SPRING BEHAVIOUR OF THE FOOT DURING IMPACT PHASE OF RUNNING

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INTRODUCTION

In human locomotion, the feet, being the first part of the body concerned by the foot strike, play an obvious role in shock cushioning. Shock absorbtion features have been attributed to the heel pad, with different mechanical descriptions through in-vitro [1], in vivo [2] and running [3] tests. Moreover, the arch of the foot has been shown, in vitro, to have spring-like qualities [4], allowing the foot to flatten at each ground contact, and probably to contribute to cushioning. Since very few data are available on the mechanical behaviour of the entire "in-shoe" foot system, the aim of this study is to describe it through different running conditions inducing various mechanical constraints.

METHODS

Eighteen physically active men ran at 12 km.h^{-1} in 5 randomized 5-min conditions: a reference condition at a freely chosen stride frequency with neutral running shoes (C_{REF}), and 4 conditions with high and low body weights (C_{OVL} : +20%; C_{UNL} : -20%) and midsole hardness (C_{SOF} : soft; C_{HAR}: hard). For each condition change, the others were let at their reference level. During each test, two foot strikes were laterally filmed at 1000 frames.s^{-1} (MEMRECAM FX K4, NAC, Japan). The absolute foot deformation was assessed on each frame by the changes in the sagittal distance between the external malleolus and the upper edge of the midsole, and then synchronized with the vertical ground reaction force (1000 Hz, treadmill dynamometer, HEF Tecmachine, France). For each filmed foot strike in the different running conditions, a force-deformation diagram was obtained over the time interval between foot landing and the first force impact peak. The stiffness of the foot was calculated with the mean slope of the force-deformation diagram between 0 and 200 N (k_{0-200}), 200 and 600 N ($k_{200-600}$) and over 600 N ($k_{>600}$). Moreover, the grand mean stiffness (K) was computed from the maximal deformation and the corresponding vertical force.

RESULTS AND DISCUSSION

Results of ANOVAs for repeated measures, used to test midsole hardness and body weight effects, are presented in Table 1. The 10 to 12 mm maximal deformations (12 to 15% relatively) are in line with the few values reported during running (10-mm foot flattening [4] and 5-mm heel pad deformation [3]). The force-deformation relationships are non-linear (Figure 1), as underlined by a significant increase of stiffness when force increases ($k_{0-200} < k_{200-600} < k_{>600}$, $p<0.05$). Such a behaviour was previously observed for the heel pad [1-3] and the arch of the foot [4].

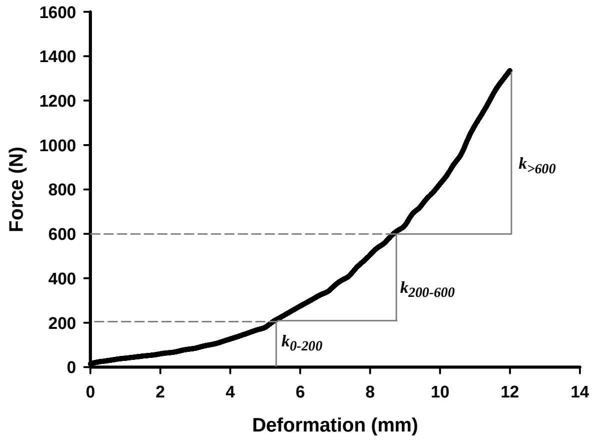

Figure 1: Typical force-deformation relationship of the foot (C_{REF}) and force ranges for which stiffness was computed.

The foot mechanical characteristics did not vary across the running conditions for a given subject. No effect of midsole hardness or body weight was shown on k_{0-200}, $k_{200-600}$, $k_{>600}$ and K (Table 1). The stiffness values (40 to 280 kN.m^{-1} for k_{0-200} to $k_{>600}$) are in accordance with those measured for heel pad and foot arch. Indeed, modelling the entire foot as two springs arranged in series, and considering the stiffness values reported for heel pad [3] and foot arch [4], the resulting-spring stiffness may be estimated from 50 to 260 kN.m^{-1} for vertical forces from 0 to 1500 N.

CONCLUSIONS

The entire foot system presents a spring-like behaviour with mechanical characteristics that do not vary across different running conditions and mechanical constraints, enabling, also through its large deformation, shock cushioning during foot strike.

REFERENCES

1. Aerts P, et al. *J Biomech.* **28**:1299-1308, 1995.
2. Aerts P and De Clercq D, *J Sport Sci.***11**:449-461, 1993.
3. De Clercq D, et al. *J Biomech.* **27**:1213-1222, 1994.
4. Ker RF, et al. Nature. **325**: 147-149, 1987.

Table 1: Mean values ± SD of maximal foot deformation, force at maximal deformation and foot stiffness characteristics in the different running conditions

	Midsole hardness effect				Body weight effect			
	Soft midsole	**Reference**	**Hard midsole**	ANOVA	**Underloaded**	**Reference**	**Overloaded**	ANOVA
Maximal deformation (mm)	10.4 ± 2.37	10.4 ± 1.88	9.83 ± 2.64	*ns*	10.7 ± 3.26	10.4 ± 1.88	11.6 ± 3.07	*ns*
Force at maximal deformation (N)	1228 ± 204	1186 ± 261	1095 ± 158	*ns*	1100 ± 213 [a]	1186 ± 261	1236 ± 251	*p<0.05*
k_{0-200} (kN.m^{-1})	45.1 ± 27.8	46.4 ± 17.6	39.8 ± 12.9	*ns*	57.0 ± 51.2	46.4 ± 17.6	39.5 ± 21.8	*ns*
$k_{200-600}$ (kN.m^{-1})	163 ± 44.7	136 ± 33.9	153 ± 60.5	*ns*	129 ± 32.0	136 ± 33.9	177 ± 102	*ns*
$k_{>600}$ (kN.m^{-1})	213 ± 58.0	263 ± 89.1	363 ± 163	*ns*	245 ± 127	263 ± 89.1	283 ± 121	*ns*
K (kN.m^{-1})	**121 ± 24.0**	**116 ± 26.7**	**119 ± 36.5**	*ns*	**111 ± 38.7**	**116 ± 26.7**	**113 ± 33.0**	*ns*

ns : no significant effect

[a] Significantly different (p<0.05) from overloaded condition