The effect of varying midsole hardness on force attenuation and rearfoot movement during running: a meta-analysis

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Introduction

Two primary functions of running shoes are to provide cushioning and stability to the foot during running (Bates, 1985; Cavanagh, 1985). One running shoe design parameter that has been found to have an effect on both of these functions is the midsole density (hardness). There have been conflicting reports regarding the effects of varying the midsole density on both cushioning and stability parameters. Some of the discrepancies reported could be attributed to differences in testing techniques; that is material tests compared to subject tests (Frederick, 1987). There has, however, been conflicting results reported among researchers who have utilized subject testing only. While some researchers have found that subject tests agree with the results of material tests regarding cushioning variables, with shoes having softer midsoles producing lower initial vertical ground reaction forces (Devita & Bates, 1988), others have reported that softer shoes produce greater initial vertical GRFs than harder shoes (Cavanagh, 1985; de Koning & Nigg, 1994; Kaelin et al, 1985; Snel et al., 1985). Still others have reported that there are no differences between soft and hard shoes in terms of impact forces (Clarke et al., 1983; Nigg et al., 1987). Conflicting results have also been reported in variables thought to be indicative of stability characteristics. Some researchers have found that softer shoes allow greater amounts of pronation than harder shoes (Clarke et al., 1983; de Wit et al., 1995), while others have reported the opposite (Kaelin et al., 1985). Still others have concluded that there are no differences in the amount of pronation allowed by softer or harder shoes (Stacoff et al., 1988).

With the contradictory results reported in these various studies, it is not possible to determine the true effect of varying midsole density on cushioning and stability variables. The purpose of this study was to objectively review the existing literature to determine the differences between running shoes with varying midsole hardnesses in regard to some important cushioning and stability parameters.

Methods

A meta-analysis, which is a quantitative summary of a large number of studies, was conducted. All published studies found to contain the relevant independent and dependent variables were included in the analysis. The only relevant independent variable was midsole hardness. The dependent variables were limited to variables related to vertical force and rearfoot motion. Two cushioning variables (vertical impact force peak, $F_{zi}$, and maximum vertical loading rate, $G_{zi}$), and two stability variables (total change in Achilles tendon angle during pronation phase, $\Delta \text{pro}$, and change in the Achilles tendon angle during the first 10% of foot contact, $\Delta_{10}$) were found to be analyzed by a majority of researchers, and have been presented as representative of important parameters measured when discussing cushioning and stability properties of athletic shoes.

In the technique of meta-analysis, results for any dependent variable in a study are converted to a data point called an effect size (ES). The equation for ES (Eq. 1) converts the findings from an individual study into standard deviation units. $\text{ES} = \frac{M_E - M_C}{SD_{pooled}}$ (Eq. 1), where $M_E$ is the mean of the experimental variable, $M_C$ is the mean of the control variable, and $SD_{pooled}$ is a pooled standard deviation. For this study, the mean values obtained from softer midsoles were subtracted from the mean values of the harder shoes for all dependent variables. Positive ESs indicated that the values of variables for the harder shoes were greater than for the softer shoes. Following the calculation of ESs, an unbiased estimate of ES was then found by multiplying ES scores by a correction factor which accounted for differences in sample size. After finding unbiased ESs for individual studies, the average ES was calculated to determine an overall treatment effect.
Results

A total of 14 relevant studies were included in the analysis, from which 41 ESs were calculated. Some studies that would otherwise have been acceptable were omitted from analysis because the relevant data were not provided in an accessible form. In several studies, three or more midsole hardnesses were compared. In these cases, all possible combinations of harder versus softer shoes were compared. A total of 289 subjects were included in the analysis. The mean ES for the four dependent variables analyzed are shown in Table 1. The number of comparisons made, along with the minimum and maximum ESs found are also shown in Table 1.

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Mean ES</th>
<th>Min. ES</th>
<th>Max ES</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_{zi}$</td>
<td>32</td>
<td>-0.36</td>
<td>-1.09</td>
<td>0.21</td>
</tr>
<tr>
<td>$G_{zi}$</td>
<td>29</td>
<td>-0.12</td>
<td>-1.60</td>
<td>1.08</td>
</tr>
<tr>
<td>$\pro$</td>
<td>16</td>
<td>0.08</td>
<td>-0.55</td>
<td>0.92</td>
</tr>
<tr>
<td>$\pro^{10}$</td>
<td>16</td>
<td>0.60</td>
<td>-0.25</td>
<td>1.61</td>
</tr>
</tbody>
</table>

Discussion

This meta-analysis appears to demonstrate that shoes with harder midsoles reduce the initial impact forces, while allowing greater rearfoot movement during the initial ground contact phase. These two factors may be related to each other since foot pronation is necessary to attenuate forces. It is possible that the greater rearfoot movement is a protective response to reduce potentially harmful impact forces. Provided that the impact forces and angles of pronation fall within "normal" physiological limitations, both responses may be favorable during running.

Three variables, including the amount of difference in defining "soft" and "hard" midsoles, running speed, and type of surface were examined as possible moderating variables. The only moderating variable that had an effect on the results was the difference in defining soft and hard shoes. When the differences in defining hard and soft midsoles increased (measured on a Shore A scale), the differences between hard and soft shoes increased in the direction of the mean difference for all dependent variables, although the effect was generally very slight. Speeds ranging between 3 and 6 ms$^{-1}$ did not appear to change the ES of any dependent variable. Similarly, the hardness of the running surface did not seem to alter the relationship between soft and hard midsoles (McCaw et al., 1993).

The large amount of variability observed between subjects and between studies indicates that individuals respond uniquely to changes in midsole hardness, suggesting that there is a need for single subject designs when evaluating the effects of running shoe design parameter differences.

References


Note: Studies included in the meta-analysis, but not cited in text are not shown.