may simply be that the diet was different from the diet normally consumed by the subjects. The cyclists' normal diet contained a mean of 264 g·d⁻¹ of carbohydrate, while the MCHO diet contained a mean of 258 g·d⁻¹. Thus, the MCHO diet was more like the subjects' normal diet, whereas the LCHO diet was vastly different. Further support for this concept can be based on the fact that two subjects verbally reported that they did not like the HCHO diet. These two subjects also scored higher in tension, depression, and anger and lower in vigor while on the HCHO diet. The other subjects generally had similar mood scores while on the MCHO and HCHO diets. It may be that in some cases a diet that deviates from a subject's "normal" diet may be perceived somewhat adversely. Support for this concept can be found with the work of Rosen et al. (9). These investigators reported that obese females placed on carbohydrate-containing and carbohydrate-restricted hypocaloric diets exhibited a tendency toward dysphoric moods and attitudes during the 1st wk of the diet, but after 6 wk on the diet the subjects' moods and attitude were not different from baseline, predicted values. Thus, some adaptation to the different diets occurred over time as the subjects became more accustomed to the diets or the diets became more "normal." In summary, the present study found that the consumption of a low-carbohydrate (13% kcal), high-protein, and high-fat diet caused significant changes in the mood state of female cyclists undergoing a training and exercise program. These changes were generally of an adverse nature and could be considered detrimental to training and performance. These changes in mood were improved with the addition of more dietary carbohydrate (54% kcal). Higher-carbohydrate diets (72% kcal) caused no further change in mood as compared with the moderate-carbohydrate diet.

Address for correspondence: Robert E. Keith, Department of Nutrition and Foods, Auburn University, AL 36849.

REFERENCE
STEVEN E. ROBBINS and GERARD J. GOW
Athletic footwear: unsafe due to perceptual illusions

ABSTRACT
ROBBINS, S. E. and G. J. GOW. Athletic footwear: unsafe due to perceptual illusions. Med. Sci. Sports Exerc., Vol. 23, No. 2, pp. 217–224, 1991. Modern athletic footwear provides remarkable plantar comfort when walking, running, or jumping. However, when injurious plantar loads debt negligible perceived plantar discomfort, a perceptual illusion is created whereby perceived impact is lower than actual impact, which results in inadequate impact-modulating behavior and consequent injury. The objective of this study was to examine how plantar tactile (mechanical) events affect perceived plantar discomfort. Effectively, this was the feasibility of a footwear safety standard we propose, which requires elimination of the above illusion. Twenty subjects gave numerical estimates of plantar discomfort produced by simulated locomotion (constant vertical 0.1-0.7 kg·cm⁻² and horizontal 0.1-0.0 kg·cm⁻² plantar loads), with the foot supported by either a smooth rigid surface or a rigid surface with 2 mm high rigid irregularities. Vertical or horizontal load alone evoked no discomfort (P > 0.05), whereas together, discomfort emanated from loads as low as 0.4 kg·cm⁻². Irregularities heightened discomfort by a factor of 1.89. This suggests that the proposed safety standard is feasible, since compliance could be achieved simply by adding surface irregularities to insoles and by other changes that heightens localized plantar load. However, until this standard is adhered to, it might be more appropriate to classify athletic footwear as "safety hazards" rather than "protective devices."

ATHLETIC INJURIES, PROTECTIVE DEVICES, INJURY PREVENTION, SHOCK ABSORPTION

Impact (shock, shock loading) is defined as "a collision between two bodies, which occurs in a very small interval of time, during which the two bodies exert on each other relatively large forces." (2) Acute overloading is injury following a single loading, e.g., falling from a high place. Chronic overloading is injury following a multitude of single loads applied over a period of time, each of which is incapable of causing acute overloading, e.g., running related injuries (47). During locomotion (walking, running) or activities where people repetitively jump (e.g., aerobics, gymnastics), the plantar surface (sole of foot) sustains repeated impact consisting of large rapidly applied vertical and horizontal plantar loads (1,11,43). The vertical component of

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plantar impact results in propagation of shock waves (20,31,38,52,65,63) that produce chronic overloading of bone and connective tissue in various mammals (18,31,42,45,52,53), and data suggest that it is equally destructive to humans (3,10,20,21,23,25-28,31-34,46,56,59-60).

The high incidence of chronic overloading during locomotion suggested to footwear designers that the lower extremity is fragile. Accordingly, over the past 15 yr athletic footwear has been designed to shield the lower extremity from damage, as is delicate merchandise when injured (4). One of the mechanisms of yielding (compliant, soft) packaging materials. The recent models have the most packaging, hence the greatest compliance and comfort, which follows compliance (12,13,17,37).

This footwear has been something less than successful protective devices. A comparison of earlier epidemiologic studies dealing with running-related injury incidence with recent reports suggests that there is presently a higher incidence of these injuries (e.g., Martin et al. (33), training injuries in year prior to running event: males 46%, females 40%); Caspersen et al. (10), training injuries in year prior to running event: males 35%, females 35%). Wearers of expensive running shoes that are promoted as having additional features that protect (e.g., more cushioning, "pad summit correction") are injured significantly more frequently than runners employing inexpensive shoes (costing less than US$40), with no major manufacturer superior to others with respect to injury incidence (32). Moreover, runners who have a footwear brand preference are more likely (P < 0.05) to be injured than those who have no brand loyalty (37). The increased incidence injury with modern running shoes can be attributed to greater impact when runners use footwear more of the current design, men who compared with footwear in use a decade earlier (37). Furthermore, when runners unaccustomed to barefoot running run barefoot, mean impact is no higher than when shod and in some cases is lower (13-15,19,27,30,54). In addition, in barefoot populations running-related injuries are rare, which indicates that
people adapted to barefoot running run with lower impact than the unadapted group referred to above (49). This also suggests that the lower extremity is inherently durable and is made susceptible to injury by footwear use (7, 57, 58). Based on the above data, notwithstanding unsupported claims by footwear manufacturers of improved protection with their products, it seems appropriate to consider expensive athletic footwear from major manufacturers (and perhaps less expensive shoes) as unsafe.

Our initial hypothesis (49), which attempted to explain the inability of athletic footwear to protect and the freedom from injury when barefoot-adapted, has progressed with the addition of recent data (47, 58, 50, 51) (Fig. 1). Our present hypothesis is as follows:

In humans, avoiding uncomfortable or painful but locally innocuous plantar cutaneous tactile stimuli moderates shock on subsequent impacts when humans walk, run, or jump repetitively. This feedback control circuit is optimized in terms of protection for mechanical interaction of the bare foot and natural surfaces. Eventually learning allows anticipatory avoidance. Modern athletic footwear is unsafe because it attenuates plantar sensations that induce the behavior required to prevent injury.

(Avoidance is a behavior that moderates stimulus intensity or evades the stimuli entirely. Natural surfaces refer to naturally deposited ground, i.e., irregular surfaces.) What support does this hypothesis have? It explains the difference in injury incidence between barefoot and shod runners (26, 33, 49) via the requirement of plantar discomfort on impact for optimized shock absorption. This is strengthened by reports indicating that, when habitual barefoot humans walk (and probably when they run), they have a greater knee flexion, which has been shown to reduce shock (35), compared with shod subjects. In addition, when running, the longitudinal foot arches deflect from highly arched to flat with each gait cycle, which likely has shock absorbing properties (6, 29).

The theory explains why material tests fail to predict actual impact when running (13–15, 19, 30, 34). The more compliant shoe, which according to material tests should attenuate shock more effectively, fails to do this because it produces greater plantar comfort (29), hence less impact-moderating behavior.

The linkage between plantar perceptual processes and impact-moderating behavior is also clear. When the plantar surface is rapidly and heavily loaded to simulate vertical loading during running, avoidance by hip flexion increases in relation to surface characteristics producing discomfort, such as irregularity (50). Furthermore, we demonstrate that, to avoid impact (irregular, rigid surfaces, heightened plantar discomfort) was more effective than barefoot activity indoors (regular, compliant surfaces) in inducing raising of the medial longitudinal arch of the foot. This adaptation can be explained by local differences in tactile sensibility along the plantar surface (48).

Moreover, in a psychophysical study we found that, when subjects were made to wear modern athletic footwear and the plantar surface is loaded to simulate the impact of locomotion, a perceptual illusion is produced whereby perceived plantar impact is less than actual impact (51). An illusion is defined as "something that deceives or deludes by producing a false impression" (Oxford English Dictionary). We refer to this as the "discomfort-impact illusion". When the plantar surface is similarly loaded but supported by a simulated natural surface (compact gravel, in which), it produces plantar discomfort load, load estimates are accurate; hence, this discomfort-impact illusion is eliminated.

In a recent report (36) relating to this illusion, impact was measured when 15 well-trained gymnasts walked off a platform 0.69 m high and landed on either yielding mats or a hard surface. With every subject, impact when landing on the hard surface was lower than on the yielding mat, and adequate stimuli of plantar deformations and distortions. According to current thinking, impact-moderating behavior is composed of three elements, but we believe that a more complex model will evolve.

**METHODS**

**Apparatus.** Similar to apparatus used in a previous report (50) (Fig. 2), the equipment used in this experiment was adjustable so that, when the subject was seated, the knee was flexed at 90 degrees. Impact was delivered by pneumatic actuators; vertical impact to the thigh near the knee and horizontal impact to the foot near the Achilles tendon attachment. The thigh and foot were conjoined to their respective impact application plates by several layers of elastic crepe bandages. With this attachment, when the loads were removed, pressure induced plantar cutaneous sensations ceased as the thigh was lifted, and the foot was passively moved so as to be repositioned for reaplication of impact. Uncomfortable sensations from the thigh and Achilles attachment were minimized by interfaces composed of elastic material.

A programmable controller and electronic air pressure regulators allowed vertical and horizontal impact to be selectable through a keypad. The retracted position of each pneumatic actuator was adjustable so as to allow positioning of the foot on the plantar contact surface in a geometry whereby plantar load was equalized with respect to the foot’s medial-lateral and anterior-posterior axes. The travel of the actuators was maintained at 6 cm vertically and 12 cm horizontally. Vertical impact was programmed to reach 0.4 kg cm⁻² prior to application of the horizontal component (Fig. 3). This was found in pilot studies to optimize the rate of loading (loading was complete in 1 s) while preventing foot horizontal movement.

**Figure 2—Positioning of subject's leg in apparatus.**

In this experiment, the impact application plates were separated by 2 cm. The force applied was 8.5 cm above and below the center line. The impact was measured in terms of load and time. The load was measured in grams, and the time was measured in seconds.

**Figure 1—The hypothesis of inanimate behavioral impact moderation in graphic form.** The dashed arrow between impact-moderating behavior and high impact indicates control exerted over high impact on subsequent impacts as a function of contact time. Footwear is seen interfering with the link between high impact and adequate stimulus of plantar deformations and distortions. According to current thinking, impact-moderating behavior is composed of three elements, but we believe that a more complex model will evolve.
Athletic Footwear: Safety Hazard

Contact surface, impact components, and movement were evaluated by analysis of variance. Least squares linear regressions were obtained for groups that contained greater than three readings at a minimum of two levels of applied load. Slopes were grouped by plantar contact surface, applied loads, and movement and were evaluated by analysis of variance. Hypotheses were tested using post hoc t-tests.

Results

Figure 4 relates plantar discomfort to vertical impact, horizontal impact, surface texture, friction, and movement.

Discomfort as a function of vertical impact. When vertical impact was below 0.4 kg·cm⁻² (groups 1–6), no relation was present between discomfort and horizontal impact (slope ∼1.79; max. slope 3.12; mean slope 0.41; P > 0.05), though, when vertical impact equaled or exceeded 0.4 kg·cm⁻² (groups 13–18), there was a significant relation between these variables (min. slope 1.59; max. slope 56.49; P < 0.05). In groups 13–18, a change in the vertical impact from 0.4 to 0.7 kg·cm⁻² increased discomfort by a mean factor of 2.26 (min. 1.18; max. 3.43).

Discomfort as a function of horizontal impact. Similarly to the above, when horizontal impact was below 0.4 kg·cm⁻², there was no relation between discomfort and vertical impact, whereas, when horizontal impact was at or above 0.4 kg·cm⁻², a significant relation was present between these variables (groups 13–18; min. slope 8.47; max. slope 56.49; mean slope 23.00; P < 0.05).

Discomfort as a function of plantar contact surface texture. When vertical impact was below 0.4 kg·cm⁻² (groups 1–6), there was no significant difference in the discomfort produced from the foot impacting the irregular or smooth surfaces (mean slope 56.49; P = 0.05), whereas, when vertical impact was 0.4 kg·cm⁻² or greater (groups 13–18), a significant difference was present between these variables (mean slope discomfort vs horizontal impact: plastic 19.10; irregular 36.49; UHMWP 19.51; P < 0.05). When considering the relation between discomfort and horizontal impact, the smooth surfaces (plastic and UHMWP) differed from the irregular plantar surface but not from each other (plastic mean slope 19.02; UHMWP mean slope 13.42; irregular mean slope 36.49; plastic vs UHMWP P < 0.05; plastic vs UHMWP P < 0.05; UHMWP vs irregular P < 0.05, from groups 13–18).

Discomfort as a function of friction and movement. The irregular surface has higher friction than the smooth surfaces. The irregular surface caused greater discomfort (P < 0.05) discomfort than the smooth surfaces. When comparing groups with the same programmed impact but differing in movement, estimates of discomfort were always higher in the non-movement groups (movement groups 4–9; mean 4.10; non-movement groups 13–18; mean 23.00; P < 0.05).

Plantar pain. Subjects considered the discomfort rating of 100 to be consistent with moderate pain, and 70 indicated mild pain.

Discussion

This experiment relates plantar loading during locomotion and jumping plantar discomfort when shod and unschoed. Both horizontal and vertical impact have persuasive importance to plantar discomfort insomuch as no discomfort resulted from impact regardless of surface if one element of impact was below 0.4 kg·cm⁻².
which is actually just mildly irregular when compared with actual natural surfaces, as a natural surface. Think of the smooth surfaces as the regular interior of modern athletic footwear. Conservatively (41), assume that horizontal load distribution is 1.0 kg cm² and is half this value with modern athletic footwear. Maximum discomfort tolerated will be considered moderate pain (100) on the ordinal scale. The maximum vertical impact is determined from the following equation: 

\[ \text{vertical impact} = \frac{\text{vertical load}}{\text{surface area}} \times (100 \text{% of body weight}) \]

From groups 14 and 17, whereas the maximum vertical impact tolerated by the shod runner would be 5.76 kg cm² (820% of body weight; groups 13, 15, 16 and 18; Fig. 4). Since a multi-component horizontal load distribution is lower than vertical impact often measured when subjects run in modern footwear, and 820% of body weight greatly exceeds the vertical impact measured when shod subjects run at maximum velocity, we conclude that plantar sensations induce the barefoot runner to mitigate vertical impact considerably, whereas the shod runner using currently available footwear is not persuaded by plantar sensations to lessen vertical impact at all. This analysis allows room for sensory attenuation from increased plantar rigidity through hyperkeratinization of the barefoot runner's sole; otherwise, without the conservative assumptions made big above, it is difficult to understand how the barefoot runner could endure running.

As previously noted (48), these experiments suggest how at the receptor and particularly sensory input is mediated. Some nociceptors with C-fiber afferents seem well equipped to satisfy all of the requirements for impact sensing (4,5,8,9,24,39,40). They are the predominant nociceptors in peripheral nerves, as this is the new proportion of the extremity in higher mammals. Also, their threshold, response to deformation and horizontal skin displacement, ease at being sensitized, and temporal response pattern to stimuli conform well to the dynamics of locomotion.

A safety standard for footwear which would require the elimination of the plantar discomfort-impact illusion feasible? An assessment of subjective variability, subjective-vehicle interaction and the evaluation of running shoes using ground reaction force data.


