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Dynamics of the ankle joint analyzed through moment–angle loops during human walking: Gender and age effects

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ABSTRACT

Aim of this study was to provide a non-invasive assessment of the dynamic properties of the ankle joint during human locomotion, with specific focus on the effects of gender and age. Accordingly, flexion-extension angles and moments, obtained through gait analysis, were used to generate moment–angle loops at the ankle joint in 120 healthy subjects walking at a same normalized speed. Four reproducible types of loops were identified: Typical Loops, Narrow, Large and Yielding loops. No significant changes in the slopes of the main loop phases were observed as a function of gender and age, with the exception of a relative increase in the slope of the descending phase in elderly males compared to adult females. As for the ergometric parameters, the peak ankle moment, work produced and net work along the cycle were slightly, but significantly affected, with progressively decrease in the following order: Adult Males, Adult Females, Elderly Males and Elderly Females. The evidence that only few of the quantitative aspects of moment–angle loops were affected suggests that the control strategy which regulates the biomechanical properties of the ankle joint during walking is rather robust and qualitatively consistent across genders and age.

1. Introduction

Kinematic and kinetic gait patterns are usually described by plotting joint angles, moments and powers as function of time. A number of relevant dynamic effects, however, can be specifically

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enlightened when pairs of locomotion variables are examined jointly and correlations among them are concurrently assessed. An example of such an approach is the analysis of the relationship between joint moments due to external forces and joint angles, all along the stride cycle (Crenna, 1998; Davis & De Luca, 1996; Frigo, Crenna, & Jensen 1996). In the case of the tibio–tarsal joint, in particular, the relationship computed during steady-state walking reveals a relatively simple, loop-shaped contour (Davis & De Luca, 1996; Frigo et al., 1996; Gabriel et al., 2008; Hansen, Childress, Miff, Gard, & Mesplay, 2004; Kuitunen, Komi, & Kyrolainen, 2002; Quesada, Pitkin, & Colvin, 2000). As shown by the example in Fig. 1, for a short time after initial contact (I.C.), the ankle joint plantarflexes and the external joint moment is negative (plantarflexor). Subsequently, when the foot sole has landed onto the floor, the ankle joint dorsiflexes in the presence of an increasing dorsiflexor (positive) moment. Dorsiflexion continues with an increasing rate of moment raise, until a peak is achieved at approximately 50% of the stride cycle. In the last portion of the stance phase, both angle and moment decrease and eventually, at the onset of the swing phase, the ankle moment becomes plantarflexor and then it stays close to zero until subsequent touch-down.

Application of the above described analysis of kinetic phenomena in movement physiology (see Josephson, 1985, 1993) affords non-invasive testing of two major aspects of dynamic joint function: the spring-like behavior of the joint and the mechanical energy exchanges. The first aspect can be assessed by focusing on the stride phases in which moments and angles change in accordance. These, with reference to the ankle joint, are the rising phase (here subdivided into an early, ERP, and a late, LRP, rising phase) and the descending phase DP depicted in Fig. 1. Over these periods, a functionally meaningful parameter is the slope of the tangent to the moment–angle curve, which in mathematical terms is: $S = dM/d\theta$ (M is the joint moment and θ the joint angle). This is sometimes interpreted as instantaneous 'dynamic joint stiffness' (Davis & De Luca, 1996; Gabriel et al., 2008; Sinkjaer, Toft, Andreassen, & Horneman, 1988), although the term 'quasi' stiffness would be probably more appro-

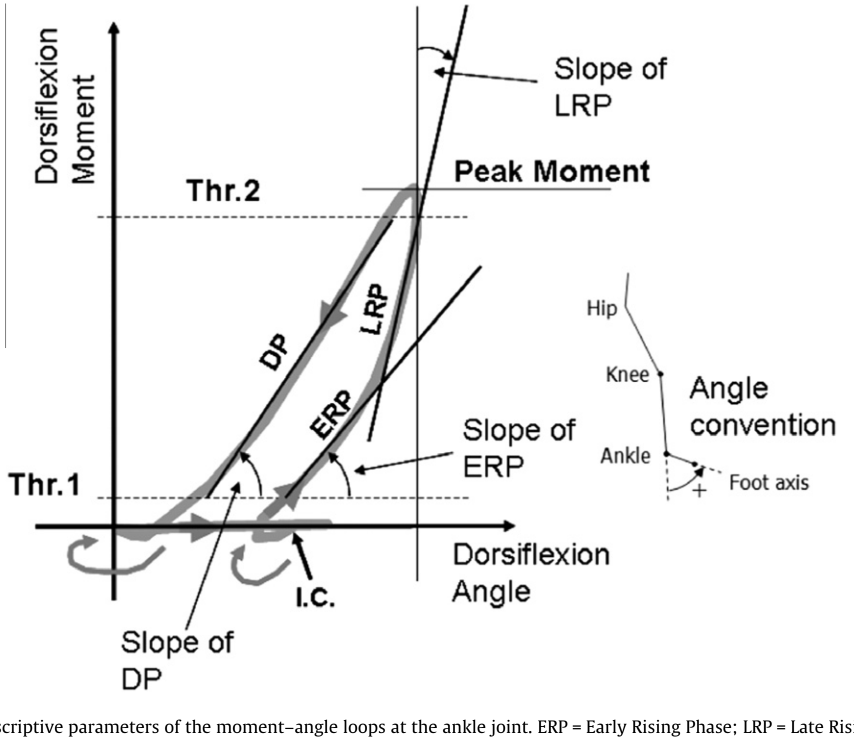

Fig. 1. Descriptive parameters of the moment–angle loops at the ankle joint. ERP = Early Rising Phase; LRP = Late Rising Phase; DP = Descending Phase; I.C. = Initial Contact. The angle convention is depicted on the right. Dorsiflexion moment is to be intended as the moment of the external forces acting on the foot.