SYMMETRY OF IN-SHOE PLANTAR PRESSURE DURING RUNNING

Moshe Ayalon and David Ben-Sira
The Zinman College of Physical Education and Sport Sciences, Wingate, Israel

Symmetry during foot contact was studied during running on a treadmill at 8 and 14 km $\cdot hr^{-1}$. In-shoe pressure was sampled during 4 right and 4 left foot contacts at each velocity. Symmetry indices (SI) were calculated for the heel, forefoot and hallux based on peak area pressure. SI was also calculated for the maximal force. Mean SIs were tested in relation to the null hypothesis of perfect symmetry (SI=0) and for differences between velocities. Bi-variate correlation coefficients were computed between all pairs of SI indices to assess velocity and area specificity. There was no evidence for velocity specificity of SI. Conversely, SI proved to be area specific. It was concluded that SI of the maximal force can not represent asymmetry in plantar pressure at the three areas of the foot.

KEYWORDS: running, symmetry, in-shoe pressure

INTRODUCTION: Running is an integral part of the physical activity habits of many people. Various studies suggest that injuries of the lower extremities may be a consequence of high ground reaction force and pressure overload at different locations on the underside of the foot (Winter, et. al., 1992, Hennig & Milani, 1995, Beck, 1998). Despite an increased focus on the prevention of running injuries, injuries resulting from over use are still rather frequent. It is important therefore, to identify the cause of the injury and treat the cause, not merely the symptoms. When injuries caused by overuse of the lower limbs are diagnosed in athletes, the structure and function of the foot should be examined. Many running injuries are manifestations of dysfunction of the kinetic chain especially among those patients with recurrent injuries. One of the suggested causes of such injuries is an asymmetric distribution of the external loads between the right and left lower extremities (Herzog et al., 1989). Therefore, it is important to identify asymmetry during the stance phase, and to locate extreme forces or pressure imbalances.
A number of studies investigated the degree of symmetry during walking and running. Hamill et. al., (1984), concluded that a high degree of symmetry in ground reaction forces exists between the preferred and non-preferred limb in running and walking. Herzog et.al, (1989) found a deviation of less than 4% from zero in the mean symmetry index (SI) for the vertical ground reaction force (GRF). Bennell et.al, (1999) reported a deviation of less than 6% from zero in the mean SI for all GRF parameters.
In-shoe plantar measurements have been used in numerous studies (Cavanagh et. al., 1992). No reference was found in the literature relating to the bilateral symmetry of plantar pressure in different areas of the foot across running velocities. The purpose of this study was two-fold: 1) to assess the influence of running velocity on the SI of plantar pressure at different areas of the foot and on the maximal vertical force, 2) to assess whether or not, the SI of the maximal force can represent over all symmetry during contact in running.

METHODS: Eleven females (Mean age = 24.8±1.3 yrs, mean height = 167.5±4.7 cm, mean weight = 60.2±6.7 kg) and nine males (Mean age = 25.3±1.5 yrs, mean height = 176.4±8.2 cm, mean weight = 71.1±4.6 kg) volunteered to participate in this study. All subjects were physical education students. Only individuals with no history of lower extremity injuries were admitted into this study. PEDAR insoles (99 sensors each) were inserted into the left and right shoes. The insole size was individually adjusted to the participants' personal running footwear, The system, was calibrated in accordance with the manufacturer's instructions. The sampling rate was 50 Hz. The subjects ran on a treadmill at 8 and 14 km*hr^{-1}. The order of running velocities was randomized. After a warm up each subject ran at least 30 seconds before data were collected. This procedure enabled familiarization with the treadmill's velocity. Four right and left foot contacts were sampled at each running velocity. Three sets of sensors were defined to represent three area of the foot: six sensors under the center of

the heel, nine sensors under the center of the forefoot and three sensors under the hallux. For each area the mean pressure was calculated and the peak value during the foot contact was selected for further analysis. In addition, maximal force (MF) was defined as the greatest force exerted on the insole at one instant during the step based on all 99 sensors.
Symmetry of all dependent variables was quantified using the symmetry index (SI) proposed by Robinson et. al. (1987):

$$SI = (XR-XL) / [0.5(XR+XL)] * 100.$$

XR and XL are the dependent variable of the right and left foot, respectively. Four SI indices were calculated at each of the two velocities: heel, forefoot, hallux and MF Mean SI values were tested in relation to the null hypothesis of perfect symmetry (SI=0) by means of a t-test ($\alpha \leq 0.05$). Each area was tested for gender and velocity effects using a two way ANOVA with repeated measures ($\alpha \leq 0.05$). Bi-variate correlation coefficients were computed between all pairs of SI indices with α set as ≤ 0.01. The higher level for rejection of the null hypothesis for the correlation coefficients was adopted because of the large number (28) of hypotheses.

RESULTS: All mean plantar pressure values were higher while running at 14 km*hr^{-1} than at 8 km*hr^{-1} (39% at the heel, 24% at the forefoot, 23% at the hallux and 18% for MF) with marginal bilateral or gender differences. Descriptive statistics of the SI are presented in Table 1. The only mean that was significantly different from zero was that of the forefoot at 14 km*h^{-1} (t_{19}=-2.76, p<0.05). A similar trend was also observed with regard to the SI of the forefoot at 8 km*h^{-1} (t_{19}=-1.86, 0.05<p<0.10). There were no significant gender or velocity effects with regard to the SI at any of the areas. Out of the 60 foot-pressure SIs (20 for each area), less than 10% difference between velocities was observed in 70% of the cases. In only 13% of cases the difference exceeded 15%. Frequency distributions of the magnitudes of the SIs are presented in Table 2.

Table 1 Descriptive Statistics of Symmetry Indices

AREA	VELOCITY (km · hr^{-1})	MEAN (%)	S.D (%)
HEEL	8	2.2	16.9
	14	7.2	18.6
FOREFOOT	8	-5.0	12.0
	14	-6.9	11.2
HALLUX	8	4.8	27.0
	14	8.9	25.1
MAX. FORCE	8	2.0	7.1
	14	1.5	8.2

Table 2 Frequency Distribution of the Symmetry Index (n=20)

		HEEL		FOREFOOT		HALLUX		MAX. FORCE	
VELOCITY (km*hr^{-1})		8	14	8	14	8	14	8	14
	< 10 %	8	10	9	9	6	8	15	17
SI	10 % - 15 %	6	1	4	5	4	2	5	2
	15 % - 20 %	1	4	5	5	0	1		
	20% <	5	5	2	1	10	9		1

Bi-variate correlation coefficients between the all SIs of foot pressure, reveal significant relationships between the two velocities at each of the areas (heel: r = .82, forefoot: r = .84, hallux: r = .86). There was a significant correlation (r = .71) between the SIs of the hallux and the forefoot at 8 km*hr^{-1} but not at 14 km*hr^{-1}. All other coefficients were in the low to moderate range and statistically insignificant. The correlation between MF and the three plantar pressure areas ranged between .12 and .39 except for a single higher correlation of .55 between the maximal force and forefoot at 8 km*hr^{-1}.

DISCUSSION: The SI that represents jogging and running paces is quite stable across the two velocities, as reflected by the high inter-velocity correlation for each area. The difference between velocities in mean SI did not exceed 5% (heel) and was as small as 0.5% for the MF. Moreover, most subjects did not exceed a difference in SI of 10% between the two velocities. Only a small number of cases showed a substantial change in personal SIs as a result of increased velocity. The relative stability in symmetry is maintained in spite of a substantial increase in mean foot pressure and MF at the higher velocity. This characteristic of the SI suggests that it is not a velocity specific index and that increased velocity does not increase the risks attributed to the magnitude of asymmetry.

The lack of significant relationships between the SIs of the different areas of the foot (except for the hallux and forefoot at the slower velocity) supports the idea of area specificity of the SIs. The implication is that relative symmetry can not be generalized for the whole foot. Subject with low levels of SI in one area can exhibit different levels of symmetry in other areas of the foot and vice versa. This phenomenon may be explained by the different functions of each area during the stance phase (Hennig & Milani, 1995). Differences in the profiles of plantar pressure symmetry may be a consequence of between or within subject variability in parameters such as foot structure (Cavanagh et al., 1997), shoe type (Hennig and Milani, 1995) and other anthropometric and neuromuscular factors (Vagenas & Hoshizaki, 1988). The low correlation between SI values of each of the plantar pressure areas and MF indicate that the later is not a valid representative index of symmetry in local plantar pressure. No structural or functional explanation could be found for the exception of significant relationship between SIs of the forefoot and the hallux at the lower velocity. Because this relationship did not appear at the higher velocity it is assumed that this observation is an artifact. The results of area specificity in conjunction with the low relationships between the SI of the MF and those of the three areas suggest that using the SI based on MF may misrepresent specific foot pressure symmetry. This is a sound conclusion from a biomechanical point of view as well because the peak foot-pressure at the three sections of the foot takes place at different phases of the stance. None of these phases correspond to the temporal occurrence of the MF.

Most of the means of SI were not statistically different from zero. This trend is consistent with observations made by Herzog et al. (1989) and Bennel et al. (1999) for parameters of ground reaction forces namely that there is no lateral preference in the sampled subjects. The exception in the current study with regard to mean forefoot SI may well be a sample specific observation. The magnitude of this SI (-6.9%) only marginally deviates from the upper value for mean SI of 6.1% observed by Bennel et al. (1999).

There is a substantial difference between areas in SI variability. Herzog et al. (1989) documented different magnitudes of variability to different indices of ground reaction parameters during walking. The MF has the lowest variability with 80% of the subjects below a SI of 10%. The highest variability in SI was observed in the hallux with almost 50% of the subjects having SI greater than 20%. Blanc et al. (1999) reported similar observations with regard to temporal parameters of the foot roll-over during gait. The underlying mechanism of this result is not clear. It can be hypothesized that the hallux will be influenced by bilateral differences in foot orientation more than the forefoot and the heel. Full explanation of the differences in SI variability will require an integration of foot pressure data with kinematic and kinetic analysis.

CONCLUSION: SI indices are area specific but are not velocity specific. The implication is that symmetry should be evaluated separately for each area and that MF can not reflect specific area symmetry. A general standard of symmetry can not be assumed because of inter-area differences in variability. Therefore, individual SIs should be evaluated in relation to their specific measure of variability (sd).

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