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Pelvic excursion during walking post-stroke: A novel classification system

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ABSTRACT

Background: Researchers and clinicians often use gait speed to classify hemiparetic gait dysfunction because it offers clinical predictive capacity. However, gait speed fails to distinguish unique biomechanical characteristics that differentiate aspects of gait dysfunction.

Research question: Here we describe a novel classification of hemiparetic gait dysfunction based on biomechanical traits of pelvic excursion. We hypothesize that individuals with greater deviation of pelvic excursion, relative to controls, demonstrate greater impairment in key gait characteristics.

Methods: We compared 41 participants (61.0 ± 11.2yrs) with chronic post-stroke hemiparesis to 21 non-disabled controls (55.8 ± 9.0yrs). Participants walked on an instrumented split-belt treadmill at self-selected walking speed. *Pelvic excursion* was quantified as the peak-to-peak magnitude of pelvic motion in three orthogonal planes (i.e., tilt, rotation, and obliquity). Raw values of pelvic excursion were compared against the distribution of control data to establish deviation scores which were assigned bilaterally for the three planes producing six values per individual. Deviation scores were then summed to produce a *composite pelvic deviation score*. Based on composite scores, participants were allocated to one of three categories of hemiparetic gait dysfunction with progressively increasing pelvic excursion deviation relative to controls: Type I (n = 15) – minimal pelvic excursion deviation; Type II (n = 20) – moderate pelvic excursion deviation; and Type III (n = 6) – marked pelvic excursion deviation. We assessed resulting groups for asymmetry in key gait parameters including: kinematics, joint powers temporally linked to the stance-to-swing transition, and timing of lower extremity muscle activity.

Results: All groups post-stroke walked at similar self-selected speeds; however, classification based on pelvic excursion deviation revealed progressive asymmetry in gait kinematics, kinetics and temporal patterns of muscle activity.

Significance: The progressive asymmetry revealed in multiple gait characteristics suggests exaggerated pelvic motion contributes to gait dysfunction post-stroke.

1. Introduction

Gait speed, step asymmetry, metabolic cost, and muscle activity patterns during walking have all been used to classify hemiparetic gait dysfunction [1–5]. Often, researchers and clinicians use gait speed changes to assess treatment-related improvements without regard to the neuromechanical walking pattern. On this background, hemiparetic gait dysfunction is only moderately responsive to treatment [6,7].

Gait speed offers myriad advantages as a classification variable [8,9]. However, speed-based classifications of gait dysfunction are inherently limited, most notably by lack of specificity. In contrast, a gait classification system based on walking mechanics is likely to reveal underlying impairments of gait dysfunction post-stroke.

Biomechanical investigations of gait dysfunction typically focus on deviations in kinematics and kinetics of lower extremity joints with little attention to motion at the pelvis.[2] Given the critical role of the pelvis as a structural link between the trunk and the lower extremities, pelvic excursion[3] is a logical biomechanical focus for investigating hemiparetic gait dysfunction [10]. Indeed, biomechanical deviations of pelvis motion, including exaggerated frontal (i.e., lateral tilt and

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[2] Pelvis, as used throughout the text, refers to the bony structure that consists of bilateral ilia, ischia, pubi, the sacrum, and the coccyx.

[3] Pelvic excursion refers to motion of the bony pelvis.

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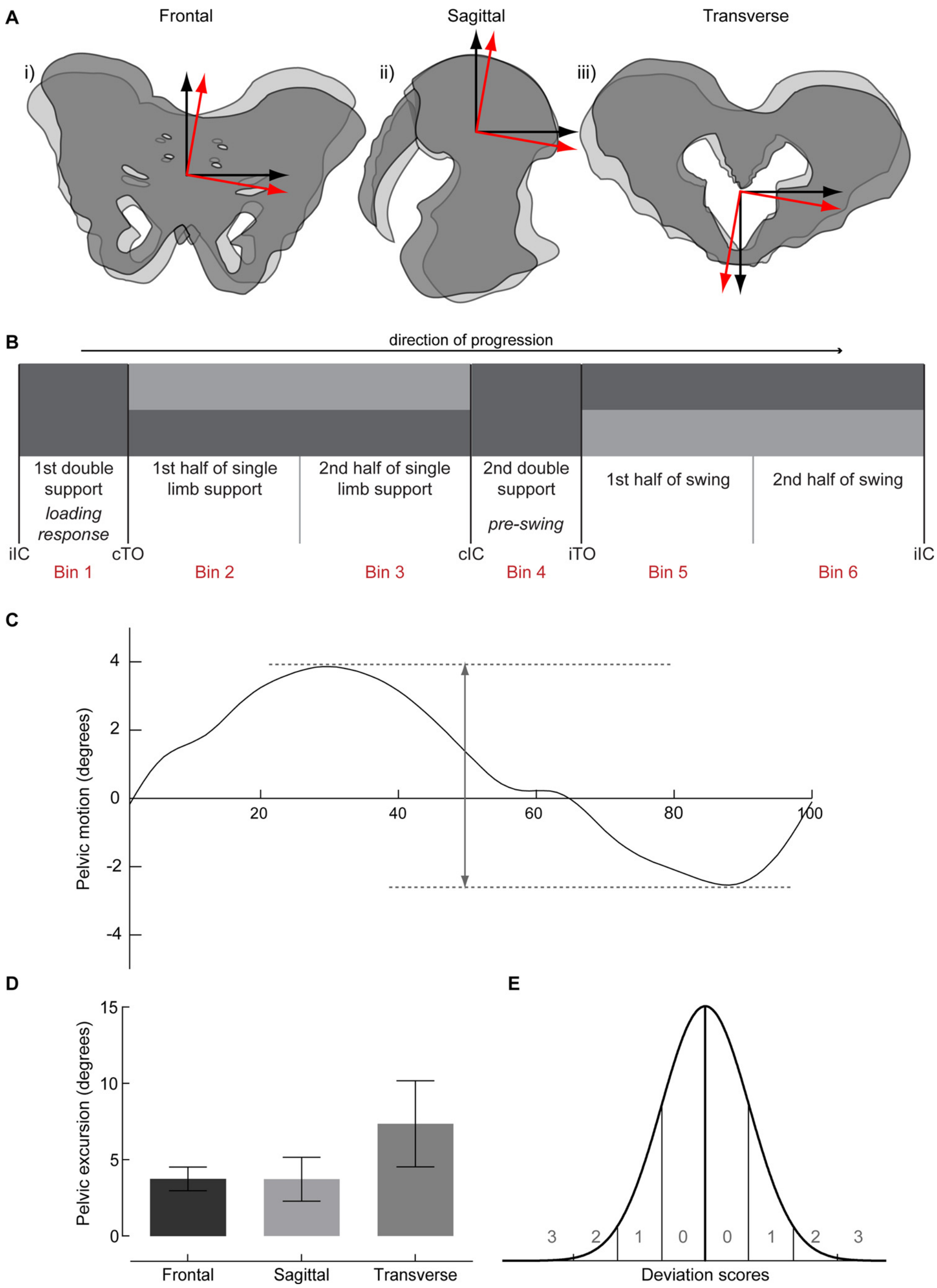

Fig. 1. Quantification of pelvic excursion. A) *Pelvic motion*. Darker structures and red arrows illustrate pelvic rotation with respect to anatomic orientation (lighter structures) within i) frontal, ii) sagittal, and iii) transverse planes with respect to the lab reference frame (black arrows). Pelvic motion was quantified across the gait cycle for each individual, in each plane. B) *Gait cycle.* We parse the gait cycle in 6 biomechanically relevant phases using the following gait events: ipsilateral initial contact (iIC), contralateral toe off (cTO), contralateral initial contact (cIC), and ipsilateral toe off (iTO). The first and second halves of single limb support and swing are delineated at the mid-point between the two adjacent gait events. Darker shading represents periods of foot-floor contact; lighter shading represents periods of reference limb swing. C) *Pelvic excursion.* Single-subject data from the transverse plane illustrated here. To establish normative data, we first measured pelvic excursion bilaterally in healthy controls and quantified the peak-to-peak magnitude of pelvic motion (degrees) throughout the gait cycle in each of the three orthogonal planes. D) *Reference data from controls*. Subsequently, raw values of pelvic excursion for healthy controls and participants post-stroke were compared against the distribution of these reference control data. E) *Deviation scores*. Pelvic deviation was defined in each plane by determining the number of standard deviations between an individual raw value and the reference control mean for a specific plane of motion, effectively computing a z-score truncated at the whole number. Thus, raw values > 1 but < 2 sd from the reference control mean produced a deviation value = 1. It follows that raw values ≥ 2 but < 3 sd yield a deviation value of 2, and raw values ≥ 3 sd a deviation value of 3.

displacement) and transverse plane (i.e., rotation) motion occur following stroke [11,12].

Despite recognition of pelvic motion impairments, our understanding of how they relate to other biomechanical gait impairments following stroke remains limited. In health, we recognize 3-dimensional motion of the pelvis decreases energy cost by minimizing vertical center of mass excursion during walking [10,13]. Excessive pelvic motion in any direction could increase the metabolic cost of walking, a well-recognized sequela following stroke [13–15]

Evidence suggests regaining control of pelvic motion may lead to better gait outcomes. For instance, individuals post-stroke who improve overground walking speed following intervention also reveal kinematic changes suggestive of reduced anterior pelvic tilt [7]. However, whether control of pelvic motion during walking is a prerequisite to or by-product of improved walking function remains unknown.

Here we report results of an exploratory analysis aimed at developing a classification scheme for hemiparetic gait dysfunction based on the magnitude of pelvic excursion deviation. We investigated differences between controls and pelvic excursion deviation categories derived from the classification. We examined neuromechanical differences by leg and quantified the magnitude of asymmetry between legs to determine if asymmetries were larger for groups with more pelvic excursion deviation.

2. Methods

2.1. Participants

Data presented here represent a secondary analysis from a cross-sectional study investigating the immediate effects of locomotor training parameters. Twenty-one healthy controls (age: 55.8 ± 9.0yrs) and 41 individuals post-stroke (age: 61.0 ± 11.2yrs; chronicity: