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SIMULATION OF PARETIC GAIT IN NORMAL SUBJECTS BY LOADING THE ANKLES

Sunday T. Eke-Okoro, Lars-Erik Larsson and Bengt Sandlund

From the Department of Clinical Neurophysiology, University Hospital, S-581 85 Linköping, Sweden

ABSTRACT. Normal subjects were loaded with increasing weights (2–6 kg) applied around the ankles. During these conditions stride length increased in relation to velocity. The percentage duration of single support in relation to stride duration increased. Provided the same load was applied around both ankles increase was symmetrical. Consequently there was also an increase of swing as well as a decrease of stance and of double support. The results contrast in all respects to what was found in previous experiments when the load was carried in the hand. During these conditions stride length decreased as well as the duration of single support. The two experimental conditions differed in that with ankle loading the swing phase was loaded while in the other case stance was loaded. The two types of experiment may help to explain why some patients with paretic legs walk with short strides, while others walk with strides that are normal or slightly prolonged.

Key words: Gait, stride length, load, paresis

The relations between stride frequency and stride length are seldom fully specified in the descriptions of different gait disorders (4). A change in this relation is, however, very often an early sign of a gait disorder. Most often this change seems to be towards a short stride length in relation to stride frequency (1), but sometimes such decrease of stride length does not appear or there is a tendency to a somewhat longer stride in relation to stride frequency (2, and unpublished observations).

Stride length results from the cooperation between the extensors and the flexors of the legs. The flexors lift and swing, the contralateral extensors push the swinging leg forward. The swing phase is dominated by the flexors and the stance by the extensors.

A relative increase of body weight, due either to paresis or to loading will primarily affect the extensors during stance. The result is a decrease of single support and an increase of double support, such as has also been shown to be the case (3). In symmetrical gait the duration of swing will consequently decrease, and, provided velocity is kept constant, stride length will be shorter. If, on the other hand, muscles acting during the swing phase are relatively weakened, then the duration of swing may be expected to increase, partly due to low acceleration and possibly also to low deceleration of the leg. With constant velocity we may therefore expect that stride length will be longer. According to Inman et al. (4) there is in fact a tendency to take longer steps when 2 kg are applied to each foot. No measurement values were presented, however.

The aim of the present paper was to test the last suggestion by investigating the effect of loading the ankles and thus changing the relation between the weight of the legs and the muscles acting during swing. If confirmed, the result may help to explain why in certain patients stride length remains comparatively unchanged in spite of increasing weakness of the legs.

MATERIAL AND METHODS

Subjects

Fifteen subjects consisting of hospital workers and students of different disciplines who were attending a course in biomechanics were used for the experiments. Five of them were women while ten were men. Their age range was 18 to 62 years while the ranges for the height and weight were 1.59 to 1.92 m, and 52 to 97 kg respectively. All were healthy without known neurological or orthopedic disorders.

Method

A foot switch method was used for the recordings. The method has been described previously in detail (6) and it has also been used in another paper to which the present work is pertinent (3). Essentially the subjects walked on a 10 m walkway consisting of a metallic net. They used thin socks with a sole dipped in plastic. Metallic tapes were fastened to the balls and the heels of the feet, and these tapes were then connected to wires which were in turn connected to the recording apparatus by means of a long cable following the subject through a pulley attachment in

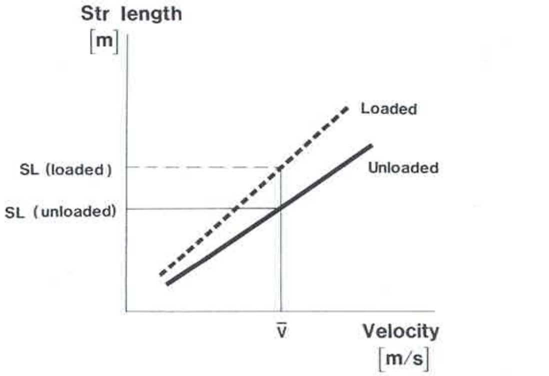

Fig. 1. Calculation of stride lengths with different loads for same velocity. v̄ = mean of all ordinary velocities for each subject, loaded and unloaded. SL = stride length.

the ceiling. The subject was asked to walk in five speeds, ordinary, very slow, slow, very fast and fast in that order. He was free to choose the speed according to the above description.

After walking without any weight for control, subjects walked carrying different weights of 2, 4 and 6 kg applied around both ankles. This aspect of the studies was done by ten of the subjects. Seven of them carried a 4-kg weight on the right ankle after they had walked without load.

Data analysis

In order to study the effect of loading on the stride lengths of the subjects, stride lengths in the control and in the experimental situations were compared at the same velocity for each subject.

The relation between stride length and velocity may be approximated by a straight line for each subject. To be able to compare stride lengths at the same speeds, linear regression lines were calculated for each subject and each experimental situation. The stride length for each subject at unloaded ordinary walking speed was calculated by using the mean velocity for all ordinary speeds for that subject as input in the regression equation (SL = A + B × V). In the same way stride lengths were determined for each experimental situation (Fig. 1), and the percentage change from unloaded stride length calculated. The same procedure was adopted for calculating the single support at the different experimental situations. Instead of velocities, mean stride duration at ordinary velocity was used.

For the subjects who carried a 4-kg weight on the right ankle the percentage changes of the single support phases were compared to each other by means of a graph with an equality line.

For further understanding of the results the following equations are helpful

$$V = SF \times SL \quad (1)$$

$$S = DS_{rl} + SS + DS_{lr} + SW \quad (2)$$

V = velocity, SF = stride frequency, SL = stride length, S = stride duration, DS = duration of double support.

The subscripts rl and lr mean the direction of weight transfer (rl = right to left, lr = left to right).

SS = duration of single support, SW = duration of swing.

In symmetrical gait SS = SW.

RESULTS

In the test conditions there was an obvious decrease of maximum as well as of ordinary velocity in comparison with the control values.

In the upper part of Fig. 2 is shown the percentage increase in stride length for all 10 subjects at ordinary velocity when both legs were loaded at the ankles with 2, 4 and 6 kg respectively. The ordinary velocity used for calculation was the average between all four tests for each subject. It is seen that stride length increased with load. The increase for all points was statistically significant in relation to zero load ($p<0.001$, paired t-test). Stride frequency decreased as a consequence of the increase of stride length at constant velocity (eq. 1).

For comparison the lower part of Fig. 2 illustrates the percentage decrease of the stride length with increasing load carried in the hand. The values

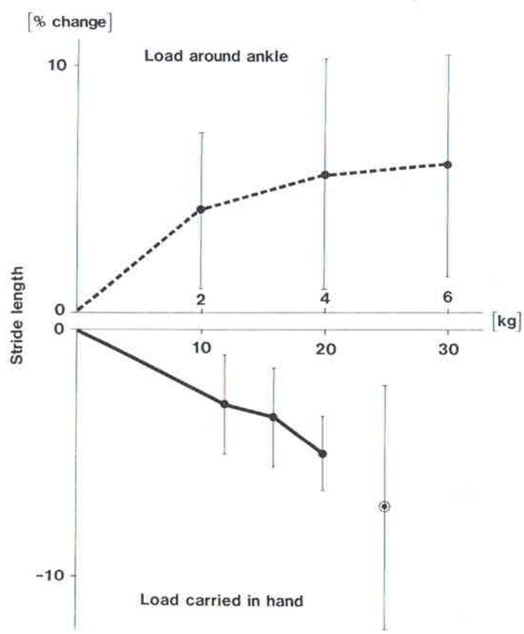

Fig. 2. Mean percentage change of stride length with load at constant velocity. Upper part: load around the ankle (2–6 kg) $n=10$. Lower part: load carried in hand (12–24 kg) $n=9$ for 24 kg and 3 for the other points. ±1 SD is represented by the vertical lines. The values in the lower part are taken from previous work for comparison.

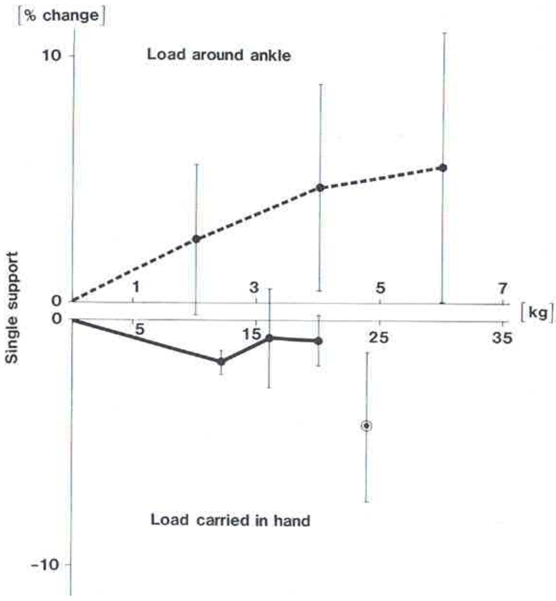

Fig. 3. Mean percentage change of single support with load at constant stride duration. Upper part: load around the ankle. Lower part: load carried in hand. Same experiments as in Fig. 2.

are obtained from 9 subjects already described (3) and are calculated as above.

In the same way the upper part of Fig. 3 shows an increase of single support with bilateral ankle loading. The increase was statistically significant both for 4 kg ($p<0.01$) and 6 kg ($p<0.05$) but not for 2 kg. The stride duration used for calculation was the average for ordinary speed for all subjects. Since in symmetrical gait swing has the same duration as single support, the inevitable consequence will be a decrease of stance and double support (eq. 2). These results were in fact obtained.

The lower part of the figure shows how single support decreased when the load was carried in the hand by the same subjects as described above.

Fig. 4 shows the percentage change of the absolute values of single support when the right leg was loaded with 4 kg at the ankle. It is seen that single support increased on the left side compared with the right. This means that swing increased on the right side and consequently stance decreased on the right. Double support increased when weight was transferred from right to left leg and decreased when transferred in the reverse direction.

In addition, slopes of the regression lines in the relations stride frequency to stride length were compared for the unloaded with the different ankle loaded conditions. There was a very slight tendency to a decrease in most subjects, but this was not statistically significant (paired t-test). The increase in the stride length with an increase of the load around the ankle must therefore be valid for all velocities tested.

DISCUSSION

In a previous paper (3) we asked normal subjects to carry a weight of 16 to 24 kg in the hand. We then found a decrease of stride length and of single support, primarily in high velocities. Consequently stride frequency increased (stride duration decreased). The changes were symmetrical. Since single support decreased, swing decreased also while stance and double support increased. In the present study, where the weight was applied around the ankles, the results contrast in all these respects.

The difference is explained by the difference of application of the load in the two test conditions. In the first condition the stance phase was mainly loaded. The subjects therefore tended to rely on both legs as much as possible, with a shortening of single support and an increase of double support. In the condition of ankle loading, the increased mass of the leg will mean an increased difficulty to accelerate (and decelerate) the leg during swing. The

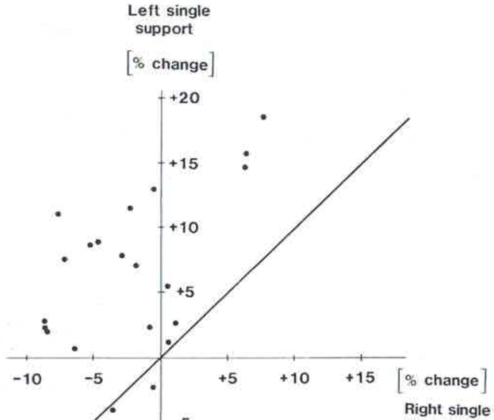

Fig. 4. Comparison of percentage changes for left and right single support. Load was carried around the right ankle. 7 subjects. A line of equality is drawn for comparison.

stride frequency will therefore decrease. To maintain a constant walking speed the stride length must increase.

In most gait disorders a relative shortening of the stride length is observed. In a previous paper (3) we tried to explain this by assuming that a paresis may partly be considered as a misrelation between muscle strength and load.

According to this, weakness during stance will result in short strides (Fig. 2, lower part). However, in certain patients stride length is either normal or slightly increased in spite of their paresis. In such cases it is possible to consider that the weight of the leg is increased in relation to those muscles involved during swing, a condition that is comparable to the ankle loading in the present study (Fig. 2, upper part). It may be significant that these "normal" stride lengths have been observed in patients with neuromuscular disorders (2) where it is known that the proximal muscles often are more affected than the distal ones.

In addition patients with above-knee amputations take longer steps with the amputated leg than with the unaffected one (5) which may be explained by the weight of the prosthesis.

The experiments with one leg loaded were done to simulate the case of a patient with one weak leg only. Since we found that the swing on the loaded side was prolonged the findings are consistent with the findings described above.

In patients with hemiparesis where the whole leg is weak the same effect appears, i.e. the swing on the weak side is prolonged in relation to control subjects. On the contrary, in patients with peripheral peroneal paresis where only distal muscles are weak the swing phase is not prolonged (3).

It seems therefore that weakness during swing will result in comparatively long strides. The fact that a leg may be weak during both swing and stance will explain why in some patients stride length remains "normal" in spite of paresis. The shortening tendency during stance will cancel the lengthening tendency during swing.

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Address for offprints

S. T. Eke-Okoro
Department of Clinical Neurophysiology
University Hospital
S-581 85 Linköping
Sweden