

Katarzyna Kaczmarczyk¹
Ida Wiszomirska²
Michalina Błażkiewicz³
Michał Wychowański³
Andrzej Wit³

FIRST SIGNS OF ELDERLY GAIT FOR WOMEN

Józef Piłsudski University of Physical Education, Warszawa, Poland
Faculty of Rehabilitation

¹ Department of Physiology

² Department of Anatomy and Kinesiology

³ Department of Biomechanics

ABSTRACT

Background: The aims of this study have been 2-fold: to attempt to reduce the number of spatiotemporal parameters used for describing gait through the factor analysis and component analysis; and to explore the critical age of decline for other gait parameters for healthy women. **Material and Methods:** A total of 106 women (aged ≥ 40 years old ($N = 76$) and ≤ 31 years old ($N = 30$)) were evaluated using a pressure-sensitive mat (Zebris Medical System, Tübingen, Germany) for collecting spatiotemporal gait parameters. **Results:** The factor analysis identified 2 factors – labelled Time and Rhythm – that accounted for 72% of the variation in significant free-gait parameters; the principal component analysis identified 4 of these parameters that permit full clinical evaluation of gait quality. No difference was found between the groups in terms of the values of parameters reflecting the temporal nature of gait (Rhythm), namely step time, stride time and cadence, whereas significant differences were found for total double support phase ($p < 0.001$). Next, seeking evidence of a critical decline in gait, we selected 3 parameters: total double support, stride time and velocity. We concluded that the women taking part in the experiment manifested significant signs of senile gait after the age of 60 years old, with the first symptoms thereof already manifesting themselves after 50 years of age. **Conclusions:** We show that among 26 spatiotemporal parameters that may be used for characterizing gait, at least a half of them may be omitted in the assessment of gait correctness; a finding that may be useful in clinical practice. The finding that the onset of senile gait occurs in the case of women after the age of 60 years old, in turn, may be useful in evaluating the ability for performing types of physical work that mainly require ambulation. Med Pr 2017;68(4):441–448

Key words: ageing, gait analysis, factor analysis, spatiotemporal parameters, elderly women, normative data

Corresponding author: Katarzyna Kaczmarczyk, Józef Piłsudski University of Physical Education, Faculty of Rehabilitation, Department of Physiology, Marymoncka 34, 00-968 Warszawa, Poland, e-mail: Katarzyna.Kaczmarczyk@gmail.com
Received: May 11, 2016, accepted: January 23, 2017

INTRODUCTION

Locomotion is frequently impaired by a variety of musculoskeletal and neurological disorders [1]. The clinical gait analysis based on normative data is essential for comparison in assessing and properly interpreting gait dysfunction, making clinical decisions, planning treatment, and monitoring the effectiveness of physiotherapy. Also, may it be important in evaluating the potential ability to perform certain professions that require frequent ambulation (which is of growing significance given the debate over the appropriate retirement age, now playing out in highly developed countries). However, normative data obtained from healthy elder volunteers is scarce or altogether lacking in the literature. Moreover, most papers deal with population-based studies (including participants who may have pathological

conditions affecting their gait performance), which typically report lower values than normative studies. In studies that do provide normative values for gait parameters, the magnitudes of values for the gait parameters are quite variable and mainly concern spatiotemporal parameters [1–6].

Given the large number (> 20) of gait-describing parameters that are measurable using standard equipment and software, some authors have attempted to use the factor analysis to reduce the relevant number of factors clinicians' need to measure to glean better understanding of an individual's gait. Verghese et al. [7], based on a selection of gait parameters, have identified 3 domains which characterize gait performance in older adults (pace, rhythm, and variability) and which are associated with different types of mental impairment whereas Hollman et al. [6] have collected normative values for a larger

number (23) of spatiotemporal gait parameters and have used the factor analysis for identifying 5 domains of gait performance in older, able-bodied adults (rhythm, phase, variability, pace, and base of support). We have largely adopted their methodology, but have conducted our own factor analysis to readdress the issue of the appropriate number of such factors and their composition.

Differences in gait variability between young and older walkers have been previously demonstrated [8–12]. The typical effects of aging on the basic gait parameters include shorter stride length, shorter step length and cadence, higher stance time and double support time in the elderly [3–4,13]. Ageing is also associated with decreased foot clearance, which is adopted by older adults to compensate for balance impairment; this corresponds to the small decrease in vertical displacement found in the older population [13]. Among all these parameters, the greatest interest has been attracted by gait velocity and its relationship to age [1,13–15]. Bohannon [14] describes a negative relationship of velocity with age ($r = -0.21$). Himann et al. [15] in turn, have reported a critical age of decline for gait velocity – 62 years old. There are no studies in the literature about a critical age of decline for other kinematic parameters.

The objectives of this study have therefore been 2-fold:

- to attempt to reduce the number of spatiotemporal parameters used for describing gait through the factor analysis and component analysis,
- to explore the critical age of decline for other gait parameters for healthy women.

MATERIAL AND METHODS

Participants

A total of 106 subjects (characterized in the Table 1) participated in the study, with 76 elder women in the

experimental group 1, divided into 3 subgroups, dependently on age: 40–49 years old ($N = 25$), 50–59 years old ($N = 25$) and 60–69 years old ($N = 26$) and 30 younger women in the control group 2. Group 2 was included for contrast; the results of group 1 were normalized against the results of group 2. The groups differed significantly in terms of age, with the women of group 1 nearly twice as old as the women of group 2. All subjects were capable of walking independently using no aids, with no other disorders of an orthopedic, rheumatologic, etc., nature that might affect their gait kinematics. The adults in group 1 were participants of the University of the Third Age at the University of Physical Education in Warsaw, Poland. All subjects were informed about the purpose of the study. The adults in group 2, in turn, were students of the Józef Piłsudski University of Physical Education in Warsaw, Poland (attending the Faculty of Rehabilitation, not involved in intensive sports training), who provided a written informed consent. An approval was obtained from the Institute's Research Ethics Commission.

Instrumentation

Gait performance was measured on an electronic walkway (Zebris Medical System, Tübingen, Germany), 304 cm long and 56 cm wide. Data was sampled at 120 Hz and stored in a personal computer which calculated spatiotemporal parameters and foot pressure distribution parameters using application software. The device had been shown to have excellent reproducibility and accuracy [16].

Procedures

All data collection was conducted at the Motion Analysis Laboratory at the Józef Piłsudski University of Physical Education in Warsaw, Poland. After 2 prac-

Table 1. Selected parameters characterizing the studied women aged ≥ 40 years old (group 1) and ≤ 31 years old (group 2)

Group and parameter	Height [cm]	Body mass [kg]	Age [years]	Body mass index [kg/m ²]
Group 1 – experimental ($N = 76$)				
Me	164	67.5	55	24.5
Q25–Q75	160–167	60.0–75.0	49–59	22.6–28.2
min.–max	152–189	50.0–94.0	40–69	20.0–34.4
Group 2 – control ($N = 30$)				
Me	168	61.2	26	21.6
Q25–Q75	160–168	52.0–78.0	24–28	19.9–24.1
min.–max	155–182	48.0–86.0	21–31	18.0–31.0

Me – median, Q25–Q75 – quartiles, min. – minimal value, max – maximal value.

tice trials, the individuals performed 3 trials of walking at their normal velocity. Twenty-six spatiotemporal parameters were collected over a 30-s capture period, equating to an average of 52 ± 5 steps of steady-state walking. These parameters were step length, left (both in cm and as % of leg length); step length, right (both in cm and as % of leg length); foot rotation, left (in degrees); foot rotation, right (in degrees); stride length (both in cm and as % of leg length); step width (in cm), step time, left (in s); step time, right (in s); stance phase, left (% of gait cycle (GC)); stance phase, right (% GC); load response, left (% GC); load response, right (% GC); single support, left (% GC); single support, right (% GC); pre-swing, left (% GC); pre-swing, right (% GC); swing phase, left (% GC); swing phase, right (% GC); total double support (% GC); stride time (in s); cadence (in strides/s); velocity (in km/h). The patients performed the walking trials barefoot and unaided, starting and finishing walking 2 m before and after the mat to minimize acceleration and deceleration effects.

Data analysis

Normalization

Normalization was carried out to rule out the potential impact of an accompanying variable (limb length) on our analysis of the basic association between gait parameters and the age of the participants. The temporal parameters (step time, stride time) were normalized by the method of Hof [17] using the formula:

$$t = t/(l/g)^{0.5} \quad (1)$$

where:

t – step time/stride time,

l – leg length (from greater trochanter to floor),

g – acceleration of gravity.

The velocity (v) was calculated by the formula:

$$v = v/(gl)^{0.5} \quad (2)$$

The cadence (f) was calculated by the formula:

$$f = f(g/l)^{0.5} \quad (3)$$

Step length was normalized as a percentage of lower limb length (step length, % of leg length). The other parameters were normalized as a percentage of the gait cycle (% GC).

Statistical methods

The results obtained were analyzed using the Statistica software v. 12, in the following sequence: first, the Shapiro-Wilk test was used for verifying the similarity of the empirical distributions to the theoretical distribution. The nonparametric Kruskal-Wallis test was used for analyzing the intergroup variance in terms of the parameters characterizing the participants. The procedure of reducing the biomechanical parameters that describe free gait in both groups was carried out in several stages. At first, elimination was performed using the factor analysis. The decision when to stop extracting factors was guided by eigenvalues which reflected the degree of variance in the data described by a given factor. Generally, the factor with the largest eigenvalue accounts for the most variance, and so on, down to factors with small or negative eigenvalues. Eigenvalues are therefore used in the factor analysis for condensing the variance in a correlation matrix, and only variables with eigenvalues of 1 or higher are traditionally considered to be worth analyzing, others usually being omitted on the grounds that they contribute little to the explanation of variances in the data.

The factor analysis enabled the parameters to be ascribed to a specific factor but did not lead to a reduction in the number of parameters for further analysis. Therefore, in the second stage of calculation we performed a principal components analysis. Through the repeated rotation of parameter, we eliminated those which mutually duplicated information describing free gait. In the third stage, the Mann-Whitney U test was used for analyzing the differences in the normalized gait parameters that were ultimately selected, between the experimental group and control group.

RESULTS

The distributions of the 3 main parameters characterizing the groups of women studied were found not to be approximate to normal distribution, and so the nonparametric Kruskal-Wallis test was used for analyzing the intergroup variance. Aside from age ($p < 0.001$), the women in group 1 differed from those in group 2, and were found to differ from those in group 2 in terms of height ($p < 0.05$), being 5 cm shorter on average. Height significantly contributed to differences in body mass index (BMI) ($p < 0.05$), as no differences in body mass were found ($p < 0.001$).

The procedure of reducing the number of parameters used for describing gait mechanics was carried

out in several stages. In the first stage of the analysis of the experimental data, we used the factor analysis (Table 2) to extract 2 gait-characterizing factors from the remaining 10 parameters of free gait in the experimental group as a whole (all 3 subgroups). The first factor loaded highly on temporal divisions of the gait cycle quantifying stance, single support, pre-swing, swing and double support phase; we labelled this a Time Factor. The second factor, identified as a Rhythm Factor, loaded highly on temporal parameters comprising step time, stride time and cadence. Overall, the gait parameters incorporated into the 2 factors accounted for 72% of the variation in significant free-gait param-

eters. Notably, the 2 factors have similar statistical weight.

In the second stage, we used the principal component analysis for reducing the number of parameters used for evaluating the quality of free gait. Using the results of the factor analysis described above, the parameters were divided into 3 groups (roots). Through successive approximations, 4 parameters were selected, with a representative quality of 98.8% of total variance. These parameters bear the greatest load in the factor analysis. This is confirmed by the value of the vectors representing the individual parameters – the directions of the vectors are significantly separate from one another, indicating that they contain little similar information about gait quality. The values of the above 4 free-gait parameters were used for comparing the differences between the 2 groups (Table 3).

Finally, using the Mann-Whitney U test to normalized data, no difference was found between the groups in terms of the values of parameters reflecting the temporal nature of gait (Rhythm), namely step time, stride time and cadence. Significant differences were found, however, for total double support ($p < 0.001$). Given the evidence of such age-related differences, we next considered the interesting question when the onset of senile gait occurred in the case of women. Seeking evidence of a critical decade in this regard, we selected the parameters of total double support and stride time (which the other parameters were derivatives of). This makes sense both in the functional (kinesiological) aspect and in the statistical aspect, resulting from the factor analysis performed. The parameter that ultimately describes the objective of the motor task, in turn, is the

Table 2. Loadings of free gait parameters of the studied women on factors extracted from factor analysis

Gait parameter	Factor	
	time	rhythm
Step length (% of leg length)	0.586185	0.062980
Step time (normalized)	-0.164591	0.952568*
Stance phase (% GC)	-0.911204*	0.119888
Single support (% GC)	0.705842*	-0.191933
Pre-swing (% GC)	-0.881926*	0.162943
Swing phase (% GC)	0.911204*	-0.119888
Total double support (% GC)	-0.948036*	0.181025
Stride time (normalized)	-0.181573	0.974280*
Cadence (normalized)	0.177611	-0.972009*
Velocity (normalized)	0.454815	0.329306

GC – gait cycle.

* Correlation coefficients are interpreted as significant contributors to the given factor.

Table 3. Selected parameters of free gait of the studied women aged ≥ 40 years old (group 1) and ≤ 31 years old (group 2)

Group and parameter	Gait parameter							
	not normalized				normalized			
	step time [s]	total double support [s]	stride time [s]	cadence [strides/s]	step time	total double support [% GC]	stride time	cadence
Group 1 – experimental (N = 76)								
M±SD	0.51±0.04	0.26±0.04	1.01±0.07	1.00±0.07	0.19±0.01	25.89±3.30*	3.67±0.25	3.62±0.29
min.–max	0.43–0.62	0.18–0.38	0.87–1.20	0.83–1.15	0.16–0.22	17.74–28.35	3.13–4.30	2.88–4.30
Group 2 – control (N = 30)								
M±SD	0.52±0.03	0.24±0.03	1.03±0.06	0.98±0.06	0.19±0.01	23.88±2.38	3.68±0.27	3.50±0.23
min.–max	0.46–0.58	0.20–0.33	0.93–1.15	0.87–1.08	0.16–0.21	19.67–28.98	3.25–4.29	2.87–3.77

M – mean, SD – standard deviation.

Other abbreviations as in Table 1 and 2.

* $p < 0.001$.

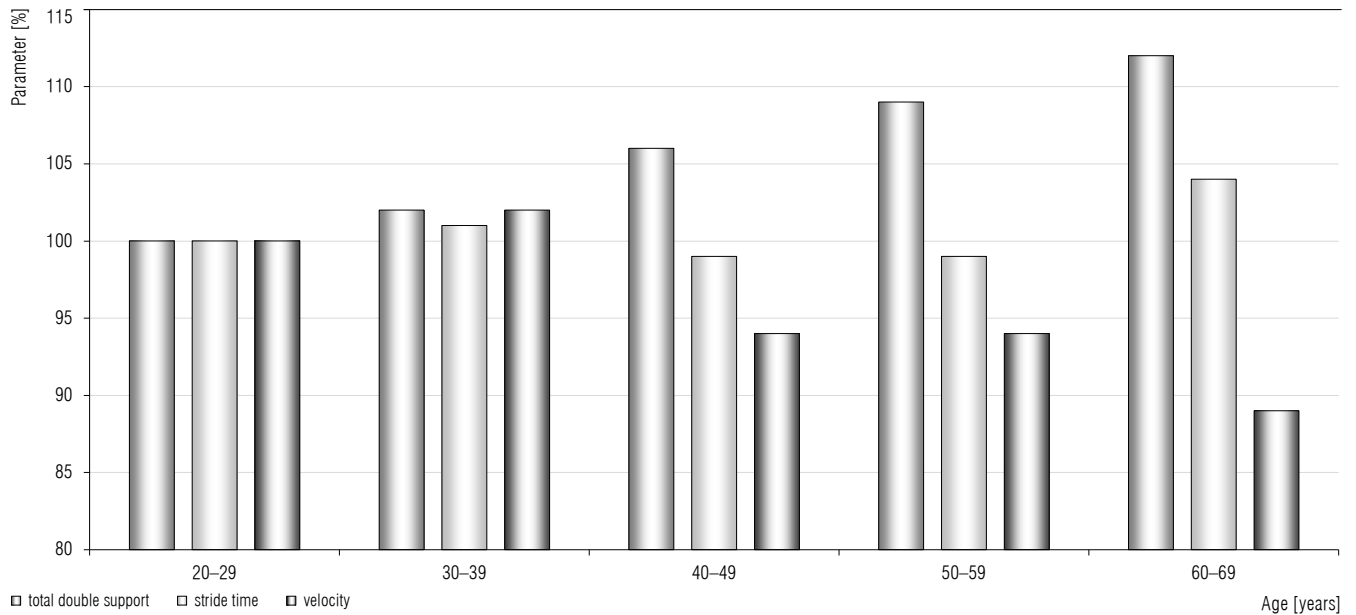


Fig. 1. Correlation between selected normalized parameters of free gait and age of the studied women

velocity of movement. Hence, these 3 parameters were plotted together (Figure 1).

If we adopt the threshold of a 10% decrease in a given parameter as being indicative of a significant change, we conclude on the basis of these 3 parameters that the women taking part in the experiment manifested significant signs of senile gait after the age of 60 years old, with the first symptoms thereof already manifesting themselves after 50 years of age.

DISCUSSION

Gait velocity has been recommended as a “vital sign” for physical performance [18,19] in elder individuals. However, interpreting decreased gait velocity might be confounded by the overall impact of age: some decline in gait performance is inevitable for older persons even for those in good health, thus it is sometimes difficult to separate the general effects of ageing from the particular effects of any disorder.

Our first finding, intended as a response to the fact that a large number of gait parameters may complicate the analysis for clinicians, lies in using the factor analysis for reducing the number of relevant parameters. We extracted 2 factors that accounted for 72% of the variance in gait performance, which we termed Time and Rhythm. Our analysis generally proceeded along the same lines as those described by previous studies along these lines, i.e., Vergheze et al. [7] and Hollman et al. [6], although our results do differ some-

what from theirs. Unlike Hollman et al. [6], who extracted 5 factors from 23 gait parameters, our analysis led us to revert to a 2-factor analysis, somewhat akin to the 3-factor analysis previously proposed by Vergheze et al. [7] based on a smaller number of parameters.

More specifically, Vergheze et al. [7] identified a Rhythm Factor characterized by cadence and swing time whereas we, in line with Hollman et al. [6], included 2 other parameters in our Rhythm Factor, namely step time and stride time. We found this factor to have accounted for 28% of the variance in gait performance. Mean step time (0.51 ± 0.04 s) is consistent with other studies reporting reference values for older adults [6,20]. Quantifying normative values for parameters representing the rhythm factor are important because gait dysfunction in these parameters may be used as predictors of preclinical stages of dementia and memory decline [7].

Authors [6–7] have identified another domain, called a Variability Factor, which was loaded heavily on gait variability measurements. Our results indicate that parameters characterizing the temporophasic divisions of gait have high informative value (28% of the variance in gait performance). The second factor we identified was a Time Factor. It was characterized by the stance phase (% GC), pre-swing phase (% GC), swing phase (% GC) and total double support (% GC). In our study, the stance phase represented 62.65 ± 1.95 and the swing phase represented 37.35 ± 1.95 of the gait cycle; this was consistent with the values reported by Holl-

man et al. [6]. Overall, therefore, our results based on the factor analysis of 26 parameters suggest that the number of clinically relevant factors may be usefully reduced to 2.

The second finding of this study is that a critical age of decline for 3 gait parameters (stride time, total double support and gait velocity) for women appears in the seventh decade of their life, when it is likely to produce functional deficits but that the first signs of senile gait already manifest themselves after the age of 50 years old. In this respect, our results are similar to those suggested by Himann et al. [15] who have reported a critical age of decline for gait velocity (62 years), after which the parameter decreases at the rate of 16% and 12% per decade of life for men and women, respectively. Similarly, Oh-Park et al. [21] found a reduction in gait velocity in a population-based sample of people over the age of 70 years old. In the study by Hollman et al. [6], in turn, 42% of people > 70 years old walked at a velocity in excess of 120 cm/s, which significantly decreased by 18% for persons > 80 years old. Although gait velocity is recommended as a clinical screening test [14] there is a growing interest in defining the role of other spatiotemporal gait parameters, which have been reported to predict mobility disability [22] and risk of falls [23].

Since gait velocity, stride time and total double support phase most strongly differentiated the groups of women we tested, we chose those 3 parameters to assess the critical age of decline for other spatiotemporal parameters. We found that total double support phase (% GC) and stride time (in s), like gait velocity, showed a significant decrease in a group of women > 60 years of age. The mean gait velocity (1.27 ± 0.14 m/s, 4.62 ± 0.50 – raw and normalized values, respectively), stride time (1.01 ± 0.07 s, 3.67 ± 0.25) and total double support phase (0.26 ± 0.04 s, $25.89 \pm 3.30\%$ GC) measurements observed in our study are slightly higher than in other studies reporting reference values for preferred gait velocity in older adults.

The literature does not include many studies presenting normative values for all the phases of the gait cycle for older individuals. Hollman et al. [6] reported mean gait velocity of 110 ± 19 cm/s, stride time 1.06 ± 0.13 s, and double support phase $27.14 \pm 4.0\%$ GC. Oh-Park et al. [21] presented mean gait velocity of 106 ± 17.9 cm/s and a mean double support of $27.1 \pm 5.7\%$ GC. These differences likely stemmed from the fact that they included subjects aged 70–85 years old, who walked slower than the participants in our study, which included women up to

the age of 70 years old. The Rancho Los Amigos (RLA) National Rehabilitation Centre, in turn, established 24% GC for the total double support phase [24]. The values differ slightly from our results, likely due to the fact that subjects represented in the RLA data walked at the average of 136 cm/s whereas our participants walked at 127 cm/s (1.27 ± 0.14 m/s).

Our group was divided into 3 subgroups: 40–49 years old, 50–59 years old, 60–69 years old. A significant decline in the value of both parameters of about 10% may have suggested that aging manifested itself for women taking part in this experiment in their seventh decade of life (roughly in the age range of 60–69 years old) but the first signs of aging in the kinesiological aspect already manifested themselves in the previous decade, after the age of 50 years old. The results provide some better understanding of normal gait performance for older adults. They may also be particularly important for professional employment. This identification of a critical decline in gait parameters, if it is borne out in further research, entails the need for professional flexibility and rotation in employment positions. This should be done in a way that adequately harnesses the knowledge and experience of these individuals while minimizing their activity in areas where physical fitness is crucial.

CONCLUSIONS

We have shown that among 26 spatiotemporal parameters that may be used for characterizing gait, at least a half of these parameters may be omitted in the assessment of gait correctness. The factor analysis showed that from this reduced number of parameters, two domains emerge – which we have called Time and Rhythm – which reflect the nature of an individual's gait well. Using the principal component analysis, we next selected 4 parameters that permit full evaluation of gait quality (understood descriptively, as a complex set of parameters describing gait mechanics). This finding may serve as a tool for prophylactic programs in clinical practice. Secondly, by normalizing the average values of 3 selected parameters in the group of younger women (stride time, double support phase and velocity), we found evidence that the onset of senile gait occurs in the case of women in the seventh decade of life (after the age 60 years old), although the first signs thereof already manifest themselves in the previous decade (after the age of 50 years old). This latter finding may prove particularly significant for professions where ambulation plays a particularly crucial role, and

further research should examine the timing of the age-related decline in other parameters that may have an impact on an individual's performance of tasks related to their professional employment.

Summary

We have found the following 4 spatiotemporal parameters to be the most useful for clinical practice in evaluation of gait quality: step time, stride time, cadence, and total double support.

1. Based on the parameters of total double support, stride time, and velocity, we have found that significant signs of the onset of senile gait occur in the case of women after the age of 60 years old (with the first symptoms thereof appearing in the sixth decade).
2. The other parameters that may have an impact on an individual's performance of tasks related to their professional employment should be verified in further studies.

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