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Objective measures of gait and balance in healthy non-falling adults as a function of age

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ABSTRACT

Background: Neurodegenerative diseases increase in incidence with age. Prior studies using differing populations and gait paradigms have reported various parameters changing with age, some of which correlate with falls and mortality. Here we use three different paradigms to evaluate gait and balance in healthy non-fallers.

Research question: What objective gait and balance parameters are correlated with aging.

Methods: Healthy subjects aged 21–79 years without histories of falls, lower extremity orthopedic procedures or chronic pain were included. Subjects walked on a 20 × 4 foot pressure sensor mat (Zeno Walkway, Protokinetics, Havertown, PA) under three different gait paradigms, (i) steady-state gait, (ii) dual-task while texting on a cellular phone and (iii) tandem gait. Data was collected and analyzed using PKMAS software (Protokinetics). Linear regression analysis, stepwise multivariate analysis, and grouped analysis of gait parameters was performed using SPSS 24 (IBM).

Results: Seventy-five subjects were enrolled. Grouped analysis and linear regression analysis showed differing significance in parameters tested. Step-wise multivariate analysis of all 31 parameters assessed from three different gait paradigms, showed weak but significant correlations in age with (i) stride-to-stride variability in (i) integrated-pressure of footsteps and (ii) stride-length during steady-state gait, (iii) mean stride-length on dual-task, and (iv) mean step-width on tandem gait ($R^2 = 0.382$, $t = 2.26$, $p = 0.026$).

Significance: In a population of healthy subjects without prior history of falls or medical illness that should affect gait, there were weak but significant age-related changes in objective measures of steady state gait and balance. Future prospective longitudinal data will help predict the relevance of this in relation to falls in the elderly.

1. Introduction

As people age, gait and balance change, leading to falls with associated morbidity and mortality [1], and an estimated 19 billion dollars in annual healthcare costs in the US alone [2]. Quality of life is significantly affected by the development of fear of falling [3]. Gait changes can be early indicators of neurodegenerative disorders such as the hypokinetic-rigid gait of Parkinson's disease [4], or neurologic manifestations of medical diseases such as sensory ataxia from neuropathy due to diabetes. Vestibular dysfunction [5] and visual contrast sensitivity [6] in the elderly can also contribute to overall gait impairment. Gait and balance impairments may also be preclinical manifestations of underlying disorders including cardiovascular disease [7] and dementia [8,9].

Before we can understand how gait changes in association with age related disease processes, it is important to understand objectively whether normal aging changes gait. There have been a number of large studies in groups of elderly subjects, and smaller studies in younger populations of subjects or comparing different age groups, that provide evidence for objectively definable changes in gait with age. Some of these include increase in stride width and decrease in gait speed [10–12], increased variability in step-length and step-width [13], stride-width [14], stride-time and swing-time, stance-time and single-support-time [15] with advancing age. Increased stride-time variability has also been correlated with increased fall risk in elderly subjects [16]. In younger individuals, the dual-task of texting on a cellular phone while walking has been reported to decrease gait velocity and increase lateral deviation [17]. In older adults, gait changes during varying dual-

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tasks have been associated with decreased gait velocity [18,19], and decreased swing-time with increased swing-time variability [20]. Decreased gait velocity in elderly subjects has not only been reported to correlate with an increased risk for falls [21], but also a predictor of cognitive decline [22] and increased all-cause mortality [23]. Some of these studies used grouped analysis of different age groups [14,15,17,19] or correlation coefficients [11,13], others used regression analysis over the entire age group they studied [10,12]. Not all studies looked at the same parameters or performed gait assessments using the same instrumentation or walking tasks. A large study combining multiple consortiums has attempted to overcome some of these issues but only looked at an older population (age > 60) of subjects [15].

An alternative hypothesis has also been proposed, suggesting that any significant gait change in the elderly is a pre-manifestation of an underlying neurological disease, not caused by “normal aging”. In support of this argument, approximately 20% of elderly individuals over age 85 had no gait dysfunction based on questionnaire and subsequent visual examination [24]. Another study defined a more “robust normal” group of subjects from a “conventional normal” group, and found a number of gait measures, including stride-velocity [25], were better in the “robust normal” group.

To our knowledge no single study has looked at all aspects of gait kinematics objectively, in a healthy population, over a wide continuum of age ranges, including assessments of dual-task and balance on the same population at the same point in time. Our current study was designed to bridge this gap. We evaluated three different conditions in a population of healthy, non-falling adults between the ages of 18 and 80; (i) steady-state gait to establish baseline gait, (ii) gait during dual-tasking using a commonplace task of texting while walking, to see whether increased cognitive load affected elderly subjects gait more than younger subjects, and (iii) tandem gait as a measure of balance.

2. Methods

2.1. Subjects

Subjects age 21–79 without prior history of falls were prospectively recruited at the University of Arkansas for Medical Sciences using flyers after obtaining IRB approval (UAMS IRB #203471). Those with history of prior orthopedic procedures on the back or lower extremities and chronic pain syndromes were excluded. All subjects completed a questionnaire that included past medical history to exclude any gait-related disease states.

2.2. Gait analysis

Subjects walked on a 20’ × 4’ pressure sensor impregnated mat, Zeno Walkway (ProtoKinetics, Havertown, PA), and data was collected and analyzed using Protokinetic Movement Analysis Software (PKMAS, ProtoKinetics) [26,27]. Three paradigms were analyzed: (1) steady-state walk: subjects walked eight full lengths of the mat, walking off at both ends, (2) dual-task: subjects walked 8 lengths while simultaneously typing on a cellular phone, and (3) tandem walked (heel-toe) the length of the mat. For steady-state and dual-task gait, the first and last steps on the mat were excluded to minimize acceleration and deceleration effects. Objective gait variables were analyzed for steady-state and dual-task gait (see supplementary materials for detailed definitions). For tandem walking, we defined two additional parameters not in PKMAS. Path-width (the distance between the two most lateral footsteps over the entire 20’ tandem walk) and step-width (the distance between consecutive steps) (Fig. 3A). In our scatter plots we show the mean value (filled symbols) and stride-to-stride variability (unfilled symbols) of each individuals’ trial for each gait parameter assessed in each of the three different gait paradigms (left side, filled symbols). Stride-to-stride variability was calculated as the percent coefficient of variation (%CV = standard deviation/mean), to allow for more accurate comparison of gait parameters with differing absolute values.

2.3. Statistical analysis

Analysis was performed using SPSS version 24 (IBM). Normality was assessed using the Schapiro-Wilk test. Linear regression analysis was performed on all variables as a function of age followed by step-wise multivariate analysis to determine the variables most influenced by age. One-way ANOVA (parametric) or Mann-Whitney (non-parametric) tests were applied for comparison between age groups. Dual-task gait changes were calculated as the ratio of dual-task/steady-state gait (texting/baseline) for each subject for each gait parameter. Using age, the predicted values for the four significant parameters in our multivariate model was calculated from the equations for their univariate linear regression fits. The residuals between the actual and predicted values were used to determine “outliers” (1–2 standard deviations from the fit), and statistical significance between age groups calculated by chi-square.

3. Results

Seventy-five subjects (mean age 46.9 ± 17.1 years; 56% female and 90% right-handed) were enrolled and analyzed. Older subjects (median-split at age 50) had a greater percentage of hypertension, hyperlipidemia, and diabetes, while two younger subjects had neuropathy (Table 1).

3.1. Steady-state gait

Linear regression analysis of the mean value of gait parameters for each individual, as a function of their age, showed weak but significant correlation for mean integrated-pressure ($R^2 = 0.06$, $p = 0.042$), stance % ($R^2 = 0.05$, $p = 0.046$), swing% ($R^2 = 0.05$, $p = 0.042$), and single support % (SS%; $R^2 = 0.06$, $p = 0.042$) (Fig. 1A, H, I, J; filled diamonds). Linear regression analysis of the stride-to-stride variability in gait parameters, calculated as the percent coefficient of variation in any given parameter for each subject (%CV) showed weak but significant correlation for all variables except stride width and foot area (Fig. 1; unfilled diamonds). On step-wise multivariate analysis of the significant variables, %CV integrated-pressure ($t = 3.82$, $p < 0.001$) and %CV stride-length ($t = 3.33$, $p = 0.002$) remained significant in the equation with an R^2 of 0.29.

In order to compare our results to previous studies that used split age groups, we also split subjects using a median age of 50. In this analysis there was no statistically significant difference in the mean values of the gait variables (Supplementary Fig. 1). The %CV was

Table 1
Subject demographics.

	All subjects (n = 75)	Age < 50 (n = 37)	Age ≥50 (n = 38)
Average age (years)	46.9 +/− 17.1	31.2 +/− 6.7	62.3 +/− 7.1
Percent Female	56%	56.8%	55.3%
Right handed	90%	89.2%	92.1%
<u>Medical Conditions</u>			
None	26.7%	43.2%	10.5%
Hypertension	22.7%	0.0%	44.7%
Hypercholesterolemia	17.3%	2.7%	31.6%
Migraines	16.0%	13.5%	18.4%
Depression or Anxiety	9.3%	8.1%	10.5%
Asthma	9.3%	10.8%	7.9%
Diabetes	6.7%	2.7%	10.5%
Gastroesophageal Reflux	5.3%	5.4%	5.3%
Seasonal Allergies	5.3%	8.1%	2.6%
Heart Disease	4.0%	0.0%	7.9%
Neuropathy	2.7%	5.4%	0.0%