SPATIO-TEMPORAL AND TIME DOMAIN KINETIC PARAMETER VARIABILITY CHANGES WITH AGE

Vassilios G. Vardaxis, John Cooper*, and David Koceja
Department of Kinesiology, Indiana University, Bloomington, IN, USA

Changes in kinematic parameters and variability in gait cycle duration with age have been associated with adaptations and/or degeneration of the human balance control system and the automated stepping mechanism. We postulated that the degeneration of the control system as related to age will be reflected in variability of selected parameters of the ground reaction force vector that are independent from the gait stride speed. To test this hypothesis we obtained quantitative measures of spatio-temporal parameters and ground reaction forces (GRF) of 45 healthy subjects 21-91 years of age. The variability in cadence and selected vertical and anteroposterior GRF parameters was found to increase significantly with age. These findings are discussed in terms of adaptations for safer gait in the elderly and/or degeneration due to aging.

KEY WORDS: gait, elderly, variability, impulse, ground reaction force

INTRODUCTION: Gait reflects the specific manner that an individual moves on foot; it is highly automated and is the result of a complex mechanical interaction of a large number of segments that work together resulting in an efficient pattern. During gait the body is in a state of dynamic equilibrium that requires the regulation of an internally initiated action to move from point to point which depends on the integration of sensory inputs from the visual, vestibular and proprioceptive systems. Deterioration of the integrative peripheral nerve function and the physiological parameters of strength and flexibility, as a result of normal ageing, have been often associated with observed changes in the locomotion of the elderly, and it has been demonstrated that a number of spatio-temporal, kinematic, and kinetic variables change with age. These findings are mainly focused on sagittal plane kinematics and kinetics and can be summarized by decreases in gait velocity, stride length, joint range of motion, peak propulsive force and peak plantarflexor power at push-off (Winter, 1990). An overall hip walking strategy seems to be prevailing for the elderly as compared to younger adults that tend to use their ankle musculature to a greater extent. From the above findings shown in the literature one can conclude that elderly tend to adopt a conservative gait pattern that aims primarily in a safer gait stride (Winter, 1990). However, some of the findings on spatio-temporal parameters (outcome measures) indicate that, increased trial-to-trial variability suggests impairment in gait and that elderly fallers display higher variability than non-fallers and young adults (Gabell, 1984; Nakamura, 1996; Hausdorff, 1997; Maki, 1997). It is hypothesized in the present study that the increased variability observed in the spatio-temporal parameters of the elderly gait is directly related to the variability in selected GRF parameters and it is not related to the speed of progression.

METHODS: Forty-five, able-bodied adults volunteered for the present study. They ranged from 21 to 91 years of age, 23 males (49.7 ± 19.9 years) and 22 females (51.8 ± 21.3 years). The subjects were recruited from the Indiana University student population and the surrounding community at large and they were screened to be free from pathological conditions and neuromuscular disorders of the locomotion system with a medical and lifestyle questionnaire. Informed written consent was obtained from all the subjects prior to participating in the study according to the procedures approved by the Indiana University Committee for the Protection of Human Subjects. Kinematic body (marker), GRF, and foot/floor contact data were acquired simultaneously via a 6-camera Vicon 370 system (Oxford Metrics Ltd, England), a single AMTI strain gauge force plate (AMTI Inc., MA, USA), and 2 sets of insole footswitches (B&L Engineering Inc. CA, USA) respectively. Marker position data were sampled at 60 Hz, and force and footswitch analog data at 1200 Hz. Joint center positions were calculated using the 3D position data from reflective markers on each side of the subject in the following locations:

mastoid process, acromial process, mid lateral brachium, lateral epicondyle of the humerus, medial and lateral wrist, anterior superior iliac spine, mid lateral thigh, lateral epicondyle of the femur, mid lateral shank, lateral malleolus, heel, and head of the second metatarsal bone, in addition to mid forehead, sacrum, and right lateral iliac crest (Kadaba et al, 1990). The location of the center of mass (c.m.) was based on a 13-body segment biomechanical model written in MATLAB 6 (MathWorks Inc. MA, USA). Values for segmental mass and position of CM were obtained from anthropometric tables (Dempster, 1955). Each subject was prepared with the full marker set and was asked to walk (practice) a number of times along a 10m walkway in the biomechanics laboratory at his/her own normal pace. Approximately 10 familiarization trials were necessary to ensure constant self-selected gait speed and good force plate contact, adjusted/controlled with a starting point marker. Once the subject was familiarized with the protocol, 8-10 good trials with right-foot force plate contact were acquired. Five trials from each individual with similar average stride velocity (within 0.1 m/s) were used for subsequent analysis. All 3D position data were smoothed using a Butterworth, zero lag, low-pass digital filter with a cutoff frequency of 6 Hz prior to the calculation of the c.m. location. The gait cycle was defined from right heel contact to the next right heel contact using the heel footswitch data. The spatio-temporal parameters were calculated as follows: stride length, from the right heel marker location in the antero/posterior direction from two consecutive foot strikes; for cadence were used the average duration of 4 consecutive footsteps 2 before and 2 after the force plate from the heel footswitch data. The average gait speed was calculated from the antero/posterior velocity of the c.m. over a single gait stride. The 3D ground reaction forces and torques were used to calculate peak and impulse parameters in the vertical and mediolateral directions, as well as the path of the center of pressure over the stance phase of the gait stride. The force and impulse related parameters were amplitude normalized to body weight (BW). While the magnitude of these parameters is important this particular project is focused on their variability as it relates to age. The gait parameters that were previously shown or found in this study to be highly correlated with the average gait speed were excluded from further analysis (Andriacchi, 1977). Parameters calculated from the antero/posterior component of GRF were not used for this reason. The standard deviation of each of the spatio-temporal and GRF parameters over the five trials for each subject was used as the measure of the within subject variability. The relationship of the variability of each parameter with age was assessed with the Pearson product correlation coefficient using age as a continuous variable.

RESULTS AND DISCUSSION: Stride length and cadence as expected were highly correlated with average stride speed. The spatio-temporal parameters, their variability and their association to age are shown on Table 1.

Table 1 Age Effect on Spatio-Temporal Parameters

Parameter	R-square	F-ratio	p
Average stride speed (m/s)	0.045	2.039	0.161
Stride length (m)	0.151	7.647	0.008 *
Cadence (step/min)	0.003	0.013	0.721
Cadence asymmetry	0.130	5.690	0.022 *
Variability in stride speed	0.002	0.106	0.746
Variability in stride length	0.001	0.027	0.871
Variability in cadence	0.143	6.341	0.016 *

*** Identifies variables significantly related with age**

The elderly subjects walk with significantly shorter stride length, and with slightly higher cadence and lower average stride speed, which were not significant. The variability in cadence increased significantly with age, as well as, the cadence asymmetry, a measure of the variability in duration between the right and left steps. Both of these cadence related parameters are a reflection of rhythmicity, as manifested in the step-to-step variations in gait cycle timing. The amplitude related changes of these parameters with age were consistent with the literature and have been demonstrated before (Winter, 1990). Ground reaction forces in 3D were plotted against the normalized percentage of stance phase for each subject. Zero percent represented heel-strike, and 100% represented toe off. A series of sample graphs illustrating a representative young subject compared with a representative elderly are shown in Figure 1. The graphs illustrate the mean (±1 standard deviation) of five trials over the stance phase. Increased variability in the vertical and mediolateral components of the GRF is visible in this exemplar elderly subject.

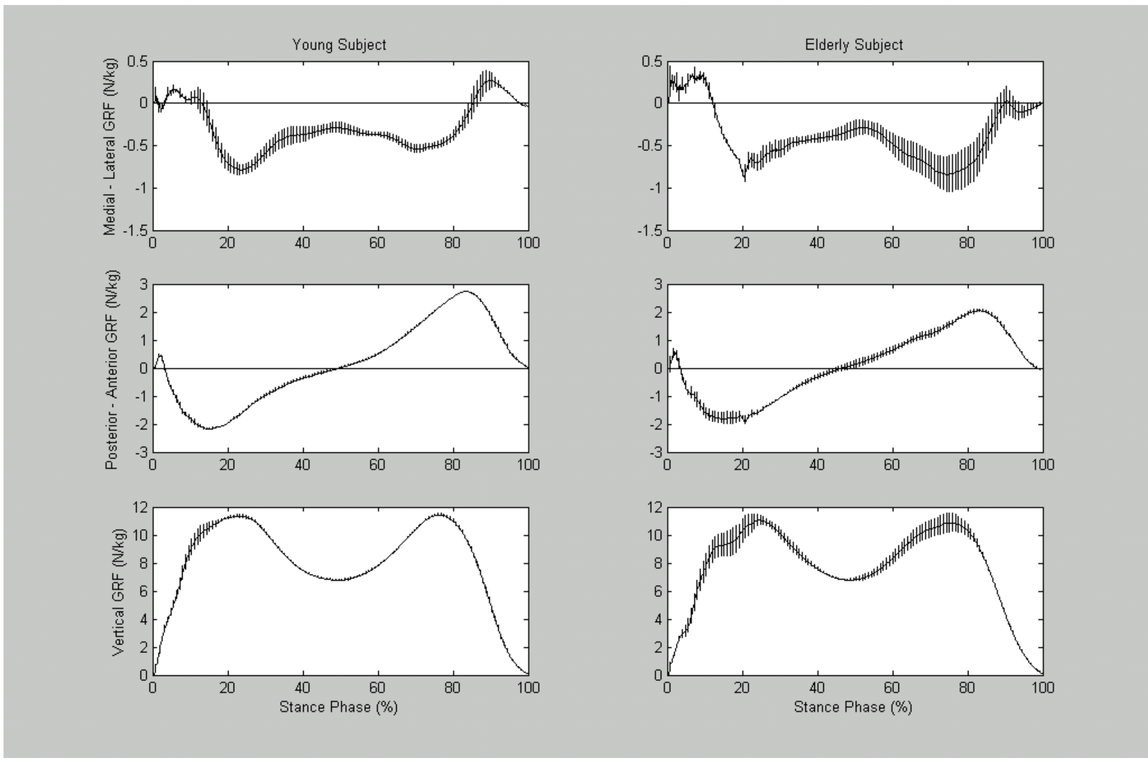

Figure1 - Mean (±1SD) of five trials of the mediolateral, antero/posterior and vertical component of the GRF of a representative young subject on the left and a representative elderly subject or the right.

Table 2 contains a summary of the selected reaction force parameters and their variability associated to age. The only parameters of the vertical reaction force component related to age were the variability of the average over the entire stance phase and the first peak during weight acceptance.

Table 2 Age Effect on Selected Reaction Force Parameters

Variable	r-square	F-ratio	P
Variability in the average vertical force	0.346	5.025	0.031
Variability in the 1st vertical force peak	0.376	6.245	0.018
Variability in net mediolateral impulse	0.380	6.594	0.014
Peak medial force	0.316	4.329	0.044
Variability in the peak medial force	0.340	4.886	0.032
Peak lateral force	0.361	5.400	0.026
Variability in the peak lateral force	0.353	4.522	0.039
Direction of the COP progression	0.491	12.08	0.001

The variability of both of these parameters increased with age, which indicates poor within subject consistency across trials, variable upward acceleration of the c.m. and thus poor

control of the body's downward velocity in the initial part of the stance phase by the elderly. Interestingly, since all of the mediolateral reaction force parameters and their variability were significantly associated with age this gives credence to the sensitivity of these measures. The increased amplitude in the medial force components in the elderly is indicative of increased mediolateral acceleration values that will affect the mediolateral excursions of the c.m. These mediolateral reaction forces may be the result of the wider base of support during double stance in the elderly, which is considered an adaptation for safety purposes during locomotion. The foot orientation (angular deviation) with respect to the line of progression was found highly correlated with age. This result was corroborated by both kinematic data of the heel and second metatarsal head markers, as well as, by the best fit line to the center of pressure (COP) location data during stance. The angular deviation increased with age, indicating increased external rotation at the hip, in a possible attempt to once again widen the base of support for safety purposes. However, the increased mediolateral forces may have a destabilizing effect on the human body since the only time over the stride that they can be safely controlled is during the double support periods, which make up approximately 20% of the gait cycle. This variability may very well be due to the degeneration of the peripheral nervous system that results in inconsistencies in the vertical and mediolateral reaction forces in the elderly. In general it is argued here that trends in the amplitude of the selected parameters may be associated with adaptations for safety purposes, however trends in the variability of the same parameters may very well be associated with the degeneration of the neuromuscular system due to normal aging.

CONCLUSION: The ground reaction force components are standard measures during gait analysis. We choose selected GRF parameters that were not related to gait speed to gain further insight into the changes in the gait characteristic of the elderly. Our results indicated that the aging neuromuscular system was significantly more variable in the mediolateral and vertical reaction forces, which may have implications in the frequency of falls in the elderly.

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