The purpose of this study was to investigate the effects of insoles and additional shock absorption foam on the cushioning properties of various sport shoes with an impact testing method. Three commercial sport shoes were used in this study, and shock absorption foam (TPE5020; Vers Tech Science Co. Ltd., Taiwan) with 2-mm thickness was placed below the insole in the heel region for each shoe. Eight total impacts with potential energy ranged from 1.82 to 6.08 J were performed onto the heel region of the shoe. The order of testing conditions was first without insole, then with insole, and finally interposing the shock absorption foam for each shoe. Peak deceleration of the striker was measured with an accelerometer attached to the striker during impact. The results of this study seemed to show that the insole or additional shock absorption foam could perform its shock absorption effect well for the shoes with limited midsole cushioning. Further, our findings showed that insoles absorbed more, even up to 24–32% of impact energy under low impact energy. It seemed to indicate that insoles play a more important role in cushioning properties of sport shoes under a low impact energy condition.

Key Words: impact testing method, shock attenuation, peak deceleration, absorbed energy

Cushioning is one of the important functions of a sport shoe. In the structure of sport shoes, the midsole plays the most important role in attenuating the impact shock. Compared to a midsole, an insole has less shock attenuation ability because of its thinner thickness. The study by Nigg et al. (1988) showed that the four tested viscoelastic insoles in running shoes did not differ in variables describing the vertical impact forces compared to the conventional insole furnished in running shoes when subjects ran at 4 m/s. In other subject tests, however, the insoles were suggested to better attenuate the impact shock compared to barefoot (Chiu et al., 1998; Gillespie & Dickey, 2003) or interposing into hard-soled shoe conditions, such as a leather shoe or military boot (Windle et al., 1999; Folman et al., 2004). The results of Nigg et al. were explained that the running shoes have inherently greater absorbing property so that additional shock absorption in the form of insoles is likely to be less effective (Windle et al., 1999).

Most previous studies that have investigated the cushioning of sport shoes asked subjects to run across a force plate (Aguinaldo & Mahar, 2003; De Wit et al., 1995; Henning et al., 1996) or on a treadmill (Verdejo & Mills, 2004). However, tests with subjects are usually very time consuming and have more intersubject variability than intershoe variability (Nigg, 1986; Knicker et al., 1993). The impact testing method has been deemed to show the mechanical properties of the soles quickly and to
save testing time, and has been suggested as a better way to test the cushioning properties of commercial shoes (Chiu & Shiang, 1999). Most of the previous studies that evaluated the cushioning properties of soles using the impact testing method used constant mass and drop height for different shoe conditions (Frederick et al., 1984; Henning & Lafortune, 1991; Henning et al., 1993; McNair & Marshall, 1994; Milani et al., 1997; McCaw et al., 2000). However, a single impact energy \(E = m \times g \times h\) cannot simulate different running speeds, so multiple tests (spanning a range of impact energy) need to be conducted to represent different responses. In Chiu’s study (2000), various impact weights and drop heights of the striker were used to test the cushioning of the shoe. The results showed that increasing impact energy would cause larger impact loading. In addition, compared to subjects wearing the same running shoe, the curves of vertical ground reaction force during the initial impact phase for running were similar to the results of impact testing. Chiu recommended that changing the impact energy into an adequate region (3–7 J) in impact testing could evaluate the impact loading rate occurring as in actual running at speed of 3 m/s.

The peak deceleration of impact striker or loading rate of vertical ground reaction force has been suggested to be a good variable to evaluate the cushioning property of sport shoes using the impact testing method. Some previous studies evaluated the cushioning of shoes from the energy aspect. The energy absorbed by the shoes in these studies was determined by the area under the load-deformation curve (Cook et al., 1985; Swigart et al., 1993). This method could show the energy absorbed by the shoe, including outsole, midsole, and insole; however, it could not calculate the energy absorbed only by the insole. To date, it has been established that the primary function of an insole is to dissipate the plantar pressure. Recently, some studies have focused on measuring plantar pressure to evaluate the functions of custom-made insoles (Bus et al., 2004; Tsung et al., 2004). However, little research has attempted to evaluate the cushioning property of insoles during the impact phase. Therefore, the purpose of this study was to investigate the effect of an insole and additional shock absorption foam on the cushioning property of sport shoes using the impact testing method. In addition, we attempted to estimate the energy absorbed by an insole in sport shoes and to isolate the role of the insole in the cushioning property of sport shoes.

**Methods**

A portable impact tester was specifically designed to impact the sport shoe with different impact energies. As shown in Figure 1a, this tester consisted of an impact striker to be released from different heights to impact the sole in the vertical direction. A low-weight accelerometer (sampling frequency: 2,000 Hz) was attached rigidly to the striker (mass: 6.2 kg) to measure the acceleration of the striker. Three commercial sport shoes were used in this study (Figure 1b). Shoe 1 (M803AT NewBalance) and Shoe 2 (Sionple) are running shoes, and Shoe 3 (18KM-2200g, Misuno) is an indoor shoe for table tennis activity in which the midsole is thinner than those in the running shoes. Shoe 1, with well-cushioned material in midsole, was advertised as having better cushioning than Shoe 2, which only has single-density ethyl vinyl acetate (EVA) foam in it. The thicknesses of the shoes without insole were about 2.8 cm, 2.3 cm, and 1.0 cm in the heel for Shoes 1, 2, and 3, respectively. Insole 1 (the insole of Shoe 1) was composed of polyurethane foam with an approximate thickness of 0.46 cm in the heel. Insole 2 (insole of Shoe 2) was made of latex foam, and had an approximate thickness of 0.34 cm in the heel. Insole 3 (insole of Shoe 3) was composed of EVA foam and had an approximate thickness of 0.42 cm in the heel. Shoes 1 and 2 were in new condition, and Shoe 3 was in used condition. A shock absorption foam (TPE5020; Vers Tech Science Co. Ltd.) with 2-mm thickness was interposed below the insoles in the heel region for each shoe to identify the influence of the different shoe properties on the cushioning effect of the same additional foam. This will help to understand the influence of the midsole on the cushioning effect of the insole in this study.

According to the results of Chiu’s study (2000), the impact energy of 3–7 J could evaluate the impact loading rate occurring as in actual running at a speed of 3 m/s. Although no results of subject walking were showed in that study, the smaller impact energy corresponding to walking could be predicted. Therefore, by varying the drop height of the striker, a total of eight impacts with potential energy ranged from 1.82 to 6.08 J (equally distributed) were per-
formed on the shoe for each shoe condition in this study. First, each shoe was impacted without an insole and then with an insole. Finally, the impact shock absorption foam was placed into the shoe. The striker was dropped to impact onto the heel region of the shoe, and peak deceleration was measured at each impact trial. A power spectrum analysis of the acceleration signals showed that most of the signal’s power has a frequency below 600 Hz. Therefore, prior to analysis, the acceleration data were filtered using a 600-Hz low-pass filter. Five trials were performed under each impact condition, and the mean peak deceleration was calculated using data from three trials after omitting the two extreme values. Consequently, the linear regression equation between mean peak deceleration and impact energy was calculated for each shoe condition. The same peak decelerations that occurred under with- and without-insole conditions indicated that they had the same cushioning ability. Therefore, the energy absorbed (ΔE between with- and without-insole conditions as having the same peak deceleration) by the insole defined in this study could be calculated from the regression equations as follows:

$$\Delta E = E_i - E = \frac{[(\alpha - \alpha_i) \times E_i + (\beta - \beta_i)]}{\alpha}$$  \hspace{1cm} (1)

For another testing condition, the shock absorption foam was interposed below the insole. With the same way, the energy absorbed by the shock absorption foam could be calculated from the regression equations with insole only and with insole plus shock absorption foam conditions.

In this study, three shoe and eight impact energy conditions were chosen. In order to identify the differences of the cushioning ability of the three shoes without insole under eight different impact energies, three peak decelerations were acquired under each condition. Two-way repeated measures ANOVA with the SPSS statistical package were used to evaluate the effect of different impact energies and shoe conditions ($p < 0.05$). Tukey’s method of pairwise comparison was used to identify specific differences between energy levels and shoe conditions.

**Results**

The mean peak decelerations for each shoe without insole under different impact energies are shown in Figure 2. As impact energy increased, the peak deceleration significantly increased for each shoe condition, $F_{(\text{impact energy})} = 352.5$, $p < 0.05$. It was significant that the largest mean peak deceleration occurred in Shoe 3 and smallest in Shoe 1, $F_{(\text{shoe})} = 1,633.5$, $p < 0.05$. As impact energy increased, the differences of peak deceleration between shoe conditions were significantly increased, $F_{(\text{impact energy}\times\text{shoe})} = 44.3$, $p < 0.05$.

From the differences of linear regressions for the three shoes (Table 1), the attenuation of peak deceleration with insole or additional shock absorption foam conditions was calculated.
absorption foam could be calculated under different impact energies (Figure 3). For Shoe 3, the attenuation of peak deceleration with insole or additional shock absorption foam was much larger than that for Shoe 2 and Shoe 1. The attenuation increased significantly as impact energy increased for Shoe 3. The percentage reduction of peak deceleration for all shoes with insole ($\Delta a_{\text{insole}}$) decreased as impact energy increased. Insole 3 had much more impact absorption ability (approx. 22 to 26%) than the other two insoles. The percentage of the peak deceleration absorbed decreased to about 7% for Insole 1 under high impact energy ($E = 6$ J). As impact energy increased, the percentage absorption of peak decelerations by shock absorption foam ($\Delta a_{\text{foam}}$) increased for Shoe 2 and Shoe 3, but decreased for Shoe 1.

Figure 2 — Mean peak decelerations for shoes without insole under different impact energies.

Figure 3 — Reduction of peak decelerations for three shoe conditions with the insole or additional shock absorption foam.
According to Equation 1, the energy absorbed by insole under different impact energies (2–6 J) would be calculated (Figure 4). As the impact energy increased, the absorbed energy ($\Delta E$, showed in Equation 1) increased for Insoles 2 and 3, but decreased for Insole 1. Interposing the shock absorption foam into the three shoes had the same results. For all insoles, the percentage of energy absorption ($\Delta E/E_i$, showed in Equation 1) decreased as impact energy increased. The abrupt decreased ratio of absorbed energy (32% down to 10%) occurred for Insole 1. However, Insole 3 still absorbed about 25% of the impact energy under high impact energy. Comparing the results with insole conditions, it is interesting that the percentage absorbed energy by the shock absorption foam interposed in Shoe 2 increased as impact energy increased.
Discussion

The purpose of this study was to investigate the effect of the insoles and additional shock absorption foam on the cushioning properties of different sport shoes. The impact testing method was carried out to determine their effects on the impact shock attenuation ability of the shoes under different impact energies. In previous studies, single impact energies ranging from 3.2 to 4.5 J were used to test different sport shoes (Table 2). Because different shoes were tested in each study, only the results of the best cushioned shoes are shown in the table. The peak deceleration of this current study seemed to be larger than the results of other studies. The higher peak deceleration should be due to the smaller impact mass (6.2 kg) used in this study. The peak inertial force (impact mass × peak deceleration) was calculated to express the impact loading to accommodate the influence of the different striker’s mass (Chiu et al., 2001). As shown in Table 2, larger peak inertial forces generally occur under higher impact energy conditions and all the peak forces measured previously are in the range of the results of this study.

The results of impact testing for the shoes without insoles (Figure 2) indicated that the midsole of Shoe 1 had better cushioning property than did the other two shoes under different impact energies. The stiffer midsole of Shoe 2, with a thickness similar to that of Shoe 1 under the without-insole condition, and the thinner midsole of Shoe 3 were probably the reasons why they cause larger peak decelerations. The results are similar to the results of Frederick et al. (1984), especially the midsole of Shoe 3 with a larger mean peak deceleration (up to 50 g) than Shoes 1 and 2 under higher impact energy conditions.

Although the three insoles were not tested alone in this study, the much higher reduction of peak deceleration with insole for Shoe 3 seemed to show that Insole 3 had more shock attenuation ability than Insoles 1 and 2. However, the mechanically degraded insole, such as the used Insole 3 in this study, has been identified to have a decrease in impact absorption ability (Dixon et al., 2003). As interposing the same shock absorption foam in the three testing shoes, the larger attenuation of peak deceleration was found for Shoe 3 than for Shoes 2 and 1. And the attenuation effect increased significantly as impact energy increased for Shoe 3. Therefore, it seems that the same shock absorption foam interposed into different shoes would have different shock absorption effects. For the bad-cushioned shoe—for example, Shoe 3 with used thinner midsole in this study—the additional shock absorption foam will absorb more peak deceleration. Thus, although placing Insole 3 absorbed more peak deceleration than did Insoles 2 and 1, this does not indicate that Insole 3 had more shock attenuation ability. The influence of mechanical property of the midsole should be considered. Comparing the data reported by Dixon et al. (2003) for the military boot condition under impact energy of 4.17 J, the percentage absorption peak decelerations for Insole 3 in this study was (approx. 22 to 26%) lower than the values of Insole A (−28%), B (−32%), and C (−50%) but larger than those of Insole D (−5%) in Dixon et al. study. However, the material property of the military boot may be much harder than the sport shoes in this study. This might be the reason for the higher percentage of reduction peak deceleration for the military boot.

The shock absorption foam used in this study

<table>
<thead>
<tr>
<th>Investigator</th>
<th>Impact mass (kg)</th>
<th>Impact energy (J)</th>
<th>Peak deceleration (g)</th>
<th>m × a (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frederick et al., 1984</td>
<td>7.3</td>
<td>3.58</td>
<td>9.8</td>
<td>701</td>
</tr>
<tr>
<td>Henning &amp; Lafortune, 1991</td>
<td>7.8</td>
<td>3.22</td>
<td>9.1</td>
<td>696</td>
</tr>
<tr>
<td>Henning et al., 1993</td>
<td>8.5</td>
<td>4.17</td>
<td>11</td>
<td>917</td>
</tr>
<tr>
<td>McNair &amp; Marshall, 1994</td>
<td>9</td>
<td>4.41</td>
<td>9.6</td>
<td>847</td>
</tr>
<tr>
<td>Milani et al., 1997</td>
<td>7.3</td>
<td>3.36</td>
<td>9.6</td>
<td>687</td>
</tr>
<tr>
<td>McCaw et al., 2000</td>
<td>8</td>
<td>3.91</td>
<td>8.7</td>
<td>683</td>
</tr>
<tr>
<td>Present study</td>
<td>6.2</td>
<td>1.82–6.08</td>
<td>9.6–20.2</td>
<td>584–1,229</td>
</tr>
</tbody>
</table>

Note. The peak inertial force (listed in rightmost column) is defined as the product of impact mass and peak deceleration.
has been designed for use in many research fields, such as the cushioning for electrical products, sports facilities, bicycles, and so on. In this study, the percentage absorption of peak deceleration by the foam increased as impact energy increased for Shoe 2 and Shoe 3. This trend is different from the results of the commercial insoles chosen in this study (Figure 3). The decreasing percentage absorption of peak deceleration as impact energy increased could be explained by the thinner thickness of the insoles. However, the thickness of the foam (2 mm) was less than that of the insoles (3.4–4.6 mm). This indicates that the material of the shock absorption foam could perform greater cushioning effect for bad-cushioned shoes under high impact energy.

The results of impact testing under different impact energies in this study showed that even though an insole or heel insertion of good cushioning material was used, its shock absorption effect could be diminished if the shoe itself has greater absorbing property. This observation could explain the findings of Nigg et al. (1988), in which the shock absorption of viscoelastic insoles was less effective for running shoes. In the study of Folman et al. (2004), the subjects wearing leather-soled shoes with limited shock absorption characteristics were asked to walk naturally along a walkway, and interposing viscoelastic heel insoles attenuated the vertical GRF and peak deceleration of forehead significantly. In our study, as the impact energy increased, the absorption of peak decelerations increased when placing the insole or shock absorption foam in Shoes 2 and 3. Although no results of subject running were shown in Folman’s study, the greater absorption of impact shock could be expected because running induces higher impact energy than walking.

According to the absorbed energy by insole or shock absorption foam calculated in this study, the role of the insole or shock absorption foam in the cushioning property of the sport shoes could be identified. As the impact energy increased, the percentage of energy absorption by the insoles decreased because of the lesser thickness of the insole; thus, the midsole would absorb more impact energy (Chiu & Cheng, 2004). The abrupt decreased ratio of absorbed energy for Insole 1 as the impact energy increased was possibly attributed to the midsole’s best shock attenuation ability of Shoe 1, which absorbed most of the impact energy. However, Insole 3 still absorbed about 25% of impact energy under high impact energy because of Shoe 3’s bad cushioning ability. Although the Shoe 2 also had limited midsole cushioning, the lesser thickness and bad-cushioned material of its insole resulted in less energy absorbed than Insole 3, especially under high impact energy. The increasing percentage absorbed energy by the shock absorption foam interposed in Shoe 2 as impact energy increased indicates again that the special material property of the shock absorption foam could perform its cushioned property well under higher impact energy for Shoe 2. The midsole of a sport shoes is believed to absorb much more impact shock than insole and outsole. In this study, however, the insoles absorbed more, up to 24–32% of impact energy under low impact energy. This finding seems to show that insoles play a more important role in cushioning properties of sport shoes under low impact energy conditions.

The range of impact energy set in this study was in comparing the vertical GRF between impact testing and subject running. In a study by Chi and Schmitt (2005), the effective foot mass ($M_{\text{eff}}$) striking to ground for moving subjects was calculated with the impulse-momentum method. And the mechanical energy of the $M_{\text{eff}}$ was determined as the sum of its kinetic energy and potential energy. Chi and Schmitt suggested that it is appropriate to use different $M_{\text{eff}}$ values for different gaits: about 6.3% and 5.3% of body mass for walking (speed at 0.98–2.06 m/s) and running (speed at 1.77–3.63 m/s), respectively. The mechanical energy of $M_{\text{eff}}$ immediately before ground impact was 0.24–2.90 J and 0.44–3.99 J for barefoot walking and running, respectively. It is obvious that the impact energy of 3–7 J estimated from Chiu’s study (2000) for subject running is larger than the results of Chi and Schmitt study. However, the subjects in Chiu’s study were asked to run wearing sport shoes. For barefoot running, the subjects had more knee flexion and larger knee flexion velocity at touchdown than running with shoes (De Wit et al., 2000). The strategy of landing barefoot while running was previously believed to reduce the effective mass of the contact leg (Wright et al., 1998; Chi & Schmitt, 2005). This can explain why the impact energy for barefoot running is smaller than for running with shoes because of the reduced effective mass of the contact leg. In our study, the impact energy from 1.82 to 6.02 J is in the range of the impact energy calculated by the

This study investigated the effects of insoles and additional shock absorption foam on the cushioning property of three sport shoes under various impact energies. The insole or additional shock absorption foam could perform its impact shock absorption effect well for the shoes with limited midsole cushioning. The results of impact test used in this study agree with previous subject tests in that insoles are likely to absorb more impact shock in a bad-cushioned midsole condition, such as a leather-soled shoe or military boot. In conclusion, impact testing appears to be a quick method for evaluating the cushioning properties of a sport shoe and the new approach carried out in this study to calculate the energy absorbed by insoles showed that insoles play a more important role in cushioning properties of sport shoes under low impact energy conditions.

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