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The relationship between allometry and preferred transition speed in human locomotion

Igor Ranisavljev [a], Vladimir Ilic [a,*], Ivan Soldatovic [b], Djordje Stefanovic [a]

[a] Faculty of Sport and Physical Education, University of Belgrade, Serbia
[b] School of Medicine, University of Belgrade, Serbia

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ABSTRACT

The purpose of this study was to explore the relationships between preferred transition speed (PTS) and anthropometric characteristics, body composition and different human body proportions in males. In a sample of 59 male students, we collected anthropometric and body composition data and determined individual PTS using increment protocol. The relationships between PTS and other variables were determined using Pearson correlation, stepwise linear and hierarchical regression. Body ratios were formed as quotient of two variables whereby at least one significantly correlated to PTS. Circular and transversal (except bitrochanteric diameter) body dimensions did not correlate with PTS. Moderate correlations were found between longitudinal leg dimensions (foot, leg and thigh length) and PTS, while the highest correlation was found for lower leg length ($r = .488$, $p < .01$). Two parameters related to body composition showed weak correlation with PTS: body fat mass ($r = -.250$, $p < .05$) and amount of lean leg mass scaled to body weight ($r = .309$, $p < .05$). Segmental body proportions correlated more significantly with PTS, where thigh/lower leg length ratio showed the highest correlation ($r = .521$, $p < .01$). Prediction model with individual variables (lower leg and foot length) have explained just 31% of PTS variability, while model with body proportions showed almost 20% better prediction ($R^2 = .504$). These results suggests that longitudinal leg dimensions have moderate influence on PTS and that segmental body

* Corresponding author. Address: Faculty of Sport and Physical Education, University of Belgrade, Blagoja Parovica 156, 11030 Belgrade, Serbia. Mobile: +38 162666681.
E-mail address: vladimir.ilic@fsfv.bg.ac.rs (V. Ilic).

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proportions significantly more explain PTS than single anthropometric variables.

1. Introduction

The preferred transition speed (PTS), or the lowest speed of transition from walking to running, has been extensively investigated as a multi-factorial phenomenon in the fields of sport and medical sciences. Previous experimental studies have shown that a variety of anthropometric (Hreljac, 1995b; Šentija, Rakovac, & Babić, 2012), metabolic (Ganley, Stock, Herman, Santello, & Willis, 2011; Mercier et al., 1994), mechanical (Raynor, Yi, Abernethy, & Jong, 2002), kinematic (Diedrich & Warren, 1995; Hreljac, 1995a) and muscle fatigue (Malcolm, Segers, Van Caekenberghe, & De Clercq, 2009; Prilutsky & Gregor, 2001; Segers, Lenoir, Aerts, & De Clercq, 2007) factors may influence gait transition in human locomotion. However, numerous researchers have reported conflicting results about factors which influence/trigger the moment of gait transition, although the main factors still remain undetermined.

The initial assumptions obtained in the studies on quadruped animals (Alexander, 1989; Heglund & Taylor, 1988) have been further extended on human bipedal locomotion. While three types of gait transitions characterize animal locomotion (walk-to-trot, trot-to-gallop, gallop-to-run), the main transition in human locomotion is walk-to-run. The early report of Alexander (1989) which stated that quadrupeds and humans share several gait characteristics and change gaits at approximately the same Froude number (~0.5), directed many researchers to a hypothesis that they may show similar correlations between physical characteristics and PTS (Hreljac, 1995b; Kram, Domingo, & Ferris, 1997). Strong mass-transition correlations ($r = .90$) during the walk-trot and trot-gallop transitions were especially high in animal species with a wide range of length and mass characteristics (Heglund & Taylor, 1988). However, considering the excessive variability associated with inter-species comparisons (in animals), when compared to the homogeneous allometric characteristics of the human population, these correlations were only weak to moderate (Hanna, Abernethy, Neal, & Burgess-Limerick, 2000; Hreljac, 1995b; Raynor et al., 2002; Šentija et al., 2012). The only study that showed a significant mass-transition relation in human population was conducted on overweight females, reporting a significant increase of PTS during a weight loss training programme (Ilić, Ilić, Mrdaković, & Filipović, 2012).

The Inverted pendulum model of walking, based on single longitudinal anthropometric variables, has suggested that the PTS occurs when walking reaches the speed when it is no longer able to successfully recover energy due to anthropometric limitations (Alexander, 1989; Kram et al., 1997). Recent model equations have shown that metabolic costs and muscle activity can be predicted from segmental body proportions if the model is based on motion efficiency according to individual morphology (Carey & Crompton, 2005). However, the results regarding the role of anthropometry on gait transition in humans are still quite conflicting. While Šentija et al. (2012) reported zero correlation between body weight and PTS in males, other studies reported up to 0.74 (Hreljac, 1995b). Additionally, Raynor et al. (2002) showed that lower leg length significantly correlated with PTS contrary to Šentija et al. (2012) who did not find a significant relation in male subjects. Moreover, none of the previous studies measured a potential influence of body composition variables on PTS value.

Taking into account that complex mechanism of gait transition in human locomotion is influenced by differences in natural preferred gait frequency (Thorstensson & Roberthson, 1987), the ratio of stride length/stride frequency (Diedrich & Warren, 1995; Hreljac, 1995b) and different information from peripheral swing and support related muscles (Prilutsky & Gregor, 2001), we hypothesized that in a research with an appropriate sample size, human segmental body proportions would be better predictors of PTS than single variables, and that the amount of muscle mass and body fat mass significantly influence PTS.