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A COMPARISON OF THE GAITS OF PARETIC PATIENTS WITH THE GAITS OF CONTROL SUBJECTS CARRYING A LOAD

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ABSTRACT. The gaits of 15 patients with peripheral and central paresis were studied. They were compared both with a control group of the same age and sex and with a group of nine subjects who carried varying weights. Velocity was low in the patients and this was due to decreases of both stride length and stride frequency. Load did not significantly decrease the velocity of the control subjects, since unlike the patients, they had the ability to compensate for a low stride length by significantly increasing stride frequency. The significant lowering of stride length in both groups was a similarity between them. The patients were also similar to the loaded normal subjects in having a shortened duration of the single support and a prolonged double support. The patients with hemisymptoms also showed significant differences between the two sides for the durations of both single and double support. The results obtained from this study justify our hypothesis that a subject who is carrying a load may in certain respects be considered as a model of a subject with paresis. The remaining differences may be explained by the fact that in the experimental situation, the leg was loaded only during stance, while in paresis the legs may be considered relatively loaded during the whole stride.

Key words: Gait, paraplegia, paraparesis, hemiplegia, peroneus parses

The contact between the foot and the ground is the most important postural reference during walking. It may be expected therefore that the duration of those phases which express the relation to the ground—primarily stance and swing—to a certain extent also will indicate how the subject controls his posture. In several investigations it has been observed that swing for instance has a shorter duration on the sound side than on the diseased side in patients with hemiparesis (1, 2). The duration of swing corresponds to the duration of single support on the contralateral side, and the observation therefore simply means that a subject with hemiparesis uses his diseased leg in single support for a shorter time than his sound leg. The observation is not limited to patients with hemiparesis and it is of great practical importance in clinical gait analysis (e.g. 5). According to Perry et al. (7) single support time together with velocity are the clinically most useful indicators of gait improvement as tested in patients with total hip and knee replacements, hemiplegia or lower limb amputations.

A change of the duration for single support results in corresponding changes also for other phases (3). This is especially true for the duration of double support and consequently of the total duration of stance. The double support is the phase during which the weight of the body is transferred from one leg to the other. Its duration may therefore be related to the way the subject handles his postural control during this part of the stride.

We therefore investigated the relation between the phases described, in three different patient groups. (A) Patients with paraparesis, (B) Patients with hemiparesis, and (C) Patients with peripheral peroneal paresis. In addition we investigated (D) a group of normal individuals carrying a heavy box in one hand. We hypothesized that a subject who is carrying a load may in certain respects be compared to a subject with paretic legs. In the paretic case it is possible to consider the load of the body weight as increased in relation to the weakened legs. If this is so, basal characteristics of the gait such as velocity, stride length, stride frequency and the phases of the stride should change in the same direction in real paresis and in experimental subjects carrying a load. By comparing the way in which a normal subject compensates for a real load with the way in which a paretic subject compensates for the burden of his paresis we expected to obtain a better understanding of the compensatory processes in the different conditions.

The general characteristics of the gaits of the patient types selected may be found in standard neurological textbooks. To be able to make interpolations for comparisons of the phases of the stride

Table I. *Clinical data on patients*

Pat.	Sex	Age	Diagnosis	Duration
1	F	31	Peroneal paresis sin	1 year
2	F	56	Peroneal paresis sin	2 months
3	M	43	Peroneal paresis sin	5 months
4	M	63	Peroneal paresis sin	1 year
5	M	68	Peroneal paresis sin	3 months
6	F	38	Peroneal paresis dx	1 month
7	F	53	Hemiparesis dx	1 year 10 months
8	F	48	Hemiparesis dx	2 years
9	F	38	Hemiparesis sin	1 year 6 months
10	M	47	Hemiparesis dx	1 year
11	M	57	Hemiparesis sin	2 years
12	M	39	Paraparesis	5 years
13	M	64	Paraparesis	30 years
14	F	37	Paraparesis	13 years
15	M	56	Paraparesis	11 years

in normal and pathological conditions it is necessary to examine when the subjects walk at different velocities. Such studies have to our knowledge not yet been made.

MATERIAL

Patients

Fifteen patients, five women and ten men were investigated. Their age range was 31–68 years. Six had peripheral peroneal paresis, four had paraparesis and five had hemiparesis. Their clinical characteristics are described in Table I.

Controls

Nine healthy subjects were asked to walk with and without carrying a box with a load of 16–24 kg. The subjects were men within the age range of 18–62 years. They were compared in the two walking conditions. In addition, we used a control group of 23 subjects (14 men, and 9 women evenly distributed between the ages 20–70 years. They had no neurological or orthopaedic diseases. Their anthropometric data are previously described (3). Regression equations obtained from these controls were used to calculate expected values for comparison with the patients, at their respective velocities.

METHOD

We used a switch recording method (3) where the subject is asked to walk on a metallic net measuring 10 m. He uses socks, with soles of plastic and which have a rough surface. Adhesive metallic tape is fastened to the balls and the heels and connected to the recording apparatus with a light cable which follows the subject through an attachment in the ceiling. Since results vary systematically with velocity, measurements are made at five speeds. The subjects are asked to walk at ordinary, very slow, very fast, and fast speeds. No other instructions are given. Walking aids are not used. The measurements are made with the aid of a computer with a special programme package. In combination with the metallic net, the conductive tape forms four switches that open and close during the stride. In this way it is possible to record velocity (V), stride frequency (SF), stride length (SL) and phase relations.

For the durations of the phases the following abbreviations are used: S = stride, ST = stance, SW = swing, SS = single support, and DS = double support.

Then it is obvious that

$$S = ST + SW \qquad (1)$$

and

$$ST = DS_{rl} + SS + DS_{lr} \qquad (2)$$

The subscripts rl (right to left) and lr (left to right) indicate the direction of weight transfer. For presentation of the phase results we used the durations of single support and double support bilaterally. It is important to remember that single support has the same duration as swing on the contralateral side. Meaurements of single and double support bilaterally will therefore give the durations of all phases defined in this paper (eqs. 1 and 2).

Loading

The load carried by the experimental subjects was a box measuring 60×30×15 cm, containing weights in the range of 16–24 kg. It was carried in one hand. In this way we hoped to obtain differences between the legs on the loaded and the unloaded side.

Statistical methods

If not otherwise stated the paired *t*-test was always used.

RESULTS

Velocity, stride length and stride frequency

The effect of artificial load. Table II shows the average velocities in very fast walking in the differ-

Table II. *Maximum values (±1 SD) of velocity (VEL), stride length (SL), and stride frequency (SF)*

The control subjects are compared with themselves when carrying and not carrying a load. The patients are compared with the control group

	Peroneal paresis $n=6$	Paraparesis $n=4$	Hemiparesis $n=5$	Loaded control subjects $n=9$	
Vel (m/s)					
Pat.	1.06±0.52	1.16±0.50	0.91±0.23	Test	1.88±0.26
Contr.	2.40±0.47	2.40±0.47	2.40±0.47	Contr	1.96±0.39
p	<0.001	<0.001	<0.001		NS
SL (m)					
Pat.	1.21±0.39	1.17±0.31	1.12±0.15	Test	1.51±0.16
Contr.	1.93±0.20	1.93±0.20	1.93±0.20	Contr	1.71±0.20
p	<0.001	<0.001	<0.001		<0.001
SF (strides/sec)					
Pat.	0.88±0.16	0.99±0.18	0.81±0.11	Test	1.24±0.14
Contr.	1.25±0.20	1.25±0.20	1.25±0.20	Contr	1.14±0.15
p	<0.001	<0.05	<0.001		<0.05

ent groups of subjects. It is seen that patients walk slower than controls. The subjects in the control group in addition walk slower when carrying a load, but the difference is slight and not statistically significant.

Fig. 1 shows the regression lines for stride frequency to stride length for one of the subjects who walked with three different loads; the slope increases with increasing load. When loaded, the subject therefore tended to increase stride frequency more than stride length in order to gain velocity. The maximum stride length for the group was significantly shorter and stride frequency higher in the loaded condition (Table II). At low velocity the change was not significant. The increase of slope was typical of all subjects when loaded ($p<0.05$ for paired t-test; if the binomial test is used, $p<0.001$).

The effect of paresis. The maximum stride length (in very fast walking) is also shorter in patients than in controls (Table II). In addition, stride frequency was lower. The patients, however, walked at a lower velocity. The shortened stride length and the lower stride frequency in relation to the controls may therefore be due to their low velocity. Since velocity is the product of stride frequency and stride length, and since in addition the relation between these factors is different for males and females, it is necessary to consider all these factors for correct evaluation. Regressions for stride frequency to stride length as obtained at different velocities were therefore calculated for each subject. The stride length was calculated from the regression in the control population of the same sex. The stride frequency at which the stride length was calculated, was chosen to be within the range of stride frequency for all patients in the respective diagnostic group. Stride length was then found to be significantly shorter in each patient group as compared with the control population ($p<0.05$ in all groups).

When the slopes of the regression lines for the patients were compared with the controls of the same sex, no significant differences were found. If any, there was a tendency to a decrease. The shortening of stride length for the patients was therefore true for all velocities. This is in contrast to what was found in the loaded experimental subjects.

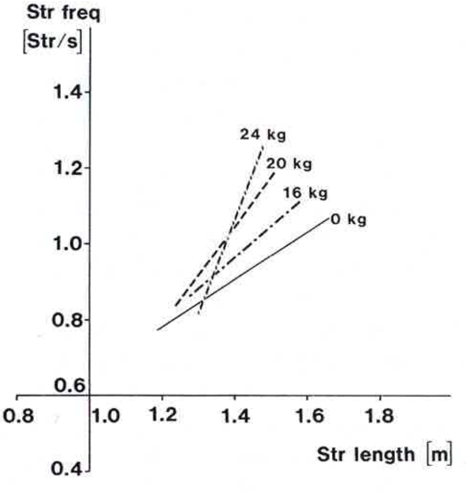

Fig. 1. Regression lines showing the effects of varying load on the relation between stride (*str*) frequency and stride length in a typical subject. Each regression line is based on observations made at five different velocities.

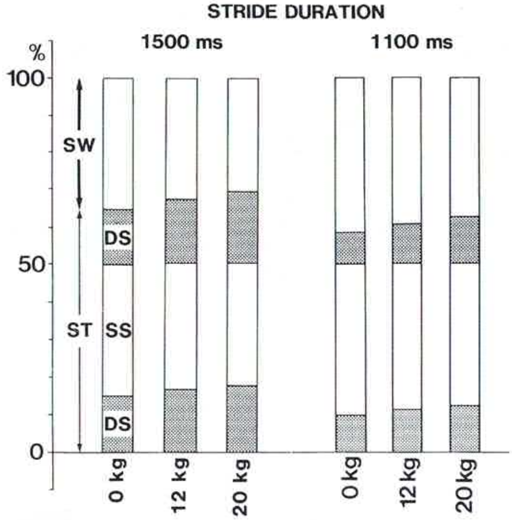

Fig. 2. Time relations between stance (*ST*), swing (*SW*), single (*SS*) and double support (*DS*) in a subject carrying different loads. Since the changes with load were symmetrical they are shown for only one leg. In this figure and in Fig. 3 the phases are normalized to the stride duration indicated, with the aid of regression equations for each subject.

The single and double support phases

The effect of artificial load. Fig. 2 shows the typical time relations between the phases of the stride for one of the control subjects when unloaded and when carrying different loads. With increasing load there is a decrease of single support and an increase in double support. Consequently there is decrease of swing and increase of stance. The changes were generally symmetrical and are therefore shown for only one leg. For some subjects there was a slight difference between the loaded and unloaded side at low velocities. It was inconsistent with respect to side in spite of the fact that the subject's trunk always deviated towards the side contralateral to the load. Our hope to find side differences between the legs by asking the subject to carry the load in one hand was therefore not fulfilled. A more detailed comparison of single support in all control subjects (Fig. 4 A), demonstrates the same shortening when the subjects are in the loaded condition. Since a lengthening of double support is a necessary consequence of the shortened single support, it is not separately illustrated.

The effect of paresis. Fig. 3 shows time relations between the phases of the stride for typical patients with paraparesis and right-sided peroneal and hemiparesis. Detailed comparisons for all patients are shown in Figs 4 and 5. Fig. 4 shows a comparison between the durations of SS on the strong and weak sides for the patients with hemiparesis (4 C) and peroneal paresis (4 D). In the patients with paraparesis who have two weak sides, the mean of both sides was compared with the expected value as obtained from the control group (4 B).

It is obvious from the figure that single support (SS) has shorter duration in the weak than in the strong legs. Again when single support of the *weak* legs in hemiparesis and in peripheral peroneal paresis were compared with the expected values from the control group, they were shorter (not shown in the figure). When the *strong* legs of the same patients were compared with the expected values in the hemiparetic and peroneal paretic patients, it was found that single support had longer duration for the hemiparetics (4 E), but not for the patients with peripheral paresis (4 F).

Since SS is short in weak legs, it may be expected that DS will be long (eq. 2). As seen in Fig. 5 E this is true in the paraparetics, where *both* legs are weak.

In DS the weight of the body is transferred from one leg to the other. When *only one* leg is weak, as in the case of hemiparesis and peroneal paresis, the question is more complicated. In these patients DS

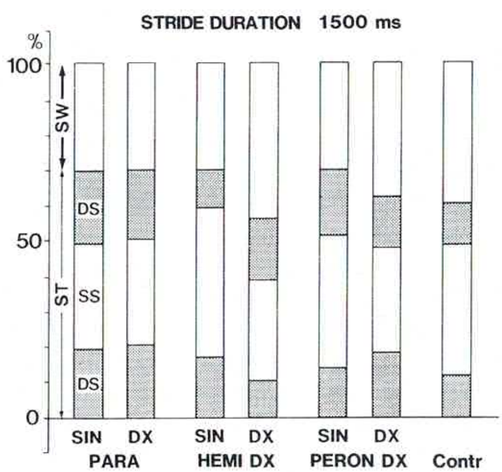

Fig. 3. Time relations between stance (*ST*), swing (*SW*), single (*SS*) and double support (*DS*) in three different patient categories and controls. The bars, which represent stride duration measured from left and from right heel-on respectively, have been phase-shifted to facilitate comparisons.

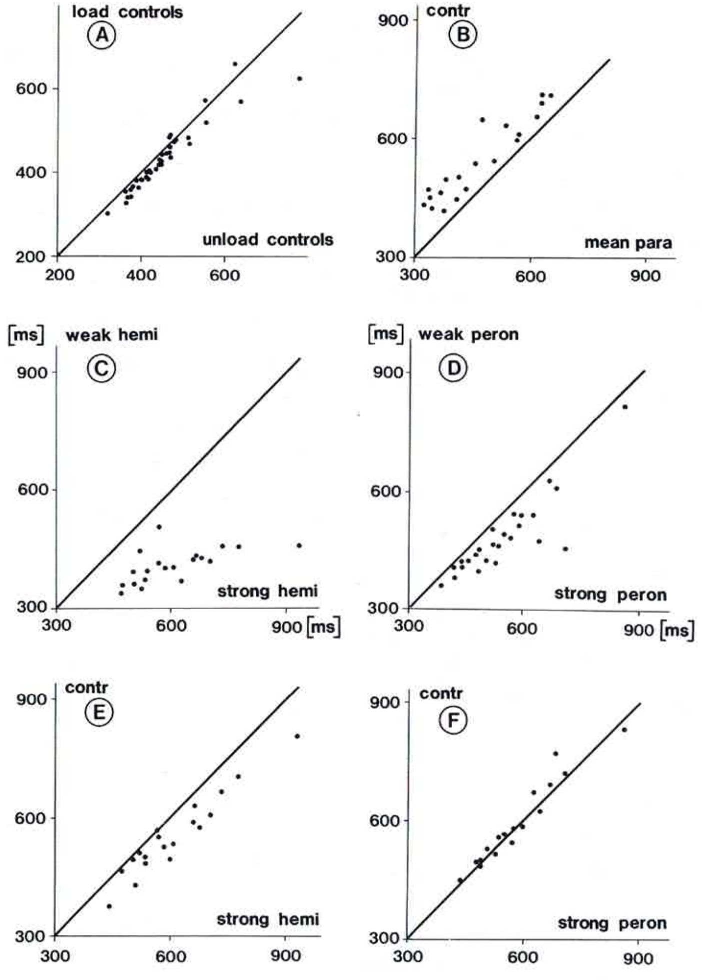

Fig. 4. Comparisons of single support duration in patients and in controls. A line of equality (45 degrees line) is drawn in each diagram. (A) Control subjects; loaded to unloaded condition (mean of both sides). (B) Paraparesis; values from control group to mean of both legs. (C) Hemiparesis; weak to strong leg. (D) Peripheral peroneal paresis; weak to strong leg. (E) Hemiparesis; values from control group to strong leg. (F) Peripheral peroneal paresis; values from control group to strong leg.

has long duration compared with the expected values from the controls when the weight is transferred from the weak to the strong leg (Figs. 5 A and 5 B). However, when weight is transferred from the strong to the weak leg, DS is longer only in the peroneal paresis (5 D) while in hemiparesis there is no certain change in relation to the expected values (5 C). If any, it tends to be shorter. In Fig. 5 F the weak and the strong legs in both conditions are compared with each other instead of with the expected values as obtained from the controls. It is seen that DS in hemiparetics is longer when the weight is transferred from the weak to the strong side, while in the peroneal paresis the reverse is true.

DISCUSSION

Our hypothesis was that subjects who are carrying a load in certain respects might resemble patients with paresis. The paresis was considered as a relative increase of load. It is obvious that the clinical concept of paresis cannot be covered by such comparison alone. Some useful information may, however, be found in the process of comparison. We found that patients as well as subjects carrying a load had a decreased stride length; the patients at all

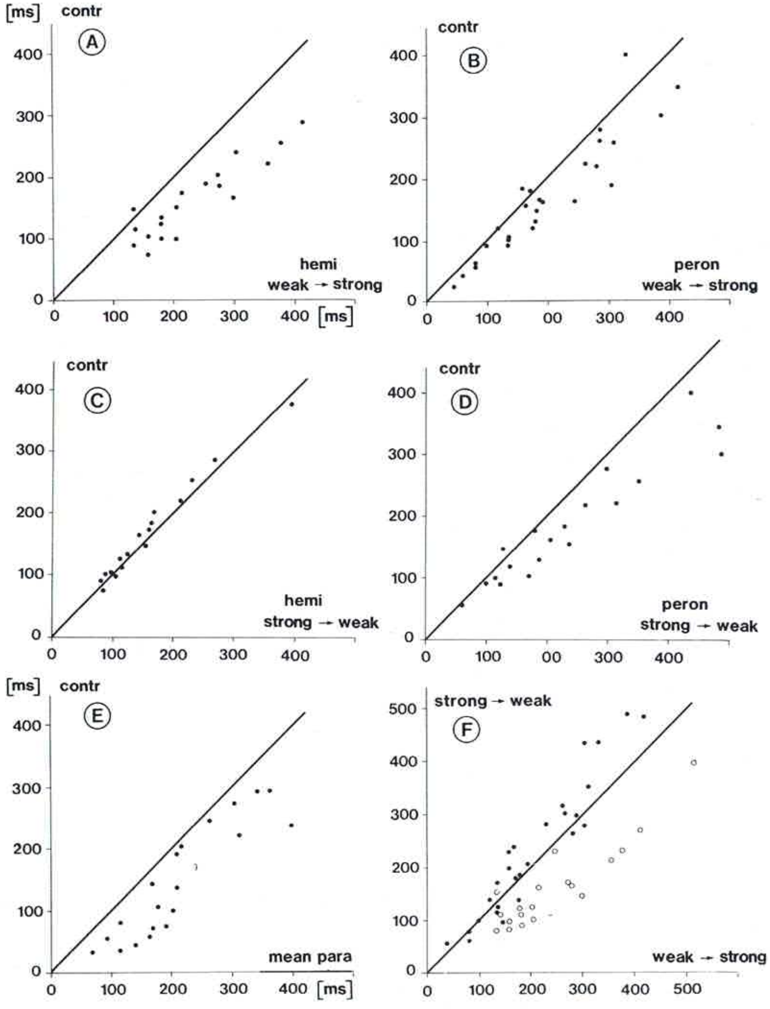

Fig. 5. Comparisons of double support duration in patients with different diagnoses. A line of equality (45 degrees line) is drawn in each diagram. (A) Hemiparesis; values from control group to values when weight is transferred from weak to strong side. (B) Peripheral peroneal paresis; values from control group to values when weight is transferred from weak to strong side. (C) Hemiparesis; values from control group to values when weight is transferred from strong to weak side. (D) Peripheral peroneal paresis; values from control group to values when weight is transferred from strong to weak side. (E) Paraparesis; values from control group to mean of both legs. (F) Peripheral paresis (filled symbols) and hemiparesis (open symbols). Values when weight is transferred from strong to weak side plotted against values when transferred from weak to strong side.

velocities, and the loaded subjects primarily at high velocity. However, maximum stride frequency was low in the patient group while it was increased rather than otherwise in the loaded subjects.

The reduction of stride length which occurs in both groups means a reduced displacement of the center of gravity in a vertical direction during the stride. This will compensate for an increase in load regardless of whether it is absolute or—as in the paretic cases—relative. The difference between the patients and the subjects with a load depends upon their ways of increasing velocity. For a given increase in velocity the paretic individuals have difficulties in increasing both stride length and stride frequency. The slope of the regression line between these factors therefore does not differ from that of the controls. According to the hypothesis, the legs of the patients are relatively loaded during the whole stride, while the legs of the control subjects are loaded only during stance. The swing of the latter group can therefore be fast, thus increasing stride frequency at high velocity. This will increase the slope of the regression line, a result which was in fact obtained.

The shortening of single support is a further similarity between the really loaded subjects and the relatively loaded patients. With respect to the patients, this fits in with previous observations (6, 7). Pearson & Duysens (4) found, in addition, a prolonged stance with loading of the extensors in cats and cockroaches. In human symmetrical gait, this is in fact the same as a shortening of single support (eqs. 1 and 2). A shortened duration of single support obviously compensates for paresis and the simultaneously prolonged duration of double support adds to the compensation.

Up till now the patients with one-sided paresis only, have not been specially considered. By asking the control subjects to carry the load in one hand only, we had hoped to find differences between the sides which could provide material for comparison. Since the side differences obtained were inconsistent, further experiments are necessary.

In patients with one-sided paresis only, the weak leg had a shortened single support, a fact which fits in well with the original hypothesis. In the hemiparetic patient, single support was found to be prolonged on the strong side, not only in relation to the weak side, but also in relation to the controls. This may be an expression not only of the fact that they had to rely on the strong leg for a comparatively longer time, but also to the hemiparetic leg being slowly moved during swing.

Compensation may also be achieved by the way in which the weight of the body is transferred from one leg to the other, that is, during double support. The double support has two phases which approximately correspond to what Perry (5) calls weight acceptance and balance assist. These terms approximately describe the fact that there are at least two possibilities to compensate during double support. One is to transfer the body weight to the good leg as fast as possible, and the other is to assist with the good leg as long as possible. The patients with hemiparesis and peroneal paresis may represent these two possibilities. In hemiparesis that part of double support is long, which corresponds to weight tranference from the weak to the strong leg, which may be interpreted as early unloading of the weak leg and correspondingly early assistance from the strong leg. In peroneal paresis on the other hand, that part of double support is long which corresponds to weight transference from the strong to the weak leg. This may be interpreted as prolonged acceptance of the load on to the weak leg and correspondingly prolonged assistance from the strong leg. Since the paretic anterior tibial muscle, which plays an important role in weight acceptance, cannot be used properly, a long duration of double support in the beginning of stance is a reasonable consequence.

The results justify our original hypothesis that a subject who is carrying a load may in certain respects be considered as a model of a subject with paresis. The similarities belong to the single and double support phases of the stride and to some extent also to a shorter stride length. Within the limits of our measurements, the experimental subject carrying a load is best compared to a paraparetic with the same degree of paresis on both sides (Figs. 2 and 3). The most obvious difference was the better ability of the normals to increase stride frequency and so maintain velocity. As suggested above, this may be related to the fact that the swing was not loaded in the experimental situation. Such experiments will be presented in a paper under preparation.

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REFERENCES

1. Carlsöö, S., Dahllöf, A.-G. & Holm, J.: Kinetic analysis of the gait in patients with hemiparesis and in patients with intermittent claudication. Scand J Rehab Med *6*: 166, 1974.
2. Hirschberg, G. & Marks, M.: Analysis of the hemiplegic gait. Ann New York Acad Sci *74*: 59, 1958.
3. Larsson, L.-E., Odenrick, P., Sandlund, B., Weitz, P. & Öberg, P. Å.: The phases of the stride and their interaction in human gait. Scand J Rehab Med *12*: 107, 1980.
4. Pearson, K. G. & Duysens, J.: Function of segmental reflexes in the control of stepping in cockroaches and cats. In: Neural Control of Locomotion (ed. R. M. Herman, S. Grillner, P. S. G. Stein & D. G. Stuart), pp. 519–537. Plenum Press, New York, 1976.

5. Perry, J.: The mechanics of walking. A clinical interpretation. Physical Therapy *47*: 778, 1967.
6. Perry, J.: The mechanics of walking in hemiplegia. Clin Orthoped Rel Research *63*: 23, 1969.
7. Perry, J., Antonelli, D. & Bontrager, E. L.: VA-Rancho Gait Analyser. Final Project Report Pathokinesiology Service Report No. 4. Rancho Los Amigos Hospital, Downey, California 902421, 1976.

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