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A new approach to detecting asymmetries in gait

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Abstract

Background. Traditional parameters used to assess gait asymmetries, e.g., joint range of motion or symmetry indices, fail to provide insight regarding timing and magnitude of movement deviations among lower limb joints during the gait cycle. This study evaluated the efficacy of a new approach for quantifying aspects of gait asymmetry.

Methods. Asymmetric gait was simulated by joint bracing. The dominant leg knee or ankle was constrained in ten healthy young adult males. Kinematic data were collected during three-minute trials for treadmill-walking conditions: unbraced, knee-braced, and ankle-braced. We created a *regions of deviation* analysis, which compared asymmetric walking (flexion/extension behavior) relative to normative (group-averaged unbraced) data. Symmetry/asymmetry between bilateral joint pairs was quantified and the behavior of specific joints relative to normative data was assessed using this analysis.

Findings. While traditional measures (e.g., maximum range of motion) grossly detected asymmetries due to bracing, these new analyses identified significant regions of asymmetry. Knee-bracing affected the knee during mid-swing, but also increased ankle asymmetry during both terminal stance and mid-swing and hip asymmetry during mid-stance and mid-swing. Ankle-bracing created asymmetries at the ankle (terminal stance and initial swing) and hip (terminal stance), but none at the knee.

Interpretation. Region of deviation analysis effectively identified the timing and magnitude of deviations *throughout* the gait cycle, and provided information about the impact of a joint-mobility perturbation on neighboring joints. This new methodology will be useful in clinical settings to identify, characterize, and monitor recovery from asymmetric behaviors associated with injuries or pathologies.

Keywords: Gait; Bracing; Treadmill-walking

1. Introduction

Limb motion during steady-state constant speed locomotion involves complicated inter-segmental and inter-limb interactions during both normal and abnormal walking (Sadeghi, 2003). Each limb segment and joint undergoes a cyclic pattern of flexion and extension and to a lesser extent rotation, abduction and adduction during each stride. An acute injury to a lower limb can create pain and discomfort that disrupts the cyclic gait pattern, and can result in asymmetric or limping gait as an injured individual attempts to maintain the ability to walk (Perry, 1992). Understanding how restrictions to joint range of motion influence movement at other joints is important when assessing acute lower limb injury and recovery. Gait pathologies that limit function are often assessed and treated using knowledge of the patient's health history, physical examination, and gait analysis (Winter, 1990). In a clinical setting, gait analysis can consist of qualitative observation (i.e., visual inspection), quantitative laboratory measurements (e.g., step length, single support time, etc.), or a combination of the two.

During a qualitative assessment, visual inspection is used to identify subtle and obvious aspects of a patient's

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gait abnormality (Perry, 1992;Whittle, 1996). Asymmetries are often symptomatic of pathological gait and can be used to identify and track problems (Griffin et al., 1995). The basis of this type of observational gait analysis is the assumption that the coordinated movement of the lower limbs has a high degree of symmetry, and understanding asymmetries provides insight into the efficacy of treatment during rehabilitation after injury.

Because visual inspection of gait is qualitative in nature, it is often supplemented with quantitative laboratory measurements that allow for greater precision and the assessment of more complex situations (Perry, 1992). Univariate parameters such as walking speed, step length, foot rotation angle, maximum joint range of motion, and durations of stance and swing phases of gait are frequently used to assess, monitor and treat gait deficiencies (Becker et al., 1995; Bruyn et al., 2003; Chodera, 1974; Craik and Oatis, 1995; Crowe and Samson, 1997; DeVita et al., 1997; Diop et al., 2004; Draper, 2000; Grieve, 1968; Griffin et al., 1995; Hausdorff, 2004; Karamandis et al., 2003; Knoll et al., 2004; Salamon et al., 2002;Skinner and Effeney, 1985). The assumption of symmetry in univariate measures has been used to identify pathology and track recovery by characterizing asymmetries with symmetry indices and ratios (Sadeghi et al., 2000). Symmetry indices evaluate the degree of symmetric behavior by calculating the difference between left and right sides for a given parameter and dividing the result by the bilateral average. Index values close to zero indicate symmetric behavior. Symmetry indices have previously been used in several studies to determine if asymmetries exist in parameters that describe the behavior of the lower limbs. The parameters used in the indices have included vertical ground reaction forces, plantar pressure distribution, speed and stride frequencies (Sadeghi, 2003).

Unfortunately, current univariate measurements lack the ability to capture the spatio-temporal complexity of the gait cycle, and provide little information on the behavior of other joints. To effectively assess injury and monitor recovery, the effect on ipsilateral and contralateral limb joints due to restriction in range of motion to one joint needs to be understood. For example, quantitative assessments of joint ranges of motion are typically conducted at discrete and easily defined points in time (e.g., heel strike, toe-off). Such measures fail to capture the motion that occurs between these discreet events, and fail to assess how problems at one joint affect other joints.

More recently, Manal and Stanhope (2004) and Crenshaw and Richards (2006) have proposed additional methods and parameters to examine asymmetric behavior. Manal and Stanhope qualitatively compared spatio-temporal data by displaying subject-specific movement pattern deviations relative to normative data by color coding magnitude and direction of the deviations. However, this technique does not provide quantitative information for the comparison and analysis of complex movement patterns, and does not examine changes in symmetry of bilateral parameters. Crenshaw and Richards quantitatively examined joint angle symmetry and normalcy using eigenvectors to compare waveforms of joint angle data. The measures of symmetry developed in this work effectively identify joint angle behavior that is no longer symmetric and has deviated from normative measurements; however, this method does not identify the timing in the gait cycle were these deviations are occurring.

Our study introduces two new quantitative analysis methods to address limitations present in current gait assessment techniques. Both methods examine joint angular displacements and identify regions of the gait cycle that deviate from normative data. The first examines bilateral symmetry/asymmetry between joint pairs at the ankle, knee, and hip. The second identifies deviations in individual joint motion. By examining these "regions of deviation" and more specifically the timing and magnitude of peak deviations during the stance and swing phases of the gait cycle, these analyses provide quantitative metrics that can be used to describe and compare motions. To test the new methods, a data set with known asymmetries was created by restricting joint range of motion using a brace at the ankle or knee. Bracing simulates gait perturbations that result from restricted joint movement caused by injury or disability. By creating a known and repeatable gait asymmetry, we can better assess how different approaches detect, track, and quantify asymmetry. These simulated data are particularly advantageous because an individual's normal gait can be compared directly to his perturbed gait. The primary focus of this study was to evaluate the efficacy of a new approach (regions of deviation analysis) for quantifying the spatio-temporal complexity of the asymmetric gait cycle. A secondary aim was to provide insight into joint motions due to bracing of a single joint, and how this restriction affects ipsilateral and contralateral joints.

2. Methods

2.1. Participants

Ten healthy males, mean (standard deviation) age 21 (2) yrs, height 1.79 (0.09) m, and mass 81 (9) kg participated in this study. Subjects had no gait impairments, no history of significant trauma to the lower extremities or joints, and were experienced treadmill walkers. All subjects indicated right leg dominance. All procedures were approved by the University Institutional Review Board, and all participants gave informed consent.

2.2. Experimental procedure

Before data collection began, subjects changed into a sleeveless top, snug-fitting shorts, and running or walking shoes. Thirty-four reflective markers were attached to the head, torso, arms, and legs. Gait parameters were derived from markers at the bilateral anterior superior iliac spine, mid-thigh, femoral lateral epicondyle, tibial tuberosity,