EFFECTS OF UPPER VAMP DESIGN AND MIDSOLE MATERIAL AND THICKNESS ON GROUND REACTION FORCES IN RUNNING

R. Ferrandis, A. C. Garcia, J. V. Dur†, J. Ramiro, P. Vera

Institute of Biomechanics of Valencia
Valencia, Spain

INTRODUCTION

During the past decade a great effort in the field of biomechanics assessment of sport equipment has been dedicated to the study of sport shoes and specially to running shoes. The main topics on which the research has been focused are the control of pronation and the reduction of impact forces. Several studies have been dedicated to analyze the effect of midsole construction in ground reaction forces (GRF) or pronation (Luethi et al., 1985; Nigg et al., 1987; Nigg et al., 1988). Nevertheless in some of them no effect associated with different hardness or stiffness has been found in ground reaction forces (Nigg et al., 1987). In a previous work it was found that a post associated with an external heel counter was an effective feature to control pronation (Ferrandis et al., 1992). Besides a new methodology has been developed to characterize the mechanical properties of the materials simulating real loads (Garcia et al., 1992). In this paper, a study of the effect of the midsole's material, the midsole's thickness and the presence or not of a post associated with an external heel counter in GRF is studied. Also, the influence of an internal wedge to control pronation in GRF is investigated.

METHODOLOGY

A previous study of the mechanical characteristics of several polyurethane (PU) compositions and densities was made following the methodology developed by the Institute of Biomechanics of Valencia (IBV) (Garcia et al., 1992). From this study three materials were selected, the characteristics of which are listed in Table 1.

Table 1. Mechanical characteristics, rigidity and loss tangent, of the three PU materials.

	Rigidity (KN/m)		Loss Tangent	
PU	1.5 cm	2.5 cm	1.5 cm	2.5 cm
1	230 E4 (4E4)	116 E4 (4E4)	0.129 (0.004)	0.138 (0.004)
2	277 E4 (4E4)	148 (4E4)	0.228 (0.004)	0.267 (0.004)
3	217 E4 (4E4)	107 (4E4)	0.106 (0.004)	0.165 (0.004)

Twelve different prototype running shoes were specially made for this project. The prototypes were specified according to a 3-factor experimental design with the following factors: 1) thickness of the midsole: high (2.5 cm) and low (1.5 cm); 2) material: three types of PU materials; 3) presence or absence of a post associated with an external heel counter. The result of the experiment was a set of twelve running shoes whose characteristics are listed in Table 2.

Six subjects were selected for the study, three of them being pronators with flat foot and the other three showing rigid cavus foot. The examination of the interactions of type of foot with the effect of midsole materials and heel counter was an aim of this work. Each subject was asked to participate in a session in which the ground reaction forces during running were measured by using a DINASCAN force plate. Prototype shoes were randomized and ten valid measures were collected for each prototype. Running speed was measured by means of a pair of photocells and trials where the speed was lower than 3.6 m/s or higher than 4.4 m/s were neglected. The three pronators were also asked to run in the prototypes without an external heel counter, placing a wedge along the medial border inside the subject's shoes to control pronation.

Table 2. Characteristics of the twelve prototypes.

	Prototypes											
	1	2	3	4	5	6	7	8	9	10	11	12
Midsole Height												
25 mm	X	X	X	X	X	X						
15 mm							X	X	X	X	X	X
Heel Counter												
With				X	X	X				X	X	X
Without	X	X	X				X	X	X			
Type of PU												
1	X			X			X			X		
2		X			X			X			X	
2			X			X			X			X

From the ground reaction forces the following parameters were considered for statistical analysis: maximum vertical force at the impact peak (Fzi) and time from initial contact to the maximum vertical force at the impact (tFzi). A multifactorial analysis of variance of the results was done for the cavus foot group, considering subject, material, midsole thickness and presence or absence of the heel counter and post as factors. For the flat foot group two analyses were performed: one for the trials without a wedge, similar to the analysis done for the cavus foot group, and the other for trials running with prototypes without a heel counter considering subject, material, midsole thickness and presence or absence of the wedge to control pronation as factors.

RESULTS AND DISCUSSION

Results obtained for both the flat and the cavus foot groups are summarized in Table 3. As it was expected, the prototypes with higher midsoles showed significantly lower Fzi forces and higher tFzi for all the cavus foot and flat foot subjects ($p<0.01$).

With respect to PU materials, both the cavus foot and the flat foot subjects showed lower impact peaks with material two, the stiffest and more energy absorbing one ($p<0.01$). No significant differences between materials were found in tFzi for either group. This agrees with several published works (Luethi et al., 1985; Nigg et al., 1988). In these papers, it has been suggested that harder shoe soles would produce greater moments around the joint axes which results in increased joint motion. This means that impact force peaks, measured with a force plate, must be smaller for shoes where the first contact occurs laterally than for shoes where the landing takes place more centrally under the heel (Denoth et al., 1986). In other papers it is explained as a bottoming out phenomenon of the softer materials (Nigg et al., 1986). As the rigidity of the materials studied in this work was measured by applying loads similar to those recorded on the force plate, it is unlikely that a bottoming out phenomenon must have occurred for the softer materials.

Table 3. Results of Fzi and tFzi for each level of the factors studied.

	Planus Feet		Cavus Feet	
	Fzi/weight	tFzi (ms)	Fzi/weight	tFzi (ms)
Height of Midsole				
25 mm	1.86 (0.01)	39.8 (0.3)	2.49 (0.02)	38.2 (0.2)
15 mm	2.043 (0.01)	32.1 (0.3)	2.59 (0.02)	31.3 (0.2)
Heel Post				
with	1.952 (0.01)	37.0 (0.3)	2.51 (0.02)	35.5 (0.2)
without	1.951 (0.01)	35.0 (0.3)	2.57 (0.02)	34.0 (0.2)
Type of PU				
1	1.990 (0.01)	36.5 (0.3)	2.55 (0.02)	34.8 (0.2)
2	1.895 (0.01)	35.5 (0.3)	2.46 (0.02)	34.4 (0.2)
3	1.969 (0.01)	35.8 (0.3)	2.60 (0.02)	35.0 (0.2)
Internal Wedge				
with	2.003 (0.01)	35.3 (0.2)		
without	1.951 (0.01)	34.9 (0.2)		

No significant differences were found in Fzi in the flat foot group due to the presence or absence of a heel counter. Nevertheless, for the cavus foot group, lower impact forces were encountered for the prototypes with heel counter and post ($p<0.01$). Also, for both the cavus and the flat foot groups, higher tFzi's were found for the prototypes with an external heel counter ($p<0.01$). These results can be explained by a better confinement of the heel pad obtained with these prototypes; as it is known, heel pad is an important shock absorbing mechanism (Jorgensen et al., 1989). In the flat foot group, the heel counter could also have an effect of reducing initial pronation, but as was found in a previous work (Ferrandis et al., 1992), this rearfoot control feature has little influence in initial pronation. Nevertheless, any small effect in pronation control of flat foot subjects would interact with the heel pad confinement effect and the total of both would be lower; this agrees with the results obtained in our study which show that cushioning in flat foot group was only significant in the tFzi variable.

Significant differences in Fzi were found because of the presence of an internal wedge ($p<0.01$), increasing Fzi when the wedge was used. This can be due to a reduction of initial pronation.

CONCLUSIONS

Similar results were found for both the cavus and flat foot groups with respect to the factors studied. For both groups, lower impact forces and higher times of impact were found with the higher midsoles. Lower impact forces were obtained with the most energy absorbing material both for cavus and flat foot runners. The presence of an external heel counter and a post was found to produce lower impact forces in cavus foot runners and higher times of impact in both groups. The use of an internal orthotic wedge to control pronation showed a significant increase of impact forces.

ACKNOWLEDGMENTS

The authors wish to acknowledge the Interministerial Commission for Science and

Technology of Spain (R.E. number 3697) and the valencian companies related to Sport Footwear Industry TERCONSA, J'HAYBER and CYKO for their financial support.

REFERENCES

Denoth, J. (1986). Load on the locomotor system and modelling. In Biomechanics of Running Shoe. B. M. Nigg (ed.). pp 63-115. Champaign, IL: Human Kinetics.

Ferrandis, R., Ramiro, J., Garcia, A. C., Hoyos, J. V., Vera P. (1992). Influence of bondings for the lacing, backers and heel counters in pronosupination movement in running. In Proceedings of 1992 ISBS Conference. R. Rodano, G. Ferrigno, G. C. Santambrogio (eds.). pp 247-250. Milano, Itlay: Edi-Ermes.

Garcia, A. C., Ramiro, J., Ferrandis, R., Clement, V., Alepuz, R., Hoyos, J. V., Vera P. (1992). Dynamic Study of Footwear Materials Simulating Real Loads. In Proceedings of 1992 ISBS Conference. R. Rodano, G. Ferrigno, G. C. Santambrogio (eds.). pp 239-242. Milano, Itlay: Edi-Ermes.

Jorgensen, U. and Bojsen-Moller F. (1989). Shock Absorbency of Factors in the Shoe/ Heel Interaction - with special focus on role of the heel pad. Foot and Ankle 9 (11):294-299.

Luethi, S. M., Denoth, J., Kaelin, X., Stacoff, A., Stuessi E. (1985). The influence of the shoe on foot movement and shock attenuation in running. In Biomechanics XI-B . G. de Groot, A. P. Hollander, P. A. Huijing, G. J. van Ingen Schenau (eds.) pp 931-935. Amsterdam: Free University Press.

Nigg, B. M., Bahlsen, H. A., Denoth, J., Luethi, S. M., Stacoff A. (1986). Factors influencing kinetic and kinematic variables in running. In Biomechanics of running shoes. B. M. Nigg (ed.). pp 139-159. Champaign, IL: Human Kinetics.

Nigg, B. M., Bahlsen, H. A., Luethi, S. M., Stokes, S. (1987). The influence of running velocity and midsole hardness on external impact forces in heel-toe running. J Biomech 20(10):951-959.

Nigg, B. M. and Bahlsen, H. A. (1988). Influence of Heel Flare and Midsole Construction on Pronation, Supination, and Impact Forces for Heel-Toe Running. Int J Sport Biomech 4:205-219.