Indian J Physiol Pharmacol 2006; 50 (1) : 33–40

TEMPORAL SPATIAL PARAMETERS OF GAIT WITH BAREFOOT, BATHROOM SLIPPERS AND MILITARY BOOTS

DHURJATI MAJUMDAR*, PRATUL K. BANERJEE, DEEPTI MAJUMDAR, MADHUSUDAN PAL, RAKESH KUMAR AND WILLIAM SELVAMURTHY

Defence Institute of Physiology & Allied Sciences,
Defence Research & Development Organization,
Ministry of Defence,
Lucknow Road, Delhi – 110 054

(Received on June 9, 2003)

Abstract : Nine temporal spatial parameters of gait were evaluated on 8 normal healthy able-bodied soldiers while walking barefoot, with bathroom slippers and military boots on, respectively. Subjects used their regular bathroom slippers and military boots for the study. A 5 camera based Expert Vision 3-D motion analysis system (M/s Motion Analysis Corporation, USA) was used while the subjects walked 10 meters along a straight and level walkway at a comfortable speed. Cleveland Clinic retro reflective marker sets for lower body were used to record static as well as walk data of both legs. Static and walk data were collected at 60 Hz and 120 Hz respectively. A minimum of 10 walking trials for each subject for each condition were obtained and at least 3 good trials having complete trajectories of all the markers covering entire gait cycle for each condition were selected for analysis as per routine gait analysis procedure. A total of 83, 81 and 74 full strides for barefoot, bathroom slippers and military boot respectively were subjected to statistical analysis. Step length and stride length increased significantly from barefoot to military boot with a significant reduction in cadence. Swing phase and single support time increased significantly from barefoot to bathroom slippers and military boot. Total support time and initial double support time decreased significantly for the same conditions compared to barefoot. The observations in this study indicated that use of footwear (bathroom slippers, military boot) caused significant changes in the gait parameters.

Key words : 3D motion analysis gat analysis step length stride length swing phase support time

INTRODUCTION

Walking with covered and tightly fitted shoes on is always considered as stable, uniform and safe. Walking with this type of shoes protect limbs against injury by reducing the magnitude and rate of initial loading at heel strike and by redistributing

*Corresponding Author : Tel. Nos. : 91-11-23935745, 23946257, Fax Nos. : 91-11-23914790, 23932869, E-mail : majum55@yahoo.com.

the ground reaction forces across the foot plantar surface, thereby reducing the load transmitted to the skeletal system (1). Windle et al (2) reported that shod walking attenuates the peak pressures at the foot-floor interface at heel strike and during fore foot loading. In India, a large part of the population wears bathroom slippers, which is normally an indoor wear, for outdoor activities as a regular footwear. As the bathroom slippers do not fit snugly, gait seems to be unstable and is known to cause accidents by slipping or tripping, specially, on uneven or slippery surfaces.

A number of studies (3–5) abroad have evaluated gait parameters during walking and running with barefoot and shoes. No gait data, either barefoot or with shoes, for Indian population has been reported so far. Also, no gait analysis study has been reported with slippers. A comparison of gait data with barefoot, bathroom slippers and military boots on will provide useful data in understanding of the relationship of gait parameters with two types of footwear *vis á vis* the barefoot gait.

The present study was therefore designed to observe the temporal spatial parameters of gait while walking barefoot, with bathroom slippers and military boots on, respectively and to look into the possible existence of any differences in gait pattern in these three conditions.

METHODS

Eight normal healthy infantry soldiers volunteered for the study. They gave informed consent before the study. They were accustomed to the gait laboratory and gait data collection procedure one day before the actual measurement of gait data. The mean (SD) age, height and weight of the subjects were 26.7 (2.73) yrs, 164.8 (4.35) cm and 59.3 (5.14) kg, respectively. During the experiments subjects wore only a vest and were fitted with appropriate markers. Static trials were recorded first followed by walk trials. Subjects were asked to use their regular bathroom slippers and military boots, which were of the same make and model. Each subject was tested first barefoot, then with bathroom slippers and finally with military boots on the same day. During walk trials, subjects were asked to maintain, as far as possible, their normal walking speed and pattern. A minimum of 10 walk trials for each condition for each subject were obtained and at least 3 good trials having complete trajectories of all the markers covering entire gait cycle in each condition were selected for analysis.

Temporal spatial data were obtained using a 5 camera based Expert Vision 3-D motion analysis system (M/s Motion Analysis Corporation, CA, USA), while the subjects walked 10 meters along a straight and level walkway at a comfortable speed. They were fitted with Cleveland Clinic retro reflective marker sets used for lower body gait data. These sets consist of rigid triads of markers in a plane that is parallel to the long axis of the bone to capture the motion of the thigh and shank in 3-D. The motion analysis system uses separate static data collection for left and right legs to define the knee and ankle centers and axes of rotation. For recording static data, other than thigh and shank triads, retro-reflective markers (1" dia) are placed on the lateral and medial sides of knee and ankle of both the legs.

During walk trials, knee and ankle markers are removed and markers are placed at toe, heel and anterior superior iliac spine on both sides of the body. A separate marker is placed on the spine at superior aspect of the L5 – sacral interface.

Static data were collected at 60 Hz frame rate for right, left and both legs for 1 sec each. Walk trials were collected at a camera speed of 120 Hz. Figure 1 describes the normal walk cycle of right leg with bare feet showing different events of gait. Table I demonstrates definitions, brief descriptions and implications of different temporal spatial parameters of gait cycle. Temporal spatial data, viz., step length, stride length, forward velocity, cadence, total support time, swing phase, initial double support time, single support time and step width were recorded with all three conditions of walking.

Data were recorded and digitized using EVa 7.0 software and subsequently analysed for temporal spatial parameters by Orthotrak 5.0 software mainly used for clinical gait analysis. Both the softwares were supplied by M/s Motion Analysis Corporation, CA, USA. At least 3 good trials for each condition for every individual were averaged. The averaged data for each condition of 8 individuals were subjected to statistical treatment to obtain mean and SD values. A total of 83, 81 and 74 strides for barefoot, bathroom slippers and military boot, respectively were subjected to analysis for obtaining temporal spatial parameters of both sides of the body, qualifying the required number of strides to obtain a

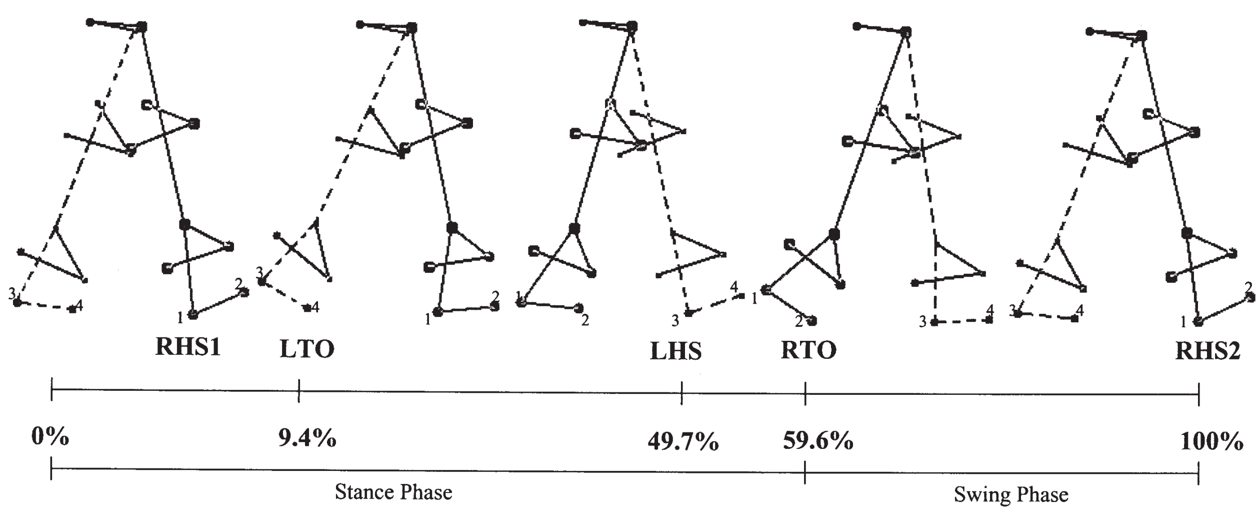

Fig. 1 : Normal walk cycle (right leg barefoot) showing the events of gait.

1 – Right Heel, 2 – Right Toe	Stride length	RHS1-RHS2
3 – Left Heel, 4 – Left Toe	Step length	RHS1-LHS
RHS1 - First Right Foot Strike	Stance phase	RHS1-RTO
RHS2 – Second Right Foot Strike	Swing phase	RTO-RHS2
RTO – Right Toe Off	Initial double support time	RHS1-LTO
LHS – Left Heel Strike	Single support time	LTO-LHS
LTO – Left Toe Off		

TABLE I : Definition, brief description and implication of different temporal spatial parameters of gait cycle.

Parameters	*Definition*	*Brief description*	*Implication*
Total Support Time or Stance Phase (%)	It is that part of gait cycle when either one or both feet are on ground and the body passes over it. It lasts from heel strike of one foot to toe off of the same foot (RFS1–RTO).	This period constitutes about 60% of the gait cycle and is further divided into three phases: 1. Initial Double Limb Support (Foot Strike- Opposite Toe off) 2. Single Limb Support (Opposite Toe off- Opposite foot Strike) 3. Second Double Limb Support (Opposite Foot Strike-Toe off)	Stance and swing durations are related closely to the cycle duration and not related to age or height. Short step length generally reduces swing phase and vice versa. Patients with motor dysfunction typically walk slower, exhibit asymmetries in stride variables and have less flexibility to vary speeds with changing conditions. Duration of gait cycle, stance and swing periods as well as single and double limb support intervals alter significantly depending on degree of dysfunction and whether there is unilateral or bilateral involvement.
Swing Phase (%)	Swing phase is calculated from the gait events of toe off to foot strike on the same side (RTO-RFS2).	This period constitutes about 40% of the gait cycle and is further divided into 1. Initial Swing (Toe off to Foot Clearance) 2. Mid Swing (Foot Clearance to Tibia Vertical) 3. Terminal Swing (Limb Deceleration) Swing time is identical with the time of contra lateral single limb support.	
Initial Double Support Time (%)	This is the part of the stance phase when both the feet are on ground at the beginning of the cycle. It continues from heel strike of one foot to toe-off of other foot (RFS1–LTO).	This constitutes about 10% of the gait cycle. The ability to walk is primarily determined by actions involved in transferring weight on to the stance limb. Critical functions that met by the limb during this period include shock absorption, weight bearing, stability and preservation of progression.	
Single Support Time (%)	Single support time is the % of gait cycle where only one foot is in contact with the floor during stance phase. It continues from opposite toe off to opposite foot strike (LTO–LFS).	This period persists from 10%-50% of gait cycle. This is divided into mid stance (10% -30%) and terminal stance (30% -50%) of gait cycle. During single support time the centre of gravity of the body sits at it's highest point. Center of mass moves forward as other foot is undergoing swing phase.	
Second Double Support Time or Preswing (%)	It is the terminal part of the stance phase (pre-swing) when both the feet are again on ground. This period starts at opposite foot strike and ends at concerned leg toe off (LFS–RTO).	This constitutes about 10% of the gait cycle. During this phase weight of the body is unloaded and transferred to the contra lateral limb.	
Stride Length (cm)	Distance between two successive placement of the same foot heel, on ground i.e. First Right Foot Strike to Second Right Foot Strike (RFS1–RFS2).	It consists of two step lengths. The stride length of the left foot is same as that of the right foot unless the subject is walking in a curve. It depicts the gait cycle time.	Increase or decrease of stride length affects all other parameters included in the gait cycle time. The nature and range of effect depends on sex, age, height, footwear and disease conditions.

Step Length (cm)	Distance along the X-axis (progression of walk) from foot strike of one foot to foot strike of the opposite foot (RFS1–LFSl).	It is the term used to describe foot placement on ground and depends on the swing phase duration.	In pathological gait it is common for the two step lengths to be different. This affects other gait parameters, e.g. cadence, forward velocity, stride length, swing phase, etc.
Step Width (cm)	Distance between the ankle centres during foot strike of each foot averaged across all foot strike events.	Side to side distance between the lines of two feet, usually measured at the mid point of the heel.	In disease condition the gait is broad based with an increase in step width.
Cadence (steps/min.)	The number of steps taken in unit time.	As there are two steps in a single gait cycle, the cadence is a measure of half cycles. Cadence is inversely related to cycle time and can be represented as given below: Cycle time (s) = 120/cadence (steps/min)	This decreases with increase in stature. When cadence increases from 40–200 steps/ min, velocity of progression increases and vice versa. Similarly step length (L) and step frequency (F) is approximately linear over a broad range of walking speed. On average, the ratio L/F is equal to approximately 0.70 for men and 0.60 for women.
Forward Velocity (cm/s)	Distance moved by a person in unit time in forward direction.	The instantaneous speed varies from one instant to another during the walking cycle, but the average speed is the product of the cadence and the stride length. Speed can be calculated as follows : Speed (cm/sec) = stride length (cm) × cadence (steps/min)/120	With increase in velocity, double support period decreases and swing phase increases. The speed and step length relationship is as follows : $L = 2.28\ V^{0.5}$

representative measure of temporal spatial parameters of gait for adults without impairment (7). Differences between barefoot and bathroom slippers, barefoot and military boot for each side of the body were assessed using paired Two-tailed Student's T-test.

RESULTS

Table II shows the results of nine variables of temporal spatial data of right and left side of the body during walking barefoot, with bathroom slippers and military boots. The stride length (cm) increased significantly from 124.6 (5.82) (Rt), 124.2 (5.86) (Lt) when barefoot to 132.9 (6.42) (Rt), 132.8 (6.65) (Lt) when wearing military boots. This was consistent with a significant increase in step length (cm) from 62.9 (2.19) (Rt), 61.5 (4.43) (Lt) when barefoot to 67.3 (3.5) (Rt), 65.7 (3.94) (Lt) while wearing military boots. In case of bathroom slippers, both the parameters increased to a smaller extent when compared with barefoot and the increase was not significant. Interestingly, total support time (stance phase %) decreased significantly from 59.6 (1.39) (Rt), 59.7 (0.9) (Lt) when barefoot to 58.8 (1.51) (Rt), 58.3 (1.2) (Lt) with bathroom slippers on and 59.0 (1.54) (Rt), 58.4 (1.37) (Lt) when wearing military boots, respectively. Cadence (steps min^{-1}) also decreased in case of bathroom slippers and military boots as compared to barefoot. However, swing phase (%) increased significantly 40.4 (1.39) (Rt), 40.3 (0.9) (Lt)

TABLE II : Mean (standard deviation) temporal spatial parameters of gait data during walking on barefoot, with batroom slippers and military boots (n=8).

Condition	*Bare foot*		*Bathroom slipper*		*Military boot*	
	Right	*Left*	*Right*	*Left*	*Right*	*Left*
Step Length (cm)	62.9 (2.19)	61.5 (4.43)	63.6 (3.39)	62.4 (4.57)	67.3*** (3.5)	65.7*** (3.94)
Stride Length (cm)	124.6 (5.82)	124.2 (5.86)	126.3 (7.25)	126.0 (7.36)	132.9*** (6.42)	132.8*** (6.65)
Forward Velocity (cm. sec^{-1})	108.9 (6.69)	108.9 (6.88)	108.8 (7.92)	108.8 (7.93)	110.4 (5.78)	110.4 (5.89)
Cadence (Steps, min^{-1})	105.4 (5.69)	105.4 (5.89)	103.9 (5.31)	103.8 (5.17)	100.0** (3.82)	99.9** (3.73)
Total Support Time (%)	59.6 (1.39)	59.7 (0.9)	58.8** (1.51)	58.3*** (1.2)	59.0* (1.54)	58.5** (1.37)
Swing Phase (%)	40.4 (1.39)	40.3 (0.9)	41.2** (1.51)	41.7*** (1.2)	40.9* (1.54)	41.5** (1.37)
Initial Double Support Time (%)	9.4 (1.38)	9.8 (1.13)	8.6** (1.36)	8.6*** (1.19)	8.8* (1.29)	8.6* (1.28)
Single Support Time (%)	40.3 (0.9)	40.4 (1.39)	41.7 (1.2)	41.2** (1.51)	41.5** (1.37)	40.9 (1.54)
Step width (cm)	11.3 (2.78)	11.3 (2.78)	10.5 (2.76)	10.5 (2.76)	10.6 (4.75)	10.6 (4.75)

*P<0.05; **P<0.01; ***P<0.001 in comparison with barefoot.

when barefoot to 41.2 (1.51) (Rt), 41.7 (1.2) (Lt) with bathroom slippers on and 40.9 (1.54) (Rt), 41.5 (1.37) (Lt) when military boots were on. It was observed that single support time (%) also increased significantly from 40.3 (0.9) (Rt), 40.4 (1.39) (Lt) when barefoot to 41.7 (1.2) (Rt), 41.2 (1.51) (Lt) with bathroom slippers on and 41.5. (1.37) (Rt), 40.9 (1.54) (Lt) while wearing military boots. There was significant decrease in initial double support time (%) when wearing bathroom slippers and military boots as compared to barefoot. No significant changes in the forward velocity and step width were observed in these conditions.

DISCUSSION

Gait patterns and their variations have been studied for many years. However, comparatively little work has been conducted to determine the influence of different footwear.

Measurements of temporal and spatial parameters of gait are commonly used for the identification of gait disorders (8) and for the evaluation of therapeutic interventions such as exercise (9, 10) and foot wear (3–6, 11).

The results of the present study demonstrated that temporal spatial parameters are useful tool to characterize the gait pattern of able bodied with two different foot wear viz., slippers and military boots. Significant increase in step and stride lengths, swing phase and single support time and decrease in cadence, stance phase and double support time were observed while walking with military boots compared to barefoot. Similar observation was made by Oeffinger et al. (12), Grieve and Gear (13) and Merrifield (14) for variety of shoes. The 6.8 cm average stride length difference between boot and barefoot may possibly be explained by the added weight of the boots (1.5 kg). An increase in distal mass had a pendulum-lengthening effect on the leg, resulting in increased inertia during swing phase and thus an increase in stride length and a decrease in cadence (12, 15). Interestingly, inspite of significant increase in step and stride lengths while wearing boots, velocity increase is small and insignificant. This might have occurred due to about 5% decrease in cadence in case of military boot. Another explanation for the increase in step and stride lengths with military boot is the added cushioning, snugness of fit and comfort provided by military boots. A possibility of a third cause for the above observation may be the low-heel component of the military boot. Grieve and Gear (13) showed that low heeled (1–2 cm) shoes produce a 2–7%. reduction in the step frequency and therefore an increase in stride length. We have observed an average 5% reduction in step frequency and about 7% increase in step and stride lengths during walking with military boot as compared to barefoot.

On the other hand, the gait characteristics with bathroom slipper remained similar to that of the barefoot with only a significant increase in swing phase and decrease in stance phase and initial double support time. Three important features such as absent fixation, excessively flexible heel counters and excessively flexible soles (sole that bends proximal to the metatarsophalangeal joints) are inherent characters of the bathroom slipper. It is more likely that bathroom slipper with these features tend to promote a shuffling gait and become separated from the foot when walking. This may explain the cause of an increase in swing duration of a gait cycle during walking with bathroom slipper. Sherrington and Menz (11) reported that wearing shoes with inadequate fixation, such as soft slippers and other indoor slip-on shoes, may predispose to falls by impairing normal gait and acting as an extrinsic tripping hazard. However, our data could not support this general belief that gait is unstable with the bathroom slippers on as far as the experimental level walk surface is considered.

Observed results in the present study puts a classical picture of the temporal spatial features of gait with two different shoes, one with rigid sole, hard heel and snugly fitted i.e., military boot and another one without having any of these features i.e., bathrooms slipper as compared to barefoot walking. Soames and Evans (16) stated that wearing of shoes has been shown to change the way in which the foot is used during gait. The ankle and knees joints as well as the joints of the foot, together with associated capsules, ligaments, tendons and muscles are subjected to different patterns of stresses. It is probable that the changed pattern of neural feedback from proprioceptors associated with these structures interact to modify the pattern of gait, which gets evident in limb segment displacements.

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