Is There A Relationship Between The Margin Of Stability And Impulsive Loading, During Gait In Young Adults?

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Introduction: Normal gait constitutes repetitive loading upon each step, some of which may be impulsive. Impulsive loads carry high frequency components which accelerate up through the body as transient stress-waves.Repeated exposure to transient stress-waves can predispose the body’s “shock-absorbing” structures to injury and fatigue failure. Repetitive impulsive loading is implicated in the initiation and progression of articular cartilage damage and osteoarthritis. Measures of dynamic stability give insight into the neuromuscular control of walking. Dynamic stability during gait concerns the regulation of the position and velocity of a body’s centre of mass (COM), in response to perturbations of varying magnitude, with respect to a constantly changing base of support (BOS). The margin of stability (MOS) is a commonly employed measure of dynamic stability, particularly in the context of perturbed gait and falls. It refers to the distance between the boundary of an individual’s BOS, behind which an “extrapolated centre of mass” (XCOM) must be maintained, before adaptive action is necessary to prevent an unrecoverable fall. Individuals less resistant to separation of the XCOM beyond the BOS have reduced time to respond to gait perturbations and complete an appropriate “adaptive stepping response.” This could in turn render them more susceptible to impulsive loading. However, little is known regarding the interaction between mechanisms of dynamic stability and impulsive loading.

To this authors’ knowledge, there have been no published studies explicitly investigating an association between the MOS and impulsive loading, during gait in young adults. We hypothesised that individuals who maintained a more positive average margin of stability (or greater resistance to separation between the XCOM beyond the BOS) would have a tendency towards exhibiting lower average impulsive loading during gait (an inverse linear correlation).

Methods: This study investigated 29 young adults, 9 male and 20 female, with mean age of 25.9 years and standard deviation of 4 years. Anonymised historic kinematic and kinetic data was obtained from patient records held by the gait analysis laboratory, at the Royal National Orthopaedic Hospital, Stanmore, U.K. Additional participants were recruited from the student/staff population at the Institute of Orthopaedics and Musculoskeletal Science. Participants were included if they were without significant history of cardiovascular, neurologic or musculoskeletal disease, visual-spatial impairment, previous trauma to the lower-limbs or spine, and otherwise without a clinically observed pathological gait pattern. The University College London Research Ethics Committee granted ethical approval and each participant provided written informed consent. Participants were required to walk barefoot, at their “normal” speed along a 6m unobstructed walkway for five trials. Kinematic data was recorded using a Codamotion Motion Capture and Movement Analysis System (Charnwood Dynamics Ltd., Rothley, Leicestershire U.K.). Kinetic data was recorded with two 4060 Series Bertec Corporation six-component Force Plates (Bertec Corporation, Ohio, USA). The margin of stability, defined as the distance between the XCOM and anterior BOS, was calculated in the sagittal plane at two time points; initial contact (MOSic) and one frame before during terminal stance (MOSts). XCOM was calculated using the following equation: horizontal position of the COM (PxCOM) + (horizontal velocity of the COM (VxCOM) / eigenfrequency of an inverted pendulum of length l) (Figure 1). Impulsive loading was identified using the vertical component of the ground reaction force for the leading leg at initial contact. An impulsive load was characterised through calculation of the rate of loading (ROL), peak transient force (PTF) and transient ratio (Figure 2). We employed Fisher’s z-transformation to determine the sample size for correlation analysis. Bivariate correlation and linear regression analysis was conducted to determine significant associations between the stability and ground reaction force variables.

Results: Relationships between force variables (ROL and PTF) and stability variables (MOSic and MOSts) are shown in Figure 3. Strong inverse correlations were observed between ROL and MOSic (r = -0.66) and between ROL and MOSts (r = -0.71). Similarly strong inverse correlations were observed between PTF and MOSic (r = -0.66) and between PTF and MOSts (r = -0.70). All correlations were statistically significant (p < 0.01).

Discussion: Impulsive loading during gait is fundamentally of multifactorial basis, being dependent on a multitude of interacting behavioural, environmental and biomechanical factors. The primary determinant for impulsive loading is the rate of momentum change. Regulation of walking speed, step length, limb segment motion and joint alignment may be important in active control strategies for reducing impulsive loading during walking. However, the extent to which the body modulates these actions and prepares for potential impulsive loading at initial contact is unclear from the literature. Furthermore, controlling adequately for relevant kinetic and kinematic variables, presents a challenge for small-scale studies. We have shown that the MOS exhibits a strong linear relationship with impulsive loading. The MOS, amongst other measures of dynamic stability, may give insight into...
an individual's ability to modulate the extent of impulsive loading, through an “adaptive step response.” Individuals able to maintain a more positive MOS during normal walking appear to generate lower impulsive loads at each step. This is likely due to the increased time available for responding to perturbations and initiating an appropriate “adaptive step response.”

Certain limitations of this study must be acknowledged. Although the biomechanical basis for the XCOM demonstrates construct validity within the current paradigm of gait mechanics, it concerns the basic inverted pendulum analogy of gait. This concept assumes a rigid stance leg and thus does not account for movement in the rear leg knee, ankle and foot. Furthermore, this model does not account for swing-leg activity or for movement in the trunk and arms during gait. We used a simple estimation of the COM within the plane of the pelvic markers; a more thorough approach would have been to connect additional markers to the upper body and limbs to track whole body kinematics, allowing for the construction of a multi-segmental model and more accurate estimation of the whole body COM. Finally, data was averaged across a small number of steps for each participant, which may not be representative of the individual’s normal gait pattern.

**Significance:** Exposure to uneconomical, repetitive, impulsive gait cycles could be implicated in the initiation and progression of osteoarthritis. Hence there is scope for quantifying and characterising the association between dynamic stability and impulsive loading during gait. Due to its simplicity and ease of calculation, the MOS may be a particularly useful measure, both in research and clinical practice, for identifying potentially pre-osteoarthritic individuals, as well as the defining and rehabilitation of neuromuscular control deficits in pathological gait. However heterogeneity in the reporting of its’ application limits comparability in the literature. Future research should also investigate other stability measures from dynamical systems theory, in the context of perturbed and pathological gait and in association with the impulsive loading observed during walking in these populations.

**Acknowledgments:**

**References:**

![Figure 2. Vertical component of the ground reaction force, displaying a transient impulsive load.](image)
Figure 1. Schematic representation of the inverted pendulum model and parameters for calculating the MOS.

Figure 3. Both ground reaction force variables (ROL and PTF) were observed to exhibit strong inverse associations with the stability variables (MOSic and MOSis).

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