ARTICLE IN PRESS

Journal of Bodywork & Movement Therapies xxx (2017) 1–6

Contents lists available at ScienceDirect

Journal of Bodywork & Movement Therapies

journal homepage: www.elsevier.com/jbmt

Comparative study

Do different methods for measuring joint moment asymmetry give the same results?

AmirAli Jafarnezhadgero [a,*], Morteza Madadi-Shad [b], Fatemeh Salari Esker [c], D.G.E. Robertson [d]

[a] Department of Physical Education and Sport Sciences, Faculty of Educational Science and Psychology, University of Mohaghegh Ardabili, Ardabil, Iran
[b] Department of Sport Biomechanics, Bu-Ali Sina University, Hamedan, Iran
[c] Department of Sport Biomechanics, University of Mazandaran, Babolsar, Iran
[d] School of Human Kinetics, University of Ottawa, Ottawa, Ontario, Canada

A R T I C L E I N F O

Article history:
Received 27 June 2017
Received in revised form
15 October 2017
Accepted 20 October 2017

Keywords:
Gait
Moment
Asymmetry
Symmetry
Kinematics
Kinetics

A B S T R A C T

Gait asymmetry is defined as a loss of perfect agreement between the dominant and non-dominant lower limbs. Conflicting results from gait asymmetry studies may be due to different definitions of asymmetry, different research methods, and/or different variables and formulas used for asymmetry calculation. As a result, this makes it difficult to compare joint asymmetry values between studies. An accurate and precise understanding of asymmetry during human walking is an important step towards developing enhanced rehabilitation protocols for pathological gait. This study examined bilateral lower extremity joint moment asymmetry during the stance phase of walking using three different methods. Fourteen male children (with flat feet) aged 8–14 years participated in this study. The three-dimensional lower limb kinetics was evaluated during a comfortable gait. Then, right and left lower limb joint moments were used to calculate the joint moment asymmetry via three different methods (Lathrop-Lambach method: equation used by Lathrop-Lambach et al. (2014); Su method: equation used by Su et al. (2015); Nigg method: equation used by Nigg et al. (2013)). Repeated-measures ANOVAs ($\alpha = 0.05$) were used to compare the values of net joint moment asymmetry calculated by the three methods. The results of the statistical analyses found that the amounts of moment symmetry between limbs calculated by the first two methods were significantly greater than that of using the Nigg method (except for the values of the frontal ankle moment computed by the Lathrop-Lambach method). Furthermore, in comparison of the first two methods, using the Su method showed a reduction in moment asymmetry for all joints and for all moments ($p < 0.05$). We conclude that, although all of three common methods for determining asymmetry between limbs have documented merit, they sometimes differ dramatically in results.

1. Introduction

Gait asymmetry has been defined as a loss of perfect agreement between the dominant and non-dominant lower limbs (Herzog et al., 1989). Gait asymmetry is thought to arise from different factors including limb dominance, disease, leg length discrepancies, and strength imbalances (Sadeghi et al., 2000). It is noteworthy that previous studies show controversial results about the existence of the symmetry of normal walking (Carpes et al., 2010; Echeverria et al., 2010; Sadeghi et al., 2000); however, many studies have demonstrated that remarkable gait asymmetry appears in many pathological conditions (Bartsch et al., 2007; Lin et al., 2006; Perttunen et al., 2004; Su et al., 2015; White et al., 2005). An asymmetrical gait may increase fall risk in relation to activities of daily living (Bautmans et al., 2011). However, according to the asymmetry literature, there is no standard method of establishing when gait symmetry has improved, or has returned to that of healthy individuals (Hesse et al., 1993; Patterson et al., 2010). The conflicting results from gait asymmetry studies are due to different definitions of asymmetry, different research methods, different variables and formulas used for asymmetry calculation. As a result, comparison of joint asymmetry values between studies is difficult. An accurate and precise understanding of asymmetry during human walking is an important step towards developing enhanced

* Corresponding author.
E-mail address: amiralijafarnezhad@gmail.com (A. Jafarnezhadgero).

https://doi.org/10.1016/j.jbmt.2017.10.015
1360-8592/

Please cite this article in press as: Jafarnezhadgero, AmirAli-g., et al., Do different methods for measuring joint moment asymmetry give the same results?, Journal of Bodywork & Movement Therapies (2017), https://doi.org/10.1016/j.jbmt.2017.10.015

rehabilitation protocols for pathological gait.

So far, different approaches for calculating gait asymmetry have been used by Lathrop-Lambach et al. (2014) (Lathrop-Lambach method) and Su et al. (2015) (Su method). These methods have been widely utilized as the standards for expressing asymmetry in variety of previous studies. Both methods use discrete time points for quantifying symmetry. In addition, to calculate asymmetry, a new equation has been introduced by Nigg et al. (2013) to compare symmetries during the whole stance phase of walking or running and across different variables (Nigg method). All of these formulas are mathematically correct, but without evidence demonstrating the similarities and differences of one formula over the others, it is difficult to define a standard and acceptable method to all biomechanists and clinical scientists.

The first purpose of this study was to compare the third symmetry method (using all data) with both Lathrop-Lambach and Su methods (using discrete time points) in different planes of motion and lower limb joints during walking. The second purpose of this study was to compare both asymmetry methods that used discrete time points (the Lathrop-Lambach and Su methods) for quantifying joint moment asymmetry during gait.

2. Methods

2.1. Subjects

A prior statistical power analysis program (G*power) revealed that for a statistical power of 0.80 at a partial η^2 of 0.199 with an alpha level of 0.05 a sample size of at least 14 subjects was required (Faul et al., 2007). Therefore, 14 male children (age: 10.2 (1.4) years, height: 150.6 (10.2) cm, mass: 42.6 (7.5) kg), free from injury for at least 10 months prior to participation, served as subjects (see Table 1). Male children with flexible flat feet deformity were identified in a school screening program. Patients with a navicular drop greater than 10 mm were selected according to previously established diagnostic criteria for flat feet deformity (Lange et al., 2004). Patients who had histories of surgery, trauma, orthopedic disease, neuromuscular problems, and wore shoe orthotics previously were excluded. Also excluded were having heavy physical tasks or exercise during the past two days. The subjects were all right-foot dominant determined by a ball kicking test (Farahpour et al., 2016; Jafarnezhadgero et al., 2017d). Ethics approval was obtained from the Research Ethics Board of University of Mohaghegh Ardabili; additionally, children gave assent and their parents provided written informed consent prior to participation.

2.2. Apparatus

3-D kinematics and kinetic data were collected using a Vicon six-camera system (Oxford Metrics, Oxford, UK) at a sampling rate of 100 Hz and two force platforms (Kistler 9281C, Kistler Instruments AG, Winterthur, Switzerland) at a sampling rate of 1000 Hz (Jafarnezhadgero et al., 2017a, 2017b). All data were analyzed using the models implemented in Vicon Clinical Manager, employing the Plug-in-gait marker set (Jafarnezhadgero et al., 2017c), and an inverse dynamics solution of joint kinetics.

Table 1
Demographic characteristics of our participants presented as means and standard deviations.

Variable	Mean ± Standard deviation
Age (years)	10.2 ± 1.4
Body height (cm)	150.6 ± 10.2
Body mass (kg)	42.6 ± 7.5
BMI (kg/m^2)	19.1 ± 3.5
Navicular drop (mm)	11.7 ± 0.8
Walking velocity	1.22 ± 0.16

Note. BMI=Body mass index.

2.3. Kinematic and kinetic data collection and analysis

On the test day, 16 reflective spherical markers (diameter 14 mm) were attached bilaterally to subjects on the following landmarks: anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), lateral mid-thigh, lateral femoral epicondyle, mid shank, lateral malleoli, heel and second metatarsal heads (mounted on the vamp of the shoe). At least six consistent trials, with no marker drop out, were captured.

All kinetics data were filtered using a fourth-order low-pass Butterworth filter with a 20 Hz cutoff frequency (Jafarnezhadgero et al., 2017b) and all were normalized to the child's body weight (BW). The kinematics data were low-passed using a digital zero-lag fourth-order Butterworth filter with cut-off frequency of 6 Hz (Jafarnezhadgero et al., 2017f). The graphical outputs were created in Polygon Authoring Tool (PAT), which interpolates all data from the stance phase of walking to 100 points (0–100%). Then, data points were exported from PAT to a spreadsheet to calculate the joint moment asymmetry in lower limbs via three different methods.

The Lathrop-Lambach gait asymmetry index for each variable for each subject was computed using the following equation (Lathrop-Lambach et al., 2014):

$$GA(\%) = 100 \times \left(1 - \frac{\text{lesser moment}}{\text{greater moment}}\right) \tag{1}$$

where, moment is net moment of force causing the joint angular acceleration. This formula, based on a previously defined limb symmetry index by Noyes et al. (1991) (Noyes et al., 1991), indicates the relative difference between limbs for each moment. Using this formula, if the greater moment is twice that of the lesser moment, there will be 50% asymmetry between limbs, and if the moments are identical there will be zero asymmetry (Lathrop-Lambach et al., 2014). In this method, finally, symmetry was calculated as: 100 −GA (%).

Another common method for calculating gait asymmetry defined by Su et al. (2015) was used as a Su method to quantify gait asymmetry as follows (Su et al., 2015):

$$GA(\%) = \frac{|x_l - x_r|}{2 \times |x_l + x_r|} \times 100 \tag{2}$$

where GA is the gait asymmetry, x is peak joint moment, x_r is the moment recorded for the right leg and x_l the moment recorded for the left leg. In the Su method, finally, symmetry was calculated as: 100 − GA (%).

Moreover, a reliable common approach developed by Nigg et al. (2013) was used as a Nigg method to find joint moment symmetry as follows (Nigg et al., 2013):

$$SI = \int_{t=t_1}^{t_2} A|x_r(t) - x_l(t)|dt \tag{3}$$

$$A = \frac{2}{range(x_r(t)) + range(x_l(t))} \tag{4}$$

where SI is the symmetry index, x is joint moment, $x_r(t)$ is the value of a specific joint moment recorded for the right leg at the time t