Human Movement Science 34 (2014) 205–216

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Is angular momentum in the horizontal plane during gait a controlled variable?

Valerie Thielemans [a], Pieter Meyns [a], Sjoerd M. Bruijn [a,b,c,*]

[a] Department of Kinesiology, KU Leuven, Belgium
[b] Department of Orthopedics, First Affiliated Hospital of Fujian Medical University, Fuzhou, Fujian, PR China
[c] MOVE Research Institute Amsterdam, Faculty of Human Movement Sciences, VU University Amsterdam, The Netherlands

ARTICLE INFO

Article history:
Available online 2 April 2014

PsycINFO classification:
2330

Keywords:
Angular momentum
Arm swing
Gait analysis
Interlimb coordination
Load

ABSTRACT

It has been suggested that angular momentum in the horizontal plane during human gait is controlled (i.e., kept minimal). However, this has not been explored in conditions when angular momentum of different segments is manipulated explicitly. In order to examine the behavior of angular momentum, 12 participants walked in 17 conditions in which angular momentum of either the arms or legs was manipulated. Subjects walked at different step lengths, different speeds and with an additional weight on either the wrist or ankle. Angular momentum of total body, arms and legs was calculated from gait kinematics. Increasing step length increased total body and leg angular momentum. When weight was added to the limbs, arm and leg angular momentum were affected and counteracted each other, so that total body angular momentum did not change. Moreover, increasing walking speed increased arm, leg and total body angular momentum. Thus, it may be concluded that if angular momentum is controlled (which only seems to be the case for conditions when weights are added), it is not strictly controlled in all gait conditions (as it may increase by walking faster/with larger steps).

* Corresponding author at: MOVE Research Institute Amsterdam, Faculty of Human Movement Sciences, VU University Amsterdam, van der Boechorststraat 9, NL-1081 BT Amsterdam, The Netherlands. Tel.: +31 618844777.

E-mail address: s.m.bruijn@gmail.com (S.M. Bruijn).
URL: https://sites.google.com/site/smbruijn/ (S.M. Bruijn).

http://dx.doi.org/10.1016/j.humov.2014.03.003
0167-9457/

1. Introduction

The coordination and function of arm swing in gait have gained considerable interest in the last couple of years (Meyns, Bruijn, & Duysens, 2013). At first sight, arm swing is a somewhat useless behavior, since, unlike movements of the legs, it has no obvious contribution to gait. Nevertheless, it has been suggested that arm swing has several functions in human gait. For instance, it reduces vertical movements of the center of mass (Hinrichs & Cavanagh, 1981; Murray, 1967; Umberger, 2008). Furthermore, gait without arm swing requires more energy (Collins, Adamczyk, & Kuo, 2009), which could be due to the contribution of armswing to the regulation of total body angular momentum in the horizontal plane (Bruijn, Meijer, van Dieën, Kingma, & Lamoth, 2008; Collins et al., 2009; Elftman, 1939; Herr & Popovic, 2008; Park, 2008). This has led to the hypothesis that angular momentum is controlled in human gait (Bruijn et al., 2008; Herr & Popovic, 2008).

Herr and Popovic (2008) hypothesized that angular momentum during the gait cycle is kept minimal throughout the gait cycle, and suggested that the arms are used to cancel angular momentum generated by the legs. Still the study of Herr and Popovic was an observational one, as the authors did not manipulate angular momentum directly. A study by Bruijn et al. (2008) may be more interesting in this regard, as this study suggested that angular momentum might be controlled in the sense that it might be kept as low as possible, since they found no significant change in total body angular momentum over a range of gait speeds, despite increasing leg angular momentum with increasing gait speed. Nonetheless, although angular momentum generated by the legs changed in the study by Bruijn et al. (2008), this was only done through a mediating variable: gait speed. In another study by Donker, Daffertshofer, and Beek (2005), interlimb coordination did not change when angular momentum of segments was directly manipulated by means of adding weights. However, Donker et al. (2005) did not analyze their data in terms of angular momentum. Still, their findings are consistent with the idea that angular momentum remains similar between conditions (since interlimb coordination did not change).

Apart from these studies in healthy subjects, there is converging evidence from pathological gait patterns suggesting that angular momentum may be controlled (i.e., kept minimal) during human gait. A study of Huang et al. (2011) showed that even though low back pain patients move the thorax more in phase with the legs, they keep their arms swinging out of phase with the legs and thus change timing between arm swing and thorax rotations. This is unexpected, but illustrative of the fact that it may be important that the arms remain out of phase with the legs. Additionally, children with cerebral palsy tend to compensate the increased angular momentum created by the affected leg with an increased arm swing on the non-affected side to keep the total body angular momentum small (Bruijn, Meyns, Jonkers, Kaat, & Duysens, 2011).

Angular momentum might be controlled for energetic benefits. Collins et al. (2009) demonstrated that in normal arm swing, out of phase with the legs, the angular momentum remains small and reduces the ground reaction moment. When participants were asked to swing their arms in phase with the legs or when the arms were kept still, it appeared that more energy was required.

All in all, there seems to be converging evidence that angular momentum in the horizontal plane during gait is a controlled variable, in the sense that it is kept minimal throughout the gait cycle. If this would be so, one would expect little to no change in total body angular momentum in a variety of conditions in which angular momentum of the arms or legs is manipulated. Thus, in this study, we looked at the behavior of total body angular momentum in conditions which were designed to change the angular momentum of arms and/or legs. To this aim, we affected angular momentum of either the arms or the legs by means of (1) changing step length, (2) changing gait speed and (3) adding weight to a limb and thereby disturbing symmetry. Angular momentum of the total body, the arms and the legs was calculated. If total body angular momentum indeed is controlled during gait, we expect, despite of these manipulations, that total body angular momentum does not change when compared to normal walking.