

ORIGINAL SCIENTIFIC PAPER

Gait Transition Speed and the Aerobic Thresholds for Walking and Running in Women

Davor Sentija¹, Vesna Babic² and Lucija Kolic²

¹University of Zagreb, Faculty of Kinesiology, Department of Kinesiological Anthropology and Methodology, Zagreb, Croatia, ²University of Zagreb, Faculty of Kinesiology, Department of Sport Kinesiology, Zagreb, Croatia

Abstract

Recently, it has been shown that the preferred transition speed between walking and running (PTS) in men does not differ from the aerobic thresholds (AT) for both walking (ATw) and running (ATr). The PTS in men was also found to be related to ATr, but not for ATw (Sentija & Markovic, 2009). No study has, to the best of our knowledge, examined these relationships in female subjects. Men and women show no significant gender differences in the gait transition speed, although women have a lower aerobic capacity (VO_2max) than men do. Therefore, the present study aimed to explore the relationship between ATw, ATr, and the PTS in young, healthy women. Eleven female PE students (19.5 ± 0.5 y, 169.4 ± 5.7 cm) performed five treadmill tests: 1) to determine the individual PTS, 2-3) two fast ramp treadmill tests, running in one (VO_2max test) and walking in the other, 4-5) two incremental tests with 4-min stages, walking in one and running in the other, in order to determine steady-state VO_2 at speeds below and above PTS (5-9 km/h). The AT in ramp tests were determined from gas exchange data (V-slope method). The ATr was similar (7.34 ± 0.52 km/h) to PTS (7.21 ± 0.27 km/h, $p > .05$), while ATw was significantly lower (6.64 ± 0.47 km/h, $p < .001$). The PTS was significantly correlated with both ATr ($r = 0.77$) and ATw ($r = 0.72$). A high correlation was also present between ATr and ATw ($r = 0.80$). Several findings in our study suggest significant gender differences in the PTS/AT relationship: 1) the ATw in female subjects was found to be significantly lower than both the ATr and PTS, suggesting that the speed at the aerobic threshold in women depends on the modality of gait, and 2) the ATw was significantly correlated to both, PTS and ATr suggesting that the ATw could also be a significant predictor of the PTS in young women. Our results indicate that the PTS and the AT in young women are similar to the values reported for young men. In young women, the PTS is highly related to ATr and, to a lesser degree, with the aerobic threshold for walking. Gender differences should be taken into consideration for the proper interpretation of the factors that determine the gait transition speed between walking and running.

Key words: gait transition speed, walking, running, ventilatory threshold

Introduction

The energy cost to walk a given distance increases with pace, while the energy requirement to run a given distance is constant regardless of running speed, if the activity is predominantly aerobic (Margaria, Cerretelli, Aghemo, & Sassi, 1963; Di Prampero, 1986; Saibene, & Minetti, 2003; Bramble & Lieberman, 2004). At lower speeds of locomotion, walking costs less, while running is more efficient at

higher speeds. When increasing or decreasing the speed of locomotion, a spontaneous transition occurs (walk-to-run, or run-to-walk) at approximately the same speed for both genders (2 m/s), and this intensity is commonly referred to as the preferred transition speed (PTS) (Hreljac, 1993b). Several metabolic, mechanical, and perceptual factors have been postulated to trigger the walk-run transition (Hreljac, 1993a, 1993b; Hreljac, 1995a, 1995b; Mercier et al., 1994;



Correspondence:

D. Sentija

University of Zagreb, Faculty of Kinesiology, Department of Kinesiological Anthropology and Methodology, Horvaćanski zavoј 15, 10000 Zagreb, Croatia

E-mail: dsentija@kif.hr

Kram, Domingo, & Ferris, 1997; Minetti, Ardigo, & Saibene, 1994; Turvey, Holt, LaFiandra, & Fonseca, 1999; Neptune & Sasaki, 2005; Prilutsky & Gregor, 2001; Raynor, Yi, Abernethy, & Jong, 2002; Segers, Lenoir, Aerts, & De Clercq, 2007; Sasaki & Neptune, 2006; Malcolm, Segers, Van Caekenberghe, & De Clercq, 2009; Kung, Fink, Legg, Ali, & Shultz, 2018). Although women demonstrate a significantly lower aerobic capacity than men do, there are no gender differences in the PTS. Recently, it has been shown that the preferred transition speed between walking and running in men: 1) does not differ from the aerobic ("lactate", or "first ventilatory") thresholds for both, walking (ATw) and running (ATr) gaits, 2) is related to the aerobic threshold for running, but not for walking (Sentija & Markovic, 2009). No study has, to the best of our knowledge, examined those relationships in female subjects.

Therefore, the study aimed to investigate the energy expenditure, the aerobic threshold for walking, the aerobic threshold for running, and the preferred transition speed in women, and to establish gender differences, by comparing the observed parameters with published data on male subjects.

Methods

Eleven female (19.4 ± 0.5 y, 169 ± 6 cm) physical education students participated in the study. All subjects were familiarized with treadmill walking and running prior to data collection (Schieb, 1986). Five tests were performed on a motorized, calibrated treadmill with a speed resolution of $0.1 \text{ km}\cdot\text{h}^{-1}$ (Run Race Technogym, Gambettola, Italy), and preceded by a short warm-up and stretching procedure. Gas exchange data were measured breath-by-breath using a Quark b2 metabolic measurement cart (Cosmed, Italy). Before each test, the gas analysers were calibrated using gasses of known concentration, and the flow-meter was calibrated using a 3-L syringe. Heart rate was recorded during the tests using an HR monitor (Polar Electro, Kempele, Finland).

Incremental running ($\text{VO}_{2\text{max}}$) and walking treadmill tests

A treadmill test to volitional exhaustion was performed for the determination of $\text{VO}_{2\text{max}}$. The starting speed of $3 \text{ km}\cdot\text{h}^{-1}$ was maintained for 3 min, after which the speed was increased by $1 \text{ km}\cdot\text{h}^{-1}$ every 60 s. The subjects walked the first two stages (up to $4 \text{ km}\cdot\text{h}^{-1}$), and continued running from $5 \text{ km}\cdot\text{h}^{-1}$ until volitional exhaustion. The last half or full stage the subject could sustain (for either 30 or 60 s) was defined as the subject's maximal speed. During recovery, the subjects walked at $5 \text{ km}\cdot\text{h}^{-1}$ for 5 min.

All subjects performed the other ramp treadmill test with a similar procedure as in the $\text{VO}_{2\text{max}}$ test, except subjects walked through all the stages. As the peak VO_2 for walking is generally 5–15% lower compared to running (Hagberg & Coyle, 1983), the maximal speed was limited to $10 \text{ km}\cdot\text{h}^{-1}$ for all subjects, regardless of whether exhaustion was achieved (at this or lower speed) or not, to minimize musculoskeletal stress and prevent injury to the lower leg muscles.

Gas exchange data (Quark b2, Cosmed) were averaged at 30 s intervals and analysed (simplified V-slope method) to determine the first ventilatory (aerobic) threshold for

each gait modality (Schneider, 1993; Sentija & Markovic, 2009). The highest oxygen uptake for any 30-second period recorded in the incremental running test was defined as $\text{VO}_{2\text{max}}$.

Determination of metabolic cost for walking and running

All subjects performed two incremental treadmill tests with 4-min stages, walking in one and running in the other, in order to determine steady-state VO_2 at speeds below and above PTS ($5\text{--}9 \text{ km}\cdot\text{h}^{-1}$). One test was performed by walking at all speeds and started at $5 \text{ km}\cdot\text{h}^{-1}$, after which the speed was increased by $1 \text{ km}\cdot\text{h}^{-1}$ every 4 min up to $8 \text{ km}\cdot\text{h}^{-1}$. The other test was performed by running at all speeds and started at $6 \text{ km}\cdot\text{h}^{-1}$ with a speed increase of $1 \text{ km}\cdot\text{h}^{-1}$ every 4 min up to $9 \text{ km}\cdot\text{h}^{-1}$. The tests were separated by a 30-min rest and were performed in randomized order. The average VO_2 achieved in the 4th minute of every stage was used as a measure of steady-state VO_2 at that particular speed. The curves of energy expenditure (VO_2/kg) in relation to gait speed were fit to the four data points for both walking and running, using a least squares regression method. A third-order polynomial model was used to fit walking data and a linear model to fit running data. The steady-state VO_2 at the PTS was interpolated from the respective curves for walking and for running.

PTS test

A fifth treadmill test was also performed with all subjects to determine their individual PTS, according to the procedure described previously by Sentija and Markovic (2009).

In all walking tests, subjects had to fulfil the criteria used in race walking, i.e., the stance leg has to be extended in the mid-stance phase (inverted pendulum model), while in the running tests the stance leg had to be flexed in the midstance (spring-mass model). All testing sessions were separated by 1–3 days and performed in randomized order.

Statistical analysis

The results are presented as means \pm SD for all subjects. The normality of appropriate data sets was confirmed with the Kolmogorov-Smirnov test. Paired t-tests were used to make comparisons between the PTS and velocities at the gas exchange thresholds and between data in this study and the findings for male subjects in a similar study by Sentija and Markovic (2009). Relationships between the PTS and velocities at the gas exchange thresholds were determined using Pearson product-moment correlations. A value of $p < 0.05$ was established a priori to determine statistical significance.

Results

The preferred gait transition speed in the female subjects occurred at $7.21 \pm 0.3 \text{ km}\cdot\text{h}^{-1}$, in close agreement with values for the PTS reported in previous studies (Hreljac, 1993a, 1993b; Raynor, 2002). The corresponding energy expenditures at PTS for walking and for running (Figure 1) were 26.6 ± 3.7 and $31.3 \pm 2.9 \text{ ml O}_2/\text{min}/\text{kg}$, respectively, and also did not differ from values reported for male subjects in the study of Sentija and Markovic (2009) (24.3 ± 3.6 and $29.5 \pm 2.6 \text{ ml O}_2/\text{min}/\text{kg}$, $\text{PTS} = 7.15 \pm 0.4 \text{ km}\cdot\text{h}^{-1}$, all $p > 0.05$).

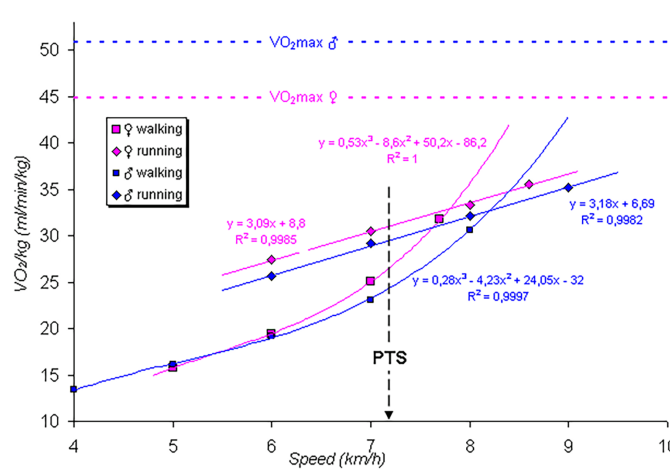


Figure 1. Preferred transition speed (PTS), average energy expenditures for walking and running and VO₂max values (data for males are added from the study of Sentija and Markovic, 2009).

The ATr had a similar average value (7.34 ± 0.5 km/h) as all female subjects (6.64 ± 0.5 km/h, $p < .001$). PTS ($p > .05$), while ATw was lower than the PTS and ATr in

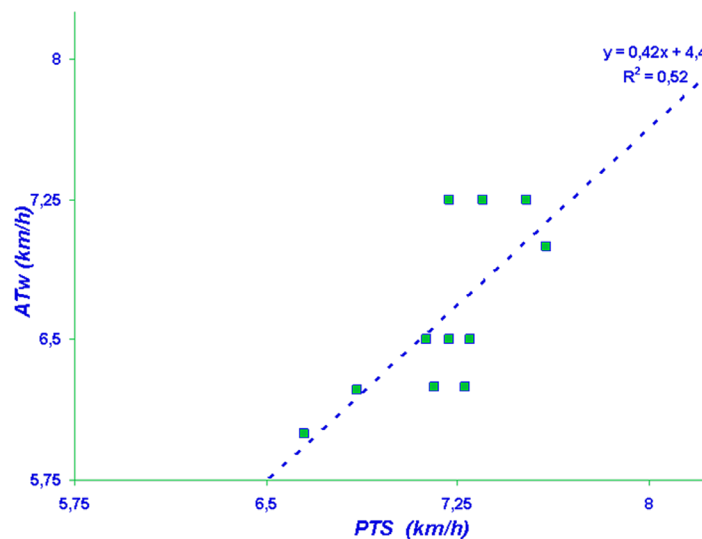


Figure 2. Relationship between PTS and ATw

The PTS was significantly correlated with both ATr and ATw were also highly correlated ($r = 0.80$, Figure 4). (Figure 2) and ATr ($r = 0.77$, Figure 3).

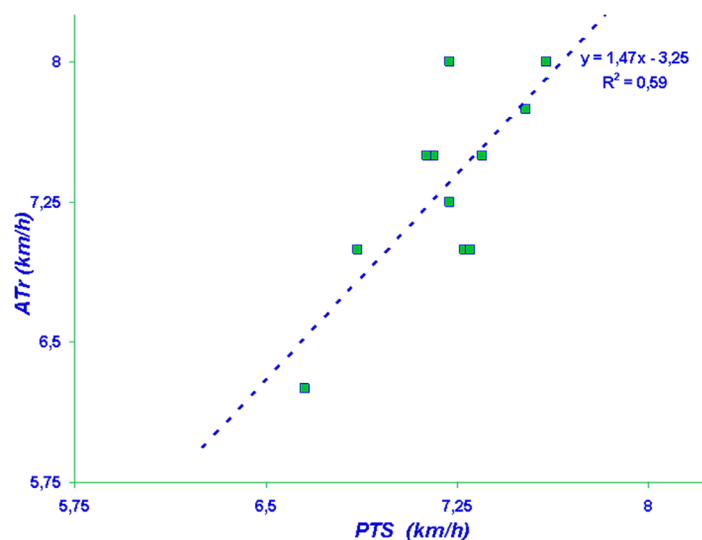


Figure 3. Relationship between PTS and ATr

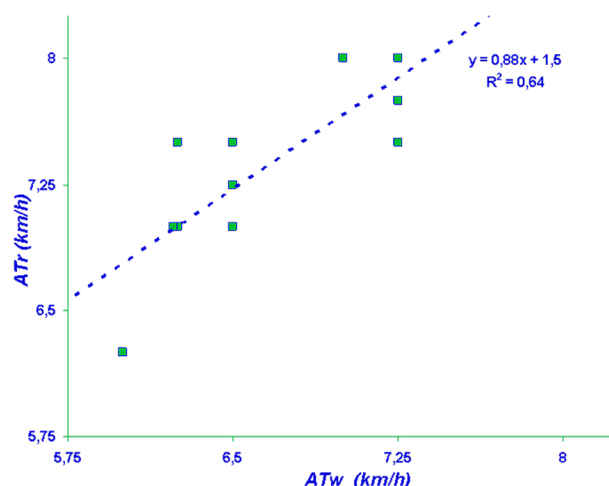


Figure 4. Relationship between ATw and ATr

The PTS in males was reported to be similar and highly correlated to ATr ($r=0.82$) but not to ATw ($r=0.06$). Furthermore, the aerobic thresholds for walking and running in men were not correlated ($r=0.26$, $p>0.05$). As expected, the VO_2max in the present study was significantly lower (44.9 ± 4.0 vs 50.8 ± 4.7 ml O_2 /min/kg, $p<0.01$) than previously found in males (Sentija, & Markovic, 2009). However, the relative energy expenditures at the PTS, expressed as percentages of VO_2max , were significantly higher in women than the values reported for males, both for walking ($59\pm 6\%$ vs. $48\pm 6\%$, $p<0.01$) and for running ($70\pm 6\%$ vs $58\pm 6\%$, $p<0.01$).

Discussion

In comparison to the results reported for males (Sentija & Markovic, 2009), several findings in our study suggest significant gender differences in the PTS/AT relationship: 1) the ATw in our sample of female subjects was found to be significantly lower than both the ATr and PTS, suggesting that the speed at the aerobic threshold in women depends on the modality of gait, 2) the ATw was significantly correlated to both, PTS and ATr suggesting that the ATw could also be an important predictor of the PTS in young, untrained women, 3) in comparison to men, women change gait at a similar absolute intensity (speed of locomotion), but significantly higher relative intensity due to lower aerobic fitness.

There is no experimental evidence explaining why women change gait at the same speed as men. The lack of difference between the PTS of male and female subjects probably reflects the pressure of natural selection that has shaped the development of a similar gait transition speed and aerobic thresholds in men and women despite significant gender differences in stature, mass and aerobic capacity. Sentija, Rakovac, and Babic (2012) investigated the relationship between anthropometric variables and the PTS in both genders. They found moderate but significant gender-specific correlations between PTS, and several body-size and body-shape variables. Female foot length is consistently smaller than male foot length, independent of absolute stature (Fessler, Haley, & Lal, 2005), which may also contribute to higher walking efficiency in women in comparison to men, due to lower inertia with increasing walking speed. Smith, Lelas, and Kerrigan (2002), and Chumanov,

Wall-Scheffler, and Heiderscheit (2008) found significant gender differences in the centre-of-mass and non-sagittal motion at the hip and pelvis, as well as greater gluteus maximus activity in females than in males.

In summary, our results indicate that the gait transition speed corresponds to, and is highly related with the aerobic threshold for running and, to a lesser degree, with the aerobic threshold for walking in young women. The observed aerobic capacity (VO_2max) in young women is significantly lower, while the metabolic thresholds and the preferred transition speed are similar to the values previously reported for male subjects. Therefore young women, in comparison with men, have a wider relative range of energy expenditure for walking. The sexual dimorphisms in body size, body shape, and locomotion kinematics established in previous studies probably reflect the intersexual selection to overcome a lower aerobic capacity in women, favouring the preservation of similar walking capacity and endurance in men and women. Gender differences should be taken into consideration for proper interpretation of the parameters that supposedly determine the preferred transition speed between walking and running.

Acknowledgements

There are no acknowledgements.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Received: 15 March 2019 | **Accepted:** 05 June 2019 | **Published:** 01 October 2019

References

- Bramble, D.M., & Lieberman, D.E. (2004). Endurance running and the evolution of Homo. *Nature*, 432, 345–352.
- Chumanov, E.S., Wall-Scheffler, C., & Heiderscheit, B.C. (2008). Gender differences in walking and running on level and inclined surfaces. *Clinical Biomechanics*, 23, 1260–1268.
- Di Prampero, P.E. (1986). The energy cost of human locomotion on land and in water. *International Journal of Sports Medicine*, 7, 55–72.
- Fessler, D.M., Haley, K.J., & Lal, R.D. (2005). Sexual dimorphism in foot length proportionate to stature. *Annals of Human Biology*, 32, 44–59.
- Hagberg, J.M., Coyle, E.F. (1983). Physiological determinants of endurance performance as studied in competitive racewalkers. *Medicine and Science in Sports and Exercise*, 15, 287–289.
- Hreljac, A. (1993a). Determinants of the gait transition speed during human locomotion: Kinetic factors. *Gait & Posture*, 1, 217–223.
- Hreljac, A. (1993b). Preferred and energetically optimal gait transition speeds in human locomotion. *Med Sci Sports Exerc*, 25(10), 1158–62.

- Hreljac, A. (1995a). Determinants of the gait transition speed during human locomotion: Kinematic factors. *Journal of Biomechanics*, 28, 669–677.
- Hreljac, A. (1995b). Effects of physical characteristics on the gait transition speed during human locomotion. *Human Movement Science*, 14, 205–216.
- Kram, R., Domingo, A., & Ferris, D.P. (1997). Effect of reduced gravity on the preferred walk-run transition speed. *The Journal of Experimental Biology*, 200, 821–826.
- Kung, S.M., Fink, P.W., Legg, S.J., Ali, A., & Shultz, S.P. (2018). What factors determine the preferred gait transition speed in humans? A review of the triggering mechanisms. *Human Movement Science*, 57, 1–12.
- Margaria, R., Cerretelli, P., Aghemo, P., & Sassi, G. (1963). Energy cost of running. *J Appl Physiol*, 18(2), 367–370.
- Malcolm, P., Segers, V., Van Caekenberghe, I., & De Clercq, D. (2009). Experimental study of the influence of the M. tibialis anterior on the walk-to-run transition by means of a powered ankle-foot exoskeleton. *Gait & Posture*, 29, 6–10.
- Mercier, J., Le Gallais, D., Durand, M., Goudal, C., Micallef, J.P., & Prefaut, C. (1994). Energy expenditure and cardiorespiratory responses at the transition between walking and running. *European Journal of Applied Physiology and Occupational Physiology*, 69, 525–529.
- Minetti, A.E., Ardigo, L.P., & Saibene, F. (1994). The transition between walking and running in humans: Metabolic and mechanical aspects at different gradients. *Acta Physiologica Scandinavica*, 150, 315–323.
- Neptune, R.R., & Sasaki, K. (2005). Ankle plantar flexor force production is an important determinant of the preferred walk-to-run transition speed. *The Journal of Experimental Biology*, 208, 799–808.
- Prilutsky, B.I., & Gregor, R.J. (2001). Swing - and support-related muscle actions differentially trigger human walk-run and run walk transitions. *The Journal of Experimental Biology*, 204, 2277–2287.
- Raynor, A.J., Yi, C.J., Abernethy, B., & Jong, Q.J. (2002). Are transitions in human gait determined by mechanical, kinetic or energetic factors? *Human Movement Science*, 21, 785–805.
- Saibene, F., & Minetti, A.E., (2003). Biomechanical and physiological aspects of legged locomotion in humans. *European Journal of Applied Physiology*, 88, 297–316.
- Sasaki, K., & Neptune, R.R. (2006). Muscle mechanical work and elastic energy utilization during walking and running near the preferred gait transition speed. *Gait & Posture*, 23, 383–390.
- Schieb, D.A. (1986). Kinematic accommodation of novice treadmill runners. *Research Quarterly for Exercise and Sport*, 57, 1–7.
- Schneider, D.A. (1993). The simplified V-slope method of detecting the gas exchange threshold. *Medicine & Science in Sports & Exercise*, 25(10), 1180–4.
- Segers, V., Lenoir, M., Aerts, P., & De Clercq, D. (2007). Influence of M. tibialis anterior fatigue on the walk-to-run and run-to-walk transition in non-steady state locomotion. *Gait & Posture*, 25, 639–647.
- Sentija, D., & Markovic, G. (2009). The relationship between gait transition speed and the aerobic thresholds for walking and running. *International Journal of Sports Medicine*, 30, 795–801.
- Sentija, D., Rakovac, M., & Babić, V. (2012). Anthropometric characteristics and gait transition speed in human locomotion. *Human Movement Science*, 31, 672–682.
- Smith, L.K., Lelas, J.L., & Kerrigan, D.C. (2002). Gender differences in pelvic motions and center of mass displacement during walking: Stereotypes quantified. *Journal of Women's Health & Gender-based Medicine*, 11, 453–458.
- Turvey, M.T., Holt, K.G., LaFiandra, M.E., & Fonseca, S.T. (1999). Can the transitions to and from running and the metabolic cost of running be determined from the kinetic energy of running? *Journal of Motor Behavior*, 31, 265–278.