IJPMR 2008 October; 19 (2): 37-42

Variability of Gait Parameters of Unilateral Trans-tibial Amputees in Different Walking Speeds

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Abstract

Objective: The purpose of this study is to compare the gait parameters of unilateral transtibial amputees walking with variable walking speeds.

Methodology: The study was based on the assessment of gait in different walking speeds and their comparison. Age and sex matched six subjects of unilateral involvement were selected. They underwent walking for a fixed time interval with self selected walking velocity (S-SWV), a slower walking speed (37% lower than S-SWV) and a higher speed (41% greater than S-SWV). Gait analysis of the selected subject was done using Computer Dynography (CDG) gait analyzer. Physiological cost index (PCI) data was calculated measuring the heart rate by a telemetry system.

Result: Gait cycle duration decreased with speed increment. The step time parameters including single support time single swing time, step length were significantly reduced ($p<0.05$) with the speed diminution while double support in both limb and step duration in prosthetic limb was augmented ($p<0.05$). The ground reaction force patterns were moreover similar in different walking speeds however there was a significant difference in the force amplitude and rate of increment with slower to higher speed.

Conclusion: Significant changes in gait parameters showed that amputee's gait is not normalized in various walking speeds.

Key words: Gait parameters, transtibial amputees, speed variation, ground reaction force.

Introduction

The transtibial amputees always want to earn the ability to maintain a steady gait without endangering their stability irrespective of their walking speed. That is why they should have some significant differences in their gait parameters as a compensation for maintaining their stability in different speeds.

It is essential that normal ranges for gait parameters should be defined with reference to speed of walking [1]. So as per the requirement, the aim of this study is to determine how selected gait parameters may change as a result of gait speeds changing. As the clinical gait analysis enables parameters of movement to be quantified[2] so in this study we preferred this tool to evaluate the changes of gait parameters with speed variation.

Spatial and temporal parameters of gait have clinical relevance in the assessment of gait efficiency, particularly in orthopaedics. Previous studies focused about walking speed influenced on the gait parameters for the osteoarthritis patients[3], total hip arthroplasty[4] or healthy subject[3, 5, 6], presented the interaction between different joint motion (lower limb) and also set a standard walking speed for patient with osteoarthritis. Where as this study was confined in the influence of gait speed on these gait parameters for transtibial amputees while wearing SACH foot with patellar tendon bearing (PTB) socket.

Although the oxygen uptake method has been shown to be a reliable method and is used by many, the instruments are cumbersome, expensive, and not available in many clinics[7]. For this study purpose an energy index was derived as a ratio of heart rate difference with the velocity,

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which indicates the gait efficiency (beat/min)[5]. However, despite certain limitations, many reports have shown that heart rate monitoring is an accurate, reliable, and convenient method of determining energy expenditure[7,8,9,10,11].

Marerial and Method

Subject selection: Six traumatic transtibial amputees (mean BMI 20.26 ± 6.25) were selected as a text subject-based on the following protocols. All the subjects were able to walk with the prosthesis, without any additional aid. None of the subjects had any residual limb pain, sores or swelling .The other limb of the subject didn't have any painful sensation and was taken like a normal limb.

Equipment set up: The gait analysis system called CDG (Computer Dynography) supplied by Infrotronics Medical Industrial Engineering[12,13,14,15] was used for data collection. Each subject was made to wrap the micro-controller called ultraflex unit around the waist and a pair of foot sensors or CDG shoes of approximate size was put below the normal and prosthetic foot to collect normalized force distribution. The cable of CDG shoes were connected to ultraflex unit. The foot sensors data were digitally acquired at a sampling frequency of 100 Hz and stored in Memory stick of Ultraflex unit. The ultraflex is a protable battery operated microcontroller unit storage facilities for off-line analysis. A portable light weight blue tooth enabled ECG transmitter was tied with elastic adjustable belt at chest and receiver at the wrist. The ECG system was used to record Heart Rate at rest and at load. The gait data of all the subjects were evaluated in gait and biomechanics lab of National Institute for Orthopeadically handicapped, Kolkata, India.

Method of data collection: Subjects were asked to walk for a fixed time period in three different speeds-a natural speed or self selected (S-SWV) speed (range: 52-81 m/min), slower (26%) than the self selected speed (range:34-64 m/min) and higher (41%) than the self selected speed (range:76-114 m/min). They were fitted with PTB (Patellar Tendon Bearing) socket along with SACH (Solid Ankle cushioned Heel) foot. Required data were collected for that fixed time interval during walking in different speed. All data were analyzed in CDG software and normalized with respect to the patients' physiological parameters. Differences in gait parameters among different speeds were determined by univariate repeated measures analysis of variance (ANOVA) with a single group factor. The Significance level was set at $p<0.05$.

Results

The synchronized data of gait parameters and Electromyography of vastus lateralis, collected from Ultra flex gait analyzer were compared for three different walking speeds. The Stride and Step parameters were obtained from the step time windows and assessment of vertical ground reaction forces were done from the force graphics and histogram windows of Ultraflex software system package.

Among the normalized data there were significant differences for stride duration ($p<0.004$), stride length ($p<0.000069$), step length (for sound limb $p<0.00077$, for prosthetic limb $P<0.000052$), single swing of sound limb ($p<0.007$), single support ($p<0.01$) and double support of the prosthetic limb ($p<0.01$), loading in the sound limb ($p<0.05$) and velocity ($p<0.01$), in three different speed when the significant level was set at $p<0.05$.

Gait cycle properties: Cadence was generally increased by 17.21% and 21.02% for the increment of speed from slower to self selected (phase-I) and from self selected to higher speed (phase-II) respectively, while the gait cycle duration decreased by 13.42% and 17.64% including a gradually increment in stride length ($p<0.0000697$).

Parameters	*Slower speed (mean ± std)*	*Self-selected speed (mean ± std)*	*Higher Speed Cadence (steps/min)*
Velocity (m/min)	49.567±13.214	66.463±11.943	93.493±15.020
Cadence (steps/min)	83.800± 14.007	97.200 ± 9.884	117.000 ± 8.093
Stride duration (sec)	1.464±0.231	1.254±0.119	1.028±0.068

Table 1: Variation of gait patterns with walking speed.

Steptime parameters: Single support time (2.64% in phase-I and 8.61% in phase-II), single swing time (5.75% in phase-I and 10.93% in phase-II) and step time duration (0.84% in phase-I and 1.96% in phase-II) for sound limb increased with the increasing velocity where as in prosthetic limb Single support time (5.75% in phase-I and 10.93% in phase-II), single swing time (2.65% in phase-I and 8.61% in phase-II) increased but step time duration (0.54% in phase-I and 1.64% in phase-II) decreased .The study revealed that in phase-I the increment in prosthetic limb was more in single support (0.036%), single swing (1.11%), step length (0.979%) than the sound limb while in phase-II, the increment in prosthetic limb was less in single support (11.99%) than for the sound limb. Double support time was decreased in both phase (phase-I: 6.94% in sound limb, 12.70% in prosthetic limb and Phase-II: 12.10% in sound limb, 22.03% in prosthetic limb) while for the prosthetic limb, decrement was less in phase-I (0.68%) compared to the sound limb.

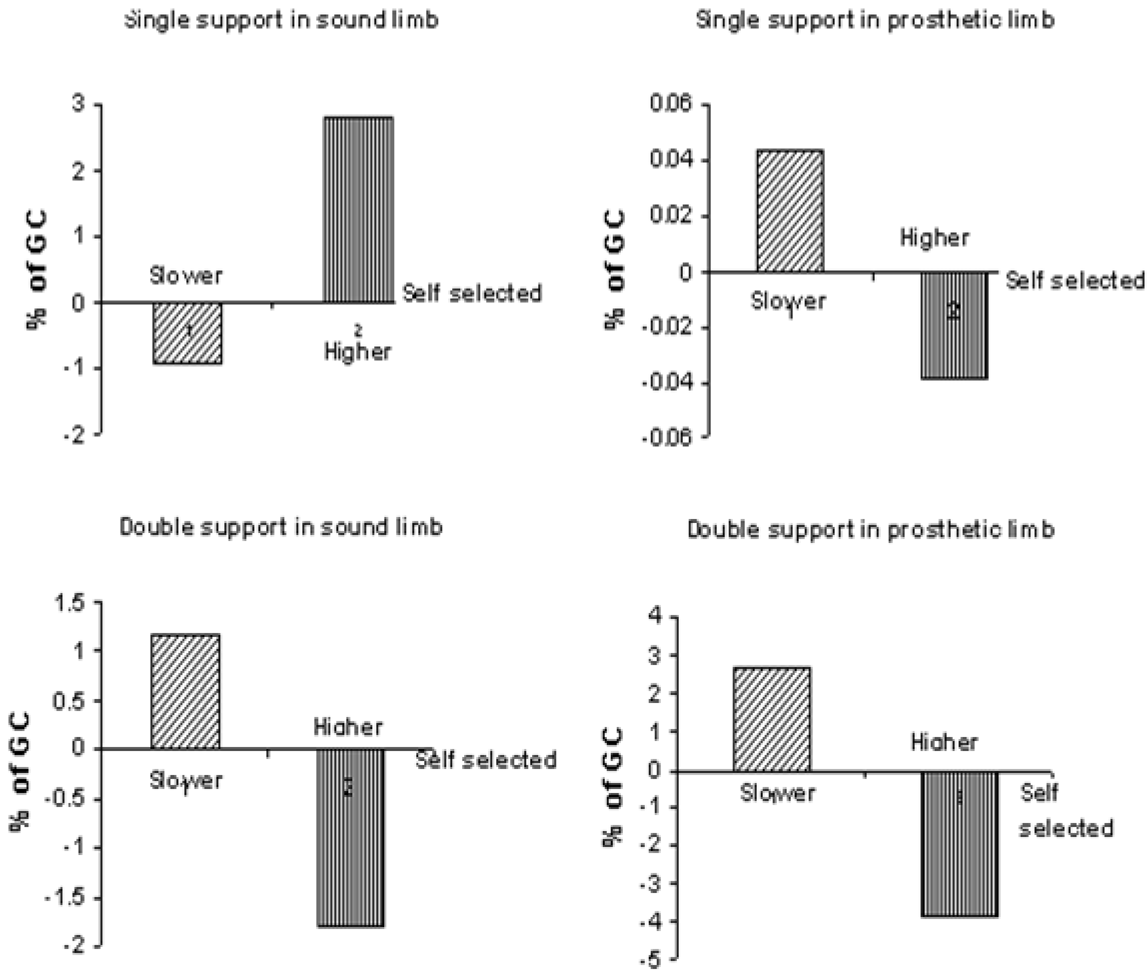

Figure 1: Single and double support time variation with variation with respect to walking velocity.

Parameters	*Slow speed (mean ± SD)*		*Self-selected speed (mean ± SD)*		*High Speed (mean ± SD)*	
	sound	*prosthetic*	*sound*	*prosthetic*	*sound*	*prosthetic*
Single support time (% of GC)	32.526±3.108	31.348±2.431	33.443±4.019	33.129±2.818	36.253±4.670	36.728±2.983
Double support time (% of GC)	16.192±1.849	20.521±2.706	15.009±2.862	17.813±1.759	13.216±3.958	13.946±2.257
Step time (% of GC)	48.441±2.980	51.594±3.032	48.806±2.354	51.260±2.340	49.752±2.202	50.412±2.177
Single swing time (% of GC)	31.348±2.431	32.526±3.108	33.129±2.818	33.443±4.019	36.728±2.983	36.253±4.670

Table 2: Variation in step parameters with respect to walking velocity

In step duration, the sound limb increment was more than the prosthetic limb for both phases. The step length (normalized with the percentage of height) increased with the velocity increment, both for the sound and prosthetic limb.

Ground reaction force: The Ground Reaction Forces (GRF) in different phase of stance was normalized, expressed as a percentage of subject's body weight. Further, the changes in different speed were observed.

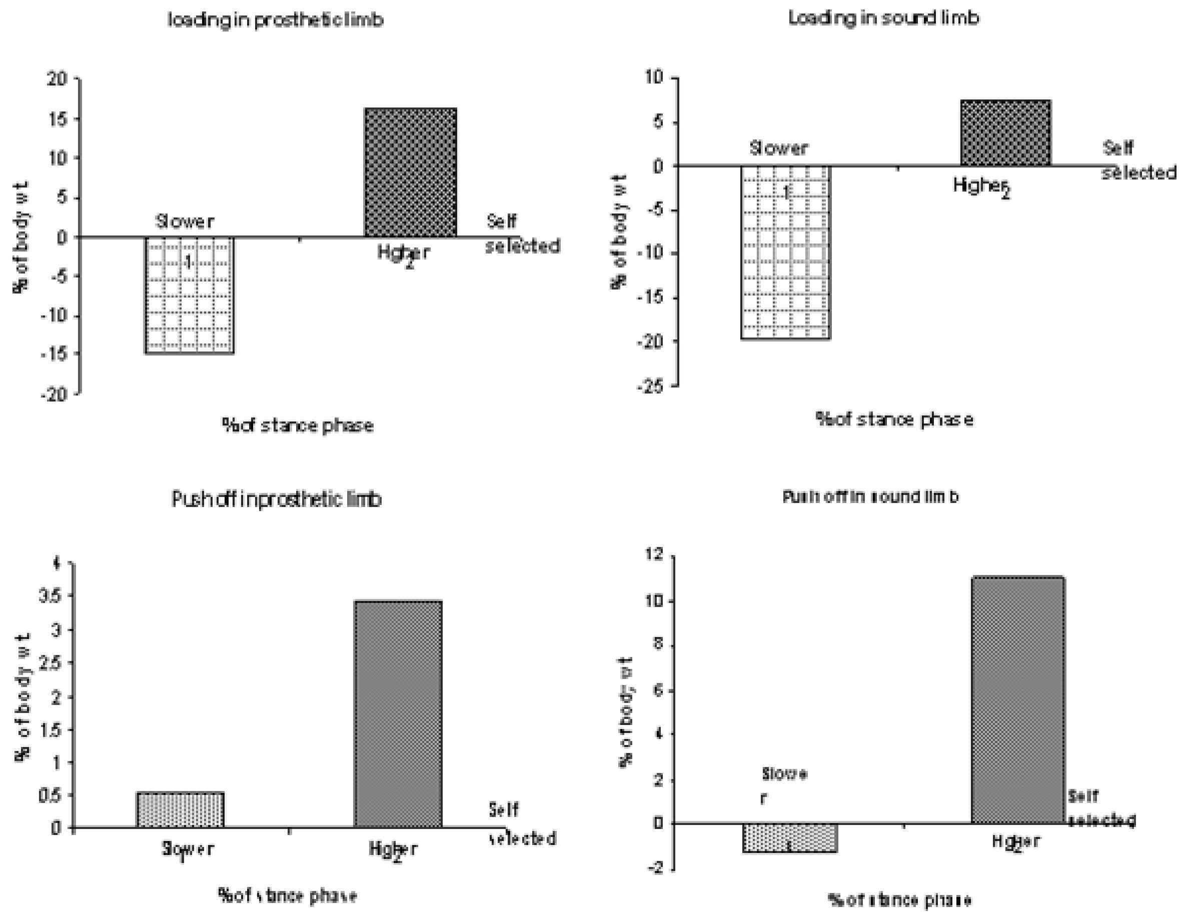

Figure 2: Ground reaction force distribution in prosthetic and sound limb.

The prosthetic (18.82%-phase-I, 15.97%-phase-II) and sound limb (33.21%-phase-I, 7.10%-phase-II) loading was increased for both phase where in phase-I the increment in prosthetic limb was 0.92% more and in phase-II 0.61% less than the sound limb. The toe-off force was increased in prosthetic limb (0.05%-phase-I, 2.87%-phase-II) and sound limb (1.77%-phase-I, 11.89%-phase-II) for both phases whereas in prosthetic limb the increment was greater, 1.89% in phase-I and 0.26% in phase-II, than the sound limb.

The GRF pattern showed a quite similarity in three different speeds. There were no differences in peak forces values among different speeds in prosthetic and also sound limb however the magnitude of the first peak showed some differences in prosthetic side which declared higher loading (110% of the body wt.) in higher walking speed. The first peak force occurred at a significantly latter time during slower and self selected velocity than during higher velocity.

Physiological Cost Index: In this present study physiological cost index (PCI) was evaluated to judge the gait efficiency**.** PCI is defined as the ratio of net heart rate to velocity in the units of beats/meter, where net heart rate is the difference between average heart rate over a fixed distance and resting heart rate[6]. Gait efficiency is conventionally measured by oxygen uptake, however Physiological Cost Index (PCI) of walking as developed by Butler et al[16] and the same were used by Nelson et al[17] to compare conventional and flex foot.

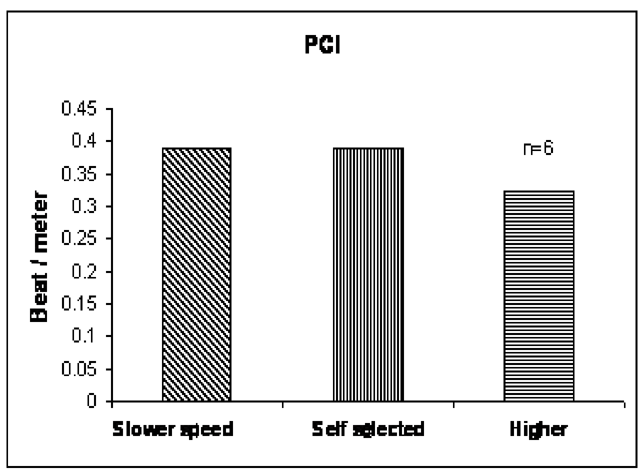

Figure 3: PCI in different walking velocity.

In contrast to the results obtained in the gait tests, there was no significant difference in PCI ($p<0.88$) in various walking speed. The figure (Fig: 3) showed a gradual drop in PCI value with the speed increment which indicated a better gait efficiency at higher speed of walking.

Discussion

Yamasaki et al described a U-shaped relationship between stride length variability and gait speed when healthy subjects walked on a treadmill[18,19]**,** where the current study ascertains the increasing or decreasing percentage of different gait parameters with the walking speed variation.

The result of this study showed no significant difference ($p<0.8875$) in PCI values when it was measured for three different speeds, however it is quite variable for different type of walking Speed[6]. A gradual drop in PCI with walking speed increment supported the improved gait efficiency. While many studies[20] show a linear relationship between PCI and walking speed for the transtibial amputees but our study differs. We collected the data only for twenty seconds. According to this; it represented the decreasing PCI characteristics in the initial period of walking. As an evidence of speed augmentation the cadences was increased and gait cycle duration was decreased. Decrement in gait cycle denotes the patients were doing less postural adjustment while walking[21]. There was a significant difference in the stride length as it is known to be sensitive variables for evaluating an amputee's gait[7]. Minimal variability of stride length occurred at self selected speed, according to the minimum standard deviation. This finding is also suggested by Yamasaki et al[18].

The mean values for two important gait variables, i.e. single and double support are graphically presented in Figure 1. With speed increment, single support and double support duration changed in reversed order in sound limb where as in prosthetic limb the single and double support duration reduced with swelled walking speed which proved the fact of step duration reduction. With increased walking speed the increment in single support duration of prosthetic limb was supplementary than the sound limb.

The current study ascertains that ground reaction force is increased in higher speed which is in accord with the previous studies[2222]

Conclusion

From this study it can be concluded that gait speed has a significant impact on the temporal and spatial gait parameters. The stride parameters changed in an increasing or decreasing order with the different walking velocity. The ground reaction forces in loading and push off is augmented from slower to higher walking speed. The minimum value of PCI indicated that better gait efficiency is achieved at higher walking speed during initial period of walking.

Acknowledgements

We are thankful to National Institute for the Orthopaedically Handicapped, Ministry of Social Justice & Empowerment, Govt. of India, for supporting this experiment. The authors gratefully acknowledge the technical assistance of Ms. Arpita, Ms Joyeeta, Mr Tilok, and Mr Avijit with data collection.

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