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Perception of Comfort, Fit, and Jumping Performance of Elite NCAA Division 1 Student-athletes: The Effect of Basketball Shoe Design – Part II

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ABSTRACT

Background: Assessing basketball shoe comfort and fit as personal protection equipment (PPE) at the collegiate level is unique. **Objective:** The purpose of Part II in this pilot study was to examine the effect of shoe design on the perception of comfort and fit after performing an acute series of jumps in elite male and female National Collegiate Athletic Association (NCAA) Division 1 basketball student-athletes. **Method:** A total of sixteen basketball student-athletes (six males, ten females) performed two rounds of acute series of four styled basketball jumps on two ForceDecks™ Force Platforms while trying to maximize jump height by tapping Vertec™ Jump Vanes. The male student-athletes selected the Adidas™ Harden Vol. 3 and the Adidas™ SM Pro basketball shoes. The female student-athletes selected the Adidas Harden Vol. 3 and the Adidas Captain Marvel basketball shoes. Upon completion of each round of jumps, the student-athlete recorded their perception of comfort on a 110mm Visual Analog Scale (VAS) and fit on a seven-point Likert rating scale based against their most comfortable basketball shoes ever worn. **Results:** Results of this pilot study reported, on average, the male student-athletes preferred comfort and fit of the Adidas SM Pro basketball shoes and the female student-athletes preferred the Adidas Harden Vol. 3 basketball shoe, though differences were non-significant at $p > 0.05$. **Conclusion:** The use of a human factors assessment tool to evaluate basketball shoe comfort and fit and the influence of rated comfort and fit parameters on basketball jumping performance proved viable.

Key words: Basketball, Shoes, Comfort, Fit, Jump, Scales

INTRODUCTION

During a series of 113 unstructured interviews with collegiate- and professional strength and conditioning coaches, and athletic trainers on the use of wearables in training and monitoring their athletes, one of the repeated concerns identified was the negative effects of sport shoes on the athlete's foot/ankle complex (T. Luczak, Burch, Lewis, Chander, & Ball, 2020). Coincidently, the news of Zion Williamson's NIKE basketball shoe blowout (Dator, 2019), led to the question of how do college teams determine basketball shoe selection? This question launched the investigation of how different basketball shoes impact elite NCAA men's and women's student – athletes, Part I (T. Luczak, Burch, Smith, Lamberth, & Carruth, 2020). One of the challenges in determining the optimal comfort and fit for a basketball shoe is based on the individualistic subjective nature of what is comfortable and how well a shoe fits (Goonetilleke, 1999). More often an athlete's choice on shoe selection is often based on the complex culmination of experiences, knowledge, perceptions, environment, and attitude resulting in a "set of principle operations" (Card, Moran, & Newell, 1986).

To help coaches and athletes improve their decision making process, the development of a Basketball Shoe Taxonomy (BST, in review), has proposed the integration of several Human Factors and Ergonomic (HFE) assessment tools to quantify and guide the individualistic nature of shoe selection. Two specific means of assessing footwear personal protection equipment (PPE) comfort and discomfort are visual analogue scales (VAS) and Likert scales (Lam, Sterzing, & Cheung, 2011; Mündermann, Nigg, Stefanyshyn, & Humble, 2002). Specific anchor words should then be added to

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categorical ratio-based scales (Borg, 1982) to gain insight on specific parameters that determine shoe preference.

Comfort has been related to "well-being and aesthetics" (Helander & Zhang, 1997), In addition, subjective psycho-physical measures such as levels of stiffness, stability and cushioning, can assist in determining the parameters of shoe design that matches the athlete's anthropometrics, physiological responses, biomechanical influence, psychological factors, and performance (Akbar-Khanzadeh, Bisesi, & Rivas, 1995; Knight et al., 2006; Llana, Brizuela1, Dura, & Garcia, 2002; Pontrelli, 1977). Mündermann et al. (2002) used the following shoe aspects to assess inserts and running shoes: overall comfort, heel cushioning, forefoot cushioning, medio-lateral control, arch height, heel cup fit, shoe heel width, shoe forefoot width, shoe forefoot width, and shoe length. Using a sport closer to the movement patterns of basketball, Llana, et. al, measured the discomfort of tennis shoes utilizing a seven-point Likert scale (anchored by "no discomfort" and "intense pain") and a three-point Likert scale ("little", "adequate", and "high") to assess 14 characteristic of footwear (Llana et al., 2002). The characteristics included: footwear floor-hold, front mid-sole height, rear mid-sole hardness, front upper vamp hardness, rear upper vamp hardness, rear height, fastening, length, front width, rear width, flexibility, arch support position, arch support height (Llana et al., 2002).

To determine the proper fit of a basketball shoe, one should be to determine "the functional geometrical match of foot and shoe" (Lam et al., 2011). How a shoe fits greatly determines whether the shoe is comfortable or causes discomfort. Determining dynamic fit parameters within contextual movement patterns including subjective fit rating, foot-last size difference, and pressure distribution of the foot-shoe interface may improve the perception of comfort(Cheng & Hong, 2010). Quantifying fit, Cheng and Hong used a VAS scale correlated to 16 flexible pressure sensors mounted to the top of the subject's foot. The results indicated a negative correlation of fit rating to pressure (Cheng & Hong, 2010). Some sensors were found to record higher pressures due to the folding of the sensors. Another wearable device, a pressure sock, was developed using textile sensors with results indicating the same negative correlation between comfort and pressure (Herbaut, Simoneau-Buessinger, Barbier, Cannard, & Guéguen, 2016). However, the question of how much pressure is uncomfortable is not universal between individuals (Herbaut et al., 2016).

General methods in determining fit using a Brannock device includes measurement of foot length and width of the foot (Caselli, 2006). This provides a standing weight bearing method for foot size, which unfortunately, cannot be utilized to define any shape deformation of the foot during movements. Limited to two dimensional measurements, new technology is improving fit through the use of scanners and three dimensional modeling (Figure 1) (Coudert, Vacher, Smits, & Van der Zande, 2006).

Coudert et al.(2006), has developed a method to produce 3D digitization of the foot using stereoscopic sensors which produces a surface, scanner-like mapping of the foot during gait cycle. Findings from this study identified temporal changes in size and pressures throughout the foot during a gait cycle which were different from standing weight bearing measures. When comparing the dimensional foot changes of recreational sprinters versus non-habitual sprinters, aside from temporary changes in overall foot size, the anatomical changes from repeated activities of the recreational sprinters resulted in other significant dimension changes in the foot including heel breadth, toe length, height of navicular, hallux of the right foot, and ball girth circumference (Chen, Chang, Wang, & Tsao, 2018). Furthermore, changes in foot size and shape during walking and running complicates the fitting process. The foot and ankle ranges of motion of nine elite American football players were optically captured then modeled using Open Sim (Stanford University, CA, USA) software synchronized with force plates to determine kinematics and kinetics during cutting, jumping, and sprinting movements. The results of this study indicated that the talocrural, subtalar, and metatarsophalangeal joints ranges of motion exceeded physiological limits (Riley et al., 2013). Understanding the changes in the foot and the kinetic forces that occur in multidirectional movement patterns can help shoe designer develop a better fitting shoe and potentially mitigate foot and ankle injuries.

Figure 1. Scanned image of a foot.

Contextually linking the subjectivity of a player's shoe comfort to their basketball specific kinetic output, has shown to be an effective means for shoe assessment (Lam et al., 2011). The importance of establishing a basketball specific comfort and fit assessment tool is to help refine the decision-making process in selecting the appropriate type of basketball shoe based on the individual athlete's style of play. In addition, quantitative assessment of the type of shoe being worn has shown that shoe design can influence running speed and jump height (Brizuela, Llana, Ferrandis, & Garcia-Belenguer, 1997), which would favor an experimental design that matches conditions of the game. Thus, correlating comfort and fit to performance may provide insight on how cognitive perception influences performance and shoe selection.

Rationale for Part II pilot study is based on the need to develop an HFE-based assessment tool for coaches, practitioners, and athletes to make evidenced-based decisions on shoe selection as part of the comprehensive shoe evaluation process identified in the BST. Part II pilot study utilized Appendix A to determine whether lower ratings in comfort and fit will negatively influence jump performance. Based on the men's and women's teams jumping results from Part I, Part II provides a 110mm VAS survey on comfort and seven-point Likert Scale on fit to determine the individual athlete's preference of shoe compared to their favorite basketball shoe ever worn. This article expands upon the research performed in the "Part I" study (T. Luczak, Burch, Smith, et al., 2020) by using the methodology of basketball-specific jumps to evaluate comfort and fit in the Part II pilot study.

METHOD

This study was conducted under the approval of the Institutional Review Board (19-351) at MSU. Before performing the test, student-athletes were informed of the testing protocol and provided a written informed consent form. Any questions were answered at that time. Student-athletes included Mississippi State basketball student-athletes on the current academic year's roster including six from the men's team (198.48cm ± 8.97, 94.48kg ± 15.96, 13.5US Men's ± 2.35) and 10 from the women's team (184.15cm ± 9.29, 78kg ± 10.84, 10US Men's ± 2.35) between the ages of 18-22 years. Student-athletes who participated in the previous jump study (Part I) completed VAS and Likert forms used in this study.

Study Design

The correlational study design is a single day testing protocol conducted after each series of jump trials. During the familiarization of the jump protocol, student-athletes were informed that they would evaluate the shoes comfort and fit (Figure 2) based against the most comfortable pair of basketball shoes they had ever worn. After completion of the first jump series, student-athletes were handed a multi-page comfort and fit assessment based on a 110mm VAS scale for comfort and seven-point Likert rating form for fit to assess the basketballs used during testing. After rest and changing into the second pair of shoes, student-athletes completed the second series of jumps and were handed a second 110mm VAS scale for comfort and seven-point Likert rating form for fit to assess the basketball shoes worn during testing.

Figure 2. Men's Shoes - Team Harden (a) and SM Pro (b), Women's Shoes - Team Harden (c) and Captain Marvel (d)

Instrumentation and Participant Preparation

Each student-athlete completed a 110mm VAS scale and seven-point Likert fit rating scale (Appendix A) on the following comfort factors: Arch Height, Heel Cushioning, Forefoot Cushioning, Heel Region, Collar, Medio-lateral Control, and Overall Comfort to the most comfortable pair of basketball shoes ever worn (Lam et al., 2011). The left end of the line was labelled 'not comfortable at all' (0) and the right end 'most comfortable condition imaginable' (Trimmel & Trimmel, 2017). The fit of the shoe was rated on shoe length, heel region, forefoot width, and collar fit. The 110mm VAS scale was set to a 0-11 cm scale for data analysis and fit ratings were subtracted by four and then transformed into absolute values to assess shoe effect (Lam et al., 2011). This identifies values closer to 0 indicating a better fit while values closer to three indicating a poorer fit which follows protocol of previous research conducted by Lam et al (Lam et al., 2011).

In addition, the student-athletes were handed a visual explanation for all the comfort and fit assessment tool (Appendix B). Any questions were answered by using the printed guide as a reference relating back to the shoe that was worn during testing. Any verbal descriptions that were said were read from the printed example directions seen in Appendix B.

Experimental Procedures

All student-athletes that participated in the previously discussed jump protocol study were included in the comfort and fit assessment study. Upon completion of the first series of jumps, the student-athlete was handed a clipboard and pen to evaluate the shoes. The researcher described the filling out of the form by indicating drawing a vertical line through the horizontal 110mm VAS comfort scale within each of the shoe comfort characteristics. The researcher then described circling the rating value on fit on how well the shoe tested fitted the student-athlete. If there were any questions, the student-athlete was directed to the visual description page and review the questioned area by talking aloud the written description. This process was repeated after the second series of jumps. Upon completion of the surveys, the student-athlete had completed the study.

Data Processing

The vertical markings on the 110mm VAS were manually measured using a 180mm ruler (Appendix A). Using a Microsoft Excel program (Redmond, WA, USA, ver. 365), each deidentified student-athletes' response was recorded in centimeters for each of the comfort parameters: Arch Height, Heel Cushioning, Forefoot Cushioning, Heel Region, Collar, Medio-lateral Control, and Overall Comfort Marked fit ratings from the seven-point Likert scale were recorded as absolute values when subtracted from 4 for each of the fit parameters: Shoe Length, Heel Region, Forefoot Width, and Collar Fit.

Statistical Analysis

A Paired Samples t-Test was conducted using Statistical Package for Social Sciences (SPSS ver.26, IBM Corporation, New York, NY, USA) to compare the ranked means of basketball shoe comfort and fit effects on two different pairs of shoes to determine men's and women's team shoe preference. A Pearson Bivariate Correlation was conducted to determine if shoe comfort and fit parameters affected jumping performance in the men's and women's teams (Akoglu, 2018).

RESULTS

This pilot study evaluated the athlete's perception of comfort and fit on new (less than 2 weeks old) basketball shoes after an acute jumping test protocol. Each athlete rated the comfort of the shoe tested to the most comfortable basketball they have ever worn and how well each shoe currently fits.

Shoe Comfort Comparisons

Table 1 provides Paired Samples Test statistics comparing shoe comfort differences for the men's team Shoe A versus Shoe B. Table 2 provides Paired Samples Test statics comparing shoe comfort differences for the women's team Shoe C versus Shoe D.

Shoe Fit Comparisons

Table 3 provides Paired Samples Test statistics to compare fit parameters of the two selected shoe models by the men's team Shoe A versus Shoe B. Table 4 provides Paired Samples Test statistics to compare fit parameters of the women's team Shoe C versus Shoe D. Lower fit ratings indicate a better fit.

Relationship between Comfort and Fit to Jump Performance

A Pearson Bivariate Correlation was conducted to compare the relationships between shoe rating of comfort and fit to jumping performance for the Men's and Women's teams.

Table 1. Results of paired samples test to evaluate differences in comfort rating between men's team Shoe A and Shoe B

Men's Team	Shoe A	Shoe B	n	95% CI for Mean difference			
Comfort parameter	M±SD	M±SD			r	t	df
Arch height	5.08±3.82	6.65±3.23	6	-5.774, 2.641	0.382	-0.957	5
Heel cushioning	5.23±1.50	5.02±2.66	6	-2.584, 3.017	0.85	0.199	5
Forefoot cushioning	4.67±2.14	6.60±2.64	6	-5.71, 1.843	0.245	-1.316	5
Heel region	4.23±2.12	5.02±2.96	6	-4.077, 2.51	0.568	-0.611	5
Collar	4.18±3.07	5.62±2.74	6	-5.072, 2.205	0.358	-1.013	5
Medio-lateral control	4.92±2.88	5.80±3.48	6	-5.732, 3.966	0.659	-0.468	5
Overall comfort	4.50±2.98	6.52±2.66	6	-5.797, 1.763	0.229	-1.371	5

Results indicate a non-significant difference between shoe comfort parameters for Shoe A and Shoe B

Table 2. Results of Paired samples test to evaluate differences in comfort rating between women's team Shoe C and Shoe D

Women's team	Shoe C	Shoe D	n	95% CI for Mean difference			
Comfort parameter	M±SD	M±SD			r	t	df
Arch height	5.45±2.48	5.04±1.52	10	-1.417, 2.237	0.624	0.508	9
Heel cushioning	5.01±1.96	6.58±1.96	10	-3.48, 0.340	0.096	-1.859	9
Forefoot cushioning	5.49±2.96	5.16±1.93	10	-2.236, 2.896	0.778	0.291	9
Heel region	5.08±3.23	5.72±2.02	10	-3.28, 2.000	0.597	-0.548	9
Collar	4.90±2.50	5.64±2.63	10	-2.241, 0.761	0.294	-1.116	9
Medio-lateral control	5.40±2.57	5.68±2.43	10	-1.954, 2.634	0.745	0.335	9
Overall comfort	6.22±2.79	5.93±2.16	10	-2.229, 2.809	0.800	0.260	9

Results indicate a non-significant difference between shoe comfort parameters for Shoe C and Shoe D.

Table 3. Paired samples test to evaluate the difference in fit rating between men's team Shoe A and Shoe B

Men's team	Shoe A	Shoe B	n	95% CI for Mean difference			
Fit parameter	M±SD	M±SD			r	t	df
Shoe length	1.17±1.17	0.67±0.52	6	-0.947, 1.947	0.415	0.889	5
Heel region	1.00±0.89	0.33±0.52	6	-0.190, 1.524	0.102	2.00	5
Forefoot width	1.17±0.75	1.00±0.89	6	0.623, 0.957	0.611	0.542	5
Collar	1.00±1.26	0.50±0.84	6	-0.601, 1.601	0.296	1.168	5

Results indicate a non-significant difference between shoe fit parameters for Shoe A and Shoe B

Table 4. Paired samples test to evaluate the difference in fit rating between women's team Shoe C and Shoe D

Women's team	**Shoe C**	**Shoe D**	**n**	**95% CI for Mean difference**			
Fit parameter	**M±SD**	**M±SD**			**r**	**t**	**df**
Shoe length	0.50±0.71	1.20±1.03	10	-1.458, 0.058	0.066	-2.09	9
Heel region	0.80±0.79	1.10±0.74	10	-1.257 0.657	0.496	-0.709	9
Forefoot width	0.60±0.70	0.50±0.71	10	-0.611, 0.811	0.758	0.318	9
Collar	1.00±0.82	1.00±0.82	10	-0.826, 0826	1.000	0.000	9

Results indicate a non-significant difference between shoe fit parameters for Shoe C and Shoe D.

Table 5. Pearson bivariate correlation results of fit ratings and jumping performance of men's team Shoe A

Men's team shoe a comfort correlations to jumping performance								
Jump outputs		**Arch height**	**Heel cushion**	**Forefoot cushion**	**Heel region**	**Collar**	**M-L control**	**Overall comfort**
CMJ PPr	Pearson correlation	0.504	-0.193	-0.189	-0.328	-0.451	-.817*	-0.541
	Sig. (2-tailed)	0.308	0.714	0.720	0.526	0.370	0.047	0.268
	N	6	6	6	6	6	6	6
CMJ Height (cm)	Pearson Correlation	0.100	-0.411	-0.391	-0.615	-0.630	-.831*	-0.794
	Sig. (2-tailed)	0.850	0.418	0.444	0.194	0.180	0.041	0.059
	N	6	6	6	6	6	6	6
DJ PPr	Pearson correlation	0.113	-0.421	-0.401	-0.623	-0.638	-.830*	-0.795
	Sig. (2-tailed)	0.831	0.405	0.431	0.186	0.173	0.041	0.059
	N	6	6	6	6	6	6	6
DJ Height (cm)	Pearson correlation	0.752	-0.001	0.016	-0.014	-0.154	-0.436	-0.081
	Sig. (2-tailed)	0.085	0.999	0.976	0.979	0.771	0.388	0.879
	N	6	6	6	6	6	6	6
STJ PPr	Pearson correlation	0.571	-0.512	-0.645	-0.738	-.837*	-.815*	-.868*
	Sig. (2-tailed)	0.237	0.299	0.167	0.094	0.038	0.048	0.025
	N	6	6	6	6	6	6	6
STJ Height (cm)	Pearson correlation	0.565	-0.524	-0.650	-0.745	-.841*	-0.809	-.865*
	Sig. (2-tailed)	0.243	0.286	0.163	0.089	0.036	0.051	0.026
	N	6	6	6	6	6	6	6
PJ PPr	Pearson correlation	-0.461	0.249	0.474	0.287	0.324	-0.230	0.107
	Sig. (2-tailed)	0.358	0.634	0.343	0.581	0.531	0.662	0.840
	N	6	6	6	6	6	6	6
PJ Height (cm)	Pearson correlation	0.295	-0.347	-0.336	-0.529	-0.598	-.877*	-0.733
	Sig. (2-tailed)	0.570	0.500	0.515	0.280	0.210	0.022	0.097
	N	6	6	6	6	6	6	6

*. Correlation is significant at the 0.05 level (2-tailed).**. Correlation is significant at the 0.01 level (2-tailed)

Comfort

Table 5 provides the results of the men's team comfort rating of Shoe A which indicates several significant negative correlations.

From Part I, student-athletes performed two sets of jumps onto two ForceDecks Dual Force Plate System (Vald Performance, Brisbane, Australia) measuring at 1000 Hz, surrounded by rubber matting with a Vertec positioned on their dominant side (upper extremity) for hitting the Vertec vanes with their dominant hand during the jumping tasks jump height (cm) and normalized body weight peak power (W/kg) production (PPr). The four jumps performed were: (1) Countermovement vertical jump (CMJ), (2) Depth jump (30cm box) (DJ), (3) Step and jump (STJ), and (4). Plyometric jump (PJ).

Results indicate there were significant negative relationships between Medio-lateral (ML) Control comfort and CMJ PPr r = -0.817, n = 6, p = 0.047), CMJ Height (r = -0.831, n = 6 = 0.041), DJ Height (r = -0.815, n = 6, p = 0.048), STJ Height (r = 0-.877, n = 6, p = 0.022), and PJ Height (r = -0.876, n = 6, p = 0.022). There were significant negative relationships between Overall Comfort and DJ Height (r = -0.815, n = 6, p = 0.025) and PJ Height (r = -0.923, n = 6, p = 0.009).

Table 6. Pearson bivariate correlation results of fit ratings and jumping performance of women's team shoe c.

Women's team Shoe C comfort Correlations to jumping performance								
Jump outputs		**Arch height**	**Heel Cushion**	**Forefoot cushion**	**Heel region**	**Collar**	**M-l control**	**Overall comfort**
CMJ PPr	Pearson correlation	0.206	0.401	0.381	0.453	-0.036	0.178	0.433
	Sig. (2-Tailed)	0.568	0.251	0.278	0.188	0.922	0.623	0.211
	N	10	10	10	10	10	10	10
CMJ Height (cm)	Pearson correlation	0.302	0.604	0.527	0.515	0.227	0.488	0.656*
	Sig. (2-Tailed)	0.397	0.064	0.118	0.128	0.527	0.153	0.040
	N	10	10	10	10	10	10	10
DJ PPr	Pearson correlation	0.236	0.423	0.523	0.342	-0.522	0.003	0.312
	Sig. (2-Tailed)	0.511	0.223	0.121	0.334	0.122	0.994	0.380
	N	10	10	10	10	10	10	10
DJ Height (cm)	Pearson correlation	0.449	0.607	0.564	.638*	0.145	0.445	0.563
	Sig. (2-Tailed)	0.193	0.063	0.090	0.047	0.688	0.198	0.090
	N	10	10	10	10	10	10	10
STJ PPr	Pearson correlation	0.373	0.545	0.388	.660*	0.447	0.697*	0.477
	Sig. (2-Tailed)	0.288	0.103	0.269	0.038	0.195	0.025	0.163
	N	10	10	10	10	10	10	10
STJ Height (cm)	Pearson correlation	0.276	0.408	0.301	0.330	0.281	0.338	0.470
	Sig. (2-Tailed)	0.441	0.242	0.399	0.353	0.432	0.340	0.170
	N	10	10	10	10	10	10	10
PJ PPr	Pearson correlation	0.286	0.419	0.319	0.330	0.261	0.327	0.487
	Sig. (2-Tailed)	0.424	0.229	0.370	0.351	0.467	0.357	0.153
	N	10	10	10	10	10	10	10
PJ Height (cm)	Pearson correlation	0.019	0.062	0.230	-0.141	-0.613	-0.359	0.063
	Sig. (2-Tailed)	0.960	0.864	0.523	0.697	0.059	0.309	0.864
	N	10	10	10	10	10	10	10

*. Correlation is significant at the 0.05 level (2-tailed).

The results of men's team comfort rating of Shoe B produced only one significant negative correlation, Medio-lateral Control and DJ PPr ($r = -0.846$, $n = 6$, $p = 0.034$).

The results of the women's team comfort rating of Shoe C produced several significant positive correlations are presented in Table 6.

From Part I, student-athletes performed two sets of jumps onto two ForceDecks Dual Force Plate System (Vald Performance, Brisbane, Australia) measuring at 1000 Hz, surrounded by rubber matting with a Vertec positioned on their dominant side (upper extremity) for hitting the Vertec vanes with their dominant hand during the jumping tasks jump height (cm) and normalized body weight peak power (W/kg) production (PPr). The four jumps performed were: (1) Countermovement vertical jump (CMJ), (2) Depth jump (30cm box) (DJ), (3) Step and jump (STJ), and (4). Plyometric jump (PJ).

Results indicate there was a significant positive relationship between Overall Comfort and CMJ Height ($r = 0.656$, $n = 10$, $p = 0.04$). There were significant positive relationships between Heel Region comfort and DJ Height ($r = 0.638$, $n = 10$, $p = 0.047$) and STJ PPr ($r = 0.660$, $n = 10$, $p = 0.038$). Also, there was a significant positive relationship between Heel Cushioning comfort and PJ Height ($r = 0.634$, $n = 10$, $p = 0.049$).

The results of the women's team comfort rating of Shoe D produce a significant negative correlation. There was a significant negative relationship between Medio-lateral Control comfort and PJ PPr ($r = -0.675$, $n = 10$, $p = 0.032$).

Fit

Table 7 indicates the results of the men's team fit rating of Shoe A Pearson Bivariate Correlation test. A positive relationship exists between Shoe Length Fit and DJ Height ($r = 0.930$, $n = 6$, $p = 0.007$). There were significant positive relationships between Heel Fit and CMJ PPr ($r = 0.900$, $n = 6$, $p = 0.014$), DJ Height ($r = 0.884$, $n = 6$, $p = 0.019$), and STJ Height ($r = 0.925$, $n = 6$, $p = 0.008$). There were significant positive relationships between Collar Fit and DJ Height ($r = 0.930$, $n = 6$, $p = 0.007$) and PJ Height ($r = 0.906$, $n = 6$, $p = 0.016$).

From Part I, student-athletes performed two sets of jumps onto two ForceDecks Dual Force Plate System (Vald

Table 7. Pearson bivariate correlation results of fit ratings and jumping performance of men's team shoe a

Men's team shoe a fit correlations to jumping performance					
Jump outputs		**Shoe length fit**	**Heel fit**	**Forefoot width fit**	**Collar fit**
CMJ PPr	Pearson correlation	0.508	0.900*	0.069	0.558
	Sig. (2-Tailed)	0.304	0.014	0.896	0.250
	N	6	6	6	6
CMJ Height (cm)	Pearson correlation	0.733	0.858*	0.180	0.765
	Sig. (2-Tailed)	0.097	0.029	0.733	0.077
	N	6	6	6	6
DJ_ PPr	Pearson correlation	0.193	0.686	-0.193	0.165
	Sig. (2-Tailed)	0.714	0.132	0.714	0.755
	N	6	6	6	6
DJ Height (cm)	Pearson correlation	0.930**	0.884*	0.431	0.930**
	Sig. (2-Tailed)	0.007	0.019	0.394	0.007
	N	6	6	6	6
STJ PPr	Pearson correlation	-0.344	0.146	-0.371	-0.238
	Sig. (2-Tailed)	0.504	0.782	0.469	0.649
	N	6	6	6	6
STJ Height (cm)	Pearson correlation	0.674	0.925**	0.162	0.722
	Sig. (2-Tailed)	0.142	0.008	0.759	0.105
	N	6	6	6	6
PJ PPr	Pearson correlation	0.168	0.607	0.122	0.299
	Sig. (2-Tailed)	0.751	0.201	0.818	0.565
	N	6	6	6	6
PJ Height (cm)	Pearson correlation	0.804	0.807	0.560	0.906*
	Sig. (2-Tailed)	0.054	0.052	0.248	0.013
	N	6	6	6	6

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed)

Performance, Brisbane, Australia) measuring at 1000 Hz, surrounded by rubber matting with a Vertec positioned on their dominant side (upper extremity) for hitting the Vertec vanes with their dominant hand during the jumping tasks jump height (cm) and normalized body weight peak power (W/kg) production (PPr). The four jumps performed were: (1) Countermovement vertical jump (CMJ), (2) Depth jump (30cm box) (DJ), (3) Step and jump (STJ), and (4). Plyometric jump (PJ).

There were no significant positive or negative relationships with the men's team Shoe B and jumping performance.

Table 8 provides the results of the Pearson Bivariate Correlation test for the women's team Shoe C fit rating correlation to jumping performance.

Results indicate there were negative relationships in Heel Fit to CMJ PPr (r = -0.665, n = 10, p = 0.034) and STJ Height (r = -0.742, n = 10, p = 0.014). There were negative relationships between Forefoot Width Fit and STJ PPr (r = -0.664, n = 10, p = 0.036) and STJ Height (r = -0.670, n = 10, p = 0.034).

From Part I, student-athletes performed two sets of jumps onto two ForceDecks Dual Force Plate System (Vald Performance, Brisbane, Australia) measuring at 1000 Hz, surrounded by rubber matting with a Vertec positioned on their dominant side (upper extremity) for hitting the Vertec vanes with their dominant hand during the jumping tasks jump height (cm) and normalized body weight peak power (W/kg) production (PPr). The four jumps performed were: (1) Countermovement vertical jump (CMJ), (2) Depth jump (30cm box) (DJ), (3) Step and jump (STJ), and (4). Plyometric jump (PJ).

For the women's team Shoe D fit rating, there was only a significant positive relationship between Heel Fit and PJ Height (r = 0.671, n = 10, p = 0.034) and no negative fit relationships.

DISCUSSION

This pilot study used a 110mm VAS comfort assessment tool to compare the comfort perceptions on two different pairs of basketball shoes with elite NCAA Division 1 men's and women's basketball teams. The results of the comfort assessment for each set of shoes on both the men's and women's teams produced an average liking below 60%. Scoring below average should reflect a concern to the coaching staff

Table 8. Pearson bivariate correlation results of fit ratings and jumping performance of women's team shoe c.

Women's team Shoe C Fit correlations to jumping performance					
Jump outputs		**Shoe length fit**	**Heel fit**	**Forefoot width fit**	**Collar fit**
CMJ PPr	Pearson correlation	-0.341	-0.665*	-0.619	-0.281
	Sig. (2-Tailed)	0.335	0.036	0.056	0.432
	N	10	10	10	10
CMJ Height (cm)	Pearson correlation	-0.371	-0.525	-0.351	-0.294
	Sig. (2-Tailed)	0.292	0.119	0.320	0.410
	N	10	10	10	10
DJ PPr	Pearson correlation	-0.364	-0.509	-0.337	-0.292
	Sig. (2-Tailed)	0.301	0.133	0.341	0.413
	N	10	10	10	10
DJ Height (cm)	Pearson correlation	0.124	-0.117	-0.374	0.231
	Sig. (2-Tailed)	0.733	0.748	0.287	0.520
	N	10	10	10	10
STJ PPr	Pearson correlation	-0.516	-0.742*	-0.664*	-0.165
	Sig. (2-Tailed)	0.127	0.014	0.036	0.648
	N	10	10	10	10
STJ Height (cm)	Pearson correlation	-0.518	-0.742*	-0.670*	-0.161
	Sig. (2-Tailed)	0.125	0.014	0.034	0.656
	N	10	10	10	10
PJ PPr	Pearson correlation	-0.257	-0.609	-0.306	0.089
	Sig. (2-Tailed)	0.474	0.062	0.389	0.806
	N	10	10	10	10
PJ Height (cm)	Pearson correlation	-0.357	-0.405	-0.289	-0.401
	Sig. (2-Tailed)	0.311	0.246	0.418	0.250
	N	10	10	10	10

*. Correlation is significant at the 0.05 level (2-tailed)

that player preference towards either shoe is not very high and may impact player performance or increase the chance of overuse injuries. Whether dislike for a shoe is a placebo effect on performance or not, coaches should consider this a realistic possibility (Beedie & Foad, 2009; McClung & Collins, 2007; Mohr, Trudeau, Nigg, & Nigg, 2016).

The question of what level of perceived comfort ratings in basketball footwear affects playing performance is individualized. However, extended levels of low comfort may lead to higher levels of discomfort resulting in poor performance and over-use injuries (Goonetilleke, 1999; Lam et al., 2011). Neither team significantly preferred the comfort of one shoe over the other. The men's team was split with three student-athlete average comfort rating higher in Shoe A and three in Shoe B. The women's team was also split with five student-athlete average comfort ratings higher in Shoe C and five in Shoe D.

With the potential like or dislike preference of a shoe to affect performance, the results of correlation testing the comfort parameters to jumping performance produced some interesting outcomes. On the men's team, significant negative correlations where reported (Table 6) for Shoe A in CMJ PPr, CMJ Height, DJ PPr, STJ Height, and PJ Height ($p \leq 0.05$) and a negative correlation occurred in Shoe B between Medio-lateral Control Comfort and DJ PPr which indicates that Shoe A and B were not comfortable per the player's perspective but their jump performance increased. This may seem counter intuitive that a shoe that isn't comfortable produced positive results, but it may have been a case of firmer midsoles or less cushioning which allowed for an increase in vertical GRFs resulting in greater power production and jump height (Stefanyshyn & Nigg, 2000). Even though additional cushioning may be perceived as being more comfortable and be used to mitigate negative GRFs shock experienced during practices and games (Goonetilleke, 1999; McClay et al., 1994), the effect of energy transfer should be considered when looking to optimize performance (Leong, Lam, Ng, & Kong, 2018; Robbins, Waked, Gouw, & McClaran, 1994). Thus, there should be a balance between landing technique to reduce shock and an appropriate level of cushioning in a shoe to optimize energy transfer and mitigate excessive forces. However, contrary to the results of the men's team, the women's team produced positive relationships between comfort rating and jumping performance in Shoe C but a negative relationship in Shoe D. This corroborates with some of the discussions among teammates that occurred during the study regarding the like of Shoe C versus dislike of color design of Shoe D. Reduced perception of hardness has been likened to more comfort and, based on previous discussions about placebo effect and performance, the perception of liking a shoe can impact work output (Goonetilleke, 1999). Thus, the increase in comfort can help to ensure an athlete that there will be a reduction of vertical GRFs upon landing and promote an effort to jump higher (Cámara Tobalina, Calleja-González, Martínez de Santos, Fernández–López, & Arteaga-Ayarza, 2013).

Using a seven-point Likert scale to rate the fit of the shoes resulted in a preferred fit rating for Shoe B for the men's team and for Shoe C on the women's team. The men's team had three student-athletes that preferred the fit in Shoe B, one student-athlete that preferred the fit in Shoe A, and two student-athletes that rated fit to be the same between Shoe A and B. The women's team was evenly divided in shoe fit preference. Investigating how each shoe's fit impacted jumping performance, significant positive relationships existed in Shoe A for men's team, but no significance difference was seen in Shoe B. Positive correlations existed in Shoe Length Fit, Heel Fit, and Collar Fit in peak power production and jump height (Table 8). On the women's team, positive correlations were seen in Shoe C and in Shoe D. The positive relationships in Shoe C included Heel Fit and Forefoot Width Fit with jump peak power and height (Table 8) and only Heel Fit and PJ Height in Shoe D. The importance of shoe fit to performance, reduction of pressure points within a shoe, and mitigation of foot pathologies (Branthwaite, Chockalingam, & Greenhalgh, 2013) should be considered and prioritized by every coach when introducing new shoes for the upcoming season. Checking for proper fit generally starts at the beginning of each season; however, understanding that the foot will change shape as it is placed under repetitive and high-levels of physiological stress (Chen et al., 2018; Coudert et al., 2006; Riley et al., 2013), new fittings and size adjustments or new shoes should take place periodically throughout the season.

The goal of this pilot study is to use HFE assessment tools to determine player's perception of comfort and fit on two different pairs of basketball shoes and identify comfort and fit parameters that may influence jumping performance. At the professional level, players are treated to private and personalized care by the major shoe manufacturers; however, shoe guidance is not provided during the athlete's formative years in high school and college where most lower limb injuries occur (Lehr et al., 2013). In *Jumping Performance of Elite NCAA Division 1 Student-athletes: The Effect of Basketball Shoe Design – Part I*, the introduction of considering basketball shoes as personal protection equipment (PPE) takes the concept of identifying which shoe is best for each player's individual jumping and landing technique to mitigate injuries and optimize performance (T. Luczak, Burch, Smith, et al., 2020). In addition, to support this process the development of the BST (in review) will become an effective coaching tool to evaluate, match, and fit the basketball shoe to the athlete's foot and playing style (Brauner, Zwinzscher, & Sterzing, 2012; Lam et al., 2011). Providing the specific assessment tools used in this pilot study adds and begins to complete the puzzle of developing a shoe PPE assessment and recommendation system for all types of athletes.

Limitations in this study include the limited number of student-athletes and volume of time each student-athlete spent in the test shoes. In addition, jumping is only part of the game as sprinting forward and backwards and changing direction places additional forces upon the feet. Rating basketball shoes after a practice or game and quantifying movement patterns on the court can help to define the type of forces the athlete places on their feet and quality of shoe comfort and fit.

Future investigations into basketball shoe comfort and fit should require longer GRF loading to establish foot-shoe interaction in determining shoe discomfort levels. Understanding how the foot changes shape during high impact movement, and how the shoe responds to game playing styles will influence the level of comfort and fit. Determining equal matching between shoe volume and 3D foot scans may offer a closer fit compared to the use 2d measuring tools. The use of wearable technology to collect on-court data could determine GRFs and assess different shoe types may offer an improved solution to assess in determining proper shoe design and fit.

An important benefit of sports research is how practitioners can utilize the information to improve their athletes. The last three authors of this study are strength and conditioning (S&C) basketball coaches at both the collegiate- and a professional-level. This section will use an autoethnographic frame to speak as practitioners to the application of comfort and fit evaluation of basketball shoes. The importance of comfort and fit in basketball shoes is a priority for the elite athlete. Basketball shoes are commonly designed and marketed under star players' names and style of play (Cole, 2001; Pribut & Richie Jr, 2004). At the elite performance level, shoe manufacturer engineers are working with the star athlete to personalize and match the proper comfort and fit to the individuals foot characteristics. However, this individualized approach stops at the professional level of the sport, is rare at the elite collegiate level, and is non-existent at lower collegiate divisions. Highlighting the need for personalized shoe fit was the infamous Zion Williamson shoe blowout that occurred on national television in early 2019. The negative impact resulted in a loss of $1.12 billion dollars for Nike (Cancian, 2019)and required a reinforced designed to match Zion Williamson's style of play (Dator, 2019).

The practitioner authors and other peers in their profession state that, in order to reduce the chance of the Zion Williamson incident from happening to one of their athletes, consideration of the architecture of the foot, the type of shoe currently being worn, and the style of play should all be evaluated in show design. Shoe parameters which could influence comfort and fit and impact jumping performance can include mass, flexibility, collar height, stability, toe shape, heel, cushioning, and many more (Blache, Beguin, & Monteil, 2011; Lam et al., 2011; Mohr et al., 2016) should be evaluated with preferential feedback from the athlete. In addition, the practitioner authors suggest that S&C coaches understand the biomechanics of the human body and GRFs that are generated during practices and games to build a knowledge base that considers the total volume of workload and activity per two weeks on the athlete, which has been shown to be a potential factor in overuse injuries in the National Basketball Association or NBA (Talukder et al., 2016). Finally, the recommendation of assessing running, jumping, and landing mechanics of each athlete with the different shoe styles can provide insight on skeletal lower limb alignments which can help in mitigating injuries.

CONCLUSION

Selecting the proper basketball shoe is not an easy task for coaches and athletes based on the individualized perception of comfort, determining proper fit, identifying an appropriate amount of cushioning, understanding player preference styles, knowing the engineered shoe design parameters, and other factors involved in matching the right basketball shoe for each player is a daunting task. To assist players and coaches given the complex physical and psychological factors involved in determining levels of shoe comfort and fit the following recommendations can be implemented: (a) use of a VAS comfort assessment tools and Likert rating scales, (b) integrated into the BST, and (c) correlated to biomechanical loads through the use of force plates or wearable ground reaction pressure sensors can help bring out a clearer understanding of the interplay between shoe comfort and fit to performance and injury mitigation. Feedback from athletes can help manufacturers improve shoe design and provide coaches and trainers insight into the physiological stressors experienced on the court throughout the season. By utilizing the assessment tools listed above, manufacturers, coaches, and athletes will be able to make informed decisions about selecting a basketball shoe that will be designed to help mitigate injuries and optimize the athlete's performance.

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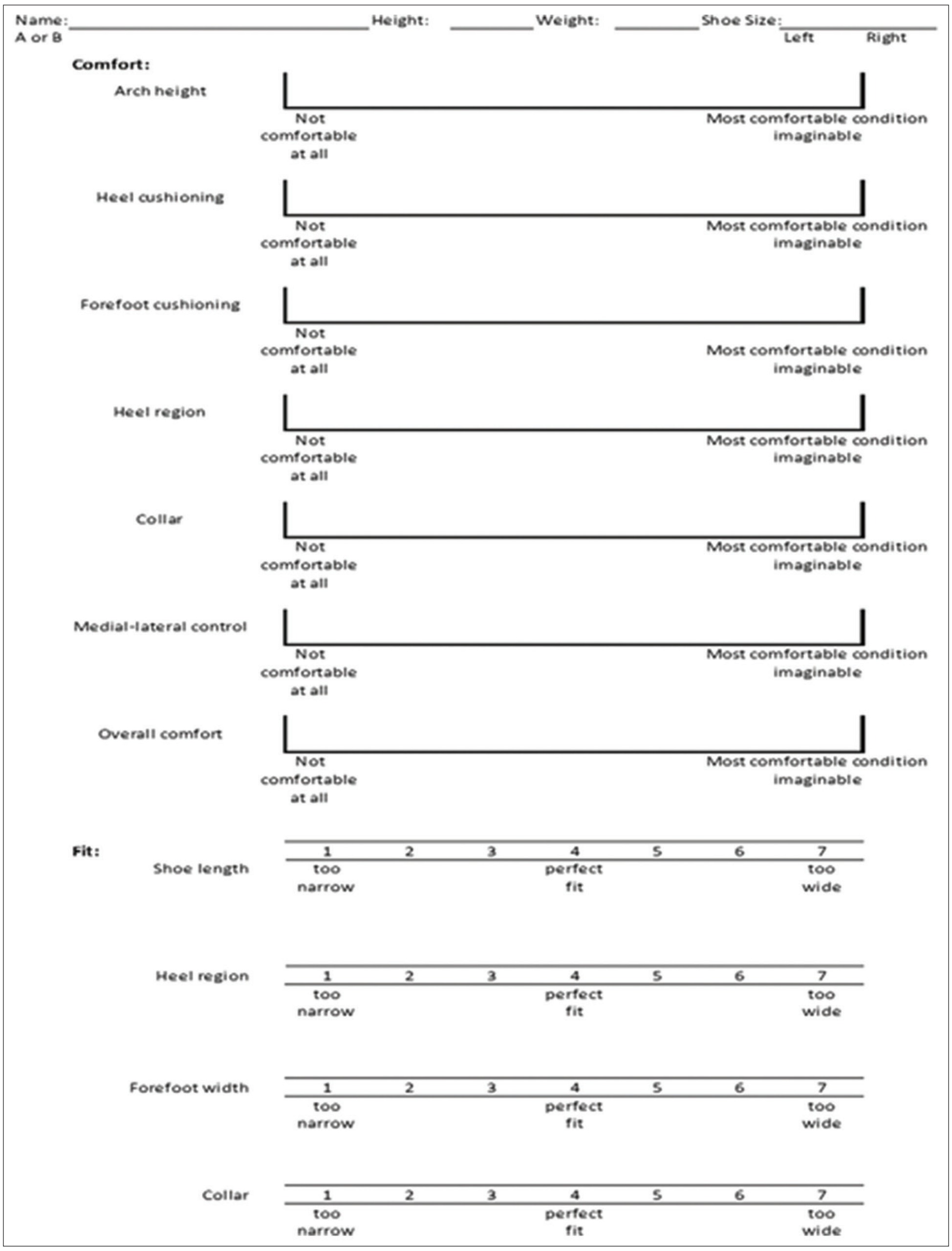
APPENDIX


Name:________ Height: ________ Weight: ________ Shoe Size:________
A or B
Left Right

Comfort:

Arch height
Not comfortable at all — Most comfortable condition imaginable

Heel cushioning
Not comfortable at all — Most comfortable condition imaginable

Forefoot cushioning
Not comfortable at all — Most comfortable condition imaginable

Heel region
Not comfortable at all — Most comfortable condition imaginable

Collar
Not comfortable at all — Most comfortable condition imaginable

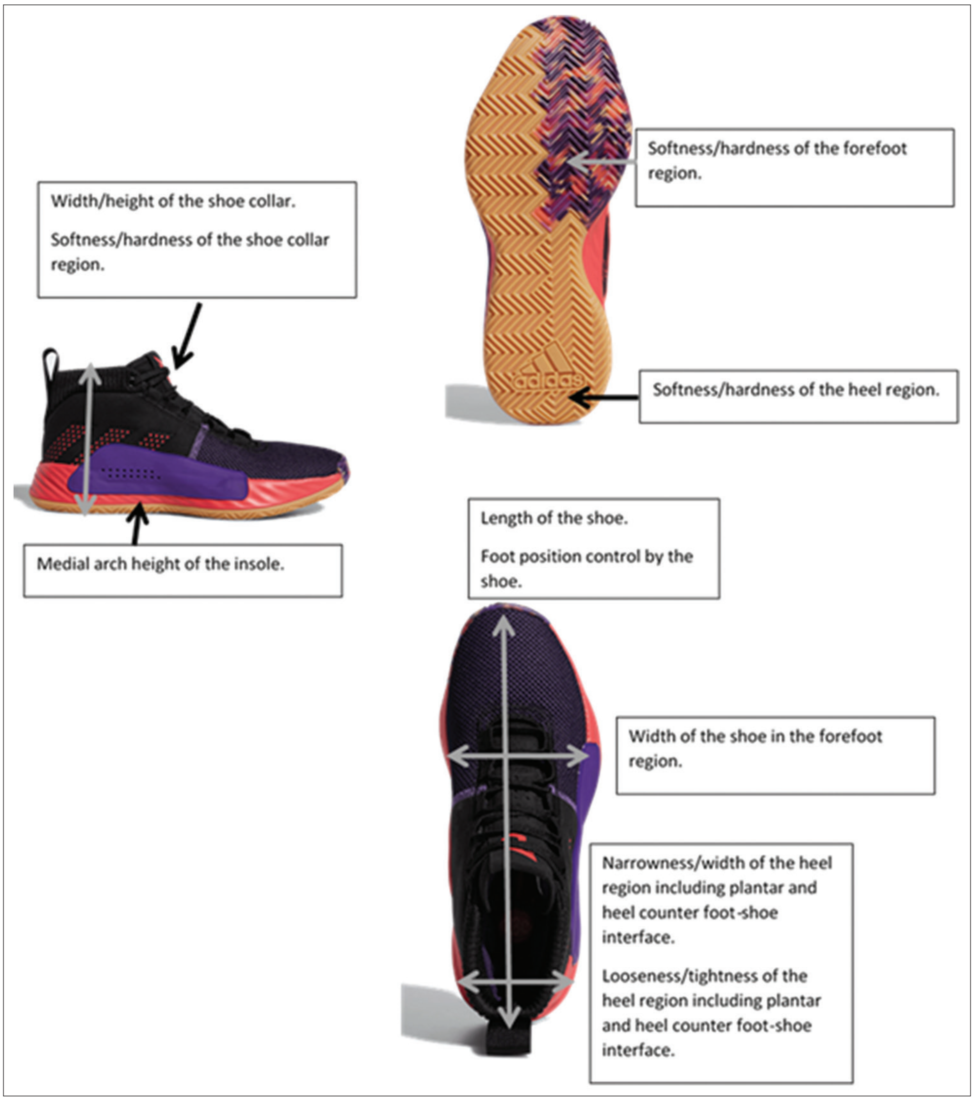
Medial-lateral control
Not comfortable at all — Most comfortable condition imaginable

Overall comfort
Not comfortable at all — Most comfortable condition imaginable

Fit:

	1	2	3	4	5	6	7
Shoe length	too narrow			perfect fit			too wide
Heel region	too narrow			perfect fit			too wide
Forefoot width	too narrow			perfect fit			too wide
Collar	too narrow			perfect fit			too wide

Appendix A. The 110 mm VAS and Likert scale used for student-athlete assessment of comfort and fit



Appendix B. Definition and description provided to each student-athlete on how to evaluate each pair of shoes