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Variability of segment coordination using a vector coding technique: Reliability analysis for treadmill walking and running

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ABSTRACT

Coordination variability (CV) quantifies the variety of movement patterns an individual uses during a task and may provide a measure of the flexibility of that individual's motor system. While there is growing popularity of segment CV as a marker of motor system health or adaptability, it is not known how many strides of data are needed to reliably calculate CV. This study aimed to determine the number of strides needed to reliably calculate CV in treadmill walking and running, and to compare CV between walking and running in a healthy population. Ten healthy young adults walked and ran at preferred speeds on a treadmill and a modified vector coding technique was used to calculate CV for the following segment couples: pelvis frontal plane vs. thigh frontal plane, thigh sagittal plane vs. shank sagittal plane, thigh sagittal plane vs. shank transverse plane, and shank transverse plane vs. rearfoot frontal plane. CV for each coupling of interest was calculated for 2–15 strides for each participant and gait type. Mean CV was calculated across the entire gait cycle and, separately, for 4 phases of the gait cycle. For running and walking 8 and 10 strides, respectively, were sufficient to obtain a reliable CV estimate. CV was significantly different between walking and running for the thigh vs. shank couple comparisons. These results suggest that 10 strides of treadmill data are needed to reliably calculate CV for walking and running. Additionally, the differences in CV between walking and running suggest that the role of knee (i.e., inter-thigh- shank) control may differ between these forms of locomotion.

1. Introduction

Coordination in human movement is necessary to organize the complex and redundant degrees of freedom of the musculoskeletal system [1]. While healthy individuals may have a preferred coordination pattern, they also have the ability to access a variety of coordination patterns to respond to perturbations or different environmental conditions [1]. Variability in the coordination of complex motor tasks has been identified as a critical determinant of the quality of human movement and flexibility of the motor system [2]. Measures of coordination variability give insight into postural stability, risk of falls [3], injury status [4], pathology, or aging [5]. Over the last decade, variability of segment coordination using a modified vector coding method [6] has gained popularity as a way to quantify movement flexibility during locomotor tasks. Modified vector coding computes coordination based on angle-angle plots of positional kinematic data, providing a metric that is directly related to traditional kinematic measures. The use of only spatial data in this measure of coordination may provide a metric which is more translatable to clinicians as compared to other metrics of coordination variability. Despite the growing use of modified vector coding, there is a lack of technical guidance for its implementation as well as comparisons of different modes of locomotion to facilitate interpretation of coordination variability values.

Segment coordination provides a measure of the relative timing and magnitude of the motion between segments [7]. Variability of segment coordination quantifies the variety of segment movement patterns an individual uses during a motion. While variability in discrete joint kinematics may be consistent across cohorts of individuals [8,9], differences in variability of the segment coordination patterns which produce these joint kinematics may vary by health status. Greater or reduced segment coordination variability may indicate either poorly controlled motion or motion which is overly-constrained, respectively, either of which could lead to injury or decreased performance [4]. Analysis of the variability of segment coordination has been shown to demarcate healthy from injured runners [10] and typical from novel running gait [11]. The ability of segment coordination variability to

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delineate between clinical or training groups suggests that this variability can be used as a tool to identify movement patterns which are different from normal.

Scientific rigor in the calculation of segment coordination variability is critical for this measure to provide quantitative insight into a breakdown in motor function, as well as for correct interpretation of changes in measures of variability [10,12]. Investigations of segment coordination variability generally compare variability between a young or healthy control group and an injured, intervention, or perturbed group with the hypothesis that variability will be greater in the control group [10,11,13,14]. While the theory of coordination variability magnitude as an indicator of motor control health or ability appears to be uniformly applied, guidelines for the appropriate application of the methodology is lacking. Currently, it is not known how many strides are needed to reliably calculate coordination variability. The number of strides used in recent studies ranges from 5 [11,13,15] to 10 [14] or 15 [10]. If too few strides are used in these calculations, reported values may not be representative of an individual or group's true coordination variability, potentially leading to inconsistent findings across studies.

In addition to the lack of methodological guidelines for modified vector coding, there is currently a lack of data demonstrating how segment coordination variability may differ between different forms of locomotion (e.g., walking and running). Most studies implementing modified vector coding focus only on running [11,13,16,17]. It may be expected that, because running requires faster motion and higher forces than walking, these forms of locomotion may display different patterns of motor flexibility. Therefore, the purpose of the current study was to assess the reliability of segment coordination variability calculated using a modified vector coding technique to different numbers of input strides and compare and contrast coordination variability between walking and running.

2. Methods

All procedures were approved by the university Internal Review Board and all individuals provided written informed consent before participating in the study.

2.1. Participants

Preliminary sample size calculations based on repeated-measures differences in lower extremity coordination variability observed in our previous work [11] indicated that at least 4 participants were needed to achieve a power of 0.8 with α error probability of 0.05. Ten healthy young adults (5 male, 5 female) were recruited to participate in this study. In order to be eligible to participate, individuals had to be 21–35 years of age, have no history of reparative surgery or major injury to the lower extremities, not currently be injured, and run for exercise at least once per week. All participants reported being familiar with walking and running on a treadmill prior to the current study.

2.2. Data collection

Kinematic data were captured at 200 Hz using an 11-camera motion capture system (Oqus; Qualisys, Inc., Gothenburg, Sweden) as participants walked and ran at preferred speeds on a level treadmill. To find participants' preferred treadmill walking speed, a study investigator started the treadmill at 3 mph and asked participants if they felt that this speed was faster or slower than their preferred walking speed. Based on the participant's response, the speed would be adjusted up or down in increments of 0.1 mph until the participant indicated that they were at their preferred speed. To find participants' preferred treadmill running speed, participants were asked what speed they would choose for a moderate run. The treadmill would be started at this speed and a study investigator would follow the same procedure for finding the participant's preferred speed as was used for walking. After 2–3 min of accommodation at preferred walking or running speed, 30 s of data were captured.

All participants wore standard laboratory footwear (T7; Brooks Sports, Seattle, USA). To calculate the motion of the lower extremity segments in walking and running, retro-reflective marker clusters were placed on the pelvis and right thigh, shank, and foot. Additional anatomical markers were used in a static calibration trial to define segment coordinate systems and joint centers for the pelvis (left and right ASIS, midpoint of left and right PSIS), thigh (hip joint center and medial and lateral femoral

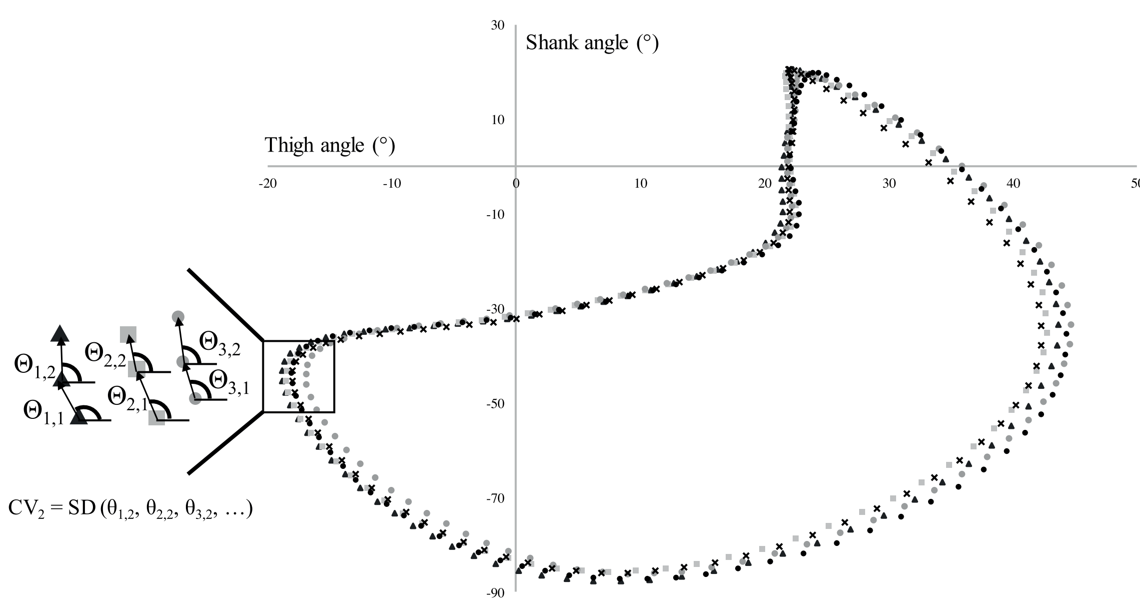

Fig. 1. Example of coordination variability (CV) calculation. Inset depicts phase angles (θ) for 2 consecutive time steps across 3 strides. CV is then calculated as the standard deviation (SD) of phase angles for corresponding time steps across the number of strides included in the calculation.