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Spatial parameters of gait related to the position of the foot on the ground

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Abstract

A number of parameters related to the position of the foot on the ground during normal level walking were analysed for a group of young and a group of old subjects, divided in two sub-groups each, according to sex.

The analysis has shown asymmetries between the left and the right side of a number of subjects, differences between sexes and differences between age groups. Changes in the parameters of gait for the old subjects served the task of providing a larger base of support and a smaller loading of the hip musculature.

Introduction

Recent work on the biomechanics of human gait has been directed mostly to dynamic and energetic aspects, while kinematic studies appear more and more rarely in literature. Following the work of the California group (Eberhart, 1947) kinematic data was provided by Levens et al (1948), Ryker (1952), Murray et al (1964, 1966, 1969, 1970), Lamoreux (1970, 1971) and more recently by Dainis (1980), Hershler and Milner (1980), Bajd and Kralj (1980), Durie and Farley (1980), Cappozzo (1981), Mena et al (1981). A small part of this work is devoted to the kinematics of the foot.

Aspects of the position of the foot on the ground during walking attracted interest many years ago. Dougan (1924) measured the angle of gait, that is the angle of the long axis of the shoe and the line of progression, for young males. The angle of gait was also studied by Morton (1932) and by Barnett (1956). The most comprehensive data on the position of the foot on the ground was provided by Murray et al (1964, 1966, 1970), who reported a series of studies of a large number of spatial and temporal parameters of free and fast speed walking for normal men and women of different ages.

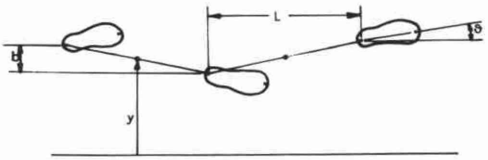

Fig. 1. The parameters analysed in the present study.

This study aims at the analysis and interpretation of a number of spatial parameters related to the position of the foot on the ground during level normal walking of young and old subjects of both sexes. These parameters, defined as shown in Fig. 1, are the following:

1. Foot angle, θ
2. Step length, L
3. Stride width, b.
4. Mid-line, y.

Apart from reporting our results on parameters that have been studied before by other investigators, this work examines the variability of these parameters from step to step of the same subject during a certain trial. It also provides comparisons between left and right side of each subject. Furthermore, values for step length and stride width are expressed not only in absolute terms but also in percent of the subject's stature (Defined as "relative" quantities by Grieve, 1968).

Method

Two groups, one of young subjects and another of old ones were tested. The group of young subjects consisted of 35 (25 male and 10 female) students, aged 17 to 24 years (Mean= 19 years, SD=2.1 yrs). The group of old subjects consisted of 24 (14 male and 10 female) boarders at a home for the aged. Their ages ranged

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between 65 and 90 years (Mean=78 yrs, SD=6.9 yrs). Cases described as pathological were not considered.

After a few trials of familiarization with the walking area, each subject was asked to walk freely at his/her natural speed along a corridor, part of which was covered by paper laid over carbon paper. The points of contact of the toes and the heel were clearly marked on the paper by small pins set at the corresponding points on the long axis of the shoe. The first and last steps of each subject on the paper walkpath were not taken into account; a tendency to make the last step shorter was evident in many cases.

The number of footprints on each side that were analysed was six for each young subject and seven for each old subject. The sample size of each of the parameters studied is shown in the corresponding table.

Mean values of a certain parameter were considered different when their difference was statistically significant ($p<0.10$, t-statistic).

Results

1. Foot angle, θ

The foot angle showed a considerable scatter not only from subject to subject, but also from step to step of the same subject. The mean foot angles of each subject ranged between −2.6 degrees and +17.4 degrees for the young and between −3.0 and +24.8 degrees for the old group.

In 16 out of 35 cases of young subjects the mean foot angle on the left was different from that on the right ($p<0.05$). The same was true in 17 out of 24 cases of old subjects.

The mean foot angles and their standard deviations for the different subgroups are shown in Table 1.

Within the same subgroup the mean foot angle on the left was in all cases smaller than that on the right. This difference, though, was statistically significant ($p<0.1$) only in the case of young males.

Table 2. Mean step length and its standard deviation (SD), in cm and in percent of the subject's stature.

Age	Young		Old	
Sex	Male	Female	Male	Female
Sample size	300	120	196	140
$\bar{L}\pm1SD$ (cm)	74.5±3.97	71.1±4.72	54.3±8.92	46.7±5.53
$\overline{(L/H)}\pm1SD$ percent	42.1±2.22	42.9±3.35	33.8±6.06	30.9±3.61

The mean foot angles of old subjects were in all cases significantly larger than the corresponding angles of young subjects ($p<0.01$).

2. Step length, L

The mean value of the step length and its standard deviation was determined for the left and for the right side of each subject. In 7 out of 35 cases of young subjects the mean step length on the left was significantly different from that on the right ($p<0.05$). This was also so in 6 out of 24 old subjects. Some of the subjects took a longer left step, others a longer right one.

When comparing the mean step lengths on the left and on the right of each sub-group—and not of each individual subject—no statistically significant difference occurred. Both left and right steps were therefore pooled together for each sub-group and the mean step length was computed. The mean step length for each sub-group is shown in Table 2, together with its standard deviation.

Table 2 shows that step lengths were longer for males than for females and for young than for old subjects ($p<0.001$).

Table 2 also shows the step length in percent of the subject's stature, H. In this case the difference betwen young males and females disappears. The common mean step length and its standard deviation become 42.2±2.50 percent of the subject's stature. The mean value for old males remains significantly larger than the corresponding value for old females

Table 1. Mean values and standard deviations (SD) of the foot angles.

Age	Young				Old			
Sex	Male		Female		Male		Female	
Side	left	right	left	right	left	right	left	right
Sample size	150	150	60	60	98	98	70	70
θ±1SD degrees	5.4±4.46	8.0±3.83	5.0±3.36	6.4±2.73	9.3±5.01	10.9±7.89	8.7±8.08	10.0±8.29

(p<0.001). Values for the old subjects are clearly smaller than the corresponding values for young subjects (p<0.001).

3. Stride width, b.

The mean value and the standard deviation of the stride width b, were determined for each subject. Negative values of b were observed in some steps, but the mean value of b for each subject was in all cases positive. The mean value of b for each sub-group was determined and is given in Table 3, together with its standard deviation.

Table 3. Mean stride width b and its standard deviation, in cm and in percent of the subject's stature.

Age	Young		Old	
Sex	Male	Female	Male	Female
Sample size	300	120	196	140
$\bar{b}\pm$1SD (cm)	6.5±3.81	5.2±4.66	6.8±4.81	8.8±3.52
$\overline{(b/H)}\pm$1SD percent	3.6±2.15	3.1±2.82	4.2±2.96	5.3±2.85

The value of the stride width b was also expressed in percent of the subject's stature. The mean value of this parameter for each sub-group is given in Table 3. Mean values for young males (3.6 percent) and females (3.1 percent) were not significantly different. On the contrary, the mean value for old females (5.5 percent) was larger than the mean value for old males (4.2 percent) at a very high level of significance (p<0.001).

Old subjects showed a significantly larger stride width than young subjects of the same sex (p<0.05). This difference was particularly stressed for females (p<0.001).

4. Mid-line, y.

The mid-line was defined as the line joining the mid-points of each step (Fig. 1). The distance y of each of these points from an axis parallel to the walkpath was determined. Then the standard deviation S_y of these distances was computed for each subject. This parameter is an index of the mean path lateral deviation of the subject. Mean values of the mid-line deviation S_y for each sub-group are shown in Table 4.

The mid-line deviation was also computed in percent of the subject's stature. Mean values of this new parameter for each sub-group are also shown in Table 4.

Table 4. Mid-line deviation in cm and in percent of the subject's stature.

Age	Young		Old	
Sex	Male	Female	Male	Female
Sample size	25	10	14	10
$\bar{S}_y\pm$1SD (cm)	2.2±1.33	3.1±1.44	2.2±0.68	2.8±1.07
$\overline{(S_y/H)}\pm$1SD percent	1.3±1.23	1.9±.94	1.4±0.45	1.9±0.71

Comparisons of the mean values of the mid-line deviation, both in cm and in percent of the subject's stature for the four sub-groups of subjects, revealed no statistically significant differences.

5. The variability of gait parameters

The standard deviation of each of the parameters presented in Tables 1, 2, 3, and 4 of this study relates to the variability of this parameter within a sample where an equal number of steps of each subject were pooled together. Although the standard deviation computed from such a pooled sample provides information about the range where any particular measurement of the corresponding gait parameter is expected to lie—with any degree of confidence—it does not describe the variability of the specific parameter from step to step of the same subject, neither does it describe the variability from subject to subject of the corresponding mean values.

The variability of gait parameters from step to step of the same subject and also from subject to subject is a piece of information necessary to the correct design of human gait experiments. It is also useful in understanding and quantifying the characteristics of normal gait.

The variability of a certain parameter is measured by its SD.

Table 5 presents

a) The mean ± 1SD of the variability from step to step of the same subject of each of the gait parameters studied in this work.

b) The variability from subject to subject of the corresponding mean values for the above parameters.

c) The variability of the above parameters within a sample, where an equal number of sequential steps of each subject were pooled together.

Table 5. Variability of gait parameters. The variability is measured by the SD. Relative quantities are expressed in percent of the subject's stature. Six steps on either side of each young subject (25 males and 10 females) and six steps on either side of each old subject (14 males and 10 females) were analysed.

		Young				Old			
		Male		Female		Male		Female	
		l	r	l	r	l	r	l	r
Foot angle θ (degrees)	From step to step of the same subject	1.68±0.751	1.77±0.688	3.51±2.115	2.95±1.632	2.94±0.964	3.08±1.432	2.86±1.192	3.03±0.524
	Mean, from subject to subject	4.45	3.79	3.14	2.52	5.06	8.11	7.81	8.05
	From step to step of all subjects	4.46	3.83	3.36	2.73	5.01	7.89	8.08	8.29
Relative step length (percent)	From step to step of the same subject	1.18±0.348		2.03±1.001		1.96±0.572		1.65±0.410	
	Mean, from subject to subject	2.17		3.16		6.04		3.54	
	From step to step of all subjects	2.22		3.35		6.06		3.61	
Relative stride width (percent)	From step to step of the same subject	1.39±0.562		2.56±0.976		1.79±0.735		1.89±0.358	
	Mean, from subject to subject	1.64		1.17		2.40		2.48	
	From step to step of all subjects	2.15		2.82		2.96		2.85	
Relative mid path lateral deviation (percent)	From subject to subject	1.23		0.94		0.45		0.71	

Discussion

Analysis of the foot angle and step length revealed statistically significant asymmetries between the left and the right side of a number of subjects considered normal. It is thought that these asymmetries have an important contribution in forming the characteristic gait of a subject. Whether these asymmetries correspond to skeletal, muscular or other asymmetries cannot be inferred from this study. This will require a larger number of parameters to be analysed and also a larger number of subjects to be tested.

Among the parameters analysed, the step length showed the least relative variability between steps of the same subject, or between subjects of the same sub-group. It seems therefore likely that this parameter may constitute a useful differentiator between normal and pathological gait.

The SD is inversely related to the sample size which would be required to define a mean value not differing from the true mean by a certain amount. For example, when it is required that a 95 percent confidence interval on the mean step length of any one normal young man will be ± 2 percent of his stature, then a sample size of n=4 steps is needed. When it is required that the same interval will be ± 1 percent of the subject's stature, then a sample size of n=16 steps is needed. The number of steps or of subjects required for any particular gait analysis depends on the variability of the parameter of interest.

The variability of sequential steps of the same subject was considerably higher for old than for young subjects. This fact is in agreement with Spielberg's (1940) theory that the motor pattern of walking goes through several stages of disintegration. At the third stage the uniformity of sequential steps is increasingly disturbed. It is interesting to note though, that such decrease of uniformity is not observed for the rest of the gait parameters analysed in this study.

Step length was relatively smaller for old than for young subjects. This feature that has been described by Spielberg (1940), has also been reported in an extensive study by Drillis (1961), and later by Murray et al (1969). It is attributed to the fact that smaller step lengths result in smaller moments about the joints of the lower limb and therefore smaller effort is required to be exercised by the weakened musculature of old subjects.

Mean values for the foot angle are reasonably close to those reported by Dougan (1924), by Morton (1932) and by Murray et al (1964, 1966, 1969, 1970).

Comparisons of foot angle, θ, and stride width, b, between young and old subjects showed a significant increase in the case of the latter. Foot angle and stride width, taken together, define the overall width of the supporting base for the walking subject. Old people who suffer more instability, due to weaker hip abductors and poorer physical condition, require a larger base of support during their gait. This is achieved by increasing both the foot angle and the stride width. The increase in stride width is particularly stressed in the case of old women. This may be due to the fact that the female pelvis is relatively wider than the male one. Murray et al (1964) observe a significant increase in the mean foot angle with age, but their analysis reveals no increase of stride width with age. They, therefore, conclude that wider base of support is achieved in old age by out-toeing and not by both out-toeing and greater stride width, as this study reveals.

It was felt likely that instability of the elderly might result in greater side-ways sway (mean path lateral deviation), than that shown by young subjects. This hypothesis was not justified by the analysis of the mid-line deviation, indicating that instability is adequately counter-balanced by the increase in the size of the supporting base. It should, nevertheless, be pointed out, that data on the mid-line deviation might be biased, as the subjects were more or less "guided" to walk along a straight line by the paper walkpath itself. To reach final conclusions about this parameter a much wider paper walkpath will be required.

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