KINETIC ANALYSES OF E-TPU MATERIAL IN BOWLING FOOTWEAR

Tsung-Lin Lu, Tom Wu, and Pamela J. Russell

Bridgewater State University, Bridgewater, United States of America

The purpose of this study was to examine the vertical ground reaction force between the traditional bowling shoes made of rubber midsole and the modified bowling shoes made of E-TPU midsole. All shoes underwent both static and dynamic performance testing on a force platform. The preliminary results indicated that the bowling footwear with the E-TPU material provided lower amount of vertical ground reaction force in both static and dynamic testing, which may potentially be beneficial to bowlers to minimize lower extremity injury. Future studies are warranted to evaluate the internal joint forces of bowling delivery mechanics with the E-TPU material footwear.

KEYWORDS: bowling, e-tpu, footwear, kinetic, midsole.

INTRODUCTION: Bowling is one of the most popular indoor sports in the world and can be divided into several categories that include five-pin, nine-pin, ten-pin, candlepin, and duckpin. In all categories players are required to wear bowling footwear to play the game. Most bowling footwear are designed with rubber or leather soles. Bowling footwear have a sticky or rubbery sole on the non-sliding foot to act as a brake, and a harder sole on the other foot to allow sliding during the last step of ball delivery. Bowling shoes are similar to other athletic footwear that are constructed with three key principles: performance, injury protection and comfort. However, many professional and amateur bowlers have experienced lower extremities injuries including knee, ankle, Achilles tendon, and foot plantar injuries. According to the National Electronic Injury Surveillance System in the United States, there was an average from 2002 to 2014 of 11,295 injuries occurred each year in bowling. The incident rate of knee injury was approximately 12%. Additionally, a recent research study was conducted to evaluate the injury rate of bowling during an intercollegiate bowling championship, and the results showed that the thigh and knee regions had an injury rate of 25.9% and 22.2%, respectively (Liu, Chung, Lin & Lee, 2011). These findings suggested that it is crucial to understand the mechanism of these injuries in bowling. One of the causes to these injuries may be due to improper footwear. The current design of bowling shoe has the midsole portion made of rubber, which does not provide much shock absorption. A typical bowling competition consists of six games, and a standard bowling championship consists of five events including single, double, trios, group, and master. If a participant uses a five step approach in his/her bowling delivery, he or she needs to deliver between 72 balls to 126 balls per event and also has to perform between 360 steps to 630 steps per event. On average each event takes between three to four hours to complete. Due to the repetitive of foot contact with the ground and the long duration of the usage as in running, serious injury may occur in the lower extremity if proper bowling footwear is not worn. Hence, it is critical to investigate different footwear material for the midsole section of the bowling shoe in order to minimize lower extremity injury.

Badische Anilin- und Soda-Fabrik (BASF), the largest chemical company in the world, has recently developed a material known as the Expanded Thermoplastic Polyure-thane (E-TPU) which combines the properties of TPU with the advantages of foams and makes shoes more comfortable to wear and provides greater shock absorption. The E-TPU can be molded into different kinds of shapes and forms which makes it very flexible in design. The most advantage and benefit of the E-TPU contains lightweight, shock impact absorption, elastic, re-bound effect, softness, resilience, and durability (BASF, 2017). The E-TPU material is been used in variety of sports footwear; however, the E-TPU material has yet been used in the bowling footwear. Therefore, the purpose of this study was to evaluate the amount of shock and force absorption that the bowling shoe with the E-TPU material could sustain in both static and dynamic testing. The results of the study enable practitioners to have a better

understanding on the effects of shock absorption on footwear with E-TPU material, so proper footwear can be worn by the bowlers to minimize lower extremity injury.

METHODS: One traditional bowling footwear and two types of modified bowling footwear (with the E-TPU Midsole and with the E-TPU Midsole plus the E-TPU Insole) underwent the static performance testing on top of an AMTI force platform in the Biomechanics Laboratory. The static testing involved in dropping a 1 pound (0.5 kg) dumbbell inside a PVC pipe from a height of 2 feet (0.61 m) at the heel cup region in each type of shoe. Three trials in each condition for static tests were conducted with the same researcher to ensure the reliability of the test. The peak vertical ground reaction force (F_z) was recorded at 1000 Hz, and the Butterworth filter function was applied. In addition, six healthy college male participants (1.8 ± 0.07 m; 75.5 ± 5.8 kg; age 27.3 ± 4.4 years old) volunteered for the dynamic testing. They were instructed how to bowl the candlepin bowling ball which has a maximum weight of 2 pounds 6 ounces (1.1kg) and has a maximum diameter of 4.5 inches (0.1 m). All participants were excluded if they had any lower extremity injury within the last six months. Participants were asked to wear the traditional bowling shoes with rubber midsole design, the modified bowling shoes with the E-TPU midsole design, and the modified bowling shoes with E-TPU midsole plus insole design. Five to ten minutes were given to the participant to warm up and become accustomed with the footwear. Data collection took place at the Biomechanics Laboratory. A five meters (15 ft.) approach was marked with tape from starting line to the force plate. This length of the approach was chosen because it is equal to the length of bowling lane approach in bowling alley. Force plate data were recorded at 1000 Hz with Vicon Nexus software to evaluate the amount of shock and force absorption. Two cushioned mats were placed on the ground behind the force plate in order to allow the participant to roll the bowling ball. Every participant was asked to bowl five balls in each type of footwear, so a total of 15 balls were collected for each participant. In the participant's ball delivery, the participant began their approach from the starting line and ended their last step on the force plate. All participants used a four-step approach and planted their sliding foot on the force plate to measure the vertical ground reaction force. All data were analyzed with SPSS (v. 24) software. A one-way repeated ANOVA test was conducted at $\alpha = 0.05$ between different shoes for the static testing, followed by a Bonferroni adjustment if a significant difference was found. For the dynamic testing, a one-way repeated ANOVA ($\alpha = 0.05$) for the vertical ground reaction force were compared among the traditional rubber midsole, the E-TPU midsole, and the E-TPU midsole plus insole in bowling footwear. Post hoc pairwise comparisons were conducted using *t*-test with Bonferroni adjustment

RESULTS: From the results this study showed the modified bowling shoes with E-TPU midsole plus insole displayed the least amount of vertical ground reaction force on the shoe in the static testing, and the traditional bowling shoes with rubber midsole displayed the most amount of static force, Table 1. The findings were consistent with the hypothesis that the traditional bowling shoes with rubber midsole would produce the highest vertical force as opposed to the modified bowling shoes with E-TPU midsole and the modified bowling shoes with the E-TPU midsole plus insole due to the hard rubber material.
From the dynamic testing, this study showed there was a significant difference between the traditional bowling shoes with rubber midsole as compared to the modified bowling shoes with the E-TPU midsole and the modified bowling shoes with the E-TPU midsole plus insole. The traditional bowling shoes with rubber midsole showed a substantial higher amount of vertical ground reaction force during the dynamic testing, Table 2. The traditional bowling shoes with rubber midsole produced 874.7 ± 160.3 N of vertical ground reaction force during the dynamic testing as compared to the modified bowling shoes with E-TPU midsole's 702.7 ± 111.0 N and the modified bowling shoes with the E-TPU midsole plus insole's 710.7 ± 89.5 N. The traditional bowling shoes with rubber midsole was not able to absorb as much force during the dynamic testing as the modified bowling shoes with the E-TPU midsole and the modified bowling shoes with the E-TPU midsole plus insole.

Table 1: Static Testing at the Heel Cup Region of Bowling Shoe

Comparisons between Shoes	Means ± SD (N)	*p*
Traditional Rubber vs E-TPU Midsole	1826.7 ± 84.3 vs 907.7 ± 33.8	0.014*
Traditional Rubber vs E-TPU Midsole + Insole	1826.7 ± 84.3 vs 524.7 ± 20.6	0.005*
E-TPU Midsole vs E-TPU Midsole + Insole	907.7 ± 33.8 vs 524.7 ± 20.6	0.001*

**Statistical significant at p < .016*

Table 2: Dynamic Testing of the Bowling Shoe

Comparisons between Shoes	Means ± SD (N)	*p*
Traditional Rubber vs E-TPU Midsole	874.7 ± 160.3 vs 702.7 ± 111.0	0.003*
Traditional Rubber vs E-TPU Midsole + Insole	874.7 ± 160.3 vs 710.7 ± 89.5	0.009*
E-TPU Midsole vs E-TPU Midsole + Insole	702.7 ± 111.0 vs 710.7 ± 89.5	1.000

**Statistical significant at p <0.016*

DISCUSSION: The findings of the static testing from this study were consistent with a previous running footwear research study on shock absorption (Lloyd et al, 2013). Lloyd et al. (2013) conducted a study on the examination of shock wave attenuation in running footwear and found the vertical ground reaction force from the same static testing was 2,962 N for Vibram FiveFingers shoe, made of rubber bottom and no cushion in attempt to mimic barefoot, compared to limited cushioned Nike Free Run's 775 N and Adidas' traditional cushioned shoe of 872 N. In this study the vertical ground reaction force of the static testing for the traditional bowling shoes with the rubber midsole, the modified bowling shoes with the E-TPU midsole, and the modified bowling shoes with the E-TPU midsole plus the E-TPU insole were 1826.7 ± 84.3 N, 907.7 ± 33.8 N, and 524.7 ± 20.6 N, respectively. These findings were similar to Lloyd's study since both studies have demonstrated footwear that has greater and thicker cushion has the ability to attenuate greater amount of vertical ground reaction force. This finding was more prominent in the static testing; however, in the dynamic testing the amount of cushion in the footwear still showed the capability of attenuate shock absorption but to a lesser degree. Interestingly, the E-TPU midsole plus the E-TPU insole has a thicker cushion but is not significantly different from the E-TPU midsole alone in the dynamic testing. Nigg, Bahlsen, Luethi, and Stokes (1987) indicated that human body may show different responses and outcomes to various kinds of midsole densities to maximize performance and minimize injury. This study supports that notion that the static impact testing on midsole materials can provide shock attenuation information but cannot fully be used to predict human performance in a dynamic environment.

Research in footwear has been primary focused on impact attenuation and response to loading rate related to injury in walking and running shoes (De Wit, De Clercq, & Aerts, 2000; Lafortune & Hennig, 1992; Nigg et al., 1987). Bowling footwear is a field that has yet been investigated extensively. Bowling delivery is unique because the lead foot acts as a break to absorb the impact force from the ground during landing; no toe off or push off is involved as in walking and running. Since landing is a critical part of a basketball game, basketball shoes are designed with materials to address this movement in order to minimize injury. Zhang et al. (2005) conducted a study to examine the effects of various midsole densities of basketball shoes on impact attenuation during landing activities. The authors found that the vertical ground reaction force at forefoot in the normal midsole and hard midsole was significantly greater than the soft midsole. Moreover, the vertical ground reaction force at heel was also significantly greater for the hard midsole than for the soft midsole and normal midsole, respectively. In this study significant differences were found between the rubber midsole, a much harder material, and the E-TPU midsole, softer cushioning material and also between

the rubber midsole and the E-TPU midsole plus E-TPU insole during the dynamic testing of bowling delivery. These findings were similar to Zhang et al.'s (2005) study that harder density material, rubber midsole, showed less capability of attenuate vertical ground reaction force. Some limitations should be considered in this study. A limitation was that there was no AMTI force plate at the bowling lane approach in bowling alley. Therefore, data collection of this study took place in a laboratory setting, which was similar to a previous study (Zhang et al., 2005). Also, the study was conducted on candlepin bowling, which the results may be different from ten-pin bowling delivery since the mass of the bowling ball for the ten-pin is much greater. Finally, this study used six male college students as participants. The results may be different from having elite or professional bowlers as participants since they are more skilled and may have an ability to adapt to different types of midsole footwear material.

CONCLUSION: The purpose of this study was to evaluate the amount of vertical ground reaction force absorption that the bowling shoe with the E-TPU material could sustain when compared with the traditional rubber bowling footwear in both static and dynamic testing. The results from this study indicated that the bowling footwear with the E-TPU material were able to reduce the vertical ground reaction force during both static and dynamic testing. The traditional bowling shoes with rubber midsole produced the highest vertical ground reaction force in both static and dynamic testing. The modified bowling shoes with the E-TPU midsole plus insole produced the lowest vertical ground reaction force in the static testing and also provided strong shock attenuation in the dynamic testing. Therefore, the findings of this study provided a preliminary understanding on the effects of the E-TPU material on shock absorption in bowling footwear. Sports footwear developers may use this information to construct appropriate footwear to minimize injury. Future studies are warranted to examine and compare the E-TPU material footwear with the traditional cushion material footwear to assess if the E-TPU material is superior. Also, research can be conducted to evaluate the mechanics of bowling delivery with elite bowlers to have a comprehensive understanding of bowling footwear development.

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