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VARIATION OF TIME–DISTANCE PARAMETERS OF THE STRIDE AS RELATED TO CLINICAL GAIT IMPROVEMENT IN HEMIPLEGICS

J. Mizrahi, Z. Susak, L. Heller and T. Najenson

From Loewenstein Rehabilitation Hospital, Ra'anana, Israel

ABSTRACT. Gait improvement was evaluated in two different ways for 20 hemiplegics during an average follow-up period of 8 weeks in early rehabilitation. One way was by weekly measuring time–distance parameters of the stride on an electrical contact system walkway. The second was a clinical evaluation of gait improvement. The parameters studied were contact time, double contact time, stride length, velocity, time symmetry and distance symmetry. The variation of each of these parameters during the follow-up period was correlated with the variation in gait evaluated clinically. This correlation showed that both evaluations agreed, supporting the usage of time–distance parameters as a tool for an objective follow-up of walking ability of hemiplegics during rehabilitation.

Key words: Gait, hemiplegia, rehabilitation

Walking ability of hemiplegic patients starts as soon as weight-bearing on the plegic leg becomes possible. In its early stages this ability is usually limited and often some kind of support is required during walking. In most cases the walking ability of hemiplegics improves with time and this improvement becomes the main expression of locomotor rehabilitation of these patients.

Numerous reports on hemiplegic gait are to be found in the literature. The gait which is typical of hemiplegia was described as slow, laborious and abrupt, as compared with that of normals (9), the reason being that these patients depend entirely on primitive patterns and lack many of the shock-absorbing and energy conserving mechanisms available to the peron with normal selective motor control and accurate proprioception.

The gait of hemiplegics has been evaluated by subjective methods (2) and is reported to be variable. A common clinical observation was that the stance phase on the affected side was considerably shorter than that of the sound leg. A more objective method included motility and functional evaluation as well as strength measurements of the legs (10). The main conclusion reached was that facilitation exercises did not improve the parameters measured.

The purely objective methods of gait analysis in hemiplegics included reactive force measurements (1, 3, 5), kinematic measurements (4, 6, 7), goniometry (12) and electromyography (3, 13). Some important findings in these works can be summarized as follows: stance phase is shorter than swing phase in the plegic leg; push-off of the plegic leg is typically weak; there is a lateral asymmetry in reactive forces and electromyography activity between the two legs.

A relatively simple and accurate method of gait evaluation for hemiplegics is based on time–distance parameters of stride (4, 11). In a separate paper (8) we have described a system for measuring of these parameters and its use to express objectively locomotor rehabilitation progress in hemiplegics. In this study we report on variations in the parameters measured for 20 patients in early rehabilitation during a follow-up program and relate them to gait improvement evaluated clinically.

METHODS

Time–distance parameters of the stride were measured by a 5-m long electrical contact system installed on the floor of a 10 m walkway. The electrical contact system, schematically shown in Fig. 1, was described fully elsewhere (8). In principle, it consisted of an electrical circuit containing a power supply and several resistance strips. Conductive strips stuck on the walkway were connected between these resistors. When the conductive and resistive strips were short-circuited by the patient's shoes (to which self-adhesive conductive tapes were attached), a circuit was completed and electrical current flowed. This current depended on the location where the 'short' occurred. After amplification, a graph of current which was proportional to distance of the patient along the walkway) versus time was recorded. A typical output is presented schematically in Fig. 2. From this graph the following factors can be measured: contact time, double contact time, swing time, stride time, stride length, all separately but simultaneously for the left and the right foot. Velocity was calculated as the ratio between stride length and

Table I. *Details of the patients tested, their follow-up period, their clinical grading and score*

Patient	Sex	Age	Plegic Side	Weeks from stroke to first test	Follow-up duration (weeks)	Clinical grading: At beginning of follow-up	Clinical grading: At end of follow-up	Clinical score
1	♂	70	R	6	6	4	4	0
2	♂	62	R	16	11	5	1	+
3	♀	62	R	22	10	4	2	+
4	♂	76	R	12	7	2	1	+
5	♀	56	R	21	13	4	4	0
6	♀	55	R	6	6	5	2	+
7	♀	82	R	5	6	5	3	+
8	♂	73	R	20	6	3	2	+
9	♂	75	R	17	6	4	3	+
10	♂	75	R	11	6	2	1	+
11	♂	51	L	7	7	3	2	+
12	♀	54	R	16	10	3	1	+
13	♀	42	L	13	16	5	3	+
14	♀	77	R	20	6	1	1	0
15	♂	74	R	15	6	4	1	+
16	♂	69	L	8	7	4	2	+
17	♀	46	L	32	7	4	4	0
18	♀	55	L	10	11	5	2	+
19	♀	58	R	5	6	3	1	+
20	♂	80	R	7	13	5	3	+

stride time. Symmetry of the stride was defined as related to time and distance as follows:

$$\text{Symm} = \frac{A_p^{i+1} - A_h^i}{A_p^{i+1} - A_p^i}$$

where
A = time or distance of first foot contact, as required
p = plegic leg
h = healthy leg
i = typical step.

By symmetry we describe the relative time or distance of the healthy leg between two consecutive first foot contacts of the plegic leg. In healthy persons the first foot contact is normally the heel strike and symmetry is near 0.5.

Each of the above parameters was calculated from every two consecutive steps in a walking test of the patient and means and standard deviations were determined.

PATIENTS

Twenty patients, 10 females and 10 males, hospitalized at the Loewenstein Rehabilitation Hospital in Ra'anana, participated in this study. These patients were referred to this Hospital from general hospitals, in which they were hospitalized after stroke. Details on the patients tested and on their follow-up periods are presented in Table I. Every patient was tested once a week, with two runs in every test, for an average follow-up period of 2 months approximately. This period corresponded to an average of 6 weekly walking tests (varying from 5 to 9) because of occasional inability of some patients to attend the tests.

The means and standard deviations of the parameters of the stride were calculated for every patient and for each walking test during the follow-up period. The trend of variation of these parameters was characterized by means of either a logarithmic or exponential regression curve. At the same time, gait improvement was clinically evaluated. The clinical evaluation of the walking ability of the patients was done according to the following grading.

Grade 1: walking freely without any support, or with a cane
Grade 2: walking with a cane indoors only
Grade 3: walking with a cane or a quadropod with supervision of a therapist
Grade 4: walking with supervision and support of a therapist

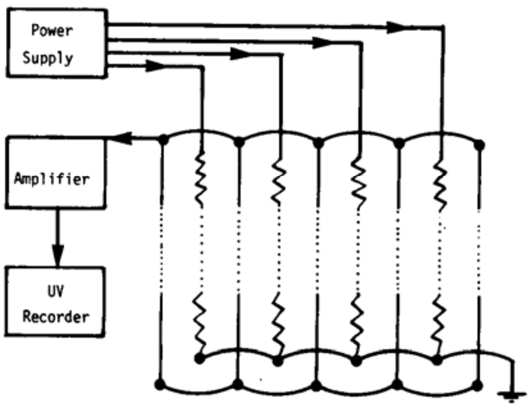

Fig. 1. Schematic description of the electrical contact system and instruments used.

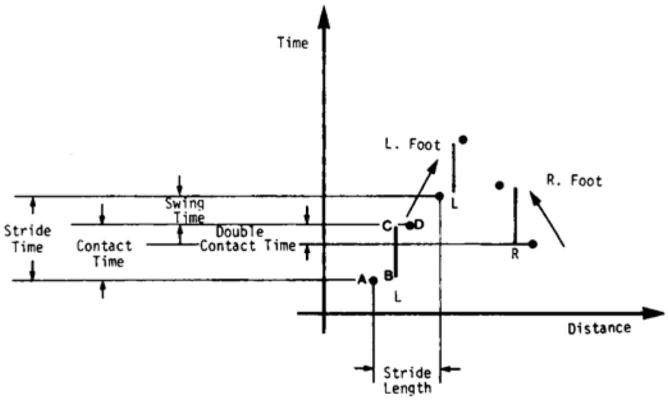

Fig. 2. Scheme of a typical output and definition of the time–distance parameters of the stride. (A = heel-strike, BC = foot-flat, D = toe-off).

Grade 5: walking with supervision, support and facilitation of a therapist.

Every week each patient was graded according to his achievements, so that at the end of the follow-up period it was possible to note whether his walking ability had improved, decreased or remained unchanged. Unchanged gait was scored 0 (zero) and those who improved were scored +, as shown in Table I. Correlations between the objective and clinical evaluations were made.

RESULTS

Variation in the parameters measured in the gait laboratory during the follow-up period can be presented in terms of the coefficients for logarithmic curve fitting, $y = b \ln x$, a, b, and the correlation coefficient r; or in terms of exponential curve fitting, $y = a \exp(bx)$, which was used whenever this fitting gave a higher correlation coefficient than the logarithmic curve fitting. Table II, in which variation of the velocity parameter is shown for all patients, demonstrates such a presentation. In the first and second columns we find the observations at the beginning and at the end of the follow-up time, respectively and in the following three columns—values of the coefficients of the curve fittings, a, b, and r^2.

Fig. 3 presents the average variation of the contact time during follow-up for all the patients. Con-

Table II. *Variation in velocity (cm/sec) during follow-up*
All curve fittings were logarithmic, except in cases denoted by an asterisk, where exponential curve fitting was done

Patient	Observation at beginning of follow-up	Observation at end of follow up	a	b	r^2
1	13.02±2.88	11.56±1.66	13.34	−1.48	0.52
2	12.69±1.12	31.19±4.09	12.44*	0.09*	0.97*
3	21.55±3.71	24.55±2.65	20.86*	0.01*	0.31*
4	34.01±6.99	45.06±5.08	33.36	5.25	0.83
5	13.80±2.37	11.29±0.84	15.35*	−0.02*	0.20*
6	19.92±1.84	23.12±4.62	17.34*	0.03*	0.22*
7	15.32±3.21	17.62±1.61	20.20	0.45	–
8	19.32±1.37	19.94±2.16	18.73	0.68	0.05
9	11.54±2.07	21.52±1.20	10.57*	0.01*	0.40*
10	28.08±4.07	46.54±8.25	25.58	9.84	0.79
11	10.25±2.37	18.71±1.09	8.80	5.04	0.74
12	16.21±2.30	21.34±3.69	18.99	2.40	0.18
13	12.09±2.36	15.82±2.97	8.98*	0.03*	0.41*
14	27.42±1.31	31.65±4.36	25.52*	0.04*	0.82*
15	18.12±2.22	27.69±2.03	17.68	3.46	0.21
16	7.73±0.80	12.74±2.59	8.34	2.36	0.86
17	6.05±2.32	7.61±1.34	6.07	0.51	0.97
18	7.91±0.26	33.12±7.19	2.66	11.39	0.86
19	27.73±3.50	52.71±3.92	29.72	10.47	0.59
20	14.44±1.25	18.53±3.05	15.37	1.89	0.66

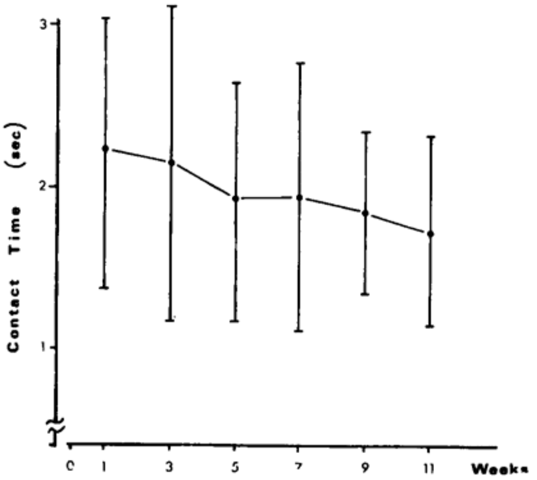

Fig. 3. Average variation (±SD) in contact time of the plegic leg during follow-up for all the patients.

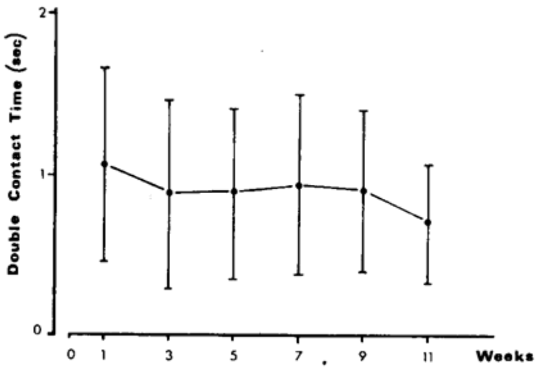

Fig. 4. Average variation (±SD) in double-contact time during follow-up (all patients).

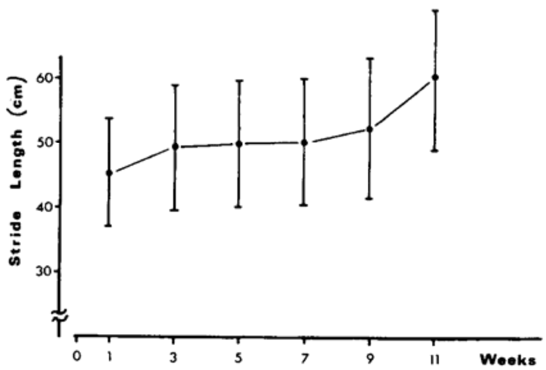

Fig. 5. Average variation (±SD) in stride length of the plegic leg during follow-up (all patients).

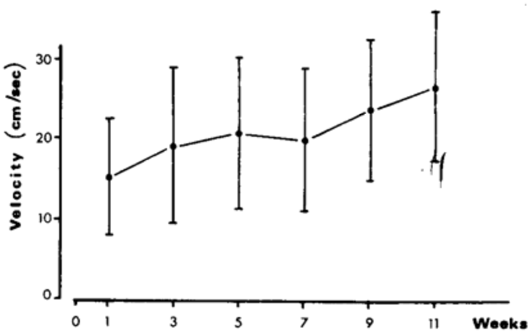

Fig. 6. Average variation (±SD) in velocity during follow-up (all patients).

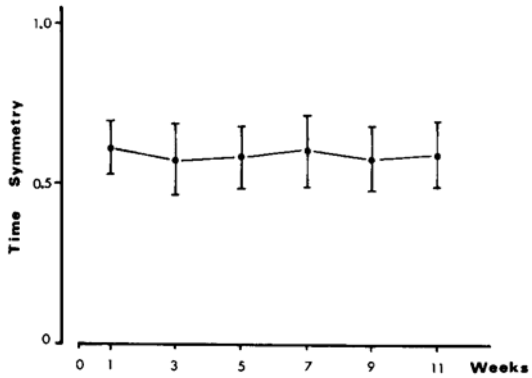

Fig. 7. Average variation (±SD) in time symmetry during follow-up (all patients).

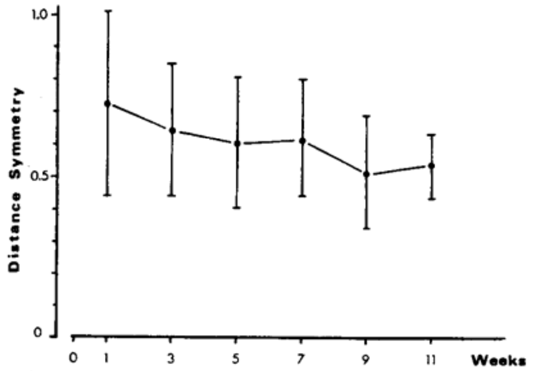

Fig. 8. Average variation (±SD) in distance symmetry during follow-up (all patients).

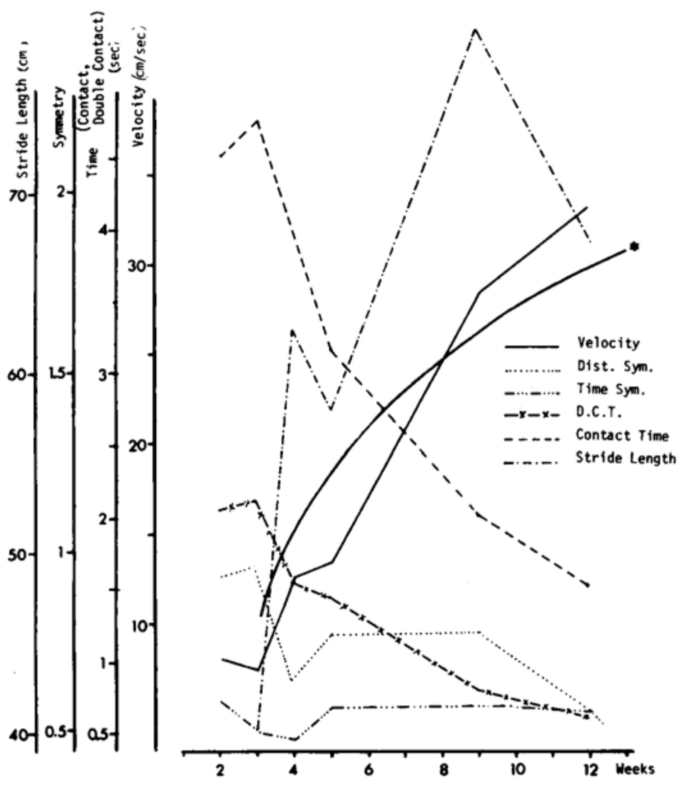

Fig. 9. Graphical presentation of the results obtained during the follow-up period for patient no. 18, who was characterized by a consistent improvement in the gait parameters. The regression curve was drawn for the velocity parameter.

tact time in the plegic leg decreased (*b* negative) in 16 of the 20 patients (80%). In 8 patients (40%) the correlation coefficient was higher than 0.68. Fig. 4 presents the average varition of the double-contact time during follow-up. This parameter represents the time elapsed between first foot contact of the healthy leg and last foot contact of the plegic leg, which follows. This parameter decreased in 16 patients (80%). In 10 patients the correlation coefficient was higher than 0.70.

Fig. 5 shows the average variation of stride length during the follow-up. In 15 patients (75%) an increase in this parameter was noted, and of these patients in 13 was the correlation coefficient higher than 0.60. Of the other 5 patients, in 3 was the correlation coefficient higher than 0.70.

Average variation of the velocity during follow-up for all patients is shown in Fig. 6. In 18 patients (90%) there was an increase in velocity, as can be seen from Table II. In 13 of these patients the correlation coefficient was higher than 0.63.

Figs. 7 and 8 show the average time and distance symmetry variations, respectively. These parameters should be examined according to their closeness to 0.50. Time symmetry improved in only 9 patients (45%), of which in only 2 patients was the correlation coefficient above 0.80. In the other patiens this parameter remained unchanged, except in one where a slight deterioration was noted. Distance symmetry improved in 14 patients (70%), of which in 6 the correlation coefficient was higher than 0.75. Of the remaining 6, only in 2 patients was there a deterioration in this parameter, with correlation coefficient below 0.60.

We demonstrate the results graphically for 2 patients, nos. 18 and 20, who showed extreme results in the gait laboratory. Patient no. 18 was characterized by a consistent improvement in most of the gait parameters, as shown in Fig. 9. He started off with two quadropod canes, which were replaced by two ordinary canes in the third week of follow-up. From the 8th week onwards this patient walked freely. In patient no. 20, improvement was moderate, with alternating progession and regression, as shown in Fig. 10. This feature finds expression in the relatively low correlation coefficients of this patient. In both Figs. 9 and 10 the regression curve was added for the velocity parameter.

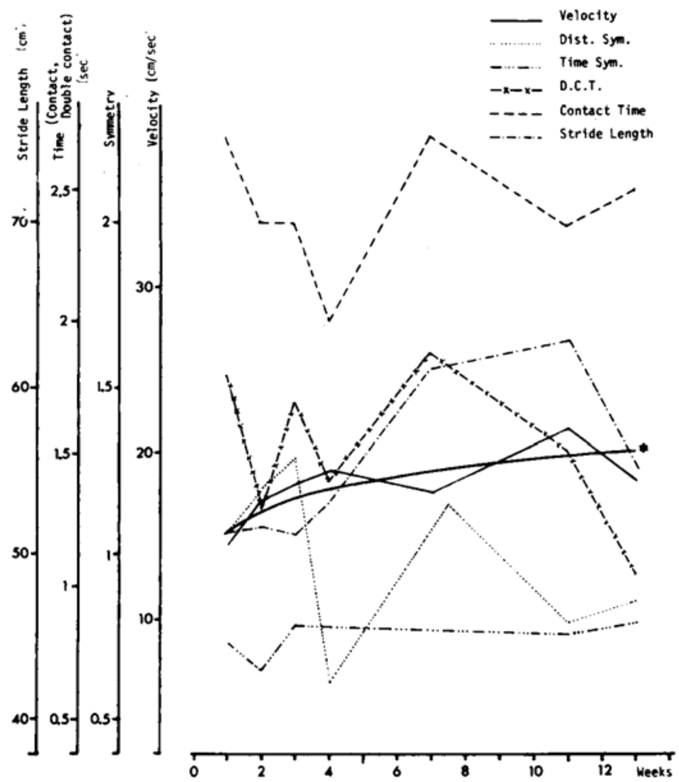

Fig. 10. Graphical presentation of the results obtained during the follow-up period for patient no. 20, whose improvement was moderate with alternate progressions and regressions. The regression curve was drawn for the velocity parameter.

Clinically, 16 patients (80%) improved in their walking ability during the period of follow-up. The condition of patients 1, 5, 14 and 17 remained unchanged. It should be added that while patients 1, 5 and 17 started as grade 4 walkers and remained so, patient no. 14 walked well (grade 1) from the beginning.

Correlation between variation at clinical evaluation and variation at objective evaluation through the parameters of the stride is given in Table III. A significant variation of every parameter was taken when the correlation coefficient was higher than 0.316 ($r^2 = 0.1$). In stride length and velocity, correlation with the clinical observation was found in 16 (80%) of the patients. In contact time in 11 (55%) of the patients and double contact time as in distance symmetry the correlation was in 8 (40%) of the patients. In time symmetry, correlation was in only 4 (20%) cases.

DISCUSSION

As has been described in the results, contact time of the plegic leg decreased in 80% of the patients. To explain this result, we should remember that contact time in hemiplegics is usually shorter in the plegic leg than in the healthy leg. Improvement in the state of the patient could imply that a decrease in contact time of the plegic leg is accompanied by a greater decrease in the contact time of the healthy leg. This, however, was not proved, since time symmetry changed only slightly and the shortening in contact time could be attributed to increase in velocity.

The same applies to double contact time, which also decreased in 80% of the patients. In a complete cycle there are two double-contact times, which are not necessarily equal. The double-contact time expressed here is the time between heel-strike of the healthy leg and the succeeding toe-off of the plegic leg. In hemiplegic this double-contact time is longer than the other one due to disturbances in coordination of the plegic leg, and it should shorten with progress in rehabilitation.

Time symmetry was above 0.5 in all cases except one, and it remained so during the follow-up period. This agreed with the fact that the swing phase of the plegic leg was more difficult and lasted longer

Table III. *Correlation between variation at clinical evaluation and variation at walkway analysis through each of the parameters of the stride*
× denotes existence of correlation

Patient	Contact time	Double-contact time	Stride length	Velocity	Distance symmetry	Time symmetry
1	×	×	×	×	×	×
2	×	×	×	×	×	
3		×	×	×		
4	×	×	×	×		
5			×	×		
6			×	×	×	×
7	×	×				
8						
9	×		×	×	×	
10	×		×	×	×	
11	×		×	×		×
12			×	×	×	
13			×	×		
14	×					
15			×	×		×
16			×	×		
17			×			×
18	×		×	×	×	
19	×	×	×	×		
20	×	×	×	×	×	

vis-à-vis the healthy leg; therefore its first contact came later than the half-way time point between two consecutive heel-strikes of the healthy leg. Improvement in time symmetry occurred in only 45% of the patients.

More direct indicators of improvement in the locomotor state of the patient were stride length, which increased in 75% of the patients, and velocity, which increased in 90%. In 3 patients, though, the increase in velocity was accompanied by a decrease in stride length.

To visualize the significance of variation in distance symmetry it is useful to refer to Fig. 11. Part (*a*) of this figure shows three succeeding steps denoted chronologically by 1, 2 and 3. The plegic leg progresses first and the healthy leg follows it to the same line. In this case, distance symmetry is by definition equal to 1. Fig. 11 (*b*) the healthy leg leads and the plegic leg follows it and close the gap. In this other case, distance symmetry is equal to zero. From these two extreme examples we can interpret the values obtained for this parameter. In those cases where distance symmetry exceeded 1, the plegic leg led and the healthy leg lagged behind, without being able to close the gap between them. There were 4 patients of this type, all of whom improved considerably. One of them, patient no. 9, even reached in his final follow-up test a 0.5 distance symmetry. Distance symmetry between zero and 1 can be regarded as intermediate cases of the examples illustrated in Fig. 11 (*a, b*). Patient 12 was exceptional and at the beginning of follow-up each of his legs stepped forward relative to each other; however, heel-strike of the healthy leg was less than half-distance between two consecutive heel-strikes of the plegic leg.

The results obtained in this study can be compared quantitatively to those reported in the literature (6) regarding velocity and stride length. By doing so it is found that the values obtained by us

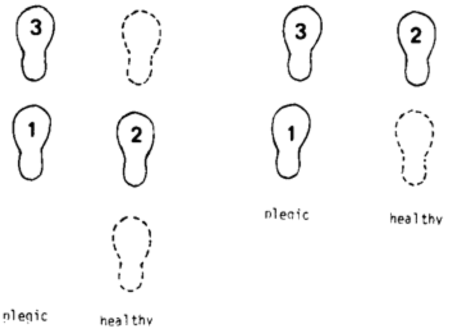

Fig. 11. Visualization of distance symmetry in two extreme cases: (*a*) distance symmetry =1, (*b*) distance symmetry =0.

were considerably lower than those previously reported. This was mainly due to the fact that the follow-up in our group of patients started only a few weeks after stroke, as compared with approximately one year in the earlier report (6) This difference may indicate that the locomotor rehabilitation period can extend in some cases over a period of one year or more.

It is of interest to estimate the error in our method. As reported previously (8), each channel had a maximal distance error of 1 cm. The common error of both channels was obtained by measuring the stride length and velocity separately for each foot. Comparison of the results obtained gives an idea on the required common error. By doing so, and by adding 1% error for the paper speed we get a total of 2.5% error, which is much smaller than the standard deviation of the mean of the parameters measured for each foot.

Apart from the attempt to investigate the gait characteristics of hemiplegic patients, we tried in this study to develop a tool for an objective follow-up of the walking ability of these patients during rehabilitation. The main objective in this case was to discover when a given patient reached a state where he did not improve considerably with time in spite of physical therapy. On reaching such a stage when the patient is unlikely to progress, he can be discharged from the rehabilitation center. This stage can be seen in cases where the logarithmic curve fit after a number of tests tends to level off, with a high correlation coefficient ($r>0.8$), as demonstrated in patient no. 20 in the velocity parameter (Fig. 10). As a final remark it is interesting to note that the correlations between the clinical evaluation and mechanical evaluations gave the same grading as the mechanical parameters obtained from the gait analysis only (Table III).

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Address for offprints:

J. Mizrahi
Loewenstein Rehabilitation Hospital
Ra'anana
Israel