Prosthetics and Orthotics International, 1996, 20, 153-158

Influence of speed on gait parameters and on symmetry in trans-tibial amputees

E. ISAKOV*, H. BURGER**, J. KRAJNIK**, M. GREGORIC** and C. MARINCEK**

**Orthopaedic Rehabilitation Department, Loewenstein Rehabilitation Hospital, Tel Aviv University School of Medicine, Ra'anana, Israel*

***Institute for Rehabilitation, Ljubljana, Slovenia*

Abstract

Normal gait is characterised by a high level of inter-leg symmetry of gait parameters. Therefore, efforts in rehabilitation of amputees are directed at the construction of a prosthesis which provides normal leg function and allows a more symmetrical gait. Analysis of the gait of trans-tibial amputees was performed when they were ambulating at their own freely selected speed and at a faster speed. The effect of speed on selected gait parameters in each leg was evaluated and the influence on symmetry established by comparing the inter-leg changes for each of the selected parameters. The faster gait trail affected significantly all temporal and distance parameters in both legs but not the level of symmetry between legs. At the faster speed, the hip angles at heel-strike and during swing and the knee angle during load response, in the normal leg, and the knee angle during swing in the amputated leg, all increased significantly. Speed of gait significantly affected symmetry between knee angles as reflected by the increased differences measured during load response (from 2.62 ±5.2 to 7.06 ±4.2 degrees) and during toe-off (from 1.80 ±7.4 to 9.50 ±9.1 degrees). Timing and sequence of selected gait events, as related to stride time, were not significantly affected by speed of gait. These results might contribute to a better understanding of gait characteristics in trans-tibial amputees and provide design guidance for prosthetic components.

All correspondence to be addressed to Dr Eli Isakov, Head, Orthopaedic Rehabilitation Dept., Loewenstein Hospital, Ra'anana, 43100, Israel.

Introduction

Gait is a complex process which differs between individuals and also from step to step in any individual. Normal gait is characterised by almost identical movements performed by both lower limbs with only small differences in kinematic and kinetic parameters. Symmetry of gait can be measured by different methods and can be reflected through various gait parameters.

Temporal and/or distance variables have been used to identify symmetry of gait in amputees and the literature suggests that amputees demonstrate asymmetrical gait patterns. Duration of stance time on the prosthetic and normal legs have been measured and symmetry defined as the difference, in seconds, between both legs. At the final stage of prosthetic rehabilitation, an asymmetry of 0.02 second between stance phases has been measured (Baker and Hewison, 1990). In other studies it was noted that during amputee gait, step-length performed with the normal leg was shorter and accomplished in less time (Robinson *et al.*, 1977), and stance time was longer on the normal leg than on the opposite leg (Breakey, 1976). Symmetry of gait has been evaluated also by comparing the ground reaction forces measured in both limbs by means of double force-plates (Isakov *et al.*, 1992). In that study, complete symmetry between limbs was considered to reflect a state where the acting forces are of equal magnitude in each leg. In trans-tibial amputees with optimally fitted prostheses, asymmetry of mediolateral forces was measured as 1.6%, of anteroposterior forces 15%, and of vertical forces 6.9%, Another method to establish symmetry of gait was based on bilateral leg/thigh angle-angle measurements (Hurley *et al.*, 1990). An estimate of congruity between two angle-angle configurations was obtained and a calculated recognition coefficient served as the criterion for intercurve comparisons expressing degree of symmetry. The mean symmetry obtained for trans-tibial amputees was 0.802 ±0.044 while lower limb mean symmetry in normals was 0.881 ±0.011. Symmetry of temporal and distance parameters was measured also in normals during gait with three speeds; slow, free/comfortable, and fast. Symmetry was determined by the use of equations where results obtained in the left leg were divided by those of the right leg (Hirokawa, 1989). During free speed, the highest value of symmetry was obtained for step length, 0.98, for stance time, 0.96, for step width, 0.93, for double limb support, 0.90, and foot angle, 0.74. When comparing slow and fast speeds, it was noted that symmetry of gait became higher when speed increased. However subjects who had the highest symmetry for one parameter did not always show high values for all others.

Gait symmetry evaluation can be applied to the process of prosthetic rehabilitation and used for different purposes. Gait symmetry has been monitored during the rehabilitation period to evaluate rate of progress. Baker and Hewison (1990) showed that symmetry in stance time improved by comparing results obtained at the initial and final stages of rehabilitation. Gait symmetry was also used to evaluate the contribution of better stability of the stump-socket complex to the quality of gait (Isakov *et al.*, 1992). In that study a Swedish knee cage was attached to a patellar-tendon-bearing prosthesis for trans-tibial amputees with very short stumps. The obtained improvement in stability was reflected in increased symmetry in stance duration and ground reaction forces measured in both limbs. Symmetry of temporal and kinematic gait parameters (Boonstra *et al.*, 1993) and electromyographic activity (Culham *et al.*, 1986) have been used to evaluate the effect on gait of different prosthetic components.

Evaluation of lower limb symmetry may contribute to a better understanding of factors interfering with normal patterns of gait in trans-tibial amputees. Therefore, this study was directed to investigate gait characteristics of two different speeds in trans-tibial amputees and the influence of speed on symmetry of selected gait parameters obtained.

Subjects

Fourteen trans-tibial amputees (3 women and 11 men) volunteered to participate in the present study. The subjects' mean age was 40.5 ±12.7 years, (range; 27 to 65 years). Amputation was performed on the right lower limb in 5 subjects and on the left in 9 subjects. Twelve amputations were a result of trauma, one was due to thrombosis, and one due to peripheral arterial disease.

The mean time elapsed from amputation to the reported test was 16.9 ±14.6 years (range; 3 to 46 years). The mean time for receiving the first prosthesis was 5.2 ±4.1 month (range; from one to 18 months). Nine prostheses were patellar-tendon-bearing, and five were patellar-tendon-supracondylar prostheses and all had a solid-ankle-cushion-heel foot. All subjects were excellent walkers who used their prostheses on a regular basis and were conducting an active normal family life. Subjects walking distance at free speed ranged from 0.5 to 10 km with mean distance of 3.14 ±1.4 km.

Methods

Subjects underwent two tests; first while walking at their own comfortable free speed and then when asked to walk at a faster speed. In one subject only the first test was performed. Before testing, all subjects were assessed by a prosthetist to ensure optimal fit and function of the prosthesis. None of the subjects had stump problems (blisters, sores, swelling, pain etc.) on the testing session. All subjects were tested ambulating with no supporting aids. The following gait parameters were measured; temporal parameters of stance, swing, double-limb support, step time and length. Hip joint angle was measured at heel-strike (1), at peak stance extension (2), at toe-off (3), and at peak swing flexion (4). Knee joint angle was measured at load response (5), at toe-off (6), and at peak swing flexion (7). Sequence and time of occurence, relative to stride period, of the following gait events; knee peak load response (a), peak extension of hip during stance (b), toe-off (c), peak knee flexion during swing (d), and peak hip flexion during swing (e) (Fig. 1).

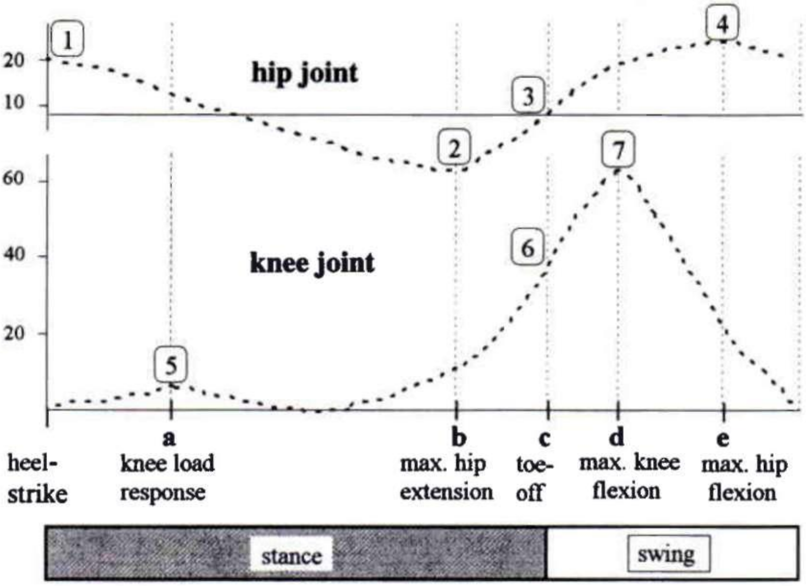

Figure 1. Sequence and time of occurrence, relative to stride period, of the measured gait events.

Temporal and distance parameters were measured by means of a 10 m long x 2 m wide non-slip conductive rubber walkway. Strain gauge goniometers were used to measure angular movements of the knee and hip joints. Signals from the electric contact system walkway and from the electrogoniometers were routed to an on-line computer and analysed. Data were analysed using commercial software for computation and processing and for statistical analysis. The significance level of the differences was determined by using Student's t-test. Results were deemed to be statistically significant at $p<0.05$.

Table 1. Means and standard deviations of gait variables measured during free and fast speed ambulation.
* Differences are significant at $p<0.001$

		Speed of gait	
Gait variables		Free	Fast
steps no.		21.71 ±4.0	20.76 ±3.7
stride time	(s)	1.32 ±0.1	1.07 ±0.0*
stride length	(cm)	123.28 ±12.1	147.15 ±9.9*
cadence	(steps/min)	91.79 ±9.2	111.51 ±9.5*
speed	(cm/s)	94.85 ±15.6	138.00 ±13.0*

Results

Values of the main gait variables measured during free and during fast speed are summarized in Table 1. At the fast speed there was a significant change of all variables ($p<0.05$). The mean number of steps analysed in each of the two tests was about 21. Table 2 details the means and standard deviations of the selected temporal and distance parameters measured on the amputated and normal sides

Table 2. Means and standard deviations of gait parameters measured separately on the amputated and on the normal sides during free and fast speed of ambulation. All differences are significant at $p<0.001$

		Amputated side		Normal side	
Gait events		Free speed	Fast Speed	Free speed	Fast speed
Stance	(s)	0.89 ±0.10	0.71 ±0.05	0.92 ±0.13	0.73 ±0.06
Swing	(s)	0.42 ±0.07	0.35 ±0.05	0.40 ±0.07	0.34 ±0.06
DLS	(s)	0.217 ±0.05	0.166 ±0.03	0.274 ±0.08	0.206 ±0.05
Step time	(s)	0.68 ±0.07	0.55 ±0.05	0.64 ±0.08	0.52 ±0.06
Step length	(cm)	63.50 ±6.9	77.00 ±6.1	60.92 ±6.5	72.15 ±5.9

Table 3. Results are means and standard deviations of differences between the amputated and the normal sides measured during free and fast speed ambulations. All differences are insignificant(p>0.05)

		Amputated – normal side differences during:	
Gait events		Free speed	Fast speed
Stance	(s)	0.022 ±0.05	0.013 ±0.05
Swing	(s)	0.023 ±0.04	0.013 ±0.04
DLS	(s)	0.056 ±0.05	0.040 ±0.04
Step time	(s)	0.034 ±0.08	0.027 ±0.08
Step length	(cm)	2.28 ±4.7	5.00 ±7.1

during two different speeds of gait. All values were significantly affected by speed but not the inter-leg differences (Table 3). In Table 4, means and standard deviations of hip and knee angles measured at selected gait events are compared in each leg during free and fast gait. Speed significantly affected normal leg hip angle during heel-strike and swing, and knee angle during load response. On the amputated side, knee angle increased significantly on swing only. Inter-legs angle changes were significant for load response and toe-off between free and fast speed of gait (Table 5). Timing of occurrence of selected gait events as related to stride time (expressed in percentage of stride time) are detailed in Table 6. Results obtained in free speed are compared with fast speed for each leg separately. Differences are insignificant as were inter-legs changes (Table 7).

Discussion

Gait inter-leg symmetry is considered to be perfect when all measured gait parameters in both lower limbs are equal. Symmetry between legs indicates a normality of gait, and therefore prosthetic rehabilitation aims at fitting amputees with an artificial limb which will reproduce as closely as possible the performances of a normal leg. Gait analysis is therefore used to evaluate the benefit of certain prosthetic components by measuring how they affect level of inter-legs symmetry as well as the energy cost of gait (Isakov *et al.*, 1985; Barth *et al.*, 1992; Boonstra *et al.*, 1993).

In the present work the authors aimed at identifying gait parameters in trans-tibial amputees, and explored whether their symmetry is speed related. For this purpose, chosen gait parameters were measured during free and fast gait trails and inter-leg symmetries were compared. The mean speed performed in the fast gait trail was higher than the comfortable

Table 5. Results are means (±SD) of differences in joints angle (in degrees) measured between both limbs. Free and fast ambulation speed are compared. *Differences are significant at p<0.05

	Amputated – normal side differences during:	
Joint angle measured at	Free speed	Fast speed
Hip:		
heel-strike	2.81 ±6.0	2.30 ±4.7
max. stance extension	0.74 ±3.3	0.16 ±3.2
toe-off	2.73 ±2.4	3.97 ±3.3
max. swing flexion	1.80 ±5.2	1.43 ±5.0
Knee:		
load response	2.62 ±5.2	7.06 ±4.2*
toe-off	1.80 ±7.4	7.79 ±5.2*
max. swing flexion	5.24 ±9.0	9.50 ±9.1

Table 4. Means and standard deviations of hip and knee joints angle (in degrees) measured in various gait stages. Free and fast gait speed are compared. *Differences are significant at p<0.05

	Amputated side		Normal side	
Joint angle measured at	Free speed	Fast speed	Free speed	Fast speed
Hip:				
heel-strike	19.64 ±5.8	22.43 ±6.2	16.83 ±3.56	20.12 ±4.6*
max. stance extension	7.31 ±2.6	8.11 ±2.3	6.57 ±2.6	7.95 ±2.9
toe-off	3.32 ±4.1	4.21 ±4.0	3.98 ±4.8	3.10 ±5.3
max. swing flexion	24.01 ±5.7	27.28 ±5.9	22.16 ±3.8	25.85 ±3.7*
Knee:				
load response	6.55 ± 2.8	7.76 ±3.8	9.17 ±3.74	14.82 ± 3.3*
toe-off	44.99 ±12.5	52.07 ±10.9	43.19 ±10.9	44.30 ±11.0
max. swing flexion	58.43 ± 6.9	64.31 ± 7.3*	53.18 ± 5.4	54.81 ± 6.1

Table 6. Sequence and timing of gait events occurrence during stride. Results, expressed in percentage, are means and standard deviations of events set during stride time. All differences are insignificant (p>0.05)

	Amputated side		Normal side	
Gait events	Free speed	Fast speed	Free speed	Fast speed
Knee load response	14.51 ±6.5	18.61 ±7.4	15.77 ±5.4	16.82 ±4.5
Hip max. stance extension	56.54 ±3.5	55.32 ±4.4	58.08 ±2.3	55.92 ±3.2
Toe-off	63.38 ±4.5	67.48 ±3.7	70.16 ±5.2	68.20 ±4.5
Knee max. swing flexion	76.08 ±3.3	74.96 ±3.1	76.51 ±2.6	74.96 ±1.8
Hip max. swing flexion	90.13 ±3.7	89.79 ±4.1	88.63 ±2.0	88.64 ±2.6

free speed to an extent that induced a significant change in all temporal and distance values in both legs. Values of temporal parameters of stance, swing, double limb support, and step time decreased significantly while values of distance parameter of step length increased significantly. The effect of increased speed on inter-legs temporal and distance parameters symmetry was insignificant.

The hip and knee angles on the amputated and normal sides were monitored and the effect of speed was established by comparing the angles measured at selected instances of gait. It was noted that a faster speed of gait induced a significant increase in flexion of the hip joint in the normal leg when measured at heel strike (from 16.83 ±3.56 to 20.12 ±4.6 degrees) and during swing (from 22.16 ±3.8 to 25.85 ±3.7 degrees). In the same leg, knee flexion increased significantly during load response (from 9.17 ±3.74 to 14.82 ±3.3 degrees). As for the amputated side, speed of gait significantly affected flexion only of the knee during swing (increased from 58.43 ±6.9 to 64.31 ±7.3 degrees). Joint angles might also serve as indicators of gait symmetry. The effect of increased speed did not affect the symmetry of hip angles as indicated by the almost similar differences between hip angles measured in free and fast speed. At the knees, speed significantly affected symmetry of angles during load response by increasing inter-leg differences (2.62 ±5.2 to 7.06 ±4.2 degrees) for the free and fast speeds respectively. This increase was due to a significant increase in knee flexion in the normal leg only. The normal load response, occurring during the initial phase of weight acceptance, is characterised by a slight flexion of the knee under the control of the eccentrically contracting quadriceps muscle. The "shock-absorbing" effect obtained by such movement is very important in the prevention of wear and tear of weight-bearing joints (Light *et al.*, 1980). Speed significantly affected symmetry of knee angles during toe-off by increasing inter-leg differences (1.80 ±7.4 degrees to 7.70 ±5.2 degrees) in the free and fast speeds respectively. This resulted from increased knee angle under influence of speed on the amputated side only. It is assumed that the exaggerated knee flexion on the amputated side is related to the prosthetic rigid ankle-foot component (Bagley and Skinner, 1991). The inability of the artificial ankle to dorsiflex (and plantarflex) during stance, is expressed also by the inability to lower the heel and straighten the knee. Thus, during toe-off, the knee on the amputated side is being "pushed" into flexion by the rigid ankle, an outcome which increases significantly in faster speed of gait.

Table 7. Sequence and timing of gait events occurrence during stride. Results express the mean (±SD) differences between both limbs measured during free and during fast speed ambulation. All differences are insignificant (p>0.05)

	Amputated – normal sides differences during:	
Gait events	Free speed	Fast speed
Knee load response	1.26 ±8.3	1.78 ±8.5
Hip max. stance extension	1,53 ±3.1	0.59 ±4.9
Toe-off	1.77 ±4.2	0.72 ±4.4
Knee max. swing flexion	0.40 ±3.3	0.03 ±3.2
Hip max. swing flexion	1.50 ±4.1	1.14 ±4.1

Timing of occurrence and the sequence of gait events relative to stride time might also indicate symmetry of gait. The following gait events were chosen; peak angle on knee load response, maximal hip extension during stance, toe-off occurrence, maximal knee flexion during swing, maximal hip flexion during swing. The exact time of their occurrence (expressed in percentage of stride time) relative to stance period was measured. This assumption was found to be erroneous as the timing of occurrence of the chosen gait events did not significantly change under the effect of speed.

In conclusion, under the conditions of the present tests, speed of gait in trans-tibial amputees significantly affected the symmetry of all temporal and distance parameters as well as the symmetry of knee angles during load response and toe-off. Analysis of gait in amputees can identify asymmetrical parameters and provide the necessary information for focusing research and development on prosthetic components which duplicate normal leg functions.

Acknowledgement

The authors would like to thank the physical therapist, Mr. Bevetek Tomaz, for his assistance during the testing procedures.

REFERENCES

BAGLEY AM, SKINNER HB (1991). Progress in gait analysis in amputees: a special review. *Crit Rev Phys Rehabil Med* **3(2),** 101-120.

BAKER PA, HEWISON SR (1990). Gait recovery pattern of unilateral lower limb amputees during rehabilitation. *Prosthet Orthot Int* **14,** 80-84.

BARTH DG, SCHUMACHER L, THOMAS SS (1992). Gait analysis and energy cost of below-knee amputees wearing six different prosthetic feet. *J Prosthet Orthot* **4,** 63-75.

BOONSTRA AM, FIDLER V, SPITS GMA, TUIL P, HOF AL (1993). Comparison of gait using a Multiflex foot versus a Quantum foot in knee disarticulation amputees. *Prosthet Orthot Int* **17,** 90-94.

BREAKEY J (1976). Gait of unilateral below-knee amputees. *Orthot Prosthet* **30(3),** 17-24.

CULHAM EG, PEAT M, NEWELL E (1986). Below-knee amputation: a comparison of the effect of the SACH foot and single axis foot on the electromyographic patterns during locomotion. *Prosthet Orthot Int* **10,** 15-22.

HIROKAWA S (1989). Normal gait characteristics under temporal and distance constrains. *J Biomed Eng* **11,** 449-456.

HURLEY GRB, MCKENNEY R, ROBINSON M, ZADRAVEC M, PIERRYNOWSKI MR (1990). The role of the contralateral limb in below-knee amputee gait. *Prosthet Orthot Int* **14,** 33-42.

ISAKOV E, SUSAK Z, BECKER E (1985). Energy expenditure and cardiac response in above-knee amputees while using prostheses with open and locked knee mechanism. *Scand J Rehabil Med* **12,** 108-111.

ISAKOV E, MIZRAHI J, SUSAK Z, ONA I (1992). A Swedish knee-cage for stabilising short below-knee stumps. *Prosthet Orthot Int* **16,** 114-117.

LIGHT LH, MCLELLAN GE, KLENERMAN L (1980). Skeletal transients on heel strike in normal walking with different footwear. *J Biomech* **13,** 477-480.

ROBINSON JL, SMIDT GL, ARORA JS (1977). Accelerographic, temporal, and distance gait factors in below-knee amputees. *Phys Ther* **57,** 898-904.

INSTITUTIONAL MEMBER

We are pleased to anounce that the following organisation was an Institutional Member of ISPO for the year 1996

Union Francaise des Orthoprothesistes (UFOP)
6 Rue Léon Jouhaux
75010 Paris
FRANCE