THE SQUEAKS IN YOUR SNEAKS:
VIBRATIONS AT THE SHOE-SURFACE INTERFACE

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INTRODUCTION

Contact between rubber-soled shoes and indoor sports surfaces commonly results in brief, high-pitched “squeaks” (Fig. 1). The classical Amontons-Coulomb friction paradigm assumed by most slip-resistance research does not accommodate vibration or sound generation. Consequently, an examination of this phenomenon offers the possibility of novel insights into the mechanics of shoe-surface interaction.

During *ad hoc* experiments with human subjects performing cutting movements on a sample of wood sports flooring, we have noted that shoes with different sole patterns elicit squeaks with a characteristic frequency. Also, squeaks appear to occur only when the shoe sole is lightly loaded (at the beginning and end of ground contact) and during relative sliding of the shoe and surface.

It is known from studies of brake “squeal” and other “stick-slip” phenomena that self-induced vibrations, and audible sounds, can occur when the mechanics of contact between two surfaces involves both elasticity velocity-dependant friction. The polymers athletic shoe soles are non-linearly elastic and do not demonstrate classical linear friction behavior. (Van Gheluwe, 1983; Valiant, 1987).

This study examined the nature and provenance of the “squeaks” induced by relative sliding motion, and their consistency with stick-slip vibration theory.

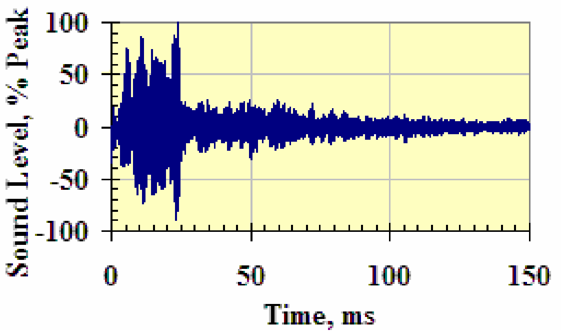

Figure 1: Example of a 5 kHz “squeak” elicited during a basketball play action.

METHODS

Squeaks elicited by two basketball shoes wirh different “herringbone” sole patterns were digitally recorded with 24-bit resolution at a sample rate of 96 kHz and subjected to frequency spectral analysis. The sliding friction coefficients of the same shoes on a sample of polyurethane coated maple flooring were measured using a standard test method (ASTM F2333). Tests were performed with normal loads on the forefoot ranging from 50 to 1000 N and sliding velocities between 0.03 to 0.5 m s^{-1}. Sliding motions were induced by means of computer controlled, linear actuator. Normal and tangential loads at the shoe-surface interface were recorded with an AMTI force plate, sampled at 500Hz.

RESULTS AND DISCUSSION

Finite element models of generic herringbone structures predict natural frequencies above 4.0 kHz, with low order vibration modes clustered in a narrow range of frequencies. This prediction is consistent with the observation that the squeaks from the two shoe samples occupy distinct, narrow frequency bandwidths centered at ~5.0 and ~6.0 kHz respectively (with harmonics observed at approximately double those frequencies; Fig. 2). Consequently the squeaks would appear to be the result of vibrations in the rubber herringbone structures rather than vibrations of the surface of other shoe components.

Traction tests results revealed a strong dependency of the sliding friction coefficient on the applied normal force and on sliding velocity at the slowest of the speeds considered (Figure 2). These nonlinear behaviors allow the possibility of audible stick-slip vibrations at the shoe-surface interface. However, basic stick-slip models (Bhushan, 1999; pp 382 &c.) must be modified to accommodate our observations. Adding non-linear dependence of the friction coefficient on normal force to basic stick-slip models has a non-linear effect on vibration amplitude, such that audible vibrations would be produced only when the normal force is within a limited, low range.

Based on our limited observations, the best explanation of the squeaks that we can offer is as follows:

The herringbone structures of the shoe outsole are induced to vibrate at their low-order natural frequencies by stick-slip contact with the surface. Their occurrence is limited to low normal force conditions by the non-linear force-dependance of the friction coefficient and by heavy damping at higher normal forces.

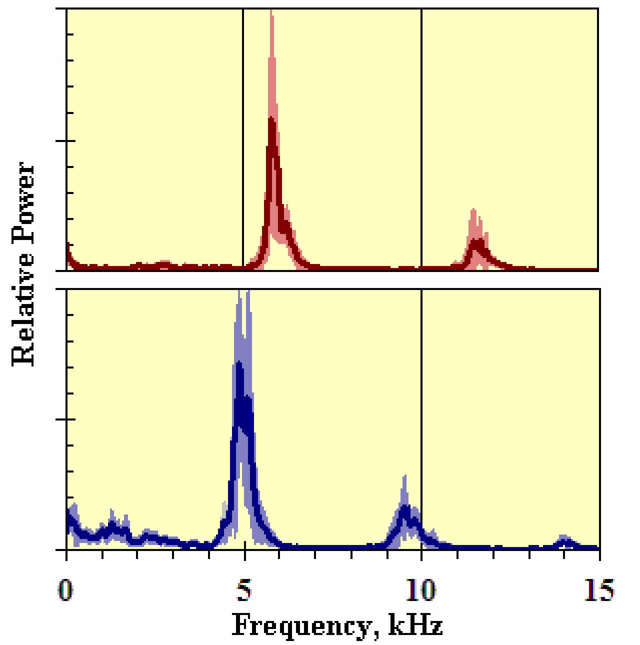

Figure 2: Amplitude-Frequency Spectra of squeaks from two basketball shoes with different sole patterns

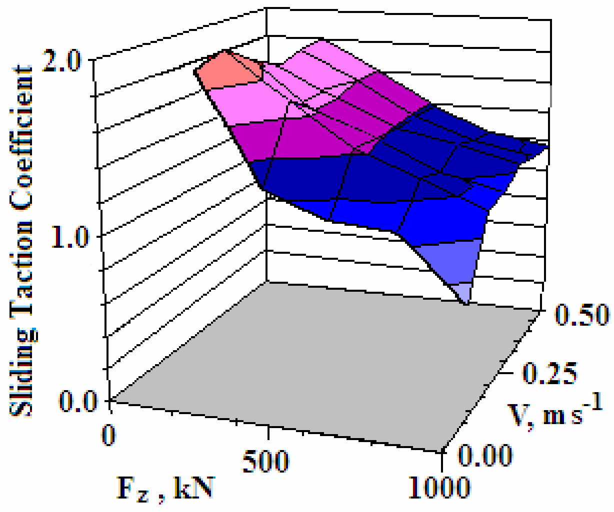

Figure 3: Sliding traction (friction) coefficient as a function of normal force (**F$_z$**) and sliding velocity (**V**).

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