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The role of gender in gait analysis in the elderly

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Abstract

The purpose of this study was to identify gender-related differences in the gait of functionally independent elderly men and women when walking at self-selected walking velocity (SSWV). A quantitative gait analysis was conducted on 59 men (mean age 75.7, SD ±5.8, range 69-91 years) and 127 women (mean age 75.2, SD ± 4.9, range 68-91 years) who could walk independently, regarded themselves to be in good health, and were independent in terms of activities of daily living. The analysis was based on foot placements in the sagittal plane recorded using a video camera. ANOVA gender comparisons revealed significant differences ($p < 0.0013$) in all phases of walking, step length, standing height and knee length, but no significant differences in walking speed. Women were found to take shorter steps at greater frequency than men to attain the same walking velocity. When phase and step length variables were normalized to a percent of each individual's stride time (phase variables) and knee height as a measure of stature (step lengths), there were no significant gender differences. These findings suggest that at SSWV gait differences in older persons are due to stature and not to gender, and that the use of norms which are gender based may be inappropriate. Thus, the gait of elderly men and women walking at SSWV may be analysed together, provided that the step length data are normalized to stature and phase data to stride time.

Research has shown that remaining active and productive is a key component of successful ageing (Clark, Azen, Zemke *et al.*, 1997). To minimize and prevent loss of independence, clinicians who work with older persons should identify levels of risk that can predict future disability and can be modified to reduce that risk or retard deterioration (Buchner & Wagner, 1992). The analysis of gait, particularly at a normal walking speed, is a commonly used measure of lower extremity function, and appears to be sensitive to future changes in functional status. In a study of older community-living persons who were independent in activities of daily living (ADL), Guralnik, Ferrucci, Simonsick *et al.* (1995) found that objective physical performance measures of lower-extremity function were highly predictive of gait impairment four years later, and that the time taken to walk 2.4 metres at a normal pace was associated with the risk of subsequent disability with faster walkers having lower risk. Clark, Lord and Webster (1993) reported that clinical qualitative assessments of abnormal gait, including any stepping abnormality, were predictive of disability.

While a qualitative analysis is effective in identifying gross abnormalities of gait, particularly when used by a trained technician or therapist, a quantitative analysis may be used to augment visual observation and to provide additional information so that more subtle problems may be identified and recorded (Gaudet, Goodman, Landry *et al.*, 1990; Wolfson, Whipple, Amerman *et al.*, 1990; VanSwearingen, Paschal, Bonino *et al.*, 1996). The use of quantitative gait analyses outside of the research laboratory setting has been limited by the need for technical expertise, expense and difficulty of access to necessary equipment. However, the development of new methods and recording devices has made quantitative gait analysis more viable in the clinical setting (Hausdorff, Ladin & Wei, 1995; Macfarlane & Nielsen, 1996; Malinauskas & Krouskop, 1989; Vaughan, Damiano & Abel, 1996).

Definitions of various gait descriptors are shown in Table 1. The quantitative variables used in gait analysis research typically include speed, cadence and stride length. By dividing each stride into short phases, as seen in Figure 1, one is able to provide information which can be used to identify any asymmetry of one leg as compared with the other, and thus the possible physiological cause of the altered gait. For example, if the time spent on the left leg from midstance to lifting the toe off the ground (left late stance phase) is short, then weakness of the left gastrocnemius or limited extension of the left hip might be suspected. Similarly, measures of individual step lengths are useful in determining asymmetry due to pain, imbalance of muscle strength, or limitation of joint flexibility. Loss of balance during walking, including tripping and slipping, has been related to specific phases of gait, such as the swing or double support phases, respectively (Patla, 1997).

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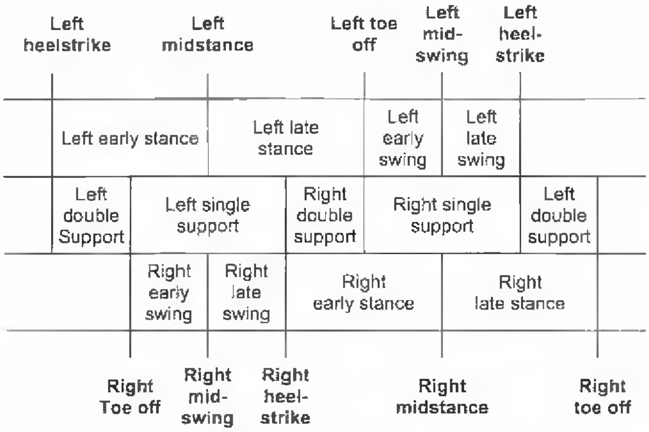
Table 1

Definitions of gait descriptors

Gait descriptor	Definition
Foot placements	
Heelstrike	first instant of foot contact with the ground
Midstance	weighted foot is directly below the swinging foot
Midswing	swinging foot is directly above the weighted foot
Toe off	first instant the foot loses contact with the ground
Phase variables	
Stance phase	duration of foot-ground contact
Swing phase	period during which foot is free of the ground
Single support	period during which only one foot is in contact with the ground
Double support	period during which both feet are in contact with the ground (named relative to the front foot)
Stride time	time between consecutive heelstrikes of the same foot
Cadence	number of strides per minute
Distance variables	
Step length	distance measured from one heel to the contralateral forward heel
Stride length	distance measured from one heel to the next forward placement of the same heel
Speed	
Self-selected walking velocity	stride length x cadence (metres per minute)

Figure 1

Gait phases for a single stride



Norms for the various subcomponents of gait, including walking speed and step length, have been developed for men and women of different ages (Andriacchi, Ogle & Galante, 1977; Blanke & Hageman, 1989; Cunningham, Paterson, Himann *et al.*, 1993; Dobbs, Charlett, Bowes *et al.*, 1993; Hageman & Blanke, 1986; Himann, Cunningham, Rechnitzer *et al.*, 1988; Murray, 1967; Murray, Kory & Clarkson, 1969; Nigg, Fisher & Ronsky, 1994; Nigg & Skleryk, 1988; O'Brien, Power, Sanford *et al.*, 1983). Walking is usually assessed at the customary walking pace of the subject, or self-selected walking velocity (SSWV). This measure is used to allow subjects to walk as "normally" as possible and negates the need for equipment to pace the subject. It has been shown to be a reliable measure and is sensitive to changes in walking ability (Guralnik *et al.*, 1995; Hausdorff *et al.*, 1996). The choice of walking speed of elderly men and women who live independently has been shown to differ significantly from that of institutionalized elderly persons (Cunningham *et al.*, 1993) and has been inversely linked to the incidence of falls (Campbell, Borrie & Spears, 1989; Tinetti & Ginter, 1988; Van Swearingen *et al.*, 1996; Wolfson *et al.*, 1990). Walking speed is used in various batteries of functional testing (Guralnik *et al.*, 1995; MacRae, Feltner & Reinsch, 1994), decreases with age (Dobbs *et al.*, 1993; Andriacci *et al.*, 1977), and may be increased following a strengthening programme (Judge, Underwood & Gennosa, 1993). The use of SSWV allows the inclusion of subjects with a wide range of walking velocities, so that even those who walk very slowly or those who use an assistive device may be included in an analysis of gait.

It is difficult to compare individuals whose walking speeds differ. During normal walking at SSWV, tall subjects may take fewer, longer steps to walk at the same speed as do shorter subjects who require more steps but have shorter step length. Himann *et al.* (1988) found that, while walking speed in individuals younger than 62 years correlated only with height, both height and age were important in those older than 62 years. In addition, Imms and Edholm (1981) found that step length in elderly men and women (mean age 78 ±7 years) correlated with walking velocity (r=0.929).

If linear gait variables (step length) are to be compared between short and tall subjects, step length measures must be adjusted (or normalized) to correspond with the individual's stature. However, standing height, the most commonly used measure of stature, may be compromised in an elderly population as a result of degenerative processes causing vertebral compression with loss of vertical height. As a result, a leg length measure would be a more reliable indicator of stature. Knee height is easy to determine accurately, and may be measured while the subject is seated with the knee at 90° of flexion and the foot flat on the ground (Kembla & Guo, 1992). It has been shown to be highly predictive of stature in both black (Prothro & Rosenbloom, 1993) and white males and females (Kembla & Guo, 1992). Similarly, in order to allow comparison between the timed subcomponents of gait, where subjects select varying walking speeds, the phases should be normalized to an individual's stride time.

The purpose of this study was to examine the influence of gender on the gait of independent elderly men and women walking at SSWV. The data reported in this study form part of the baseline data collected in a longitudinal study designed to examine changes in the mobility status of healthy independent elderly.

Subjects and methods

The subjects were volunteers who live independently in a retirement community in KwaZulu-Natal, who regarded themselves as being in good health and able to perform activities of daily living without assistance. To be eligible for inclusion in the study, they were required to be 68 years or older, to be able to stand up from a chair without using their arms, to walk independently without the use of an aid other than a walking stick, and to climb five stairs without assistance. Those subjects who had medical conditions which were likely to be adversely affected by their participation, or which made completion of the tests unlikely, were excluded from the study.

The purpose of the study was explained to the participants and written consent was obtained from each participant. Each subject underwent a three-hour assessment by researchers who were specially trained for this purpose. The assessment included the administration of questionnaires to gather baseline demographic data and data on health status, mood and cognitive status, and physical activity. A medical examination was performed, as well as physiological and anthropometric testing, and various physical performance measures, including gait analysis.

Approval for the study was obtained from the Ethics and Research Committees of the universities involved, as well as from the board of the retirement village where the study was conducted. Confidentiality was ensured, and the participants' medical practitioners were notified of any abnormal finding.

Gait recording

The gait recording was made in a large indoor facility which had plain brown, indoor carpeting with minimal pile. A walkway was marked off by placing two brightly coloured chairs 16 metres apart. The subjects were asked to walk the distance of the walkway in a normal fashion at their regular walking speed and without speaking. All wore comfortable shoes, had their hands free and walked independently. The researcher stood where he could ensure that the subjects did not deviate from the walkway.

A video camera (Panasonic AG-190-P) was mounted on a tripod and set back 10 metres from and perpendicular to the middle 8-metre section of the walkway, where it was expected that the subjects would be walking at a steady pace with minimal changes in speed. To minimize any distraction which might have been caused by the presence of the camera, it was placed out of view of the subjects and ran continuously as they walked. Prior to each recording, a 1,6 metre long linear measure was positioned in the plane of walking, videotaped and then removed.

Each subject walked the distance at least four times, with extra recordings being made if the subject appeared to be self-conscious, took any unusual steps, or left the assigned plane of walking. Most repeat recordings were made because the subject did not swing the arms freely throughout the trial, spoke to the researcher, or deviated laterally from the pathway whilst walking.

Measures of stature

The height of the right knee was measured whilst the subject was seated bare-footed on a dining-room chair with the tibia perpendicular and the foot flat on the ground. A metal vernier calliper was placed lateral and parallel to the lower leg so that its base was on the floor with the arm on the proximal border of the patella. The distance from the floor to the calliper arm was recorded to the closest millimetre. The patella was selected as a landmark in preference to the upper border of the condyles of the femur, the measure used by Kembla and Guo (1992). The proximal patellar border was palpable in all subjects, whereas measurements at the femoral condyles was subject to error in subjects who were oedematous or had large fat deposits at the knee.

Data reduction

Data were obtained from the videotape using the method described by Macfarlane and Nielsen (1996). To perform the analyses, the video image was projected (Sharp LCD Projector XG-1100U) perpendicularly onto a white wall in such a way that the image size was enlarged to a width of 1,2 metres. This large image size served to minimize measurement error. The video recorder (Panasonic AG 1730) included a jog shuttle control which allowed for slow motion and image-by-image viewing (60 images recorded per second). The recording of the third acceptable walking trial was the one selected for analysis, unless changes in the walking speed were seen during review of the videotape, in which case the next good trial was used. If, after initial analysis, the walking cadence was noted to have varied (standard deviation of any of the mean phase variables >3 sec^{-100}), another trial was selected. In this way, only trials with constant walking speeds were used for analysis.

Phase data

To calculate the phase data, a time code was inserted onto each field of recorded video using a time code generator (Comprehensive TCG-1000 Reader/Inserter). The time codes for each heelstrike, midstance and toe off for at least three strides (six steps) of the trial regarded as acceptable for analysis were then recorded. These measures were entered into a computer programme written specifically for this method of gait analysis. The phase variable data were derived from all strides analysed and were saved to a data base for statistical analysis. Mean cadence (strides/min) and stride time were also calculated. All phase variables were normalized to stride time and then expressed as a percentage (mean phase value/stride time x 100) to allow comparison of subjects walking at different speeds.

Distance data

The distance data consisted of the mean left and right step lengths and the walking velocity (SSWV) based on all steps analysed (at least three with each foot). The length of the linear scale was measured off the video image and entered into the programme, which adjusted all linear measurements taken from the video to metric units. Consecutive foot placements were recorded and entered for each subject as he or she walked across the screen.

Mean step lengths (cm) were calculated for each foot. The walking speed (m/min) was calculated using the mean stride and the cadence, and step length data were normalized as a percentage of knee height (step length/knee height x 100). This allowed step length comparisons between subjects of different stature.

Data analysis

Descriptive data for each variable were calculated separately for men and women, and for the right foot and the left foot independently. Inter-gender comparisons were made using analysis of variance (ANOVA) with a p-value of 0.0013 set as the level of significance. The p-value was calculated using a Bonferroni adjustment to an alpha level of 0.05 to protect against a type I error when making multiple comparisons (0.05 / 38 which is the number of variables) (Huberty & Morris, 1989). All data were reported as means and SD.

Results

There were 186 subjects, 59 men (mean age 75.7 (SD=5.8), range 68-91 years) and 127 women (mean age 75.2 (SD=4.9), range 68-91 years), all of whom completed the walking task without difficulty. A walking stick was used as an assistive device by two subjects, both of whom could walk without the stick but preferred to use it.

Table 2 is a summary of the ANOVA results for the basic phase and distance variables. A significant gender difference was found for each of the phase and distance variables but not for walking speed. Step length and the duration of each of the phases was shorter for females than for males. However, while females had a shorter stride time, they had a higher cadence than the males. Thus, in order to attain the same

Table 2

Basic phase and distance variables

Variable		Males (n=59)		Females (n=127)		
		Mean	SD	Mean	SD	p
Phase variables						
Stance (sec^{-100})	R	76.1	7.9	69.4	6.9	<0.001*
	L	76.3	7.9	69.8	7.1	<0.001*
Early stance (sec^{-100})	R	35.8	3.9	32.9	3.5	<0.001*
	L	36.6	4.0	33.6	3.9	<0.001*
Late stance (sec^{-100})	R	40.3	4.2	36.5	3.8	<0.001*
	L	39.7	4.3	36.2	3.6	<0.001*
Swing (sec^{-100})	R	37.5	2.8	34.6	2.0	<0.001*
	L	37.9	2.9	34.8	2.0	<0.001*
Early swing (sec^{-100})	R	17.1	1.8	15.9	1.4	<0.001*
	L	17.1	1.5	15.9	1.4	<0.001*
Late swing (sec^{-100})	R	20.4	1.5	18.7	1.4	<0.001*
	L	20.8	1.9	18.9	1.5	<0.001*
Double support (sec^{-100})	R	18.7	3.5	17.0	3.2	<0.001*
	L	19.5	3.1	17.7	3.4	<0.001*
Single support^{a} (sec^{-100})	R	37.9	2.9	34.8	2.0	
	L	37.5	2.8	34.6	2.0	
Stride time (sec^{-100})		113.6	9.9	103.9	8.0	<0.001*
Cadece^{b} (Strides/min)		53.2	4.6	58.1	4.3	
Distance variables						
Height (cm)		173.5	10.1	158.2	9.3	<0.001*
Knee height (cm)		54.3	2.5	49.6	2.6	<0.001*
Step length (cm)	R	70.3	7.0	63.5	7.5	<0.001*
	L	71.4	6.9	64.1	7.3	<0.001*
Speed						
m/min		75.8	9.3	74.2	11.6	0.3603

*	Significant gender differences (p<0.0013).
a	Single support phase = contralateral swing phase.
b	Cadence derived directly from stride time.

walking velocity as men, women took shorter steps but these were more frequent.

Table 3 shows the results of the ANOVA comparisons when the data were normalized to a percent of stride time (phase variables) and to a percent of knee height (distance variables). No significant differences due to gender were found for any of the normalized variables.

Discussion

The primary goal of this quantitative analysis of the gait of elderly men and women was to study gender comparisons with subjects walking at SSWV. ANOVA analysis revealed that the walking pattern of women was significantly different from that of men in that the women tended to take shorter but more frequent steps in order to walk at the same speed as the men did. The men were significantly taller than the women and had significantly longer knee height measures.

Contrary to expectations, there were no gender differences observed when the data were normalized for stature. For both men and women, most of the variance in stature is accounted for by differences in knee height. The differences in step length noted between men and women disappeared once step lengths had been normalized using knee height as a measure of stature, suggesting that the step length differences noted initially are a consequence of height and not of gender.

In this study, significant differences were noted in all of the phase (timing) variables and these appeared to be related to gender. However, the differences were no longer evident once the data had been normalized, in keeping with the fact that, in general, men are taller than women and need fewer, longer strides to walk at the same SSWV.

In conclusion, gait data for men and women have traditionally been reported separately. However, this study suggests that the use of gender-based norms may be inappropriate, and that stature rather than gender is the important variable. Thus, in a sagittal plane gait analysis, elderly men and women may be grouped together, provided that the step length is normalized to stature and the phase data to stride time. This finding is of particular value in gait studies involving older populations, especially in the very old group where women outnumber men and where it may be difficult to collect data on a sufficiently large number of male subjects.

Further research is required to determine whether these results are generalizable to all elderly persons, including those who live in institutions, and whether they hold true for younger subjects as well. It would also be important to know whether the findings would be valid if the walking speed was prescribed rather than self-selected.

Table 3

Normalized gait variables (mean units (± SD))

Variable		Males (n=59)		Females (n=127)		
		Mean	SD	Mean	SD	p
Phase variables						
Stance (% stride)	R	66.9	1.7	66.7	2.0	0.4077
	L	67.1	1.8	67.0	2.3	0.9473
Early stance (% stride)	R	31.5	1.3	31.6	1.4	0.8068
	L	32.2	1.3	32.2	1.9	0.8590
Late stance (% stride)	R	35.4	1.1	35.1	1.5	0.1762
	L	34.5	1.4	34.8	1.5	0.7539
Swing (% stride)	R	33.1	1.7	33.3	2.0	0.4077
	L	33.4	1.8	33.6	2.2	0.7305
Early swing (% stride)	R	15.1	1.3	15.3	1.3	0.2424
	L	15.1	1.2	15.3	1.5	0.3230
Late swing (% stride)	R	18.0	1.0	18.0	1.4	0.9669
	L	18.3	1.1	18.2	1.4	0.6039
Double support (% stride)	R	16.4	1.9	16.2	2.0	0.5919
	L	17.1	1.6	16.9	2.2	0.5504
Single support (% stride)	R	33.4	1.8	33.5	2.2	0.7305
	L	33.1	1.7	33.4	2.0	0.4077
Distance variables						
Step length (cm)	R	129.7	13.4	127.9	14.2	0.4158
	L	131.6	12.4	129.3	14.1	0.2789

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cose levels were maintained during the heat of the KwaZulu-Natal summer.

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