Original Research

An investigation of lower-extremity functional asymmetry for non-preferred able-bodied walking speeds

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ABSTRACT

Int J Exerc Sci 3(4) : 182-188, 2010. Functional asymmetry is an idea that is often used to explain documented bilateral asymmetries during able-bodied gait. Within this context, this idea suggests that the non-dominant and dominant legs, considered as whole entities, contribute asymmetrically to support and propulsion during walking. The degree of functional asymmetry may depend upon walking speed. The purpose of this study was to better understand the potential relationship between functional asymmetry and walking speed. Bilateral ground reaction forces (GRF) were measured for 20 healthy subjects who walked at nine different speeds: preferred, +10%, +20%, +30%, +40, -10%, -20%, -30%, and -40%. Contribution to support was determined to be the support impulse: the time integral of the vertical GRF during stance. Contribution to propulsion was determined to be the propulsion impulse: the time integral of the anterior-posterior GRF, while this force was directed forward. Repeated measures ANOVA (α = 0.05) revealed leg × speed interactions for normalized support (p = 0.001) and propulsion (p = 0.001) impulse, indicating that speed does affect the degree of functional asymmetry during gait. Post hoc comparisons (α = 0.05) showed that support impulse was approximately 2% greater for the dominant leg, relative to the non-dominant leg, for the -10%, -20%, and -40% speeds. Propulsion impulse was 12% greater for the dominant leg than for the non-dominant leg at the +20% speed. Speed does appear to affect the magnitude of bilateral asymmetry during walking, however, only the bilateral difference for propulsion impulse at one fast speed (+20%) was supportive of the functional asymmetry idea.

KEY WORDS: locomotion, right, left, lower limbs, dominance, lateralization, symmetry

INTRODUCTION

A comprehensive understanding of walking, one of the most universal of all human motions, is important. Although able-bodied gait has been extensively studied, there are still facets of walking that are not well understood. For example, various bilateral asymmetries have been documented for kinematic [1], kinetic [9, 12], and electromyograhical [3] data, however, the cause(s) of these asymmetries are unclear. *Functional asymmetry* is an idea that has been put forth numerous times as a potential explanation for bilateral asymmetries during *able-bodied gait* [6, 7, 12, 13]. Within this specific framework, it has been hypothesized that the non-dominant and dominant legs, when considered as a whole entities, contribute asymmetrically to support (upward acceleration of the center of mass) and propulsion (forward acceleration of the center of mass) during able-bodied gait [13]. Whole-leg contributions to support and propulsion during walking can be quantified by calculating the impulse due to the vertical and propulsive ground reaction force (GRF) [15].

Although it is clear that walking speed affects walking biomechanics [2, 8], the relationship between speed and certain aspects of bilateral asymmetry during walking is unclear. Some previous research has indicated that functional asymmetry may be influenced by walking speed [6, 7, 15]. A study was recently conducted indicating that although functional asymmetry does not likely exist during preferred-speed walking, it may exist during walking at non-preferred speeds [15]. This fits with the results of two other previous studies that also provided support for the idea that degree of functional asymmetry is influenced by walking speed [6, 7]. Specifically, these two studies showed that bilateral asymmetries for stance time [7] and certain characteristics of the vertical GRF [6, 7] are different for preferred speed and non-preferred speed walking. A limitation, however, related to each of the studies mentioned in this paragraph is that walking speeds greater than or less than 20% of preferred were not observed. If walking speed influences the degree of functional asymmetry during gait, an evaluation of functional asymmetry across a very wide spectrum of walking speeds may provide additional insight concerning the relationship between functional asymmetry and walking speed during able-bodied gait.

The purpose of the present study was to better understand functional asymmetry, as a potential explanation for bilateral asymmetries during able-bodied gait; particularly for walking at non-preferred speeds. Specifically, we addressed the following research questions: (1) Does functional asymmetry exist across a wide spectrum of non-preferred walking speeds? and (2) What is the nature of the relationship between functional asymmetry and walking speed? In relation to these research questions, we formulated two hypotheses. First, functional asymmetry does exist for walking at certain non-preferred speeds. Second, functional differences between the non-dominant dominant legs become larger as the difference between actual and preferred walking speeds increase; in other words, the degree of exhibited functional asymmetry will increase as walking speeds increase or decrease.

METHODS

Participants
Ten males and ten females (age = 24 ± 3 yrs; height = 1.71 ± 0.11 m; mass = 69.6 ± 14.0 kg) who were free from lower-limb injury and a history of neurological disorder participated in this study. The appropriate ethical committee approved this study and subjects gave informed consent prior to data collection.

Protocol
After informed consent was obtained, the dominant leg was identified as the leg chosen to forcefully strike a soccer ball [4]. The preferred walking speed was then calculated as the mean speed of five initial walking trials across a 10-m carpeted walkway. Eight non-preferred walking speeds, each relative to the preferred speed, were then determined; four speeds were greater than preferred, and four speeds were less than preferred (-40%, -30%, -

20%, -10%, +10%, +20%, +30%, and +40%). Five satisfactory trials were collected for each speed. The speed order was completely randomized. Each trial was deemed satisfactory when the: (1) left and right foot contacted separate force platforms (1200 Hz; AMTI, Amherst, NY, USA) during consecutive gait cycles, and (2) walking speed was within ± 2.5% of the predetermined target speed. Walking speed was calculated using an opto-electronic timing device (Brower Timing Systems, Draper, UT, USA). Subjects were given immediate feedback regarding walking speed.

Bilateral support and propulsion impulse were quantified in order to determine the contribution of each leg to support and propulsion [15]. The support impulse was calculated as the time integral of the vertical GRF during the entire stance phase of the gait cycle. The propulsion impulse was calculated by integrating the anterior-posterior GRF over the time that the GRF was directed forward (approximately the second half of the stance phase). The support and propulsion impulse were then averaged across the five satisfactory trials for each speed and leg. These means were then normalized to the product of body weight and $\sqrt{\text{limb length} \div \text{gravity}}$ [10]. Custom algorithms were used to calculate, average, and normalize impulse (Matlab, The MathWorks Inc., Natick, MA, USA).

Statistical Analysis
A repeated measures ANOVA was performed (SPSS Inc., Chicago, IL, USA) to determine the effect of the two independent variables (leg and walking speed) on the two dependent variables (support impulse and propulsion impulse; $\alpha = 0.05$). Tukey's post hoc comparisons were used to detect differences across speed for each leg for support and propulsion impulse ($\alpha < 0.05$). Effect sizes (d) were also calculated in order to better understand the results of the post hoc comparisons.

RESULTS

The means and standard errors for support and propulsion impulse for each leg and all observed walking speeds are presented in Figure 1. Means and standard errors for the actual walking speeds are shown in Table 1. The repeated measures ANOVA indicated that walking speed did influence the degree of bilateral asymmetry related to support and propulsion impulse: significant leg × speed interactions existed for support (p = 0.001) and propulsion impulse (p = 0.001). The post hoc comparisons showed that for the preferred walking speed, neither the support nor propulsion impulse exhibited significant bilateral differences. The post hoc comparisons did, however, indicate statistical bilateral differences for support impulse at the -40%, -20%, and -10% speeds, and for the propulsion impulse at the +20% speed (Figure 1). Support impulse was 2% greater for the dominant leg than for the non-dominant leg for the -40% (d = 0.04), -20% (d = 0.05), and -10% (d = 0.05) speeds (Figure 1A). Propulsion impulse was 12% greater for the dominant leg, relative to the non-dominant leg, for the +20% speed (d = 0.60; Figure 1B). In summary: (1) walking speed significantly affected the degree, or magnitude, of bilateral asymmetry between the non-

Table 1. The mean walking speeds (m/s) for all participants during the present study. Preferred speed (PS) is in the middle; slow (-) and fast (+) speeds are on the left and right, respectively.

Target Speed	-40%	-30%	-20%	-10%	PS	+10%	+20%	+30%	+40%
Actual Speed	0.94 (0.1)	1.09 (0.1)	1.25 (0.2)	1.41 (0.3)	1.56 (0.3)	1.71 (0.3)	1.88 (0.3)	2.03 (0.4)	2.20 (0.4)

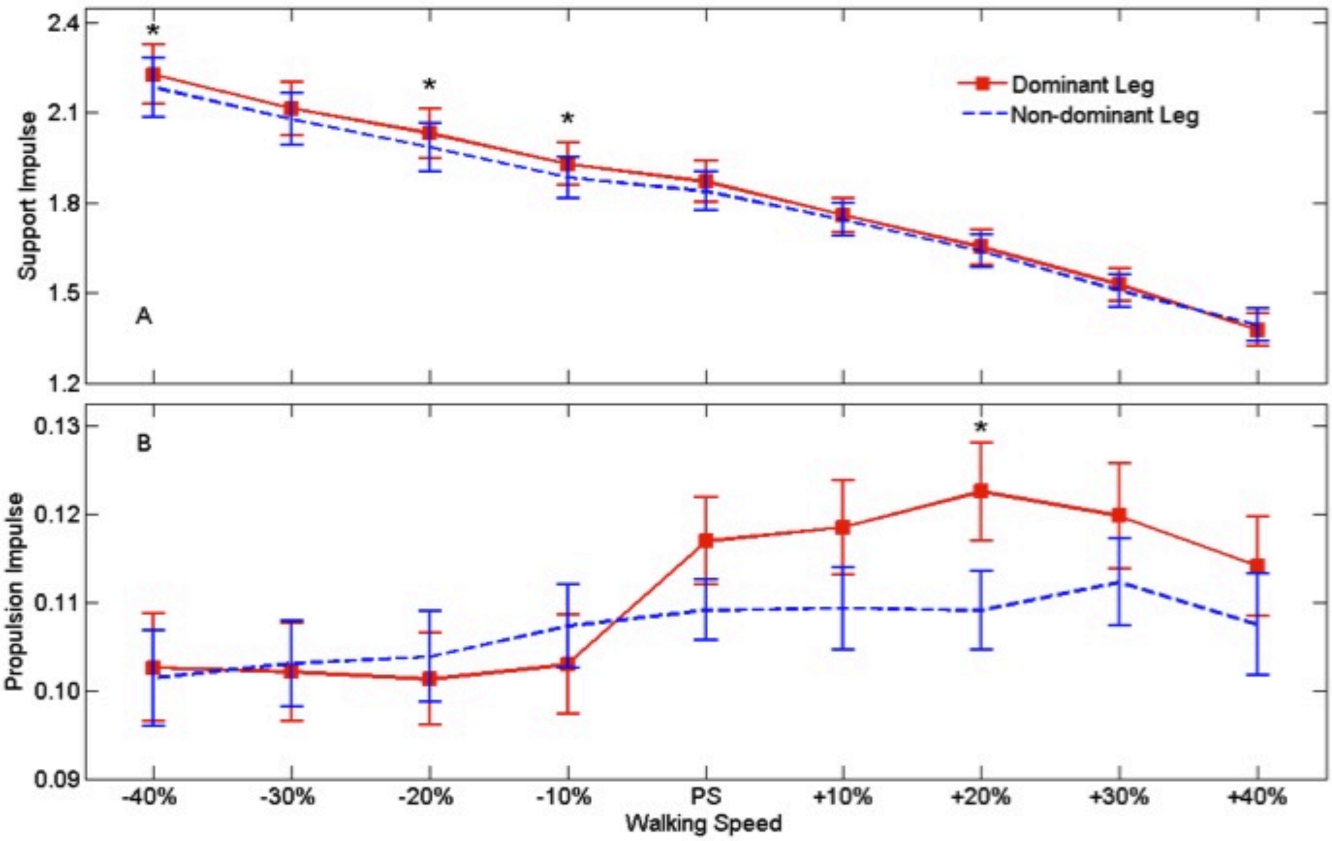

Figure 1. Means and standard errors for normalized support (A) and propulsive (B) impulse for nine different walking speeds. Normalized impulse and walking speed are shown on the horizontal and vertical axes, respectively. Preferred speed (PS) is in the middle; slow (-) and fast (+) speeds are on the left and right. Generally, contributions to support increased disproportionately more for the dominant leg with decreases in walking speed, while contributions to propulsion increased disproportionately more for the dominant leg with increases in walking speed. * Indicates significant difference (P<0.05).

dominant and dominant legs for both support and propulsion impulse; (2) although the bilateral differences were rather small (very small effect sizes), dominant leg support impulses were generally greater for the slower-than-preferred walking speeds; and (3) dominant leg propulsion impulse was greater for one faster-than-preferred walking speed (+20%).

DISCUSSION

The purpose of this study was to increase our understanding regarding the idea of functional asymmetry, as a potential explanation for *able-bodied* gait asymmetries. Functional asymmetry is a specific idea that has been discussed extensively in the scientific literature [13]. According to this idea, the non-dominant and dominant legs contribute disproportionately more to support and propulsion, respectively, during able-bodied gait. Specifically, we were interested in learning more about the potential influence of walking speed on functional asymmetry. We attempted to answer two research questions: (1) Does functional asymmetry exist across a wide spectrum of non-preferred walking speeds?, and (2)

How is functional asymmetry influenced by walking speed? Related to these questions, we hypothesized that functional asymmetry does exist at some non-preferred walking speeds, and that the degree of functional asymmetry increases as the difference between actual and preferred walking speed increases. Our data only partially supported these hypotheses.

The present data failed to support the first hypothesis. Although we found four statistical asymmetries for four different non-preferred walking speeds, only one of these asymmetries was congruent to the functional asymmetry idea: the propulsion impulse asymmetry for the +20% speed (Figure 1B). Additionally, this propulsion impulse asymmetry was the only asymmetry for which the effect should be considered to be sizeable, according to the calculated effect sizes [5]. The other asymmetries, all support impulse asymmetries, were for slower-than-preferred speeds (-40%, -20%, and -10%) and were all relatively small (Figure 1A). Based upon the functional asymmetry idea, we expected that the non-dominant leg would exhibit greater support impulses than the dominant leg, however, the opposite was observed: dominant support impulses were greater than non-dominant impulses (Figure 1A). Consequently, the answer to our first research question is no, functional asymmetry does not exist across a wide variety of non-preferred walking speeds. The present data indicate that the only speed for which the functional asymmetry idea may be a valid explanation for bilateral asymmetries is the +20% speed. This finding corroborates previous research [15].

Our data partially supported the second hypotheses. For the propulsion impulse data, the leg × speed interaction and bilateral asymmetry for the +20% speed support the idea that functional asymmetry exists, but may be dependent on walking speed (Figure 1B). The propulsion impulse data demonstrate that, with increases in walking speed up to +20%, dominant leg contributions to propulsion increase disproportionately, relative to the non-dominant leg; this fits with the functional asymmetry idea. The dominant leg may contribute more to propulsion because propulsion requirements increase with increases in walking speed. A visual inspection of the propulsion impulse data (Figure 1B) indicates that the greatest change in degree of functional asymmetry appears to occur roughly somewhere between the -10% and +20 % speeds. Thus, the answer to our second research question appears to yes, walking speed does affect functional asymmetry for speeds ranging from just less than preferred to approximately 20% greater than preferred. It should be emphasized, however, that the previously mentioned range is based upon the aforementioned visual inspection of the propulsion impulse data (Figure 1B). Finally, although we did observe small asymmetries for support impulse, that were affected by walking speed, none of these asymmetries were in a direction that supports the functional asymmetry idea.

This study is important because it is the first study to evaluate the functional asymmetry idea, using support and propulsion impulse, across a wide spectrum of walking speeds. Propulsion and support impulses were recently observed in a similar context [15], however, only three walking speeds were observed (-

20%, preferred, and +20%). Our results match these previously reported findings; i.e., dominant leg contributions to propulsion increase disproportionately, relative to non-dominant leg contributions to propulsion, as walking speed increases from preferred to greater-than-preferred walking speeds [15]. Our results differ, however, from data related to the control subjects (able-bodied subjects) of previous research that indicated that speed does not influence bilateral asymmetries for propulsive impulse for able-bodied subjects [16]. This difference in results may be related to differences in observed walking speeds. Observed walking speeds for this previous study were 0.6-1.5 m/s[16], while speeds observed during the present study ranged from 0.94 m/s to 2.20 m/s. Specifically, during the present study, propulsion impulse asymmetries were only observed at the speed of 1.88 m/s (Table 1).

Related specifically to the present data, the causes of the observed asymmetries and their dependence on walking speed are unclear. Speculating, one potential cause of asymmetrical propulsion impulse during walking may be asymmetrical arm swing. Previous researchers have demonstrated that individuals tend to swing their arms asymmetrically during able-bodied walking, and that the arm swing motion is increased with increases in walking speed [11]. Theoretically, asymmetrical arm motions that are magnified by increases in walking speed may potentially contribute to asymmetries for propulsion impulse that are influenced by walking speed. Additional research should be conducted to better understand this issue: the analysis of other mechanical (e.g., net joint moments) and neuromuscular (e.g., electromyography amplitudes) variables for a wide walking at wide variety of non-preferred speeds would likely increase our understanding of the causes of documented asymmetrical impulses.

There are potential limitations associated with the present study. Although the spectrum of speeds utilized in this study might be considered rather wide from a biomechanical standpoint, it might be argued, from a motor control perspective, that the speed spectrum was not wide enough. Assuming the perspective of the generalized motor program theory [14], the speeds involved during the present study might be considered to be relatively similar and the subjects may have been able to use the same generalized motor program for each walking speed. Consequently, these changes in speed resulted in fewer measureable changes than were expected. Also, the method we used to determine leg dominance (the preferred kicking leg) merits some discussion. Although some previous gait researchers have utilized this method to determine leg dominance [15, 17, 18], it is not without its problems, especially within a gait context. The dominant leg, as defined using a kicking task, may not be the dominant leg during walking. The process of determining leg dominance for walking should be further examined, as the motor task for walking may be distinct from the motor schema involved with kicking. Leg dominance requires a narrow task specific definition, as well as an identifying protocol.

In conclusion, whole-leg contributions to support and propulsion were shown to be symmetrical between the non-dominant and dominant legs during preferred-speed gait. This finding fits with previous research [7, 15] and supports numerous clinical assumptions of symmetry. Specific bilateral asymmetries exist, however, for whole-leg contributions to support and propulsion during certain non-preferred walking speeds. Contributions to support are greater for the dominant leg than for the non-dominant leg for walking speeds that are 40%, 20%, and 10% slower than preferred. Contributions to propulsion are greater for the dominant leg for one greater-than-preferred walking speed (+20%), supporting the previously hypothesized idea of functional asymmetry for this greater-than-preferred speed (+20%).

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