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Effect of walking speed on gait sub phase durations ☆

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ABSTRACT

Gait phase durations are important spatiotemporal parameters in different contexts such as discrimination between healthy and pathological gait and monitoring of treatment outcomes after interventions. Although gait phases strongly depend on walking speed, the influence of different speeds has rarely been investigated in literature. In this work, we examined the durations of the stance sub phases and the swing phase for 12 different walking speeds ranging from 0.6 to 1.7 m/s in 21 healthy subjects using infrared cinematography and an instrumented treadmill. We separated the stance phase into loading response, mid stance, terminal stance and pre-swing phase and we performed regression modeling of all phase durations with speed to determine general trends. With an increasing speed of 0.1 m/s, stance duration decreased while swing duration increased by 0.3%. All distinct stance sub phases changed significantly with speed. These findings suggest the importance of including all distinct gait sub phases in spatiotemporal analyses, especially when different walking speeds are involved.

1. Introduction

Spatiotemporal gait parameters are quantitative measures that describe gait performance (Hollman, McDade, & Petersen, 2011). They can be severely affected by musculoskeletal or neurological diseases (Cole, Silburn, Wood, Worringham, & Kerr, 2010; Leardini, O'Connor, & Giannini, 2014). Therefore, these parameters play an important role for classification between healthy subjects and patients at different stages of diseases showing pathological gait (Elbaz et al., 2014; Pradhan et al., 2015; Şen Köktaş, Yalabik, Yavuzer, & Duin, 2010) or for evaluating effects of interventions such as knee replacement surgeries in knee osteoarthritis (Levinger, Lai, Begg, Webster, & Feller, 2009; McClelland, Webster, & Feller, 2007). In elderly populations temporal variability and spatial parameters of gait can also discriminate between fallers and non-fallers (König, Taylor, Armbrecht, Dietzel, & Singh, 2014).

Basic temporal parameters usually include the duration of swing and stance phases, but distinct sub phases during stance should also be considered. Astephen and Deluzio (2005) determined a high discriminatory ability of the loading response

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phase in end-stage knee osteoarthritis patients. Stability of gait in elderly subjects might also be affected mostly during the loading response phase (Ihlen et al., 2012). As an additional factor, gait speed can serve to distinguish and compare healthy and rehabilitating subjects based on spatiotemporal parameters (Andriacchi, Ogle, & Galante, 1977). The dependency of gait phase parameters on gait speed might provide insights in understanding pathological gait as different responses to speed have been observed in osteoarthritis and healthy populations (Bejek, Paróczai, Illyés, & Kiss, 2006). Further, gait speed has been shown to be an important factor affecting the variability of temporal gait parameters (Kiss, 2010). Therefore, the dependency of distinct gait sub phases on gait speed should be taken into account when analyzing gait using spatiotemporal parameters.

A prerequisite in the use of temporal gait analysis is the quantitative definition of gait phases and their durations in healthy subjects. Perry (1992) stated a possible definition, splitting up the gait cycle into gait sub phases according to respective biomechanical tasks of each phase such as weight transfer or limb support (Fig. 1). In our study, we used this definition for separating distinct sub phases based on kinematic and kinetic data using an infrared cinematography system and an instrumented treadmill.

Only a few studies have investigated speed dependency of gait sub phase durations. Blanc, Balmer, Landis, and Vingerhoets (1999) investigated stance, swing and double support times at self-selected speeds, but no investigation of speed dependency was presented. Schwartz, Rozumalski, and Trost (2008) analyzed the effect of speed on different spatiotemporal, biomechanical, and neurophysiological parameters using kinematic and kinetic data. However, they roughly defined five speed ranges by grouping self-selected speeds and investigated speed dependency of only double limb support, single limb support and swing phase. Liu et al. (2014) investigated gait sub phase variations of healthy subjects over different self-selected velocities. A high-speed camera was used with manual gait event detection and 285 steps were analyzed in order to describe the relationship between phase duration and speed. Although self-selected speed is a reasonable choice in gait analysis, the speed definitions used are not applicable to accurately quantifying the effect of walking speed given variability of the inter-individual perception of "normal", "slower than normal" and "faster than normal". Further, classification into only three speeds, as presented by the authors, may result in loss of information as the speed ranges might overlap. A comprehensive investigation of gait speed dependency of the duration of these sub phases over a wide speed range as well as modeling of this relationship using a large set of high resolution data is therefore still missing from the literature. We believe that analyzing changes of gait sub phases with speed is a critical step towards a comprehensive spatiotemporal analysis of gait.

The goals of our study were (1) to quantitatively describe healthy gait in terms of the proportional durations of sub phases during stance and (2) to model speed dependency of the durations by regression models.

2. Methods

2.1. Participants and preparation

Twenty-one healthy heel striking subjects (10 male, 11 female, age: 23.8 ± 3.3 years, height: 172.8 ± 9.4 cm, mass: 66.6 ± 10.9 kg) without injuries or musculoskeletal disorders participated in this study. The study was approved by the ethical committee of the University Hospital Erlangen (Re.-No. 106_13 B). All subjects gave informed consent before participating.

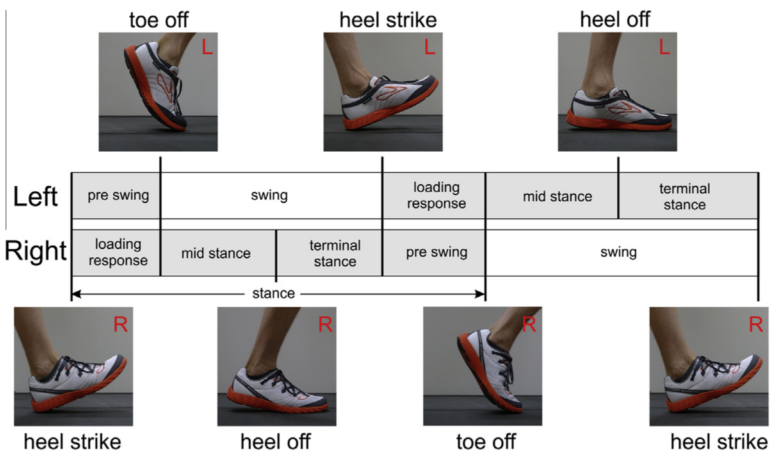

Fig. 1. Overview of the gait cycle and its sub phases that are analyzed in this study. Total gait cycle (HS–HS), stance (HS–TO, grey shaded), swing (TO–HS), loading response (HS–TO of contralateral leg), mid stance (TO of contralateral leg–HO), terminal stance (HO–HS of contralateral leg), pre-swing (HS of contralateral leg–TO). HS = heel strike, HO = heel off, TO = toe off. Definition of the phases according to Perry (1992).