STUDY ON THE INFLUENCE OF MIDSOLE HARDNESS AND SURFACE TYPE ON LOADING RATE IN HEEL-STRIKE RUNNERS

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High loading impact (LI) associated with heel strikes causes running injuries. This study aimed to investigate how midsole hardness and surface type affect LI. 12 runners ran at a fixed speed along an 18m runway with different midsole hardness (Asker C-45, 50, 55, 60) and on different surfaces (Rubber and Concrete). We conducted repeated-measures ANOVA on LI measures, and one-sample t-tests to compare VALR with a threshold value. Midsole hardness and surface type mainly affected VALR. Several combinations of midsole and surface reduced VALR below threshold: C-45 with both surfaces (R: 69.72±8.10 BW/s, C: 71.37±12.50 BW/s), and C-50 with a rubber surface (68.21±10.52 BW/s). Combining softer midsole and surface results in the greatest cushioning, which demonstrates the benefit of considering both factors in reducing running injuries.

KEYWORDS: midsole hardness, running surface, loading rate.

INTRODUCTION: Approximately 37-56% of runners experience injuries annually, with over half resulting from overuse linked to repetitive high-impact forces during running(Van Mechelen, 1992). Therefore, it is important to reduce impact load, which can be accomplished through modifications of shoes and running surfaces used by frequent runners.

To reduce impact load, cushioning mechanisms have been developed through footwear modification. Changing midsole characteristics (e.g., midsole hardness) is the most common approach to modifying cushioning in footwear. Midsole hardness values range from Asker C-40 to C-70 in running footwear. In vitro studies show varied results (Baltich et al., 2015; Malisoux et al., 2021), possibly influenced by differing running surfaces affecting impact loads. Different running surfaces significantly impact loading rates, affecting shoe cushioning. For instance, grass reduces vertical impact force, while harder surfaces like concrete and asphalt increase average loading rates. However, only a few studies, limited to tennis and football, have manipulated surface and midsole hardness to evaluate their combined effects on loading rate(Damm et al., 2013; Low & Dixon, 2014). The combined effects of surface type and midsole hardness on loading rates are not yet clear, necessitating more systematic research.

Impact load has been extensively quantified using ground reaction force (GRF) in the vertical direction. Loading rate is characterized by the rate of increase in vertical GRF between initial contact with the ground and the first transient peak. Excessive vertical average loading rates (Abbreviated as VALR) strongly correlates with running injuries, with threshold values ranging from 57.4 to 80 BW/s across studies, beyond which VALR is likely to cause running injury (Johnson et al., 2020; Shih et al., 2019).

Therefore, this study aimed to investigate the effect of midsole hardness and surface type on loading impact measures that affect loading rate during running. We used four different values of midsole hardness and two surfaces commonly encountered in daily running. Based on previously reported changes in impact loading and running injuries, we hypothesized that softer midsoles and surfaces would decrease VALR under 80 BW/s. We also hypothesized that the effect of midsole cushioning would depend on surface hardness.

METHODS: We conducted an *a priori* power calculation to determine the number of participants needed for this study. We set the effect size to 0.4, alpha level to 0.05, and total sample size to 12 to reach a power of 88% in repeated measures (Malisoux et al., 2021). Twelve healthy male adults (22.5 ± 3.2 years; weight 65.0 ± 6.3 kg; height 173.2 ± 3.0 cm) participated in this study. All participants were habitual heel-strike runners and were free of muscular or neurologic impairments that might influence locomotion. This study was approved by the Institutional Review Board of Beijing Sport University (IRB Number: 2021176H).

Four force plates were embedded in the middle of an 18 m runway. Concrete and rubber surface plates (same size as the force plates, thickness = 15 mm) were placed on top of force plates on the runway. The concrete surface plates were made from cement and fiber, and the rubber surface plates were cut from a prefabricated rubber running track (hardness: Asker A-50). Both materials were detachable, allowing the runway surface to be changed. Participants were provided with custom-sized shoe prototypes with different values of midsole hardness.

The order of shoe hardness and surface types was randomized for each participant. All participants performed three heel-strike running trials at fixed speeds of 3.33 ± 0.15 m/s for each shoe and surface combination, 24 trials in total. If foot contact with the force plate was partial, or the participant completed the trial faster or slower, the data was discarded, and a new trial was conducted until the collected data satisfied the requirements of the study.

Force plate data were sampled at 1000 Hz. Nineteen retroreflective markers were placed on the participant's lower limb based on a modified Helen-Hayes model. Kinematic data were tracked at 200 Hz by an 8-camera Motion Capture system. Kinematic data were filtered using a 4th zero-lag low-pass Butterworth filter with a cutoff frequency of 8 Hz using Cortex software. Kinetic data were filtered using a 4th low-pass Butterworth filter with a cutoff frequency of 50 Hz. Heel contact and toe off were identified with vertical GRFs at 10 N.

The peaks of the GRF time profile during a stance were identified for each trial. In trials where the first peak (i.e., VIPF) was present, the VALR was quantified by the average slope of the vertical GRF time profile over 20–80% of the time to VIPF. In trials where VIPF was not present, the force value at 13% of stance was designated as VIPF (Davis et al., 2016). Foot strike patterns were described by the foot strike angle. The angle was calculated as the angle between the foot segment and the ground at initial contact.

Repeated-measures two-way ANOVA tests were conducted to determine the effect of midsole hardness and surface type on VALR and foot strike angle. When there were significant main or interaction effects, pairwise comparisons were conducted using Tukey's adjustments. One-sample t-tests were used to determine if the VALR values were significantly lower than 80 BW/s. All statistical tests were performed using SAS 9.3, with alpha equal to 0.05.

RESULTS: No significant interaction between midsole and surface was observed for VALR and foot strike angle used in the present study.

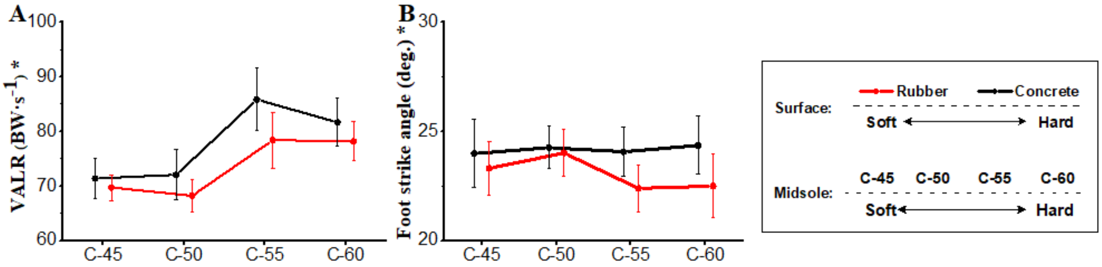

Figure 1. Mean (SE) of VALR and foot strike angle as a function of the midsole hardness and surface types. C-45, C-50, C-55 and C-60 are midsole hardness Asker values from soft to hard. Red lines indicate rubber surface. Black lines indicate concrete surfaces. Post hoc comparisons among levels within the factor of midsole and surface type were indicated by letters and asterisks respectively. Midsole hardness levels with different letters are significantly different from each other. Asterisks indicate a significant difference between the two surfaces.

There were significant effects of surface (F[1,77] = 4.26, p = 0.042) and midsole (F[3,77] = 9.84, p < 0.001) hardness on VALR (Fig. 1A). VALR for the rubber surface was significantly less than that for the concrete surface (p = 0.042). VALR for the Asker C-45 midsole was significantly less than that of the Asker C-55 (p < 0.001) and Asker C-60 (p = 0.007) midsoles, and VALR for the Asker C-50 midsole was significantly less than that for the Asker C-55 (p < 0.001) and Asker C-60 (p = 0.005) midsoles.

One-sample t-tests revealed that VALR for Asker C-45 (p = 0.043) on concrete and Asker C-45 (p = 0.001) and Asker C-50 (p = 0.003) on rubber were significantly lower than 80 BW/s. More specifically, the values for Asker C-45 (p = 0.026) and Asker C-50 (p = 0.032) midsoles on rubber were lower than 76 BW/s.

There was a significant effect of surface on foot strike angle (F[1,77] = 4.14, p = 0.045; Fig. 1B). The foot strike angle of the rubber surface was significantly less than that of the concrete surface (p = 0.045). There was no significant effect of midsole hardness on foot strike angle (F[3,77] = 0.51, p = 0.678).

Table 1. Individuals' across-trial VALR (Mean and SD) by surface type and midsole hardness. BOLD indicate VALR lower than 80 BW/s.

		Midsole Hardness							
Surface type	No.	Asker-C 45		Asker-C 50		Asker-C 55		Asker-C 60	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Rubber	1	**75.59**	7.20	**77.52**	11.78	89.99	10.04	102.90	7.16
	2	**72.74**	8.81	80.49	10.18	109.92	1.99	89.69	9.25
	3	**73.81**	13.15	**77.42**	4.69	89.76	5.02	**78.44**	4.85
	4	**76.44**	4.07	**68.51**	4.03	94.56	1.24	95.58	7.49
	5	**63.62**	8.12	**64.55**	2.82	**60.62**	1.68	**71.85**	2.71
	6	**58.29**	5.27	**61.55**	3.80	80.48	18.95	**64.75**	9.99
	7	**63.52**	2.54	**62.05**	3.32	**70.85**	10.64	**61.25**	5.69
	8	**63.32**	12.40	**75.43**	13.28	**53.53**	4.89	**72.14**	5.67
	9	**74.32**	2.68	**69.34**	14.27	**70.51**	20.12	**70.39**	4.69
	10	**77.15**	7.36	**42.74**	11.69	**49.86**	16.99	**67.68**	6.82
	11	**55.53**	4.07	**59.33**	10.44	**73.61**	2.50	**75.01**	3.54
	12	82.28	1.24	**79.56**	11.71	97.22	8.76	88.14	2.84
	Total	69.72	8.10	68.21	10.52	78.41	17.72	78.15	12.48
Concrete	1	89.34	19.71	98.76	19.27	103.39	15.76	107.60	11.40
	2	84.25	6.48	101.78	19.35	113.20	21.46	94.97	4.33
	3	**65.73**	9.20	**72.93**	17.92	95.10	7.80	83.47	5.64
	4	82.00	6.08	82.83	10.47	106.33	16.24	101.11	3.08
	5	**57.06**	2.77	**55.08**	9.44	**65.82**	5.59	**61.36**	7.98
	6	**50.41**	6.07	**53.56**	12.47	**68.04**	12.28	**56.00**	15.02
	7	**75.99**	4.50	**57.56**	2.65	**78.92**	13.00	80.80	14.76
	8	**77.28**	5.39	82.60	2.53	95.28	9.14	90.90	1.75
	9	**72.16**	6.96	**73.19**	6.80	90.48	14.08	87.62	13.25
	10	**70.26**	18.11	**69.90**	9.65	**42.04**	15.81	**65.06**	3.41
	11	**50.44**	2.82	**54.74**	10.49	**72.51**	3.36	**76.66**	6.79
	12	81.47	1.36	**61.64**	14.23	98.68	10.59	**74.16**	8.94
	Total	71.37	12.50	72.05	16.02	85.82	19.79	81.64	15.22

DISCUSSION: The purpose of this study was to investigate the effect of the hardness of shoe midsoles and surface materials on impact cushioning during overground heel-strike running. We systematically manipulated midsole hardness and surface type to explore the combined effect and potential interference between the two variables. The results support our first hypothesis, that reduced hardness of midsoles or surfaces decreases VALR under 80 BW/s. Our second hypothesis, that there is an interaction between the midsole and surface type, was not supported as we did not observe a statistically significant interaction between the two factors. However, using the VALR threshold, several combinations of the two reduced VALR below 80 BW/s, indicating that surface hardness does have an effect on overall cushioning and therefore should be a consideration in footwear selection.

To investigate the clinical relevance of the cushioning effect, we compared the values of VALR observed here to the 80 BW/s reported previously. For the rubber surface, we found that both the Asker C-45 and C-50 midsoles decreased VALR to below 80 BW/s, but for the concrete surface, this was the case only for the softest midsole (Asker C-45; Table. 1), which highlights the role of running surface in the overall cushioning effect.

VALR was a function of surface and midsole hardness (Fig. 1A), with the softer midsoles and surfaces reducing loading rate during running. Our results on the dependence of VALR on midsole and surface hardness are consistent with those of Stiles et al. (2011) and Dixon et al. (2000), but inconsistent with the study of Malisoux et al. (2021) using a treadmill, who found no dependence of VALR on midsole hardness. These possibly result from intra-belt speed variations and loading rates for heavier subjects (Malisoux et al., 2021; Van Hooren et al., 2020). As loading rate could be affected by running behavioural change, even without a change in the environment, we calculated the foot strike angle to further confirm the source of differences in loading rate measures. In our study, foot strike angles did not depend on midsole hardness (Fig. 1B) and were slightly greater on concrete than on rubber (23.0 vs. 24.2°), although the difference may not be enough to change the foot strike pattern. Therefore, we conclude that our observations result from cushioning effects from midsole and/or surface changes, not changes in individual foot strike behaviour.

CONCLUSION: The combination of a softer midsole and surface material (e.g., rubber) maximally reduced loading rate (under 80 BW/s) and would likely reduce the related risk of running injury for males. Future research on shoe cushioning effects should consider surface hardnesses typically used for over-ground or treadmill running and gender differences.

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