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Gait symmetry measures: A review of current and prospective methods

Slavka Viteckova[a,*], Patrik Kutilek[a], Zdenek Svoboda[b], Radim Krupicka[a], Jan Kauler[a], Zoltan Szabo[a]

[a] Czech Technical University in Prague, Faculty of Biomedical Engineering, Sitna sq. 3105, 272 01 Kladno, Czech Republic
[b] Palacky University Olomouc, Faculty of Physical Culture, trida Miru 117, Olomouc, Czech Republic

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ABSTRACT

Gait symmetry is important in measuring gait pattern alterations for establishing the level of functional limitation due to pathology, observing its changes over time and evaluating rehabilitative intervention effects. The aim of this topical review is twofold: 1) to present used symmetry measures and summarize their application to a diverse range of gait data and to demonstrate their capabilities in their utilization in research and practice, 2) to expose newly developed symmetry measures and highlight their perspectives. We divided symmetry measures into four subgroups: symmetry indices, complete gait cycle symmetry measures, statistically-based measures and approaches, and nonlinear measures. For each, we will discuss their advantages and limitations and raise new questions and recommendations about their development and clinical use.

Highlights:

- Normative data for physiological gait asymmetry is currently missing.
- Useful recommendations for particular acquisition devices should be given.
- A substantial portion of measured data is not employed in symmetry analysis.
- A new subgroup of symmetry measures has emerged — complete gait cycle measures.
- The definition of gait symmetry should be reconsidered.

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* Corresponding author.
E-mail address: vitecsla@fbmi.cvut.cz (S. Viteckova).

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1. Introduction

Bipedal locomotion is a fundamental activity for all humans. It is an essential component of maintaining independence and a quality of life. Despite its apparent simplicity, human gait is a cyclic spatiotemporally complex act. In healthy individuals, it involves periodic and complementary movement of limbs under the control of the central nervous system. Gait requires interaction between multiple body segments and coupling across multiple joints of the complex kinematic chain of the human body. However, it is understood that physiological changes that accompany aging, neurodegenerative diseases, etc. undermine the neuromuscular system's ability to maintain a consistent level of mobility to the extent that gait function can be seriously compromised. Thus, assessing gait deviations is a useful measurement for overall health [1], quality of life [2] and it can serve as a predictor for cognitive decline [3] and fall risk [4].

A variety of inter-limb deviations form the basis for a significant feature of gait: asymmetry. The terms symmetry and asymmetry are used interchangeably in literature. The term asymmetry is associated with the amount of divergence between the left and right side of the body, e.g. left and right lower limbs. Asymmetry in the lower limbs is not only associated with the manifestation of a pathology but is also found to be present in able-bodiedness. Gait in a healthy individual is symmetrical with minor deviations: able-bodied people show minimal laterality with only subtle differences between the dominant and non-dominant leg. Thus, asymmetry, or lack of symmetry, appears to be a relevant aspect for differentiating between a normal and pathological gait [5]. There is no general consensus on the presence, or degree, of lower limb asymmetry in healthy populations [6]. Asymmetric gait is not efficient as it increases oxygen consumption and energy cost of locomotion [5,7]. Gait asymmetry may lead to loss of bone mass density and osteoporosis of the affected leg [8], a higher dynamic load on the contralateral limb and joints and an increased risk of osteoarthritis and musculoskeletal injury [9]. For these reasons, it is essential to understand if asymmetry exists, and the extent of asymmetry found in various gait parameters.

Today, the most common gait symmetry evaluation includes determining the magnitude and location of asymmetries in an individual with gait pathology, assessment of recovery from injury or surgery, and the examination of asymmetries in a healthy gait (e.g. with respect to lateral dominance). Also, numerous studies have shown that gait symmetry is particularly sensitive to the differences between healthy individuals and those with gait impairments [10–12]. In addition to using asymmetry to distinguish between a healthy and impaired patient, several studies have focused on gait symmetry refinement to distinguish what stage a patient is in a disease [13,14]. E.g. early stages of the disease are manifested by a low level of asymmetry while later stages of the disease are manifested by higher asymmetry. Other researchers investigate the effects of rehabilitation [15].

Quantifying the differences in upper or lower limb movement symmetry during gait is a common clinical and research objective. A broad range of characteristics of measured kinematic variables are used to describe gait performance, such as variability, complexity, regularity and symmetry/asymmetry. In 2000, Sadeghi et al. [6] published an extensive review of symmetry measures and related findings. However, new methods of symmetry quantification have recently emerged. In the past, discrete methods and statistical parameters were the only two classes of symmetry quantifiers [16,17]. Currently, the most common approach used to assess symmetry is by finding a single discrete value, known as an index, and describing symmetry/asymmetry for spatiotemporal, kinetic, and kinematics parameters between the right and left sides or affected and unaffected limbs. The latter work focuses on evaluation with not only discrete, but also continuous values to quantify side-to-side relationships.

According to data sources, time-series are often used (e.g. positions, joint angles, muscle forces, joint moments, etc.) to quantify the symmetry of parameters of gait and other human movements. The discrete value is usually extracted from a measured time-series. Beyond this, these continuous waveforms offer an application to a new methods (a method that uses time series for gait symmetry quantification) and forms a new class of symmetry quantifiers – a complete gait cycle method. Recently, the use of traditional methods and their modifications (especially the use of new modifications of discrete indices) is widespread in clinical practice, however there are new complex methods for the evaluation of symmetry which have also been designed and used. An overview of symmetry measures classification is shown in Fig. 1.

The aim of this paper is to concisely review new and current quantitative symmetry assessment methods for gait. This paper presents recent applications of symmetry measures and describes their suitability. Then, a summary of their application to a diverse range of gait parameters is included, to demonstrate their capabilities and flexibility for their utilization in research and practice. Nevertheless, the intent of this paper is not to review clinical interpretations of asymmetries relating to various diseases and impairments, or to review work done regarding the assumption of lower limb symmetry during able-bodied gait or verify conflicting reports on this topic, because this would go beyond the technical focus of the article. The primary focus of this paper is to assess methods and recap gait variables together with data acquisition equipment to give an overview about data sources available to quantify the level of symmetry. Shortcomings of existing measures are discussed and possibilities of new research directions in the field of symmetry measures are outlined.

According to the previously mentioned classification of symmetry measures, this paper is organized as follows. Section 2 depicts the methodology of a review. Then, a description of symmetry assessment approaches is divided into three sections. Each section is devoted to one class of symmetry approaches, namely discrete (Section 3), complete gait cycle (Section 4), and statistically-based (Section 5). Discussion about current employment of symmetry measures with respect to available data sources, and challenges for future development are stated in Section 6. Finally, a summary and concluding remarks are given in Section 7.

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