Gait & Posture 62 (2018) 92–98

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

Age related differences in segment coordination and its variability during gait

Jocelyn F. Hafer*, Katherine A. Boyer

Musculoskeletal and Orthopedic Biomechanics Laboratory, Department of Kinesiology, University of Massachusetts Amherst, United States

ARTICLE INFO

Keywords:
Vector coding
Physical activity
Older adults
Motor control

ABSTRACT

Background: Aging is associated with a loss of mobility and altered gait mechanics. Loss of function and mobility may be due to or exacerbated by low levels of physical activity in the aged. The mechanisms linking age-related changes in physiology, altered mobility and gait may be elucidated by examining movement coordination and coordination variability.

Research question: The purpose of this study was to examine the impacts of age and habitual physical activity level on segment coordination and coordination variability during gait.

Methods: A modified vector coding technique was used to calculate segment coordination and coordination variability during treadmill gait for three groups of healthy adults: young (21–35 years), older highly active (55–70 years), and older less active (55–70 years). Segment couples of interest included those whose coordination could contribute to typical age-related changes in gait mechanics at the hip, knee, and ankle.

Results: Differences in coordination and its variability occurred mainly during terminal swing and midstance and in couples across the hip and ankle. Across the hip, coordination differed between older highly active adults and the other cohorts, while variability was higher in young compared to all older adults. Across the ankle, young adults displayed different coordination and greater variability than all older adults except for the sagittal couple in midstance, where older highly active adults had greater coordination variability than the other cohorts.

Significance: These results suggest that older adults, independent of habitual physical activity, may use a different strategy to control hip and ankle motion during periods of single-limb stance.

1. Introduction

Declining mobility is a hallmark of aging and is often associated with age-related differences in gait mechanics [1]. Differences in gait mechanics between young and older adults occur in parallel with differences in muscle function [2], sensory function [3], and musculoskeletal health [4], however, the mechanisms linking these factors are unclear. Measures of movement coordination and its variability that provide information on the organization and flexibility of gait patterns may elucidate the mechanisms by which systemic physiological changes ultimately affect resultant gait mechanics. Thus, determining the extent to which movement coordination differs with age, both in terms of magnitude and site of difference, may provide a window into the mechanisms behind age-related changes in gait.

Coordination patterns provide information about both the timing and magnitude of movements and represent the organization of multiple degrees of freedom into a simpler control strategy [5,6]. Segment coordination describes patterns used to produce joint angles and individuals or cohorts could have similar joint kinematics but different segment coordination. Altered segment orientations with respect to gravity or other segments would require altered muscle activity and could alter joint loading, potentially increasing the risk of age-related pathologies such as knee osteoarthritis [7,8]. The use of fewer coordination patterns to produce a given kinematic pattern would result in a reduction in segment coordination variability. A reduction in coordination variability could put older adults at greater risk of falls [9] as a smaller variety of movement patterns could limit solutions to perturbations such as obstacles or tripping. Additionally, decreased coordination variability could result in a concentration of chronic loads in a small area of tissue [10] which, in combination with an age-related change in segment coordination, could concentrate loads on tissues which were not adapted to this environment earlier in life.

The impact of healthy aging on movement coordination is not well understood. Few studies have described differences in movement coordination between older and young adults during level gait [11,12] and have shown that older adult gait is less complex [13,14] and

* Corresponding author. Present address: Central Campus Recreation Building, 401 Washtenaw Avenue, Ann Arbor, MI 48109.
E-mail address: johafer@umich.edu (J.F. Hafer).

https://doi.org/10.1016/j.gaitpost.2018.02.021
Received 20 July 2017; Received in revised form 8 February 2018; Accepted 19 February 2018

potentially less flexible in response to perturbations. While these studies suggest a change in coordination with age, the factors that contribute to altered coordination in older adults are not clear.

Differences, if present, in segment coordination and coordination variability between older and young adults may be exacerbated by exertion. Older adults are more susceptible to muscle fatigue than young adults, especially in dynamic contractions such as those that occur about the knee during walking [15]. Older adults display changes in gait [16] and balance [17] in response to bouts of walking exercise, and moderate bouts of walking can also induce measureable muscle fatigue in older adults [18] suggesting that changes in gait or balance in response to bouts of walking may be due to fatigue. Few studies have compared the effects of fatigue on young and older adults' coordination [19], and whether bouts of walking exercise affect coordination similarly in young and older adults is unclear.

In addition to understanding if there is a relationship between age and segment coordination, it is important to determine if this relationship differs by physical activity level as this would provide a target for exercise or lifestyle interventions. Therefore, the primary aim of the current study was to determine if there is a difference in lower extremity segment coordination and its variability by age or physical activity level. We hypothesized that less active older adults would display different segment coordination and decreased coordination variability compared to young adults but that highly active older adults would not differ from young adults. To determine if older adults' greater susceptibility to muscle fatigue could result in additional changes in coordination, the secondary aim of this study was to examine the effect of a bout of walking exercise on lower extremity coordination. For this secondary aim, we hypothesized that there would be an effect of a bout of walking exercise on segment coordination and coordination variability for less active older adults but not for young and highly active older adults.

2. Methods

2.1. Participants

Young adults (Y, age 21–35, recreationally active), older highly active adults (OHi, age 55–70, running $\geq$15 miles/week), and older less active adults (OLo, age 55–70, participating in $\leq$three 30 min bouts of moderate exercise/week) were recruited for this study. This older age range coincides with rapid decreases in musculoskeletal health [20] and physical activity [21]. Examining coordination in this age range may help determine when mobility issues appear and at what age interventions need to be targeted. To reduce variation from factors other than age and physical activity level, participants were free of major musculoskeletal injury or surgical history, reported no lower extremity arthritis or joint pain, had no cardiovascular or neurological pathology, and had BMI < 30 kg/m^2. Prior to any procedures being performed, all participants completed informed consent documentation. Physical activity was quantified using hip-worn triaxial accelerometers (GT3X, Actigraph) for $\geq$5 days of participants' self-described typical activity level.

2.2. Data collection

Three dimensional gait kinematics were captured as individuals walked on a treadmill at preferred walking speed. Preferred walking speed was determined at an earlier visit by having participants walk 400 m overground. If the participant indicated that their overground preferred walking speed was uncomfortable on the treadmill, speed was adjusted until the participant indicated that they were walking at their preferred treadmill speed. Once participants reported that the treadmill speed was comfortable, they were given a brief accommodation period, and then 30 s of motion capture data were collected.

Kinematic data were collected at 200 Hz using an 8 camera motion capture system (Oqus, Qualisys). Pelvis and right thigh, shank, and rearfoot/foot coordinate systems were calculated from a static trial using markers on the anterior and posterior superior iliac spines, greater trochanter, medial and lateral femoral epicondyles, medial and lateral malleoli, calcaneus, and 5th metatarsal. The pelvis was tracked using its anatomic markers and the thigh, shank, and rearfoot/foot were tracked with clusters of markers under rigid body assumptions. Ten consecutive strides of data were extracted and analyzed [22].

After the initial 30 s data trial, participants continued to walk on the treadmill for 30 min. At minutes 7, 17, and 27, treadmill grade was increased to 3% for one minute and then returned to level. At the end of the treadmill walk, 30 s of kinematic data were again captured and ten consecutive strides of these data were extracted and analyzed.

2.3. Data processing

Segment angles for the pelvis and right thigh, shank, and rearfoot/foot were calculated with respect to the global (lab) coordinate system, lowpass filtered at 8 Hz, and normalized to 101 points for each of 10 individual strides (Visual 3D, C-Motion). Heel strikes were determined as minima in the vertical position and toe-offs were determined as maxima in the vertical velocity of a calcaneal marker (similar to [23]). Segment angles were then exported for each stride.

Segment coordination was calculated using a custom MATLAB vector coding program implementing functions from the CircStat circular statistics toolbox [24]. Angle-angle plots were created for segment angle couples corresponding to hip, knee, and ankle joint angles that may change with age (Fig. 1). Phase angles were calculated as the angle of a vector connecting consecutive data points in each angle-angle plot with respect to the right horizontal (Fig. 2) using Eq. (1), where $0 \leq \theta \leq 360^{\circ}$, y and x represent the angles of the distal and proximal joints, and j is a percent of the ith stride.

$$\theta_{i,j} = \tan^{-1}[(y_{i,j+1} - y_{i,j})/(x_{i,j+1} - x_{i,j})] \quad (1)$$

Phase angles represent the segment coordination pattern, while the standard deviation of the phase angle at each point of the gait cycle represents the segment coordination variability. Phase angles describe the rotation (clockwise vs. counterclockwise) of segments relative to each other and are categorized into one of four coordination patterns: in-phase, anti-phase, distal segment phase, or proximal segment phase (Fig. 1). In-phase motion represents segments of interest rotating the same direction. Anti-phase motion represents segments of interest rotating in opposite directions. Distal and proximal phases represent one segment rotating while the other segment is relatively stationary. Note that each of these coordination patterns can occur at two separate ranges (Fig. 1, bottom pane) that are differentiated by the direction of motion of the adjacent segments. For example, the clockwise sagittal pelvis vs. sagittal thigh motion depicted in the top pane of Fig. 1 would be an in-phase pattern in the range of $202.5^{\circ} \leq \theta < 247.5^{\circ}$ with equal magnitudes of pelvis and thigh rotation occurring at 225°, while counter-clockwise rotation of these segments would be an in-phase pattern of $22.5^{\circ} \leq \theta < 67.5^{\circ}$ with equal magnitudes of pelvis and thigh rotation occurring at 45° [25].

As vector coding data are directional, circular statistics were used to calculate mean phase angles and the standard deviation of the mean for each segment angle couple for the 10 strides [22] from the beginning and end of the 30 min treadmill walk. Segment coordination and segment coordination variability were examined during four phases of the gait cycle when the limb is preparing to support or supporting body weight: terminal swing (last 15% of swing), and early, mid, and late (thirds of) stance. Segment coordination and segment coordination variability outcomes were calculated as the mean phase angle and average variability in each gait cycle phase of interest.