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Alterations in gait speed and age do not fully explain the changes in gait mechanics associated with healthy older women

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ABSTRACT

Older adults exhibit modified gait patterns compared to the young, adopting movement strategies in response to changes in musculoskeletal function. Investigating the functional mobility of older women is particularly important because of their increased life expectancy and greater falls risk compared to men. We explored the relationships between gait parameters and age in healthy older women whilst accounting for declining gait speeds. Kinematic and kinetic data were collected from thirty-nine women (60–83 years) whilst walking at a comfortable cadence. Regression analysis assessed the capacity of gait speed and age to explain the variance in gait associated with older age. Speed explained the majority of variance in many gait parameters. By including age in the regression, the total explained variance (R^2) for foot clearance (70%), ankle plantarflexion angle (30%), peak ankle plantarflexor moment (58%), and hip power generation (56%) were significantly ($p < 0.05$) greater than for speed alone. Nonetheless, changes in speed and age did not fully explain the variance in gait mechanics associated with older age and other contributing factors must exist. Losses of 1.2%/year in gait speed were predicted by age, exceeding previous predictions of -0.7%/year. Furthermore, the accumulation of apparently small decreases of 0.2 cm/year in peak foot-to-ground clearance has clinical implications and offers insight into the mechanisms by which gait becomes hazardous in older age.

1. Introduction

Walking relies on the systematic and combined actions of the musculoskeletal system and is an important daily task. Older adults display reduced musculoskeletal function resulting from physiological and neuromuscular changes [1,2]. These age-related modifications contribute to reduced muscle strength and lower limb joint range of motion (ROM) [3]. Consequently, older adults must make adaptations to their movement patterns and gait function is diminished.

Older adults display an increased stance phase and a shorter step/stride length [4], resulting in reduced speeds, compared to younger adults [5]. Many of the gait adaptations of older adults may be attributed to temporal-spatial variations, and specifically to declines in gait speed, which reportedly reduces by 0.7%/year [6]. Slower walking speeds are associated with decreased initial peak vertical forces and peak powers, and increased vertical forces mid-stance [7,8]. Age-induced gait adaptations such as reduced hip extension, increased anterior pelvic tilt [9] and reduced swing phases [4] have been identified as independent of speed.

Many of the aforementioned studies have compared a young group (typically 20–40 years) to an 'old' group (typically 55–80 years) with few studies including adults > 80 years [5,9,10]. This approach assumes that old age can be categorised into a single group, without regard for the continuing process of ageing. Therefore, the extent of musculoskeletal deterioration within the older age continuum remains unclear. Furthermore, the independent effects of age-induced functional loss and declining speeds on gait parameters are unknown, with a large volume of work attempting to control speed by analysing: slow *vs.* comfortable *vs.* fast/maximal speeds [5,8,9,11–14]; percentages of preferred speed [3,7]; and by controlling cadence [15]. These differing approaches demonstrate the confounding influence of speed on many gait variables.

Understanding the rate of functional decline throughout old age is essential for informing the design of exercise interventions to maintain independence and mobility. This knowledge may be particularly valuable to older women due to their increased life expectancy [16] and greater risk of falling [17] compared to men. The aim of this study was to explore the relationships between gait parameters and age in healthy older women whilst accounting for

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declining gait speeds. This was accomplished by (i) quantifying the relationship between gait variables and speed, and (ii) exploring the rate of change in gait parameters with age.

2. Methods

2.1. Participants

Thirty-nine healthy females gave written informed consent to participate in this study [mean(SD) age 71.5(7) years, range 60–83 years; height 163.3(6.6) cm; mass 70.6(11.9) kg]. Participants were recruited from the local community. Local NHS ethical approval was granted (Ref:08-H1305-91). Strict recruitment criteria were implemented to reduce the chance of observing pathology-associated changes. Participants were excluded if they had any known musculoskeletal or neurological disorder, a history of falls, or were prescribed medications likely to influence dynamic locomotion. Participants attended the laboratory wearing comfortable flat shoes, shorts and a t-shirt.

2.2. Protocol

Motion capture data were collected from 14 ProReflex MCU1000 cameras (Qualisys, Sweden) sampling at 100 Hz. The measurement volume was calibrated using a 750 mm wand and L-frame that defined the lab origin. Ground reaction force (GRF) data were obtained from complete foot contacts using two 400 × 600 mm Kistler piezoelectric platforms (Winterthur, Switzerland) sampling at 500 Hz. Kinematic and kinetic data were synchronised using Qualisys Track Manager (Qualisys, Sweden). A six degrees-of-freedom marker set was used to capture the 3D motion of the lower limbs bilaterally [18]. Participants walked at a natural pace along a 10-m walkway completing 8–12 trials depending on functional ability. Gait speed was not manipulated in order for natural gait patterns to be observed.

2.3. Data analysis

Labelled marker coordinates and, kinematic and kinetic data were exported to Visual 3d^{TM} modelling software (C-Motion, USA). Kinematic data were interpolated and filtered using a low-pass (<6 Hz) Butterworth filter. GRF data were filtered using a low-pass (<25 Hz) filter. Gait events were identified from the kinetic data. Joint kinematics and kinetics were normalised to the gait cycle. GRF data were normalised to 100% stance.

2.4. Variables

Temporal-spatial parameters of gait including speed, stride length, cycle time and phase parameters such as stance (%) and double limb support (%) are reported. The peak posterior (Fy1) and anterior (Fy2) GRF values were identified in the first and second half of stance, respectively. The first and second peak vertical GRF (Fz1 and Fz3, respectively) and the minimum vertical GRF mid-stance (Fz2) were analysed. The loading (LR) and decay rates (DR) were calculated as the positive slope of the vertical force from initial contact to Fz1, and the negative slope from Fz3 to toe off, respectively. Joint moments and powers of the lower limb joints were calculated through inverse dynamics. Peak internal sagittal joint moments (Nm/kg) and powers (W/kg) were determined. Peak power bursts were identified and labelled for the hip (H1–3), knee (K1–4) and ankle (A1–2) [19].

2.5. Statistical analysis

Between-limb differences were assessed with paired samples *t*-tests. Significant differences were found for stance (%) and Fz2 (N/kg), out of the 40 variables of interest. The maximum percent difference (max%diff) was low for stance (<3.5%), so differences were considered minimal and symmetry was assumed. Consequently, the average of both limbs was used for further analysis. The max%diff between right and left Fz2 were high and 12 participants exceeding 5% were removed from further analysis for Fz2.

2.5.1. Regressive procedures

Linear regression determined the relationship between age and natural gait speed. Multiple regression explored the explained variance in gait variables attributable to speed and age. The predictor (independent) variables were inserted using a forced-entry method with speed entered first followed by age. Three outliers were found from the standardised residuals (>3SD). Cook's distance and leverage statistics revealed that no case exerted undue influence on the model [20]. For completeness, models including and excluding outliers are presented within the tables and the table footnotes, respectively.

Statistical assumptions of regression were assessed and met for the variables. Variance inflation factors (VIF) assessed multicollinearity between the two independent variables and revealed that this assumption had been satisfied (VIF < 1.4) [21]. Whilst the correlation between speed and age was of moderate strength ($r = -0.57$), this was not considered to violate the multicollinearity assumption as correlations > 0.8 are usually regarded as cause for concern. This cut-off is influenced by sample size and the number of predictors [22], therefore the explained variance between the 2 independent variables was considered and indicated that a perfect correlation did not exist ($R^2 = 32\%$).

2.5.2. R^2 and slope coefficients

The magnitude of variance (R^2) in gait parameters explained by speed, and speed and age combined, is presented. The slope coefficients (B) are presented for both independent variables and statistical significance indicated that the gradient of the regression line (B) was significantly different from 0 and the predictor significantly contributed to the model.

When both speed and age significantly contributed to the variance explained, semipartial correlations (sr_i^2) assessed the shared variance using the part correlation. ANOVA data assessed whether the model was significantly better at predicting the outcome compared with using the mean for estimation. Statistical significance was accepted at $p < 0.05$ and analyses were performed using PASW v18.0 software (SPSS Inc., Chicago, IL).

3. Results

The relationship between speed and age revealed a linear relationship of moderate strength ($r = -0.57$, $p \leq 0.01$). The trend line was plotted according to the regression equation (Fig. 1). According to the line gradient, reductions in speed with age were 1.2%/year and 6.1% over a 5-year period. Speed explained variance in all temporal-spatial parameters as expected ($p \leq 0.02$, Table 1), except stride width. Age improved the explained variance (≤6%) in stride length and cycle time; however, slope coefficients were small ($B = 0.005$ and $B = 0.004$, respectively) compared to those presented for speed ($B = 0.609$ and $B = -0.377$, respectively).

Speed explained variance ($p \leq 0.03$) in many of the peak kinematic variables (Table 1). Peak hip extension was the only joint angle that produced a negative slope coefficient ($B = -11.028$, $p < 0.05$) but, as hip extension was negative, the negative slope coefficients indicated greater hip extension with increased speed. Hip, knee and ankle ROM, and knee flexion all increased with speed ($5.739 \geq B \leq 18.825$). 30% of the total variance in the plantar-flexion angle was explained by speed and age combined with increases of 0.371 degrees/year. The majority of variation observed in foot clearance (70%) was explained by a combination of speed and age ($sr_i^2 = 40\%$).

Many GRF and peak joint moments were significantly explained by speed (Table 2). Moderate-to-high proportions of variance were explained by speed (R^2 = 49–64%) for posterior GRF, Fz2, LR and DR. 95% confidence limits for these variables were small indicating that the slope coefficients were predicted very precisely. All joint

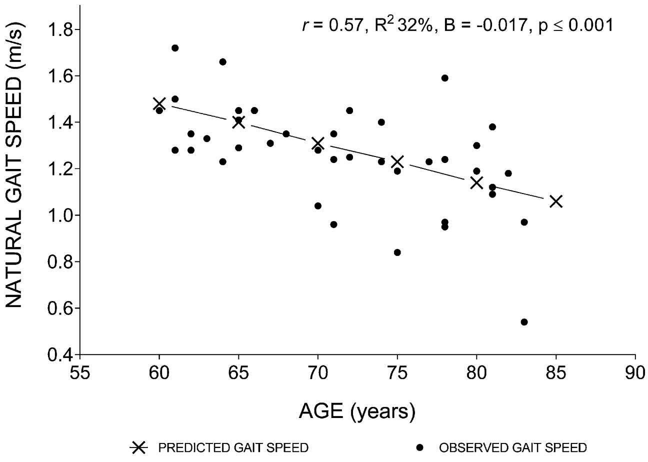

Fig. 1. Relationship (r) between age (years) and natural gait speed (m/s). Sample observations (circle) and predicted values for ages between 60–85 years in 5 year increments (crosses) are presented.