Title: Relationships between walking speed, T-score and age with gait parameters in older post-menopausal women with low bone mineral density

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Conflicts of Interest

The authors declare that there are no conflicts of interest.

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Ethical approval

NHS Health Research Authority approved (REC Ref. 11/YH/0347). All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Title: Relationships between walking speed, T-score and age with gait parameters in older post-menopausal women with low bone mineral density

Background: The gait patterns of women with low bone mineral density (BMD) or osteoporosis have not been thoroughly explored, and when examined, often studied in relation to falls and kyphosis.

Research question: The aim of this study was to investigate the relationships between gait parameters and comfortable, self-selected walking speed and BMD in older post-menopausal women with a range of T-scores (healthy to osteoporotic).

Methods: 3D kinematic and kinetic data were collected from forty-five women mean (SD) age 67.3 (1.4) years during level walking at their preferred speed. Multiple regression analysis explored the explained variance attributable to speed, femoral neck T-score, and age.

Results: The mean (SD) walking speed 1.40 (0.19) $m \cdot s^{-1}$ explained the variance in most temporal-spatial, kinematic and joint powers (R^2=12-68%, $P \leq 0.001$). T-score accounted for (R^2=23%, $P \leq 0.001$) of the shared explained variance in stride width. It also increased the explanatory power for knee flexion (R^2=7%, $P \leq 0.05$) and knee range of motion (R^2=12%, $P \leq 0.01$). Power absorption by the knee flexors in terminal swing (K4) was the only power burst resulting in significant slope coefficients for all predictor variables (R^2=52 and 54%) ($P \leq 0.001$) and (R^2=68%, $P \leq 0.05$).

Significance: Speed alone explained much of the variance of gait parameters, while speed and T-score combined increased the explained variance in some knee variables. Our findings demonstrate that older post-menopausal women with a broad range of T-scores can walk at comfortably fast speeds. The results also suggest that strengthening the hip abductor, knee extensor and flexor muscle groups may benefit the gait patterns of older postmenopausal women with low BMD.

Introduction

Osteoporosis is a systemic skeletal disease that is identified by decreased areal bone mineral density (BMD, g/cm^2) and bone loss [1]. Osteoporosis can be a debilitating condition that predisposes primarily older women to an increased risks of fractures [1]. Every year, more than 8.9 million fractures worldwide are associated with osteoporosis, with 70% and 80% of these fractures occurring at the hip and forearm of women between 50 to 75 years of age, respectively [2]. The consequences of a fracture can be devastating with detrimental effects on a person's well-being and independence, and high healthcare costs related to treatment and follow-up care.

Normal age-related changes in gait, such as reduced walking speed, decreased hip extension and reduced power generation at the ankle, have been well established in older adults [3–6]. However the gait patterns of individuals with low BMD or osteoporosis have not been thoroughly investigated, and when examined, often studied in relation to falls and kyphosis (vertebral fracture) [7–9] or temporal-spatial gait parameters only [10,11]. In one study, older women with low BMD exhibited increased gait variability in step and stance time when compared to their peers with healthy BMD levels [10]. Increased gait variability has been associated with greater falls risk in older adults [12], but can also improve local dynamic stability when walking slowly in young adults [13]. Temporal-spatial data do not examine the complex interactions between joint movements and mechanical power outputs by the muscles acting about the hip, knee and ankle joints during walking [14]. There is limited evidence of altered gait profiles for older women with low BMD including less hip extension, reduced power generation at the hip in early stance (termed H1 power burst [15]) and pre-swing (H3), less knee power absorption during terminal swing (K4) and smaller ankle power generation at push-off (A2) in comparison with women with normal BMD [16]. Nevertheless, there is a dearth of knowledge on the gait biomechanics of older women with low BMD and osteoporosis. This is important because walking is a recommended form of physical activity for the treatment of low BMD, particularly at the hip and femur [17] as the musculoskeletal loading can promote bone formation and attenuate further bone loss [18,19].

Previous studies investigated how much of the variance in BMD was explained by the peak hip joint moments in all three dimensions during level walking using multiple regression analysis [19–21]. In these studies, 40% to 93% of the femoral BMD variance was explained by hip joint moments [19,20]. However, the results from a further study [21], which analysed the hip joint moments independent of body mass, did not fully corroborate with the previous studies [19,20] as the relationship between hip joint moment and BMD was reduced to essentially zero when scaled allometrically. Therefore, this relationship warrants further investigation. This information is important to enable the development of effective, safe and timely exercise-based interventions for older women.

To the authors' knowledge, there has been only one study to date which has explored three-dimensional joint kinematic and kinetic gait parameters in women with osteopenia [16]. However, the participants' gait speed was not reported [16] and yet the significant effects of speed on gait variables is well established [22]. Therefore, it is unclear how much of the explained variance could be attributed to speed alone in the study [16]. The aim of the current study was to investigate the relationships between gait parameters and self-selected, comfortable walking speed and BMD in older women with a broad range of T-scores (healthy to osteoporotic). It was hypothesised that walking speed would explain most of the variance in gait parameters but that adding T-score into the regression model would contribute to the explained variance for joint kinetic parameters about the hip and knee.

Methods

Participants

Forty-five women (13 women with healthy BMD levels, 26 with osteopenia and 6 with osteoporosis) were recruited from the local Centre for Metabolic Bone Disease. Inclusion criteria stipulated participants were women aged 65-70 years with a BMI of 18-30 kg/m^2 (normal to overweight), who must have had a DXA scan within the previous 12 months, a T-score of 0 to -4, and without any cardiac problems. Participants were excluded if they had any known neurological disorder or obvious gait abnormalities, also if they had received any treatment of glucocorticoids, teriparatide and bisphosphonate or hormone replacement therapy during the five years prior to the commencement of the study. All participants gave their written informed consent to take part in the study. Ethical approval was obtained through the NHS (REC Ref. 711/YH/0347). Participant demographics are presented in Table 1. For ease of communication, the authors hereafter refer to older postmenopausal women as older women.

In accordance with the World Health Organisation criteria [1] participants were categorised as healthy, osteopenic or osteoporotic if they had T-scores higher than −1 SD of the T-score of a young, healthy adult, between -1 to -2.5 SD, and lower than -2.5 SD, respectively. Bone mineral density (T-scores) was obtained in the year preceding entry into the study via Dual X-ray Absorptiometry (DXA) by the same technician in all cases, as part of the participants' regular treatment at the Centre.

Protocol

Twelve Pro-Reflex MCU1000 motion capture cameras (Qualisys, Sweden) sampling at 100Hz measured 3D marker trajectories during level walking at the participants' comfortable self-selected walking speed. The measurement volume was calibrated using a 750mm wand and L-frame that defined the lab origin. Ground reaction force (GRF) data were simultaneously recorded at 500Hz with two Kistler piezoelectric platforms (model 9286AA, Kistler, Switzerland). A lower limb 6 degrees of freedom (6DOF) marker set was used to track the lower limb segments and pelvis [23]. Markers were placed bilaterally on the iliac crest, anterior and posterior superior iliac spines (ASIS and PSIS), greater trochanter, medial and lateral femoral epicondyles, medial and lateral malleoli, 1st, 2nd and 5th metatarsal heads and calcaneus. Virtual projections of the medial and lateral malleoli markers onto the floor allowed the creation of a virtual foot parallel to the floor, thus making the ankle angle zero, or close to zero, in the static calibration pose. Tracking markers (clusters of four markers) were positioned onto the thighs and shank bilaterally. Participants completed 10 trials walking at comfortable self-selected speed along a 10m level walkway. Kinematic and kinetic data were synchronised using Qualisys Track Manager 2.09 software.

Data analysis

Biomechanical data were analysed further within Visual 3D v3.0™ (C-Motion, USA). 3D marker coordinate data were first interpolated and then filtered using a low-pass (6Hz) Butterworth filter. Force data were filtered using a low-pass (25Hz) Butterworth filter. Gait events were automatically identified from the kinetic data. Gait data were averaged for both limbs during steady-state walking. Gait variables included temporal-spatial parameters; peak lower limb joint angles and range of motion in the sagittal plane; peak hip abduction angles; peak anterior-posterior and vertical ground reaction forces (GRF); and loading and decay rates (defined respectively as the positive slope from initial contact to first peak vertical force in loading; and the negative slope from peak vertical force during push-off to toe off and reported as (N/kg/s)). Inverse dynamics were used to calculate the peak internal sagittal joint moments and powers. Power bursts were labelled for the hip (H1-H3), knee (K1-K4), and ankle (A1-A2) according to Eng and Winter [15]. Joint moments and powers were normalised to the gait cycle and to body mass, and expressed as Nm/kg and W/kg, respectively. GRF data were normalised to 100% stance and body mass (N/kg).

Statistical analysis

Multiple regressions explored the explained variance in gait variables related to speed, T-score and age. Despite the fact that our age group spanned a narrow range (65 to 70 years), age was considered to be a possible important predictor variable. This was due to the fact that a previous study [5] found a reduction in gait speed of 1.2% per year in older women.

Histogram of residuals were checked to confirm data normality. Collinearity was tested for and the average variance inflation factor (VIF) between T-score, speed and age was found to be 1.02 indicating no evidence for collinearity [24]. The three predictor (independent) variables were inserted using a blockwise-entry method with speed entered first, followed by T-score and then age. This generated three regression models as follows: (1) gait speed as the only predictor variable; (2) gait speed and T-score jointly as predictor variables, and (3) gait speed, T-score and age in combination as the predictor variables.

The magnitude of variance (R^2) in gait parameters explained by gait speed alone, speed and T-score, and speed, T-score and age combined are presented. The slope coefficients (B) are presented for all independent variables, and statistical significance ($P \leq 0.05$) indicated that the gradient of the regression line (B) was significantly different from 0, and the predictor significantly contributed to the model. The Stata statistical computer package (Stata, USA) was used to analyse the data.

Results

The participants' mean (SD) walking gait speed was 1.40 (0.19) $m \cdot s^{-1}$ and explained (R^2=12-68%) of the variance in temporal-spatial parameters ($P \leq 0.01$) (Table 2). T-score alone accounted for R^2=23% ($P \leq 0.001$) and 6% ($P \leq 0.01$) of the shared explained variance in stride width and double support time, respectively. However slope coefficients were smaller (B=0.013 and B=0.01, respectively) compared to those presented for speed alone (B=0.039 and B=-0.155, respectively). When gait speed and T-score were introduced to the regression model, the 95% confidence intervals were (95% CI: [0.01 to 0.021]) for stride width and (95% CI: [0.003 to 0.017]) for double support. Diminutiveness of these variables are indicative of the precision in predicting the slope coefficients. Introducing T-score into the regression model increased the explained variance for stride width and double support. However, adding age into the model did not account for a significant proportion of explained variance for stride width or double support.

Speed alone explained the variance ($P \leq 0.01$) in many of the peak kinematic variables (Table 2). The inclusion of T-score to the regression model increased the explanatory power only in the following variables:

peak hip abduction, knee flexion in initial swing phase and knee range of motion. These accounted for 8%, 7% and 12% of the shared explained variance respectively ($-0.72 \geq B \leq 1.17$). In the third model, 13% of the total shared variance in the knee range of motion (ROM) was explained by speed, T-score and age combined.

A substantial amount of variance in peak GRFs, including load and decay rates, and joint moments was significantly ($P \leq 0.001$) explained by speed only (Table 3). Speed explained 59% of the variance in load rate and 68% in decay rate with the following slope coefficients ($B=8.312$ and $B=6.231$, respectively) (Table 3). Inclusion of T-score to the regression model did not affect internal joint moments or GRF parameters (Table 3). Only the first vertical GRF peak (Fz1) explained $R^2=6\%$ ($P \leq 0.05$) more of the shared variance when age was introduced into the model.

Speed explained considerable variance in all joint powers ($R^2=14\text{-}61\%$) (Table 4), except for the peak ankle power absorption of the plantarflexors during terminal stance (A1). Power absorption by the knee flexors (K4) was the only power burst resulting in significant slope coefficients for all predictor variables in all three regression models. Upon introduction of the T-score and age to the models, the shared explained variance increased by $R^2=2\%$ ($P \leq 0.001$) and $R^2=14\%$ ($P \leq 0.05$), respectively. Figure 1 represents the participants' mean (SD) joint power profiles during level walking for the sagittal plane hip, knee and ankle joints.

Discussion

The aim of this study was to characterise the explained variance of the predictor variables (gait speed, T-score and age) on temporal-spatial parameters, lower limb joint kinematics, GRFs and joint kinetics during level walking in a sample of older women with T-scores ranging from healthy to osteoporotic. The regressive statistics presented in this study allowed for the control of multiple predictors to be entered into the regression progressively. The findings demonstrate that speed explained much of the variance in gait parameters, but that T-score and age explained changes in some temporal-spatial variables which were related to dynamic stability and also in some joint kinematics and kinetics. These findings were as hypothesised and confirmed that studies should report walking speed and account for it statistically, as this predictor variable explained a significant amount of the gait variance in this population.

In this study the participants' mean (SD) gait speed was 1.40 (0.19) $m \cdot s^{-1}$ which was considered fast for older women as it was higher compared to other studies with older women of a comparable age range:

0.92(0.27) $m \cdot s^{-1}$ (mean (SD) age of 73.5(5.9) years) [25], 1.29(0.21) and 1.27(0.21) $m \cdot s^{-1}$ (for women in their 60s and 70s years of age, respectively) [3]. Our participants' temporal-spatial data were more similar to those of younger adults [3,26] and indicated that the participants were functioning at a high physical level despite their range of T-scores. Moreover, their fast gait speed was attributed more to a high cadence (i.e., step rate) rather than step length. The participants self-reported keeping active with walking-based activities on average five days per week which may explain their fast walking speed (Table 1).

Some previous studies [27,28] have examined a single gait parameter as the predictor variable (e.g., hip joint moment) to explain the variance in BMD. This is valid for a single variant regression model. In multivariate regression models, variance inflation factor (VIF) (collinearity) must be checked to avoid excessive correlation between the predictor variables. In the current study, the gait parameters related to temporal-spatial patterns had raised VIF (>15), while kinematics had excessively large VIFs (>200 000). Both values were clearly above the safe threshold of VIFs >10, providing evidence of collinearity of the predictor variables [24]. Using gait speed, T-score and age as three independent predictor variables avoided this limitation, while explaining the variance in the gait parameters.

Inclusion of the T-score into the regression model for temporal-spatial parameters did not increase the explanatory power of models, except for stride width and double limb support time (Table 2) and explained no more than 23% and 6% of the shared explained variance, respectively. These findings were consistent with a previous study, where older and osteoporotic individuals seemed more likely to increase their double support time, especially when they encountered more challenging surfaces [10]. Increased stride width, and thus base of support, and longer double limb support time are associated with dynamic stability during walking [29]. In the current study, all participants were aware of their T-score, which was measured within the previous 12 months or less prior to study enrolment. It is possible that those with lower BMD may have adapted their gait patterns to enhance their dynamic stability to avoid an unexpected fall, even in apparently low-risk walking environments. However, we are unable to understand this exact relationship, and its cause and effect nature, with our cross-sectional study design.

When T-score was introduced to the regression model for joint kinematic parameters, the explanatory power of models was only increased for peak hip abduction, knee flexion during swing and knee range of motion. The shared explained variance rose by 8%, 7% and 12% respectively when compared to the previous model (when speed was the only independent variable). The hip abductor musculature plays an important role in maintaining dynamic balance control of the trunk [30]. It is possible that older women with low BMD utilise more hip abductor strength to stabilise the trunk in the frontal plane during initial swing, when the body moves from a more stable double support phase into a more vulnerable single support. This may be an important muscle group to target during exercise programmes suited for older women, and for those with low BMD particularly.

A previous study reported diminished knee extensor and flexor muscle strength in older women with low BMD [31]. Our findings suggest that older women experienced an increased range of motion at the knee which was associated with higher gait speed and T-score (Table 2). Adequate joint mobility and strength of the knee extensor and flexor muscles are important for walking and many other daily activities, such as rising from a seated position, sitting down from standing and completing other transfer tasks; however weakness in these muscle groups has been reported among older adults previously [32]. Exercise programmes tailored for older women, irrespective of T-score, should emphasise range of motion and strength, especially eccentric, at the knee. In addition to load-bearing activities, such as walking, enhancing knee extensor eccentric strength, required during the downwards or deceleration phases of daily movements (i.e., sitting down and downhill walking, respectively) would be especially beneficial for women with low BMD due to the increased mechanical loading on the femur through eccentric knee muscle contraction [33,34].

Speed alone explained the variance in all GRF parameters (R^2=12-71%) (P≤0.001) and joint moments (R^2=19-57%) (P≤0.001) (Table 3). In the current study, participants' load and decay rates (Table 3) were similar to a group of healthy older women of comparable age and somewhat slower gait speed (mean(SD) 1.26 (0.23) $m \cdot s^{-1}$) [5]. High and positive slope coefficient values for load and decay rates (B=8.312 and B=6.231, respectively) highlight the strong and synergetic interrelation of GRF with speed. Load rate indicates the rate of force application to the body following weight acceptance and decay rate emphasises the rate of push-off force in pre-swing. Therefore, we suggest that studies exploring osteopenia and osteoporosis in relation to gait should also report load and decay rates.

Speed alone also explained considerable variance in most joint powers (R^2=14-61%) (Table 4). Knee power absorption in terminal swing (K4 power burst) which is when the knee flexor muscles absorb energy to decelerate the swinging leg (Figure 1) was the only power burst resulting in significant slope coefficients for all three regression models.

A previous study has identified and attributed most of the explained variance in gait parameters, including hip joint moments and many power generation and absorption bursts at the hip, knee and ankle, to BMD values at the femoral neck [16]. However as walking speed was not reported or accounted for in their study, it remains unclear how much of the explained variance could have been attributed to walking speed, rather than femoral neck BMD alone. Our study has revealed that walking speed alone explained the majority of the variance in gait parameters, therefore the previous results [16] may have overestimated the explained variance related to BMD.

The current findings support our hypothesis that walking speed explained significant variance in gait parameters in older women, and not BMD (as represented by T-score) alone, as almost all of the explained variance was attributed to speed. This highlights the significance of accounting for gait speed when examining gait patterns associated with low BMD or ageing. Knee power absorption in terminal swing (labelled K4) is involved with eccentric activation of the knee flexors. It is evident that BMD is influenced by the level of local strain on the bone [33] which is determined by the muscle forces and joint reaction forces experienced during physical activity. A previous study reported significant improvements in mid-femur BMD after 18 weeks of eccentric training in young women [34]. Further research is warranted to evaluate the optimal dose response of eccentric training for older women, including those with osteopenia or osteoporosis, before specific recommendations can be made. However, the findings from this study suggest that physical activities for older women with low BMD could include downhill walking, which requires eccentric muscle activation and generates musculoskeletal loading patterns that could attenuate further bone loss.

Some limitations of the current research should be noted. Firstly, our participants were on the younger side of the older adult spectrum with the mean age of 67.3 years and it is possible the joint kinematic and kinetic patterns of women older than 75 years and with low BMD may have been markedly altered. Furthermore, our participants were functioning at a high level, as evidenced by their walking speed and self-reported physical activity levels. We may have found different gait patterns with a more sedentary group of women. In future, asking participants to walk at comfortable and fast walking speeds may help understand more of the explained variance in gait parameters related to walking speed. The participants only self-reported their physical activity levels using a bespoke pre-exercise questionnaire and did not self-report intensity or duration of the exercise. Future research should gather more detailed information on physical fitness and use activity monitors to quantify daily activity levels objectively.

Conclusions

The results from this study suggest that older women across a wide range of T-scores can demonstrate level gait patterns similar to younger adults when walking at comfortable, but overall fast, self-selected speeds. Consistent with our hypothesis, speed was the most important predictor variable, not T-score and/or age. Our findings suggest walking speed should be taken into consideration when analysing the effects of BMD on gait parameters. Our findings also suggest the hip abductor, knee extensor and flexor muscle groups should be targeted, especially via eccentric strength training, and that these recommendations should be evaluated through intervention studies.

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Figure 1. Mean (±1SD; dashed lines) sagittal lower limb joint powers during level gait. Positive values indicate power generation, negative values indicate power absorption. Power bursts are labelled (H1-H3, K1-K4, A1-A2) according to Eng and Winter (1995).

Table 5. Participant (n=45) characteristics.

	Mean	SD	Range
Age (years)	67.3	1.4	65 to 70
Height (cm)	161.4	4.9	151 to 172.5
Mass (kg)	63.5	8.6	47.8 to 80.4
BMI (kg/m^2)	24.1	2.8	18.6 to 29.2
Femoral neck T-score	-1.5	0.8	0.9 to -3
Number of days physically active[a] (days per week)	5.0	2.3	0 to 7
Commencement of menopause (age in years)	50.0	4.5	38 to 58
Number of falls (last 12 months)	0.3	0.6	0 to 3
Number of fractures (>50 years old)	0.5	0.9	0 to 4

[a] Activities included walking, Zumba, badminton, golf and general gym exercises.

Table 2: Mean (SD) value, explained variance (R^2) and slope coefficient for temporal-spatial and joint kinematics during level walking.

Gait parameter	Mean (SD)	Predictor variable	R^2 %	Predictor variable	Slope coefficient (B)	95% Confidence interval (CI)	
Temporal-spatial parameters							
Stride width (m)	0.10 (0.02)	GS	12	GS	0.039**	0.006	0.072
		GS & TS	35	TS	0.013***	-0.01	0.021
		GS & TS & A	36	A	-0.002	0.007	0.016
Cycle time (s)	1.02 (0.08)	GS	53	GS	0.296***	-0.38	-0.21
		GS & TS	54	TS	0.001	-0.02	0.03
		GS & TS & A	55	A	-0.009	-0.02	0.007
Stance phase (%)	62 (6)	GS	63	GS	-0.245***	-0.30	-0.18
		GS & TS	64	TS	0.001	-0.02	0.023
		GS & TS & A	64	A	-0.004	-0.01	0.007
Double limb support time (s)	0.21 (0.04)	GS	68	GS	-0.155***	-0.18	-0.12
		GS & TS	74	TS	0.01**	0.003	0.017
		GS & TS & A	74	A	-0.003	-0.01	0.003
Joint kinematics (degrees)							
Hip abduction (initial swing)	-3.1 (2.1)	GS	1	GS	-0.675	-4.0	2.649
		GS & TS	9	TS	-0.726*	-1.50	0.072
		GS & TS & A	9	A	0.055	-0.39	0.501
Hip extension (pre-swing)	-17.5 (5.5)	GS	17	GS	-11.498**	-19.3	-3.6
		GS & TS	17	TS	-0.579	-2.50	1.342
		GS & TS & A	17	A	-0.021	-1.11	1.066
Hip flexion (mid-swing)	31.9 (4.7)	GS	1	GS	2.277	-5.16	9.717
		GS & TS	1	TS	-0.135	-0.19	1.675
		GS & TS & A	1	A	0.309	-0.71	1.335
Hip sagittal RoM[a]	49.6 (4.7)	GS	38	GS	14.88***	9.087	20.68
		GS & TS	39	TS	0.566	-0.83	1.968
		GS & TS & A	40	A	0.261	-0.53	1.055
Knee flexion (loading[b])	19.1 (5.9)	GS	12	GS	10.537**	1.751	19.32
		GS & TS	12	TS	-0.208	-2.30	1.89
		GS & TS & A	16	A	-0.842	-2.03	0.345
Knee flexion (initial swing)	67.1 (3.5)	GS	1	GS	-0.651	-0.61	4.813
		GS & TS	8	TS	1.172*	-0.06	2.496
		GS & TS & A	9	A	0.224	-0.49	0.948
Knee sagittal RoM	67.3 (4.0)	GS	6	GS	5.004	-1.56	9.233
		GS & TS	18	TS	1.64**	0.565	3.123
		GS & TS & A	31	A	1.002**	0.278	1.726
Ankle dorsiflexion (terminal stance)	14.6 (2.9)	GS	15	GS	-5.83**	-10.1	-1.63
		GS & TS	15	TS	-0.091	-1.11	0.934
		GS & TS & A	16	A	-0.153	-0.73	0.427
Ankle plantarflexion (initial swing)	-14.0 (4.1)	GS	1	GS	-2.464	-8.84	3.919
		GS & TS	3	TS	-0.594	-2.14	0.952
		GS & TS & A	3	A	-0.231	-1.10	0.644
Ankle sagittal RoM	28.6 (4.0)	GS	3	GS	-3.59	-9.627	2.882
		GS & TS	4	TS	0.502	-1.019	2.025
		GS & TS & A	4	A	0.077	-0.783	0.939

Explained variance (R^2) in temporal-spatial and joint kinematic (degrees) gait parameters explained by gait speed alone (GS), gait speed with T-Score (GS & TS), and gait speed, T-Score and age combined (GS & TS & A). Slope coefficients (*B*) are presented for gait speed (GS), T-score (TS) and age (A). Significant findings areas were shaded whereby the point estimate of the regression slope (*B*) was significantly different from 0 at the following alpha levels; *$P < 0.05$, ** $P < 0.01$, and *** $P \leq 0.001$.

[a] Range of motion, [b] Loading response.

Table 3: Mean (SD) value, explained variance (R^2) and slope coefficient for ground reaction forces and peak joint moment during level walking.

Gait parameter	Mean (SD)	Predictor variable	R^2 %	Predictor variable	Slope coefficient (B)	95% Confidence interval (CI)	
GRF (N/kg) and Loading & decay rates (N/kg/s)							
Posterior GRF[a] (mid stance)	-0.20 (0.05)	GS	53	GS	-0.174***	-0.225	-0.12
		GS & TS	55	TS	-0.011	-0.028	0.005
		GS & TS & A	57	A	0.044	-0.005	0.014
Anterior GRF (terminal stance)	0.21 (0.04)	GS	49	GS	0.132***	0.091	0.174
		GS & TS	50	TS	0.006	-0.007	0.019
		GS & TS & A	51	A	-0.001	-0.01	0.01
Vertical Fz1[b] GRF (loading[c])	1.09 (0.12)	GS	40	GS	0.393***	0.244	0.541
		GS & TS	42	TS	-0.011	-0.056	0.033
		GS & TS & A	48	A	-0.021*	-0.04	-0.002
Vertical Fz2[d] GRF (mid-stance)	0.68 (0.11)	GS	71	GS	-0.473***	-0.565	-0.381
		GS & TS	72	TS	-0.005	-0.046	0.034
		GS & TS & A	72	A	-0.005	-0.028	0.017
Vertical Fz3[e] GRF (pre-swing)	1.15 (0.07)	GS	12	GS	0.123***	0.022	0.223
		GS & TS	15	TS	-0.01	-0.035	0.014
		GS & TS & A	16	A	-0.001	-0.015	0.012
Loading rate	7.54 (2.12)	GS	59	GS	8.312***	6.159	10.46
		GS & TS	59	TS	0.249	-0.534	1.033
		GS & TS & A	59	A	-0.074	-0.522	0.372
Decay rate	-8.68 (1.48)	GS	68	GS	6.231***	4.911	7.556
		GS & TS	69	TS	-0.011	-0.56	0.536
		GS & TS & A	69	A	0.11	-0.20	0.42
Moments (Nm/kg)							
Hip extensor (loading)	0.87 (0.28)	GS	57	GS	0.926***	0.699	1.225
		GS & TS	57	TS	0.026	-0.065	0.117
		GS & TS & A	57	A	0.007	-0.045	0.06
Hip flexor (terminal stance)	-0.93 (0.30)	GS	21	GS	-0.544***	-0.878	-0.211
		GS & TS	21	TS	-0.007	-0.093	0.079
		GS & TS & A	23	A	-0.031	-0.079	0.017
Knee extensor (loading)	0.41 (0.23)	GS	22	GS	0.552***	0.229	0.875
		GS & TS	22	TS	0.019	-0.064	0.103
		GS & TS & A	24	A	-0.016	-0.064	0.032

Knee flexor (terminal stance)	-0.31 (0.20)	GS	19	GS	-0.419***	-0.686	-0.153
		GS & TS	19	TS	-0.007	-0.077	0.061
		GS & TS & A	20	A	-0.125	-0.052	0.026
Ankle dorsiflexor (loading)	-0.13 (0.08)	GS	22	GS	0.368***	0.157	0.578
		GS & TS	25	TS	-0.021	-0.077	0.034
		GS & TS & A	26	A	-0.004	-0.063	0.027
Ankle plantarflex (pre-swing)	1.43 (0.15)	GS	19	GS	-0.188***	-0.31	-0.066
		GS & TS	19	TS	0.006	-0.022	0. 035
		GS & TS & A	23	A	0.011	-0.004	0.028

Explained variance (R^2) in peak ground reaction forces (N/kg), load and decay rates (N/kg/s) and internal joint moments (Nm/kg), explained by gait speed alone (GS), gait speed with T-Score (GS & TS), and gait speed, T-Score and age combined (GS & TS & A). Slope coefficients (*B*) are presented for gait speed (GS), T-score (TS) and age (A). Significant findings areas were shaded whereby the point estimate of the regression slope (*B*) was significantly different from 0 at the following alpha levels; *P < 0.05, ** P < 0.01, and *** $P \leq 0.001$.

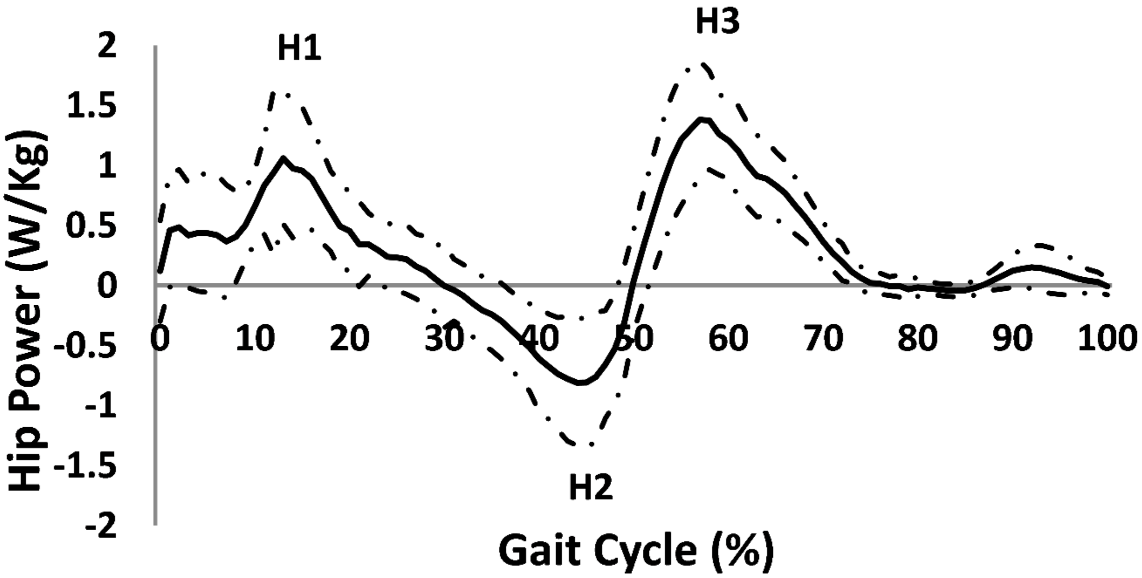
[a] Ground reaction force, [b] The first vertical ground reaction peak, [c] Loading response, [d] The minimum vertical ground reaction force, [e] The second vertical ground reaction peak force.

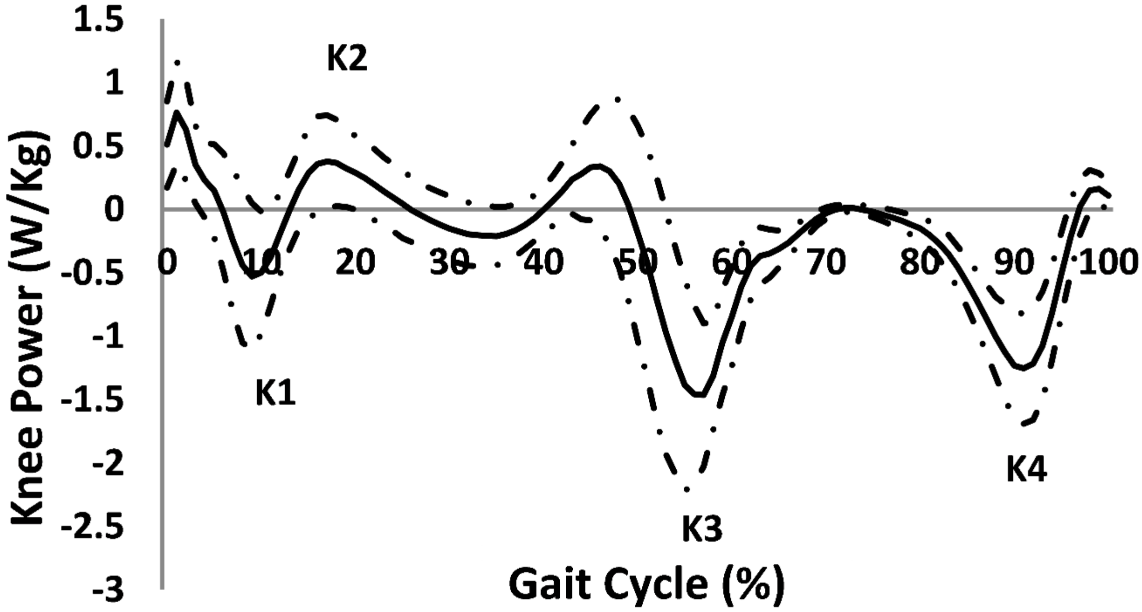
Table 4: Mean (SD) value, explained variance (R^2) and slope coefficient for peak joint powers during level walking.

Peak power parameter[a]	Mean (SD)	Predictor variable	R^2 %	Predictor variable	Slope coefficient (*B*)	95% Confidence interval	
H1	1.24 (0.54)	GS	14	GS	1.059**	0.261	1.858
		GS & TS	18	TS	0.151	-0.041	0.345
		GS & TS & A	19	A	-0.031	-0.145	0.082
H2	-0.94 (0.42)	GS	16	GS	-0.85***	-1.469	-0.23
		GS & TS	16	TS	-0.031	-0.187	0.127
		GS & TS & A	19	A	-0.051	-0.139	0.036
H3	1.57 (0.40)	GS	61	GS	1.622***	1.228	2.015
		GS & TS	62	TS	0.741	-0.073	0.222
		GS & TS & A	62	A	0.022	-0.062	0.107
K1	-0.67 (0.48)	GS	39	GS	-1.549***	-2.145	-0.95
		GS & TS	40	TS	-0.037	-0.214	0.139
		GS & TS & A	42	A	0.029	-0.071	0.137
K2	0.85 (0.43)	GS	43	GS	1.483***	0.961	2.005
		GS & TS	44	TS	0.042	-0.117	0.202
		GS & TS & A	44	A	0.035	-0.056	0.126
K3	-1.75 (0.44)	GS	29	GS	-1.235***	-1.821	-0.64
		GS & TS	30	TS	-0.073	-0.236	0.089
		GS & TS & A	30	A	-0.013	-0.106	0.08
K4	-1.31 (0.43)	GS	52	GS	-1.607***	-2.076	-1.13
		GS & TS	54	TS	-0.113***	-0.262	0.052
		GS & TS &A	68	A	-0.117*	-0.201	-0.03
A1	-0.91 (0.34)	GS	2	GS	-0.298	-0.828	0.23
		GS & TS	4	TS	0.033	-0.93	0.159
		GS & TS & A	10	A	0.053	-0.016	0.123
A2	2.91 (0.72)	GS	42	GS	2.421***	1.563	3.278
		GS & TS	45	TS	-0.051	-0.318	0.216
		GS & TS & A	45	A	-0.011	0.016	0.14

Explained variance (R^2) in joint powers (W/kg) explained by gait speed alone (GS), gait speed with T-Score (GS & TS), and gait speed, T-Score and age combined (GS & TS & A). Slope coefficients (*B*) are presented for gait speed (GS), T-score (TS) and age (A). Significant findings areas were shaded whereby the point estimate of the regression slope (*B*) was significantly different from 0 at the following alpha levels; *P < 0.05, ** P < 0.01, and *** P ≤ 0.001.

[a] H1: hip power generation during the loading response, concentric hip extensor activity; H2: hip power absorption in mid-stance, eccentric hip flexor activity; H3: hip power generation in pre-swing, concentric hip flexor activity; K1: knee power absorption during the loading response, eccentric knee extensor activity; K2: knee power generation in mid-stance, concentric knee extensor activity; K3: knee power absorption in pre-swing, eccentric knee extensor activity; K4 knee absorption in terminal swing, eccentric knee flexor activity; A1: ankle power absorption in mid-stance eccentric plantarflexor activity; A2 ankle power generation, concentric plantarflexor activity. All power bursts are labelled (H1-H3, K1-K4, A1-A2) according to Eng and Winter [22].


H1
H3
H2
Hip Power (W/Kg)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
10
20
30
40
50
60
70
80
90
100
Gait Cycle (%)


K2
K1
K3
K4
Knee Power (W/Kg)
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
0
10
20
30
40
50
60
70
80
90
100
Gait Cycle (%)

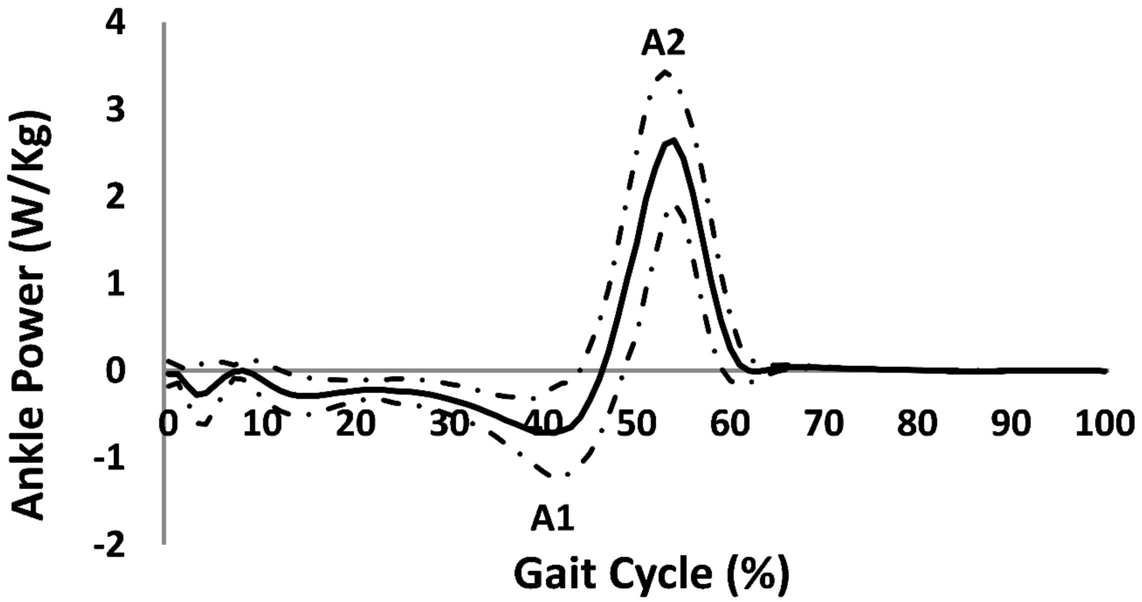

A2
A1
Ankle Power (W/Kg)
4
3
2
1
0
-1
-2
0
10
20
30
40
50
60
70
80
90
100
Gait Cycle (%)

Figure 1. Mean (±1SD; dashed lines) sagittal lower limb joint powers during level gait. Positive values indicate power generation, negative values indicate power absorption. Power bursts are labelled (H1-H3, K1-K4, A1-A2) according to Eng and Winter (1995).