*	66.86±3.93*	22.66±3.87	25.93±4.13
	8.8	24.84±6.37	55.49±6.23*	65.57±4.19*	22.29±3.57	25.41±3.76

$* p<0.05$; $** p<0.01$ *Significant differences between two adjacent speeds*

Increase in gait speed didn't affect the changes in ventilator equivalents, without significant difference between all adjacent speeds ($p>0.05$). EqO_2 and $EqCO_2$ were somewhat above during walking in compare to running across the range of speeds without statistical differences.

Discussion

The results of the present study indicate that walking at speeds above PTS, require significantly higher exertion of cardiovascular and respiration system in compare to running. Also, running below the PTS is energetically and functionally inefficient locomotion pattern, due to significantly higher oxygen consumption, ventilation and oxygen pulse. Thus, the most significant functional capacity variables as HR, V_E and VO_2 had lower values during walking below and running above PTS which implies the influence of cardio-respiratory variables in gait reorganization.

The PTS reported in our study was in line with previously reported (Ranisavljev et al. 2014a, 2014b). Since, untrained and obese subjects have lower PTS than trained and normal weights (Ilic et al., 2012; Ziv & Rotstein, 2009), for accurate examination of PTS phenomenon, it is vital to include a homogeneous group of subjects who have similar level of morpho-functional abilities. Sample selection regarding the gender, age, anthropometrics and training status (Kung et al., 2017; Ranisavljev et al. 2014a; Ziv & Rotstein, 2009) was performed in order to reduce the potential influence of confounding variables and to estimate the alternation in cardiovascular and respiratory variables during walking and running at speeds corresponding to PTS. In order to minimize an impact of mechanical efficiency, which might influence energy consumption and cardiorespiratory response, all subject had 15 minutes adaptation by walking and running on treadmill (Simoni et al., 2020). Furthermore, experimental protocol was long enough to ensure locomotion in steady state conditions and precise data collecting.

Heart rate measurement is an objective method for examination of the cardiovascular response during sub-maximal exercise. In determinate range of speeds, increase in HR was higher during walking in comparison to running. During walking at speed below PTS, HR was lower in compare to running, while at PTS, HR values during walking and running were almost equal. Previous studies also showed that differences in HR during walking and running around PTS are mainly small (Rotstein et al., 2005; Ziv & Rotstein, 2009; Ganley et al., 2011). In the study with group of non-runners (Rotstein et al., 2005) there was no significant difference in HR during walking and running at PTS (131.10±14.30 and 137.52±12.32 bpm; $p=0.131$, respectively). Otherwise, runners group had similar, but significantly lower HR on PTS during both conditions (113.40±13.44 vs. 116.63±7.28 bpm). These results are expected considering differences in cardiorespiratory functional capacities of the tested groups. It should be noted that large inter-individual variability in HR was evidenced at PTS during both types of locomotion. We recorded more extensive range of HR during walking at PTS (from 114 to 162 bpm) than during running (from 113 to 150 bpm). Similar data were reported in study of Monteiro et al. (2011) where subjects HR during walking at PTS was in the range from 108 up to 145 bpm. Coefficient of variance was higher than 30% with a tendency to increase with further accelerating. This phenomenon was not explained in detail, and for this reason, this group of authors stated that the cardiovascular response as a possible trigger conversion movement should be observed with some caution.

Our results indicate that increase of walking speed was closely related to linear increase of oxygen pulse, while during running O_2/HR remained relatively constant. Few studies showed that there was no significant difference in oxygen pulse between walking and running on equal speed (Farinatti & Monteiro, 2010; Monteiro et al., 2011). However, recent papers (Freire et al., 2017; Monteiro et al., 2017) found that in untrained young and senior male adults, running promotes greater cardio-respiratory response in compare to walking at the WRT. Generally, walking at speeds above PTS induce higher HR and consumption of O_2.while running in the equal speed range produce minimal O_2/HR changes. Thus, it could be assumed that running as a form of training or testing is more suitable for low-trained individuals and patients with cardiovascular and respiratory system disabilities.

Calculated from oxygen consumption rate, present results show that PTS occurs at the same speed as EOTS (PTS=100.4% EOTS). This supports previous results of Mercier et al. (1994) who found almost identical oxygen consumption during walking and running in the small sample homogenized to the age. According to these results, authors suggested that energetic optimization is crucial in transition during bipedal locomotion. However, in the study of Brisswalter and Mottet (1996) in the group of 10 young subjects (no data about aerobic capacity), authors reported that EOTS was significantly higher than the PTS (7.89 vs 7.66 km/h, respectively). In similar study, Hreljac (1993) in mixed sample of 20 young healthy adults (10 males, 10 females) who walked and run in the range of speeds according to individual PTS, also found significantly higher EOTS (2.24 m/s) in compare to the PTS (2.06 m/s). In experiment with adolescents divided in three age groups, Tseh et al. (2002) reported significantly higher EOTS than PTS in each age group. In one of the very few studies regarding the influence of training status (Ziv & Rotstein, 2009) reported PTS was 7.33±0.33 km/h in controls and 8.20±0.54 km/h in race-walkers. In the same time, EOTS was significantly greater in both groups (8.00±0.48 km/h in controls and 8.46±0.55 km/h in racewalkers). Contrary to our findings, the VO_2 was higher during running at the PTS in both groups ($p<0.05$), while response of HR and V_E were higher at the PTS in racewalkers group in compare with controls. Therefore, this group of studies indicates that decrease in energy utilization is not a crucial factor in the conversion of movement form.

During both gait patterns at PTS, V_E was almost equal, while significant difference was noted at speeds above and below PTS. Our results showed that gait transition considerably impacted V_E and BF variations. Increase in V_E was followed with reciprocal decrease of BR. Still, even at the highest walking speed (8.8 km/h), BR of the lungs was still preserved (53.68±6.60 l/min) which supports the statement that respiratory system has large functional reserve during exercise (Dempsel, La Gerche & Hull, 2020). We have found three studies that presented data regarding respiratory response during gait transition (Mercier et al., 1994; Monteiro & Araújo, 2009; Monteiro et al., 2011). These authors measured V_E and ventilator equivalents of O_2 and CO_2 as respiratory variables. Breathing frequency and BR were not reported in any previous study about gait transition. Mercier et al. (1994) reported that V_E did not differ between walking and running at PTS and PTS+0.5 km/h. Additionally, during walking ventilation was significantly higher on both speeds below PTS. In determinate range of speeds (PTS±1 km/h) significant differences in EqO_2 between walking and running were not found. However, small sample size and heterogeneity of anthropometric characteristics limit the results of this study. Monteiro et al. (2011) showed that in more homogenous sample, respiratory variables (V_E, EqO_2, $EqCO_2$) during walking at 110% of PTS, were higher in compare to running. However, at PTS and at 90% of PTS, these variables did not show difference between gait patterns.

Ventilator equivalents of O_2 and CO_2 represent the relation between V_E and volume of consumed oxygen or eliminated carbon-dioxide, respectively. In present study EqO_2 and $EqCO_2$, as parameters of functional capability of respiration system, did not show significant increase during walking at speeds above PTS, which is opposite to previously reported (Monteiro et al., 2011). The reason for slight increase of EqO_2 and $EqCO_2$ was almost reciprocal increase in V_E, and oxygen consumption and CO_2 elimination. Therefore, walking at speeds above PTS might be demanding for persons with respiratory problems and chronically obstructive lung diseases (Ringbaek et al., 2008).

Conclusion

In conclusion, the present findings indicated that in young, physically active males walking at the speed above PTS implied higher cardiorespiratory demand in compare to running. We showed that walk-to-run transition leads to a significant decrease in cardiovascular and respiratory systems loading, due to decline of heart rate, oxygen consumption and ventilation. Considering that tissue oxygen and energy demands are significantly higher during walking at speed above PTS, transition from walking to running should be considered as the energy saving mechanism. This suggests that physiological underlying mechanisms might be relevant factors in human gait transition.

The results obtained on the increased oxygen consumption during walking at a speed higher than the PTS can also have practical significance and could help coaches and physicians in designing a training protocol. For example, walking at speeds above the preferred transition speed could increase the energetic response and could be more favorable than running at those speeds, when the goal of the training program is increased energy expenditure in cardio-aerobic training aimed at weight loss. On the other hand, the results indicate that walking at speeds above optimal causes an increase in the response of the cardiorespiratory system compared to running at those speeds, so individuals with cardiorespiratory problems should be careful when using walking at high speeds that exceed the PTS. Therefore, understanding of cardiorespiratory response is very important for loading control during locomotion and planning individual training programs based on walking and running around individual PTS.

Further research is warranted to confirm influence of cardiorespiratory loading and energy optimization throughout gait reorganization in other population groups such as females, children and older subjects, and untrained individuals.

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