RELIABILITIES OF PLANTAR PRESSURE MEASURES: SYMMETRY INDICES DURING RUNNING AT TWO DIFFERENT VELOCITIES

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Reliabilities (REL) of 4 plantar pressure parameters (PPP) and 4 symmetry indices (SI) were assessed during the support phase of treadmill running at 8 and 14 km*hr^{-1}. Bilateral plantar pressure was recorded for 11 female and 9 male students with Pedar insoles during 4 right and 4 left foot contacts at each velocity. The RELs of 4 PPP (total peak force and peak pressures under the hallux, forefoot & heel) and their symmetery indices (Sis) were estimated by intraclass correlations (ICC). The ICCs for the PPP were in the range of 0.75-0.99 for 1 contact and 0.92-0.99 for 4 contacts. ICCs of the SIs were substantially lower than for PPP (0.41-0.85 for 1 contact and 0.74-0.96 for 4 contacts). ICCs at the heel were lower than at all other areas. A single measure of PPP provides high REL for all areas studied, except at the heel. A larger sample of foot contacts is necessary in order to ascertain highly reliable SIs.

KEYWORDS: running, symmetry, in-shoe pressure, reliability, intraclass correlation

INTRODUCTION: Plantar pressure parameters are used to evaluate a variety of lower extremity functions in human locomotion. In previous research, it has been suggested that indices of In-shoe plantar pressure are indicative of footwear quality and susceptibility to injury in sports (Hennig and Melani, 1995, Kernozek and Willson, 1999). In rehabilitation research (Cavanagh et al., 1992, Frietch et al., 1998). Miller (1990) argued that such parameters are more sensitive measures for such purposes than parameters of ground reaction forces of the whole foot obtained by means of force platforms. During the last decade, plantar pressure parameters have been widely used in studies of both walking and running.

Both walking and running are cyclic human motor behaviors. Since most human behavior is known to be an inconsistent phenomenon due to trial to trial fluctuation in performance, predetermination of the reliability of performance parameters is an essential prerequisite of data quality (Brown, 1976). Thus, acceptable reliabilities are paramount when human movement parameters are evaluated. The reliability of discrete motions, as well as that of cyclic movements, is dependent on the magnitude of the inconsistency inherent in the particular skill and on the level of skill of the subjects. The greater the magnitude of the inconsistency, the greater is the number of trials required to secure acceptable reliability.

The reliabilities of several parameters of ground reaction forces, obtained from a force platform, were evaluated by Bennel et al (1999) during a 4 m*s^{-1} (14.4 km*hr^{-1}) run. The intraclass correlation coefficients (ICC), based on 10 trials were reported to be 0.82 or higher. Several in-shoe plantar pressure indices have been used to evaluate the function of the human foot during walking and running with the intention of reflecting the time - pressure characteristics of the different sections of the plantar surface (Hennig and Melani, 1995, Kernozek et al., 1996). The reliability of the Pedar in-shoe system was evaluated in walking velocities of 3.2 km*hr^{-1}, 4.0 km*hr^{-1} and 4.8 km*hr^{-1} (Kernozak et. al, 1996) as well as in running on the treadmill at velocities of 8 km*hr^{-1} and 11.2 km*hr^{-1} (Kernozak & Zimmer, 1999). Based on a sample of between 10 and 16 walking footsteps, ICCs of plantar pressure and plantar forces at different sections of the foot were reported to be higher than 0.70 for a single foot contact, with higher reliability coefficients for a greater number of foot contacts. For running, ICCs of 0.84 or higher were reported for plantar pressure parameters in several regions of the foot.

One possible threat to the integrity of the locomotion system is that of asymmetrical forces applied through ground contact during walking and running. Such an asymmetrical imbalance may adversely affect higher sections of the locomotion system specific areas (Herzog et al., 1989) as well as in the foot. The degree of symmetry in human locomotion is reported as an index of symmetry (SI), expressed as the percentage difference between the

contra-lateral extremities in the measured parameter. Bennel et al (1999) reported ICC coefficients of SIs, based on force platform parameters, in the range of 0.53 to 0.91 with the exception of the slope of the vertical impulse force. In a comprehensive literature search, estimates of the reliabilities of SIs of plantar pressure parameters could not be found.
One purpose of this study was to reassess the reliability of foot pressure parameters at three sections of the foot, namely the heel, forefoot and the hallux, during slow running. This evaluation was extended to include a higher running velocity than those reported in the literature, namely 14 km*hr^{-1}.A second purpose of the study was to assess the reliabilities of four SIs derived from plantar pressure measurements of the foot.

METHODS: Subject group was comprised of 11 females and 9 males. All were physical education students with mean ages of 24.8±1.3 and 25.3±1.5 years respectively who consented to participate in the experiment. All subjects were reported to be free of lower extremity injury during data collection and free of any history of severe lower extremity injury. Subjects performed on a treadmill at velocities of 8 and 14 km*hr^{-1}. Running order was randomized with half of the subjects tested in the slower velocity first and the other half tested in reversed order. Subjects were allowed a personal warm up before the test. They then ran at least 30 seconds at each velocity before data were collected. This procedure has been selected to enable the subject to get familiar with the treadmill and to adopt a natural running pattern in rhythm with the pace of the belt.
Pedar insoles were inserted into both shoes of the subject. The insoles were fitted to the subject's shoe size and the shoes were tied to prevent relative movement between the foot and the insole without inducement of discomfort. The insoles were calibrated in advance in accordance with the manufacturer's specifications.
Four right foot and four left foot contacts were recorded and subjected to further analysis. Three areas of the foot were defined (Figure 1) each by a specific set of sensors as follows: 3 sensors represented the hallux (A1), 9 represented the forefoot (A2) and 6 represented the heel (A3). The pressure at each area was calculated as the mean of all the sensors that define the particular area. The peak mean pressure of each area during the support phase was selected for computation of bilateral symmetry. In addition, the maximal force exerted on the foot during the contact phase was subjected to similar procedures, based on the reading of all 99 sensors of the insole.

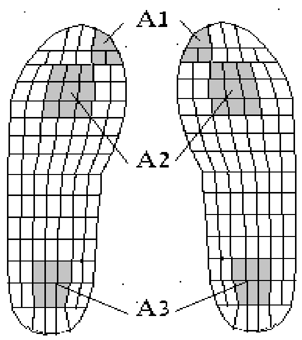

Figure 1 - Definitions of the three plantar pressure areas of the foot.

Four symmetry indices (SI) were defined according to Robinson et al. (1987) as follows:

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

XR and XL are the measured values of a particular parameter of the right and left foot, respectively.
The reliability of each parameter was estimated separately for each foot by means of ICC based on an ANOVA model (Baumgartner, 1989). In addition, ICCs for all SIs were

computed in a similar manner.

RESULTS: ICCs of the raw plantar pressure parameters are presented in table 1. When all four foot-contacts were used to assess the ICCs, the coefficients were 0.92 or higher. When a single foot contact was used, ICCs for all variables were 0.92 or higher except for the heel, where ICC ranged between 0.75 and 0.90. The ICCs of the SIs are presented in table 2. The coefficients are lower than those observed for the respective unilateral parameters. The ICCs ranged from 0.41 to 0.85 for a single foot contact and from 0.74 to 0.96 for four foot-contacts.

Table 1 ICC Coefficients for a Single Foot Contact and for a Sample of 4 Foot-contacts

VELOCITY	N OF	HEEL		FOREFOOT		HALLUX		MAX FORCE	
$km*hr^{-1}$	CONTACTS	left	right	left	right	left	right	left	right
8	1	0.90	0.75	0.94	0.95	0.96	0.92	0.99	0.98
14	1	0.75	0.83	0.95	0.97	0.93	0.93	0.97	0.98
8	4	0.97	0.92	0.99	0.99	0.99	0.98	0.99	0.99
14	4	0.93	0.95	0.99	0.99	0.98	0.98	0.99	0.99

Table 2 ICC of SIs for a Single Contact and for a Sample of 4 Foot-contacts

VELOCITY	N of TRIALS	HEEL	FOREFOOT	HALLUX	MAX FORCE
8 $km*hr^{-1}$	1	0.42	0.78	0.80	0.83
14 $km*hr^{-1}$	1	0.41	0.82	0.85	0.73
8 $km*hr^{-1}$	4	0.75	0.94	0.94	0.95
14 $km*hr^{-1}$	4	0.74	0.95	0.96	0.91

DISCUSSION: The reliability estimates of the plantar pressure parameters are high and support similar previous observations with regard to parameters of force plate ground reaction forces (Bennel et al., 1999) and plantar pressure parameters in both walking (Kernozek et al., 1996) and running (Kernozek & Zimmer, 1999). These results extend the findings of Kernozek & Zimmer (1999) regarding the high reliability characteristics of peak pressures of plantar areas up to running velocities of 14 $km*hr^{-1}$. Nevertheless, caution is required with regard to generalization of these findings to other populations. For example, Ahroni et al. (1998) reported much lower ICCs for foot pressure parameters using the F-scan in-shoe system in a sample of 51 diabetic veterans. Such differences may be due to different population characteristics or due to use of different measuring equipment.

It is noteworthy that the reliability levels at the heel were generally lower than those observed at the forefoot and the hallux. Such differentiation has not been documented in previous studies. Thus, while an analysis of a single support phase can provide a reliable measure of plantar pressure at the forefoot and the hallux, it is recommended that more than a single foot contact be used for the evaluation of plantar pressure at the heel. Using the Spearman-Brown prophecy formula (Brown, 1976; Baumgartner, 1989) it is estimated that the two heel ICCs of 0.75 for a single contact will increase to 0.86 if two foot-contacts are sampled and to 0.90 if three foot-contacts are sampled. The reason for the lower coefficients at the heel are not clear, but it might relate to the fact that initial peak heel pressure is a passive impact event (Novacheck, 1998), in which the runner can exercise minimal control.

The reliability coefficients of the SIs are lower than the reliabilities of the parameters that compose each index. This phenomenon is often recognized when using difference scores (Brown, 1976). It can be explained by the fact that SI is a composite score that comprises the errors that are inherent in the plantar pressure measurements of both the right and the left feet. Using the current results in conjunction with the Spearman-Brown prophecy formula, the SIs of the forefoot, hallux and maximal force require samples of 3 to 4 foot-contacts to reach reliability levels of .90 or higher. However, the SIs at the heel reach reliability levels of only

0.74 and 0.75 on the basis of 4 foot-contacts. Such levels might be sufficient in experiments that are designed to identify general trends in a population based on a relatively large sample of subjects. This level of reliability is insufficient for personal diagnostic purposes. When higher accuracy is required according to the prophecy formula, 12 foot-contacts are necessary in order to reach reliability levels of 0.90 or higher at the heel.
An interesting result of this study is the lack of significant differences in SI reliabilities between slow and fast running. It suggests that the same number of trials is appropriate in protocols that are planned for the identification of plantar pressure symmetry at different velocities.

CONCLUSION: a) The fact that high reliabilities characterize plantar foot parameters in running has been reconfirmed and extended to higher velocities. Specific parameters that display relatively lower reliability characteristics, such as the peak plantar-pressure at the heel, require extended sampling to obtain highly reliable data. Therefore, the general trend of high reliabilities can not be automatically assumed and its levels should be verified for different plantar pressure areas. b) Composite parameters, such as symmetry indices, are less reliable than the individual parameters of which they are composed. Therefore, a larger sample of foot-contacts is required in order to establish high levels of SI reliability than for similar reliability levels of individual parameters.

REFERENCES:
Ahroni, J.H., Boyko, E.J., & Forsberg, R. (1998). Reliability of F-scan in-shoe measurements of plantar pressure. *Foot & Ankle Int.,* **19**, 10, 668 - 673.
Baumgartner, T.A. (1989). Norm referenced measurement: Reliability. In: M.J. Safrit & T.M. Wood (eds.), *Measurement Concepts in Physical Education and Exercise Science* (pp. 45 - 72). Champaign. Il. Human Kinetics.
Brown, F.G. (1976). *Principles of Educational and psychological Testing*. New-York: Holt, Rinehart & Winston.
Cavanagh, P.R., Hewitt, F.G., & Perry, J.E. (1992). In-shoe plantar pressure measurement: A review. *The Foot*, **2**, 185 - 194.
Fritch, R., Daumling, S., & Riele H. (1998). Analysis of the stabilizing effect of the Aircast ankle brace for walking along an inclined plan. In: H.J. Riehle and M.M. Vieten (eds.), *Proceedings of the XVI international symposium on biomechanics in sports I* (pp. 458 - 461). University of Konstanz.
Hennig, E.M., & Melani, T.L. (1995). In-shoe pressure distribution for running in various types of footwear. *J. of Appl. Biomech*., **11**, 299 - 310.
Herzog, W., Nigg, B.M., Read, L.J., & Olsson, E., (1989). Asymmetries in ground reaction force patterns in normal human gait, *Medicine and Science in Sports and Exercise*, **21**(1), 110-114.
Kernozek, T.W., Lamote, E.E., & Dancisak, M.L. (1996). Reliability of an in-shoe pressure measurement system during treadmill walking. *Foot & Ankle*, **17**, 4, 294 - 209.
Kernozek, T.W., & Zimmer, K.A. (1999). Reliability and running speed effects on in-shoe loading measurements during treadmill running. In: W. Herzog & A. Jinha (Eds.) *International Society of Biomechanics XVIIth Congress: Book of Abstracts* (p. 769). University of Calgary.
Miller, D.I. (1990). Ground reaction forces in distance running. In: P.R. Cavanagh (Ed.), *Biomechanics of Distance Running* (pp. 203-224). Champaign. IL. Human Kinetics.
Novacheck, T.F. (1998), The biomechanics of running. *Gait and Posture*, **7**, 77 – 95.
Robinson, R.O., Herzog, W., & Nigg, B.M. (1987). Use of force platform variables to quantify the effects of chiropractic manipulation on gait symmetry. *J. of Manipulative and physiological Therapeutics*, **10**, 172 - 176.