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Walking speed of normal subjects and amputees: aspects of validity of gait analysis

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Abstract

This study investigated some aspects of the validity of walking speed recording in 15 normal subjects, 16 trans-femoral amputees and 8 knee disarticulation amputees. The variability and test-retest reliability of walking speed and the influence of simultaneous recording of EMG and goniometry on comfortable and fast walking speeds were studied.

The variability between sessions was mainly determined by the variance within each session. The variance of speed within sessions while walking with fast speed, was higher when walking without equipment than when walking with equipment. The variances of speed within sessions of the normal subjects were higher than those for both amputee groups. The test-retest reliability, expressed by the intra-class correlation coefficient, was good: between 0.83 and 0.98. The speed when walking without equipment was significantly higher both in normal subjects and amputees than the speed when walking with equipment.

Introduction

Measurements of walking speed by means of gait analysis are based on the assumption that walking speed is a basic gait parameter which, when measured objectively, can be useful in characterizing an individual's walking ability. In studies of prosthetic components, walking speed is often used as a parameter for the quality of performance (Barth *et al.*, 1992; Godfrey *et al.*, 1975; Murray *et al.*, 1983). Validity of speed recordings is essential. There are several aspects of validity. One of these is the test-retest reliability. Normal subjects show good reliability, but studies have been limited to the test-retest reliability of the natural walking speed (Kadaba *et al.*, 1989; Waring and McLaurin, 1992; Winter, 1984) or have included only a few subjects (Winter, 1984). In neurologic patients (Holden *et al.*, 1984; Wade *et al.*, 1987) and post-polio patients (Waring and McLaurin, 1992) the test-retest reliability has been shown to be satisfactory.

Another aspect of the validity concerns the question about the relationship between speed recordings measured during gait analysis and the walking speed of the patient in his/her own surroundings. So far, nobody has answered this question. An important problem in gait analysis, affecting the validity, is the simultaneous recording of speed, goniometry and EMG. It is unknown how the walking speed is influenced by the equipment and the wires attached to a patient for gait analysis.

In this paper, a study is presented of the variability of walking speed and the test-retest reliability, based on repeated recordings of comfortable and fast speed in normal subjects and amputees. The study also examined the influence of simultaneous recording of goniometry and EMG on walking speed.

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Material and methods

Subjects

The study included 15 normal subjects, 16 trans-femoral amputees and 8 knee disarticulation amputees. All gave informed consent.

The study of test-retest reliability was limited to the 15 normal subjects and 8 trans-femoral amputees.

The mean age of the normal subjects was 30 years (range 18–45, that of the trans-femoral amputees 40 years (range 15–63) and that of the knee disarticulation amputees 38 years (range 20–70). Ten of the trans-femoral amputees used a quadrilateral socket, six used a (modified) ischial containment socket (socket with narrow mediolateral dimension). All the trans-femoral prostheses had a 4-bar linkage knee with mechanical swing phase control (3R20, Otto Bock); all but one had a Multiflex foot. One prosthesis was fitted with a Lager Bock foot.

All the knee disarticulation prostheses were fitted with an end-bearing socket, 4-bar linkage knee with mechanical or hydraulic swing phase control and a Multiflex foot.

Prosthetic component design and alignment of the amputees' prostheses were all directed towards obtaining optimal gait. During the study neither the prostheses nor the shoes were changed.

Gait analysis

The recordings were taken on a 10 metre walkway. Two infra-red beams at the beginning and the end of a 7 metre trajectory started and stopped the measurements automatically. The normal subjects and amputees first walked without any goniometer or electrodes. The speed of comfortable walking and of fast walking ("as fast as possible") was measured. This was repeated once. Thereafter electrodes on the gluteal muscles, electrogoniometers (Penny & Giles) for hip, knee and ankle and aluminium strips on the shoes for stance phase and swing phase recordings were attached to the subject. The goniometry, EMG and stance/swing phase recordings were used for a different study. The goniometers, electrodes and strips were connected to a box on the back of the subject. The box was connected by one cable to the computer. The investigator guided the subject while walking. The subject walked two more times at comfortable and fast speed.

The normal subjects were investigated on two days, with an interval of 2–7 days. Eight trans-femoral amputees were measured twice, with an interval of 3 to 6 weeks.

This meant that all 15 normal subjects and 8 trans-femoral amputees walked two sessions consisting of 4 runs each, two runs without and two runs with equipment. Eight trans-femoral amputees and all 8 knee disarticulation amputees walked one session consisting of 4 runs, two runs without and two runs with equipment.

Statistical analysis

The variability of speed recordings was studied separately in each of the three groups, for each of the two walking speeds and with and without equipment. The within-session variance, sd^2_{within}, was calculated as the mean of the variances calculated within each session. The between-session variance component was estimated by $sd^2_{between} = sd^2_{session} - ½sd^2_{within}$, where $sd^2_{session}$ is the variance of the session means.

The test-retest reliability can be described by the intra-class correlation coefficient between the means of the two sessions. This coefficient was estimated by $(sd^2_{group} - ½sd^2_{session}) / (sd^2_{group} + ½sd^2_{session})$, where sd^2_{group} denotes the variance of the subject means in a given group.

Group means of the repeated measures were compared using ANOVA. The effect of carrying equipment was evaluated by means of the paired t-test (comparison of means) and the signed-rank test (comparison of variances).

Table 1. Mean and standard deviation (sd) of the comfortable speed (m/s).

group	number of subjects	walking without equipment		walking with equipment	
		mean	sd	mean	sd
normal subjects	15	1.45	0.175	1.36	0.194
trans-femoral amputees	16	1.04	0.214	0.97	0.201
knee disarticulation amputees	8	1.19	0.251	1.09	0.234

Table 2. Mean and standard deviation (sd) of the fast speed (m/s).

group	number of subjects	walking without equipment		walking with equipment	
		mean	sd	mean	sd
normal subjects	15	2.10	0.249	1.90	0.276
trans-femoral amputees	16	1.26	0.297	1.16	0.292
knee disarticulation amputees	8	1.46	0.359	1.36	0.311

Tests were performed at 5% level of significance (two-sided if applicable).

Results

The mean comfortable and fast walking speeds and standard deviations are summarized in Tables 1 and 2.

The comfortable and fast speeds of the normal subjects were significantly higher than those of the trans-femoral and knee disarticulation amputees (comfortable speed: $p<0.02$; fast speed: $P<0.001$). The different variance components are summarized in Tables 3 and 4.

The within-session variance was higher for normal subjects than that for both amputee groups (P-values: comfortable speed: normal subjects—trans-femoral amputees: 0.02; normal subjects—knee disarticulation amputees: 0.09; fast speed: normal subjects—trans-femoral amputees: 0.01; normal subjects—knee disarticulation amputees: 0.01). The within-session variance was higher while walking with equipment than while walking without equipment for the fast speed ($P=0.002$); for the comfortable speed the difference was not significant ($P=0.47$).

The variability between sessions was mainly determined by the variance within each session, as shown by the low between-session variance components.

The between-session variance was not

Table 3. Variance components: comfortable speed (m/s).

group	number of subjects	$sd^2_{within} \times 10^{+3}$		number of subjects	$sd^2_{between} \times 10^{+3}$	
		without equipment	with equipment		without equipment	with equipment
normal subjects	15	6.95	5.06	15	2.26	1.72
trans-femoral amputees	16	1.92	4.03	8	2.33	0*
knee disarticulation amputees	8	3.36	1.23			

*negative variance component.
sd^2_{within} is the mean of the variances calculated within each session.
$sd^2_{between} = sd^2_{session} - \frac{1}{2} sd^2_{within} \times$, where $sd^2_{session}$ is the variance of the session means within each subject.

Table 4. Variance components: fast speed (m/s).

group	number of subjects	$sd^2_{within} \times 10^{+3}$		number of subjects	$sd^2_{between} \times 10^{+3}$	
		without equipment	with equipment		without equipment	with equipment
normal subjects	15	11.0	5.39	15	3.02	4.68
trans-femoral amputees	16	2.37	0.49	8	3.34	3.72
knee disarticulation amputees	8	7.66	1.89			

sd^2_{within} is the mean of the variances calculated within each session.
$sd^2_{between} = sd^2_{session} - \frac{1}{2} sd^2_{within} \times$, where $sd^2_{session}$ is the variance of the session means within each subject.

Table 5. Intra-class correlation coefficients.

group	number of subjects	comfortable speed		fast speed	
		without equipment	with equipment	without equipment	with equipment
normal subjects	15	0.83	0.89	0.87	0.91
trans-femoral amputees	8	0.93	0.98	0.95	0.95

significantly different while walking with equipment than while walking without equipment (P-values>0.20). The between-session variance in normal subjects was not higher than in the amputee group (P-values: comfortable speed: without equipment: 0.52; with equipment: 0.95; fast speed: without equipment: 0.05; with equipment: 0.89).

In each session both normal subjects and amputees showed a tendency to walk slower in the first run than in the second run (mean comfortable speeds for all subjects while walking without equipment were, respectively, 1.17 m/s and 1.20 m/s), but the difference did not reach significance (P-values>0.1).

The comfortable and fast speeds of the first session did not differ significantly from those of the second session, neither in normal subjects nor in amputees (P-values>0.1).

The intra-class correlation coefficients of the data for both sessions are summarized in Table 5.

The speed while walking without equipment was significantly higher than while walking with equipment, both in normal subjects and amputees (P-values<0.01). The difference in fast speed with and without equipment was bigger than the difference in comfortable speed (see Tables 1 and 2).

Discussion and conclusion

The study presented investigated the variability and test-retest reliability of speed recordings both in normal subjects and amputees as well as the influence of equipment like goniometers and EMG electrodes on the walking speed. A good reliability was found for speed recordings both at comfortable speed and at fast speed. The variances of speed within each session and between two sessions were acceptably low. The low value of the between-session variance components indicates that the main part of the within-subject variability is already present within one session.

The within-session variance of speed recordings was lower for amputees than for normal subjects. This may be explained by the mechanical properties of the prosthesis, especially the knee-joint. Because of the almost fixed duration of the flexion-extension motion of the knee-joint, the amputee is forced to vary his/her walking speed only by means of one leg, the sound one. This may have led to the lower variation.

The test-retest reliability, as expressed by the intra-class correlation coefficient, was good (between 0.83 and 0.98). The correlation coefficient is comparable with the Pearson correlation coefficient found by others for speed recordings in patients with other diseases (Godfrey *et al.,* 1975; Kadaba *et al.,* 1989; Wade *et al.,* 1987; Waring and McLaurin, 1992).

As has already been shown by others (James and Oberg, 1973), amputees walk slower than normal subjects.

The speed of both comfortable and fast walking is influenced by the equipment put on a patient for electrogoniometry and EMG; it is reduced by about 8% when walking with equipment. Hence, the validity of speed recordings demands that the walking speed is measured without equipment for electrogoniometry and EMG.

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