THE EFFECTS OF MIDSOLE CONSTRUCTION ON BOWLING DELIVERY

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The purpose of this study was to examine the effects of midsole construction on the mechanics of bowling delivery. Twelve participants performed five candle bowling ball deliveries in three footwear conditions (barefoot, traditional and modified with E-TPU). Both kinematic and kinetic analyses were conducted. The results of the barefoot condition showed hip, knee and ankle joints at 92.3 ± 9.9°, 133.0 ± 14.5°, and 111.6 ± 11.2°, respectively, which were not significantly different from the modified condition of 93.9 ± 9.9° (p =.289) 132.1 ± 14.5° (p =.758), and 117.7 ± 9.4° (p =.123). Also, no significant difference was found in peak vertical force to body weight ratio. These findings provide a preliminary understanding on the effects of footwear on bowling delivery. Future studies are warranted to evaluate 3D motion analysis with experienced bowlers at the bowling alley.

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

INTRODUCTION: Bowling is a popular and sophisticated sport that requires precise motion and timing, and the most common bowling deliveries are the four-step and five-step which involve three different phases, preparation, movement, and follow through. In the mechanics of bowling delivery, the lower extremity is crucial because the ability to slide the front foot consistently affects bowler's ability to deliver the bowling ball more accurately (Razman et al., 2010). Improper gait, mechanics, or footwear can possibly increase the risk of lower extremity injuries such as adductor muscle strains, ankle sprains, and knee ligament injuries (Hsiao et al., 1996). Kerr et al. (2011) examined bowling-related injuries and presented findings to the US emergency departments, showing that there were 8,754 injuries in bowling from 1990 to 2008. Most common were lower limbs injuries found in the ankle, foot and toe, and the rate of occurrence with lower extremities was approximately 14.9%. In addition, according to the National Electronic Injury Surveillance System in the United States between 2002 and 2014, there was an average of 11,295 injuries occurring each year in bowling. The incident rate of knee injury was approximately 12%. These findings suggest that it is crucial to understand the mechanism of these injuries in bowling. One cause for these injuries may be attributed to improper footwear. Bowling footwear can be classified into three different categories: rental, athletic, and performance. Bowling shoes are similar to other athletic footwear in that they are constructed with three key principles: performance, injury protection and comfort. The current design of a bowling shoe has the midsole portion made of minimalist leather for rental bowling footwear, and rubber, Ethylene Vinyl Acetate (EVA) or Polyurethane (PU) for athletic and performance bowling footwear, which may potentially influence the mechanics of bowling delivery. 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 foam and making shoes more comfortable to wear and providing for greater shock absorption. In addition to shock impact absorption, the use of E-TPU provides a rebound effect, elasticity, resiliency, durability as well as softness and being light weight (BASF, 2017). The E-TPU material continues to be used in a variety of sports footwear; however, E-TPU has yet to be used in bowling footwear. Therefore, the purpose of this study was to examine the effects of midsole construction (barefoot, traditional bowling shoes with minimalist midsole design, and modified bowling shoes with E-TPU midsole design) on the mechanics of bowling delivery. The results of the study would enable practitioners to have a better understanding of the effects of footwear cushioning on athletic performance for athletic performance improvement and minimize lower extremity injuries.

METHODS: Twelve healthy college aged right-handed recreational male participants (height: 1.76 ± 0.06 m; weight: 76.5 ± 10.8 kg; age: 25 ± 4 years old) participated in this study. All participants used a candlepin bowling ball (mass: 1.1 kg; diameter: 0.1 m). Participants were asked to perform three different footwear conditions: barefoot, traditional bowling shoes with minimalist midsole design, and the modified bowling shoes with E-TPU midsole design. Four joint reflective markers were fixed to the right side of the participant's body at the greater trochanter of femur, lateral malleolus, lateral epicondyle of femur, the base of the fifth metatarsal, and three markers were fixed at the left side of the participant at the medial malleolus, medial epicondyle of femur, and the base of the first metatarsal. Data collection took place at the Biomechanics Laboratory. A five meters (16 ft.) approach was marked with tape from the starting line to the cushioning mats. The length for this approach was chosen because it is equal to the length of the bowling lane approach in a bowling alley. Two ten meters cushioning mats (64 ft.) were placed on the ground to allow the participant to roll the bowling ball. Participants used a four-step delivery approach to have their left foot land on an AMTI force plate (1,000 Hz). A Casio high speed camera (Model: EX-FH 25) was set up to capture the right sagittal view of the motion of the bowling ball delivery at 120 Hz in conjunction with a 650 watts spotlight. Every participant was asked to bowl five balls in each type of footwear with maximum effort while rolling the ball straight. A total of 15 balls were collected for each participant, and a total of 180 trials were collected in this study. Each participant had a one-minute rest between each ball and a three-minute rest between each type of footwear. Video trials from each type of footwear at the instant the ball released were selected and used for data analysis. The Ariel Performance Analysis System (APAS) software was used to conduct the two-dimensional body joint angles and velocities of hip, knee, and ankle, stride length, and linear ball velocity at the instant of ball release while the left foot was on the force plate. Digital filter function was applied with appropriate cut of frequency (x and y = 9 Hz). The peak vertical ground reaction force during the delivery was identified with the Vicon Nexus software to evaluate the amount of shock and force absorption with respect to each participant's body weight. All data were analyzed with SPSS (v. 25) software. A one-way repeated measure ANOVA ($\alpha = 0.05$) for the mean joint angles and velocities of hip, knee, and ankle, stride length, linear ball velocity, and peak vertical force to body weight ratio were conducted between the three different footwear conditions.

RESULTS: A one-way repeated measure ANOVA ($\alpha = 0.05$) was conducted with Greenhouse-Geisser. The results of this study indicated that there was no statistically significant difference found between barefoot, traditional bowling shoes with minimalist midsole design, and the modified bowling shoes with E-TPU midsole design in the mean left hip, knee and ankle joint angles at the instant of ball release, Table 1. Similarly, no significant difference was found in the mean joint angular velocities of the left hip, knee, and ankle, Table 2.

Table 1
Kinematic Comparisons of the Joint Angle between Footwear Conditions

Body Joint	Means ± SD (Degree)			*P*
	Barefoot	Traditional	Modified	
Hip	92.3 ± 9.9	94.0 ± 10.3	93.9 ± 9.9	.289
Knee	133.0 ± 14.5	131.9 ± 12.4	132.1 ± 14.5	.758
Ankle	111.6 ± 11.2	115.9 ± 8.6	117.7 ± 9.4	.123

**Statistical significant at p < .05*

Table 2
Kinematic Comparisons of the Joint Velocity between Footwear Conditions

Body Joint	Means ± SD (Meter/Second)			*P*
	Barefoot	Traditional	Modified	
Hip	.61 ± .16	.58 ± .23	.53 ± .20	.535
Knee	.60 ± .21	.68 ± .22	.66 ± .29	.614
Ankle	.58 ± .19	.58 ± .32	.53 ± .29	.764

**Statistical significant at $p < .05$*

Moreover, the mean stride length ($p = .314$) did not show any significant difference between three different footwear conditions (Barefoot: .78 ± .12 m, Traditional: .80 ± .13 m, and Modified: .80 ± .10 m). Also, no significant difference was found in the mean linear ball velocity ($p = .497$) between barefoot (2.05 ± .33 m/s), traditional (2.02 ± .39 m/s), and modified (2.01 ± .39 m/s). For the kinetic analysis, there was no significant difference found in the peak vertical ground reaction force with respect to each participant's body weight, Table 3.

Table 3
Kinetic Comparisons of the Peak Vertical Ground Reaction Force to Body Weight between Footwear Conditions

Ratio	Means ± SD			*P*
	Barefoot	Traditional	Modified	
Peak vertical force/body weight	1.35 ± .13	1.42 ± .23	1.38 ± .18	.271

**Statistical significant at $p < .05$*

DISCUSSION: Bowling is a sport that has features of walking, running and landing movements. The characteristics of the gait cycle in the bowling approach is similar to walking and running in that it contains the rear-foot contact, fore-foot contact, heel-off, and toe-off. Interestingly, the last step of the bowling delivery is unique because the front foot acts as a slide and brake simultaneously during landing. Moreover, in basketball, landing is a critical part of the game, and therefore, basketball shoes have been 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 during landing activities, and the authors found that there was no significant difference in the hip and ankle joints for the range of motion and the maximal velocity between different midsole densities. Similarly, in this study no significant difference was found on the effects of midsole construction between barefoot, traditional, and modified footwear conditions on joint angles and velocities of the lower extremity at the instant of ball delivery. Research studies on bowling techniques have been primary focused on kinematic analyses (Chu et al., 2002; Hung et al., 2012; Razman et al., 2010). In the mechanics of bowling delivery, lower extremity is crucial because the ability to slide the front foot consistently will affect the bowler's ability to deliver the bowling ball more accurately (Razman et al., 2010). Chu et al. (2002) conducted a study to examine the mechanics of delivery in ten-pin bowling, and the authors found that the stride length between the front toe and back toe at ball release were 1.16 ± 0.20 m for male bowlers and 1.09 ± 0.06 m for female bowlers. In this study there was no significant difference found between the three different footwear conditions (Barefoot: .78 ± .12 m vs Traditional: .80 ± .13 m vs Modified: .80 ± .10 m) for the stride length. A slight difference in the stride length of this study when compared with Chu et al.'s (2002) study may be due to the different skill levels of the participants, the midsole construction on bowling footwear, and the type of bowling (candlepin vs ten-pin). This study was conducted using candlepin bowling, and the results may be different from the ten-pin bowling delivery since the mass of the bowling ball for the ten-pin is much greater, therefore a greater stride length may be needed in order to provide for better balance and stability during delivery. Linear ball velocity has commonly been considered as the reference of performance in many sports. In this study there was no significant difference found between the three different footwear conditions on the performance measure of linear ball velocity at the instant of ball release. Further, from a kinetic performance measure perspective, the modified footwear condition did not show significantly better shock absorption than the traditional and barefoot conditions. Some limitations should be considered in this study. This study used twelve male college aged students as participants, and the results may be different from that of more experienced bowlers as participants. Experienced or higher skilled bowlers may have better consistency in the mechanics of their bowling delivery which may improve the variability of the results. In addition, this study was conducted with two-dimensional analysis since the primary underarm motion of the bowling delivery occurred in the sagittal plane, and the participants in the study were asked to bowl the ball straight with maximum effort. Previous literature has also showed studies conducted with 2D motion analysis on softball windmill pitching with the similar rationale (Ashley et al, 2012). Nonetheless, future studies are warranted with a 3D motion analysis to obtain a comprehensive understanding of the bowling delivery. Furthermore, this study took place at the Biomechanics Laboratory, providing for a preliminary understanding on the mechanics of bowling delivery. The results may be different from conducting the study at a bowling alley.

CONCLUSION: The purpose of this study was to examine the effects of different midsole constructions in bowling footwear (barefoot, traditional and modified with E-TPU material) on the mechanics of bowling delivery. The results from this study indicated that no significant difference was found in the joint angles and velocities of hip, knee and ankle, stride length, linear ball velocity and peak vertical ground reaction force to body weight ratio. Therefore, the findings of this study suggest that midsole construction of bowling footwear has minimal impact to the mechanics of bowling delivery. This study provides an important preliminary understanding on the mechanics of bowling delivery, which had not yet been investigated until now. Future studies are warranted to examine the 3D mechanics of bowling with more experienced bowlers at a bowling alley to acquire a comprehensive understanding of this sport skill.

REFERENCES

Ashley, J., Wu, T., & Postlmayr, C. (2012). The examination of softball pitching fatigability in lower extremities. *36th annual American Society of Biomechanics,* Gainesville, USA.

BASF (2017, December 10). *The First Expanded TPU*. Retrieved December 10, 2017, from https://www.basf.com

Chu, D. P. K., Zhang, B. M., & Mau, K. (2002). Tenpin bowling technique on elite players. 20th International Conference on Biomechanics in Sports, 123-125.

Hung, C. H., Hsieh, L. C., & Wu, H. W. (2012). Development of a simple force prediction model and consistency assessment of knee movements in ten-pin bowling. *Maejo International Journal of Science and Technology*. *6* (02), 297-314.

Hsiao, K. C., Chen M. C., & Tu, C. H. (1996). Bowling injuries. *Journal of Orthopaedic Surgery, 13*, 111-114.

Kerr, Z. Y., Collins, C. L., & Dawn Comstock, R. (2011). Epidemiology of bowling-related injuries presenting to US emergency departments, 1990-2008. *Clinical Pediatrics*, *50* (8), 738–746.

National Electronic Injury Surveillance System (2017, December 10). *Injuries caused by bowling*. Retrieved December 10, 2017, from http://product-injuries.healthgrove.com/l/18/Bowling

Razman, R., Abas W., & Othman, N. (2010). Front foot slide variability and its relation to tenpin bowling performance. 28th International Conference on Biomechanics in Sports, 1-2.

Zhang, S., Clowers, K., Kohstall, C. & Yu, Y. (2005). Effects of various midsole densities of basketball shoes on impact attenuation during landing activities. *Journal of Applied Biomechanics*, *21*, 3-17.