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Biomechanics Analysis of Basketball Shooting via OpenPose Motion Capture System

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ABSTRACT

In basketball, it is crucial to understand the optimal shooting pattern for each individual in terms of gender and shooting distances from the basket. However, incorporating biomechanics shooting analysis quantitatively into the learning process is not preferable. Hence, the purpose of this study is to determine the quantitative aspect of basketball shooting for biomechanics analysis using the OpenPose motion capture system. This marker-less motion capture system generated the biomechanical parameter data subjected to a significant difference test for shooting performance. A total of four players – two males and two females, divided into two levels (intermediate and novice) performed ten continuous jump shots from two different shooting distances (4.57 m and 6.40 m) from the basket. Each individual's biomechanical parameters were tested in a statistical or independent t test to determine which significant parameter has a measurable difference in shooting performance. When the effects of different body angles on missed to scored baskets were compared, only the right elbow angle (intermediate female player), the right shoulder angle (novice male player) and the left hip angle (intermediate female player and novice male player) showed a significant difference ($p < 0.05$) towards shooting performance. In the comparison of the velocity of right upper limb key points, only the velocity of the right shoulder (intermediate male player) showed a significant difference ($p < 0.05$) toward shooting performance. In conclusion, the findings of this study suggest that shooting analysis should be done quantitatively to demonstrate a more profound and clear understanding of biomechanics when considering an improvement in shooting performance.

1. Introduction

Basketball is well known as a sport with high dynamic movement, in which Csataljay *et al.,* [1,2] also agree that the team players have to perform shots from several distances to the basket. Beyond that, the ability to shoot an effective shot in the sport of basketball is crucial to a player's success.

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The ability to shoot a successful shot provides the following scoring advantages to a player: (a) accuracy, (b) speed, and (c) the possibility of releasing the ball from several distances from the basket [3]. However, up until now, it is a skill that depends only mostly in qualitative aspects, as related to the player's posture and approach time to get a prefect shot. Instead, in this field of training, quantitative aspects are the least recognized. It is different from another aspect, as it requires extra time and human resource (coaching) for this particular skill. It requires equipment in large scale for recording the repetition of shooting training if there is no on-scene human resource (coaching) available.

The shooting techniques of different basketball players seem similar, although the differences are sufficiently large to the point that each player can be considered to have a unique shooting style [4]. These biomechanics of shooting are usually their own movement patterns of shooting they are comfortable with. However, not all shooting modes are correct. It can be observed that novice players are more variability in movement patterns of shooting than expert players [5] due to their playing experience in this sport. This event usually requires some time for novice players to develop appropriate movement pattern if they need to learn by experience and coaching from time to time.

In the basketball sport, despite the universal characteristics of the jump shooting phases, researchers have identified individual difference in the movement patterns between players [6]. For example, there may be other sources of inter-individual variation, such as genetic factors, different physical characteristics, the presence of diseases, and multiple drug interactions [7]. One factor that affects individual differences during jump shot is the player's experience [8]. This is because each player has its own pattern that is unique performance mode, although some of these movements have been identified as common mode of patterns used by all the players to initiate jump shots [9].

Experience divides the differences between novice players and expert players. This is the individual differences of novice players, which is more obvious than expert players [10]. Expert players who can jump successfully are due to their consistency in selecting the appropriate control parameters and their high degree of consistency in the kinematics [5,10]. However, novice players have limited freedom of joint movement. Their central nervous system is affected by the need for 'control' to reduce the accompanying movements of the shoulder, elbow, and wrist joints during the jump shot release phase [10]. In addition, it is observed that the horizontal shift of the centre of gravity of highly-skilled shooters during shooting is smaller than low-skilled shooters [11,12]. Hence, Okazaki *et al.,* [10] concluded that novice players (a) cannot synchronize the maximum angular velocity of the joint with the instant moment of ball release, (b) their throwing accuracy and height are lower, (c) they show a greater displacement of centre of gravity in the direction of the basket, (d) the trunk has a greater inclination. Compared with experienced players, these are the characteristics of novice players in terms of shooting performance [2,9].

Different basketball players' shooting techniques may seem similar, but the differences are significant enough that each player can be considered to have distinct shooting styles [4]. These shooting biomechanics are usually the player's shooting patterns that they are comfortable with. However, not all shooting patterns are appropriate. Coaches have mostly moderated these skills in qualitative aspects based on their observations of the athletes' biomechanics. This is because anyone, especially non-experts in this sport, cannot easily understand the qualitative aspects other than the coaches themselves. On the other hand, quantitative measurements involve large-scale data acquisition, resulting in more options for further analysis of shooting performance. Thus, quantitative analysis provides more understandable information to non-experts. It also allows the coaches to gain a deeper understanding and assist them in making precise measurements for their athletes to perform well [13].

The purpose of this study is to determine the quantitative aspect of shooting analysis using a marker-less motion capture system. The motion capture system used in this study was OpenPose Demo, an open-source pose estimation application. With the help of this application and the evaluation of MATLAB programming, it is possible to retrieve all the numerical data, such as shooting angles and movement velocity of the human joints. Numerous biomechanical parameters may influence a player's shooting performance, but this study will focus entirely on specific body angles as well as the velocity of the player's right upper limb. These biomechanical parameters will be tested separately with a statistical test, with a significant difference of $p < 0.05$ towards shooting performance.

2. Methodology

2.1 Data Collection and Equipment

The data collection was conducted on four players – two males and two females, each with two different levels of basketball experiences – intermediate and novice, respectively. Every player was required to make ten continuous jump shots from two different shooting distances: 4.57 m and 6.40 m. These movements were then recorded using a smartphone camera (1K conditions, 1920 x 1080 pixels resolution). The travel of the ball from the release hand to the basket, as well as the follow-through of the player's hand and the complete landing on both feet, must be visible. To avoid multiple players from being in the frame simultaneously during motion recording, the research was conducted one player at a time. Then, OpenPose Demo 1.7.0 was used to run with GPU settings set to default.

2.2 Data Acquisition from OpenPose Demo and MATLAB

Data acquisition from OpenPose Demo required a command-line tool, such as Windows PowerShell to operate. The data of each key point's x and y coordination were then evaluated by MATLAB programming to generate the numerical data of body angle and joint velocity. It is noted that a few mathematical methods were considered during the MATLAB programming.

The method for calculating the angle between two vectors was used to determine the body angle. Figure 1 shows the overview of two different vectors, each with different coordinates and an angle between them.

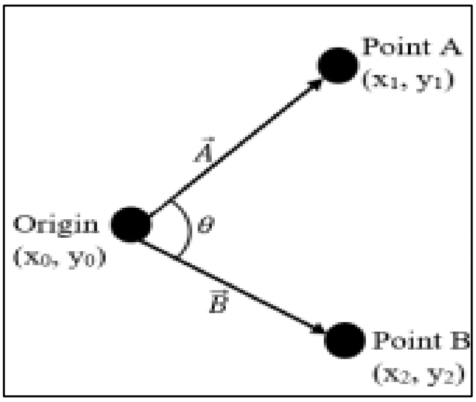


Fig. 1. Vector A from origin to point A and Vector B from origin to point B

The vectors A and B were obtained by using the coordinates of the points from Eq. (1) and Eq. (2) respectively:

$$\vec{A} = \langle (x_1 - x_0), (y_1 - y_0) \rangle = \langle x_A, y_A \rangle \quad (1)$$

$$\vec{B} = \langle (x_2 - x_0), (y_2 - y_0) \rangle = \langle x_B, y_B \rangle \quad (2)$$

After vectors A and B were obtained, the product of vector A and vector B, as well as the magnitude of vector A and vector B were calculated by using Eq. (3), Eq. (4) and Eq. (5) respectively:

$$\vec{A} \cdot \vec{B} = (x_A)(x_B) + (y_A)(y_B) \quad (3)$$

$$Magnitude\ of\ \vec{A} = \|\vec{A}\| = \sqrt{x_A^2 + y_A^2} \quad (4)$$

$$Magnitude\ of\ \vec{B} = \|\vec{B}\| = \sqrt{x_B^2 + y_B^2} \quad (5)$$

Lastly, the angle ϑ was obtained using Eq. (6)

$$\theta = \left(\frac{\vec{A} \cdot \vec{B}}{\|\vec{A}\|\|\vec{B}\|} \right) \quad (6)$$

The displacement data was required for the calculation of the velocity of the key points. In this case, the number of pixels travelled by the key points were used to calculate the displacement. The calculation was done by subtracting the coordinate of the key points on the first frame (x_0, y_0) from the coordinate of the key points of the current frame (x_n, y_n). Eq. (7), Eq. (8) and Eq. (9) were used to convert the displacement measurements from pixels to metres:

$$Metre\ per\ pixel = \frac{Height\ of\ the\ subject\ (m)}{Height\ of\ the\ key\ points\ (pixel)} \quad (7)$$

$$Displacement\ (pixels) = \sqrt{(x_n - x_0)^2 + (y_n - y_0)^2} \quad (8)$$

$$Displacement\ (metre) = \big(Displacement\ (pixels)\big) \times (Metre\ per\ pixel) \quad (9)$$

The displacement of key points in the recorded video was calculated in metres using Eq. (7) and Eq. (8). After obtaining the displacement, the time was calculated before calculating the velocity. Eq. (10) was used to calculate time:

$$Time\ (s) = \frac{Number\ of\ frame}{Frames\ per\ second\ (FPS)} \quad (10)$$

The velocity of the key points over time was then calculated by dividing the displacement of the key points by the time taken. This is shown in Eq. (11):

$$Velocity = \frac{Displacement\ (m)}{Time\ taken\ (s)} \quad (11)$$

2.3 Statistical Analysis

Experimental data from all biomechanical parameters were required to run a statistical test to determine if it had a significant effect on shooting performance. The data was exported as txt files and then imported into a Microsoft Excel file, which displayed the respective human body diagram clearly. All values were expressed as mean ± SD. The normality of distribution using Shapiro-Wilk test in SPSS was done before running any of the statistical test. The independent t test was then used to determine if there was a significant difference between made and missed baskets while considering body angles and right upper limb velocity. The significance was set to $p < 0.05$.

3. Results

3.1 Purpose of Study

The purpose of this study is to determine which biomechanical parameters had a significant effect on made and missed baskets by jump shooting. This paper also aimed to determine the possible link by comparing between biomechanical parameters of players of the same gender with different skill levels and their shooting performance.

3.1.1 Experimental analysis

The experimental analysis obtained body angles in total movement (º) and velocity for all key points after entering the six frames required for data acquisition in OpenPose Demo 1.7.0. The OpenPose Demo application was able to generate twenty-five key points. However, only fourteen were selected; neck, right shoulder, right elbow, right wrist, left shoulder, left elbow, left wrist, middle hip, right hip, right knee, right ankle, left hip, left knee, left ankle. The x and y coordinates from the selected key points were entered into MATLAB for data acquisition to analyse the body angle's biomechanical parameters. This was mainly for the right shoulder, left shoulder, right elbow, left elbow, right hip, left hip, right knee, and left knee. The theory of calculating the angle between two vectors was used in analysing the body angle. Figure 2 illustrates the OpenPose Demo skeleton, and its reference key points are shown in Table 1. The velocity of the key points was calculated using MATLAB in the unit of pixel travelled per second. The angle data and the velocity of key points were presented in mean and standard deviation after the independent t test.

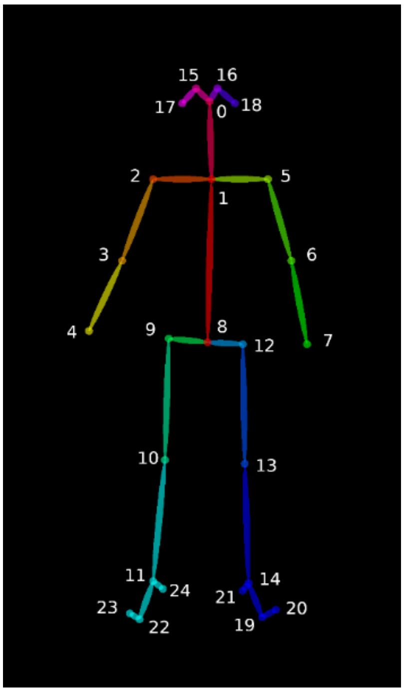
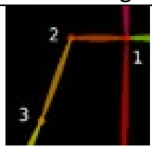
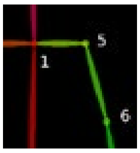
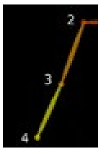
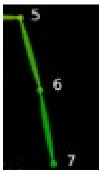
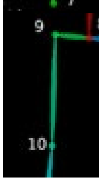
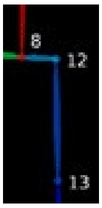
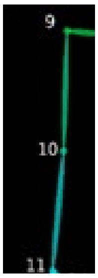


Fig. 2. OpenPose Demo Skeleton

Table 1
Reference key points used from OpenPose Demo skeleton

	Skeleton figure	Reference keypoints
Right shoulder		Origin R-shoulder (2) Linked Neek (1) and R-elbow (3)
Left shoulder		Origin L-shoulder (5) Linked Neek (1) and L-elbow (6)
Right elbow		Origin R-elbow (3) Linked R-shoulder (2) and R-wrist (4)
Left elbow		Origin L-elbow (6) Linked L-shoulder (5) and L-wrist (7)
Right hip		Origin R-hip (9) Linked Mid-hip (8) and R-knee (10)
Left hip		Origin L-hip (12) Linked Mid-hip (8) and L-knee (13)
Right knee		Origin R-knee (10) Linked R-hip (9) and R-ankle (11)
Left knee		Origin L-knee (13) Linked L-hip (12) and L-ankle (14)

3.1.2 Statistical test of significant difference for biomechanical parameters towards shooting performance

The statistical test for biomechanical parameters was done for body angles in total movement (º) for made and missed baskets at a 4.57 m shooting distance. The results indicated that there was a significant difference between made and missed shot for right elbow and left hip in an intermediate female player [t (8) = -2.599, p = 0.032 and t (8) = -2.887, p = 0.020, respectively] and right shoulder and left hip in a novice male player [t (8) = 2.737, p = 0.026 and t (8) = 2.746, p = 0.025, respectively]. These results supported the findings made from previous research which indicated that shoulder angles and hip angles have minor effects on shooting by influencing the player's hand velocity [14,15]. Previous research had also shown that shoulder motion was an important factor to consider for successful shots [16,17]. Furthermore, when the shooting distance was different, the extension angle of the elbow played an important role in providing the required angle for the ball to reach the basket [18,19]. The relationship between body angles in total movement with significant difference between made and missed baskets at a 4.57 m shooting distance is shown in Table 2.

Table 2
Body angles in total movement with significant difference between made and missed baskets in 4.57 *m* shooting distance

Variables	Body angles	Made/missed baskets (*p)*
Intermediate female player	Right elbow	<0.05
	Left hip	<0.05
Novice male player	Right shoulder	<0.05
	Left hip	<0.05

Furthermore, the velocity of the intermediate male player's right shoulder key points showed a significant difference between made and missed baskets [t (8) = -2.362, p = 0.046]. This was due to the shoulder rotation contributing to the vertical component of the ball's releasing velocity, and other joints such as the elbow and the wrist that contributed to the horizontal component of the ball's distance to the basket. The optimal scored shot was a backspin ball shot with the forearm and hand close to the vertical release, which would imply more shoulder rotation [18]. The velocity of the right shoulder with a significant difference between made and missed baskets at a 4.57 m shooting distance is shown in Table 3.

Table 3
Velocity of right shoulder with significant difference between made and missed baskets in 4.57 *m* shooting distance

Variables	Velocity	Made/missed baskets (*p)*
Intermediate male player	Right shoulder	<0.05

However, for the effect of different biomechanical parameters in the jump shot for 6.40 m shooting distance, there were no significant differences in body angles of total movement (º) or velocity of right upper limb key points (right shoulder, right elbow and right wrist) between the made and missed baskets. This was due to the significant differences being greater than the significance set (p > 0.05). The relationship between body angles in total movement and velocity of the right upper limb and made/missed baskets in jump shooting is shown in Table 4.

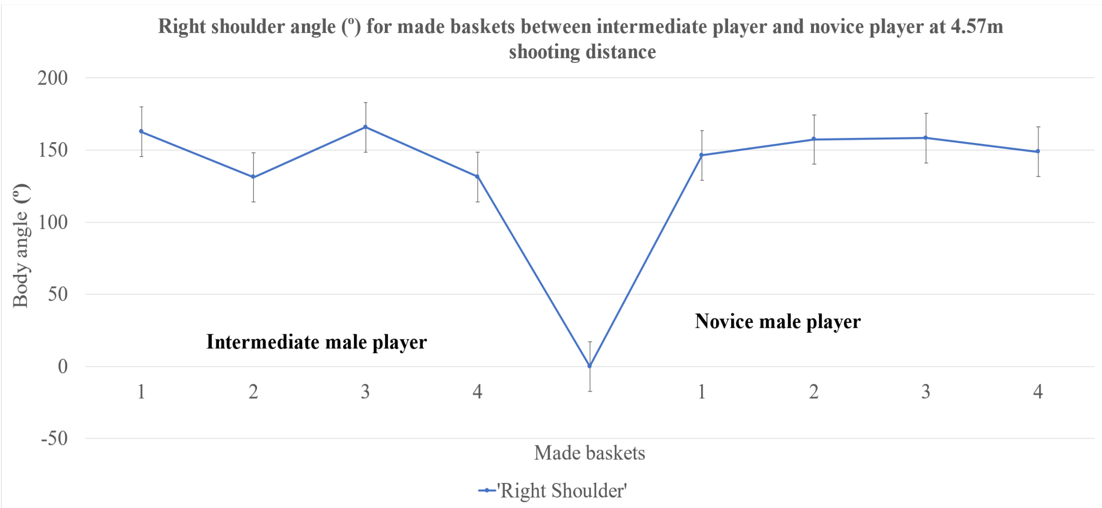
Table 4
Relationship between body angles in total movement and velocity of right upper limb and made/missed baskets in 6.40 m shooting distance

Variables	Body angles	Made/missed baskets (*p)*
Body angles	Right shoulder	>0.05
(All level of players)	Left shoulder	>0.05
	Right elbow	>0.05
	Left elbow	>0.05
	Right hip	>0.05
	Left hip	>0.05
	Right knee	>0.05
	Left knee	>0.05
Velocity	Right shoulder	>0.05
(All level of players)	Right elbow	>0.05
	Right wrist	>0.05

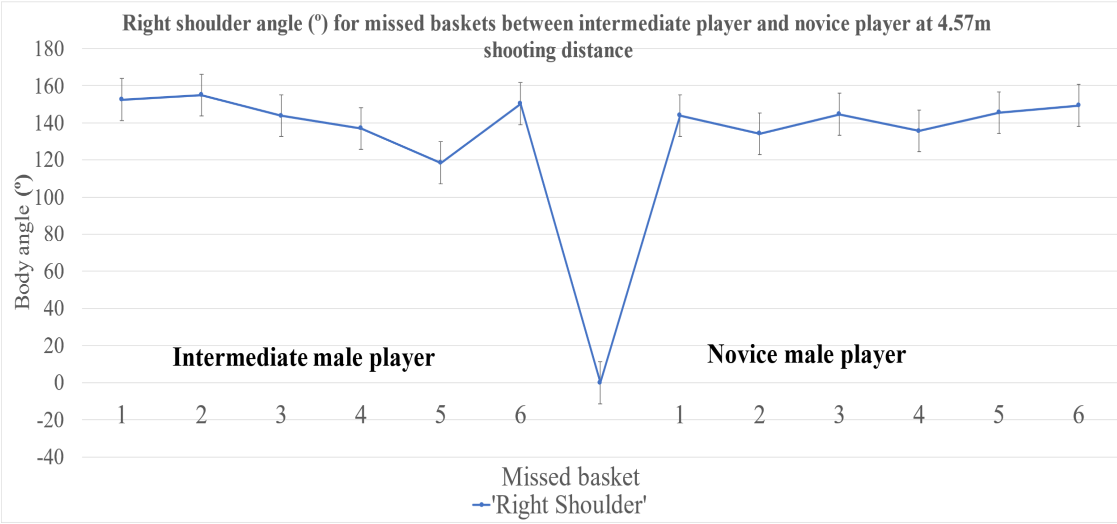
3.1.3 Comparison of different biomechanical parameters with respect of gender in missed and made baskets

Further analysis including biomechanical parameters that showed a significant difference between made and missed shots after the independent *t* test was performed.

Figure 3 compared the intermediate and novice male players' right shoulder angles at a shooting distance of 4.57 m. In the comparison of made baskets, the average right shoulder angle for the intermediate male player was 147.7^o, while the novice male player was 152.7^o. This resulted in a 3.0% difference. When comparing missed baskets, the average right shoulder angle of the intermediate male player was 142.8^o, while the novice male player's average right shoulder angle was 142.2^o. This indicated a 0.4% difference.



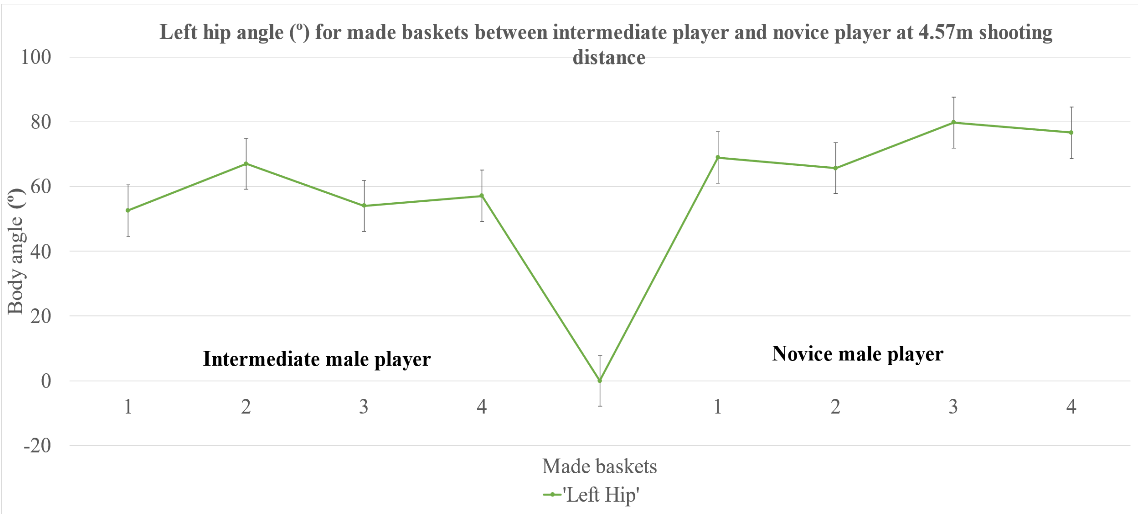
(a)



(b)

Fig. 3. Comparison on (a) Made baskets and (b) Missed baskets for right shoulder angle between intermediate and novice male player

Figure 4 compared the intermediate and novice male players' left hip angles at a shooting distance of 4.57 m. In the comparison of made baskets, the average left hip angle for the intermediate male player was 57.7°, while the novice male player had a left hip angle of 72.7°. This indicated a 26.0% difference. In terms of missed baskets, the average left hip angle of the intermediate male player was 59.3°, while that of the novice male player was 71.6°. This resulted in a 21.0% difference.



(a)

(b)

Fig.4. Comparison on (a) made baskets and (b) missed baskets for left hip angle between intermediate and novice male player

Figure 5 compared the intermediate and novice female players' right elbow angles at a shooting distance of 4.57 m. Because the novice female player failed to make any successful shots, the only comparison that could be made was the missed baskets between the two players. In this case, the intermediate female player's average right elbow angle was 118.8^{o}, while the novice female player's average right elbow angle was 137.6^{o}. This indicated a 16.0% difference.

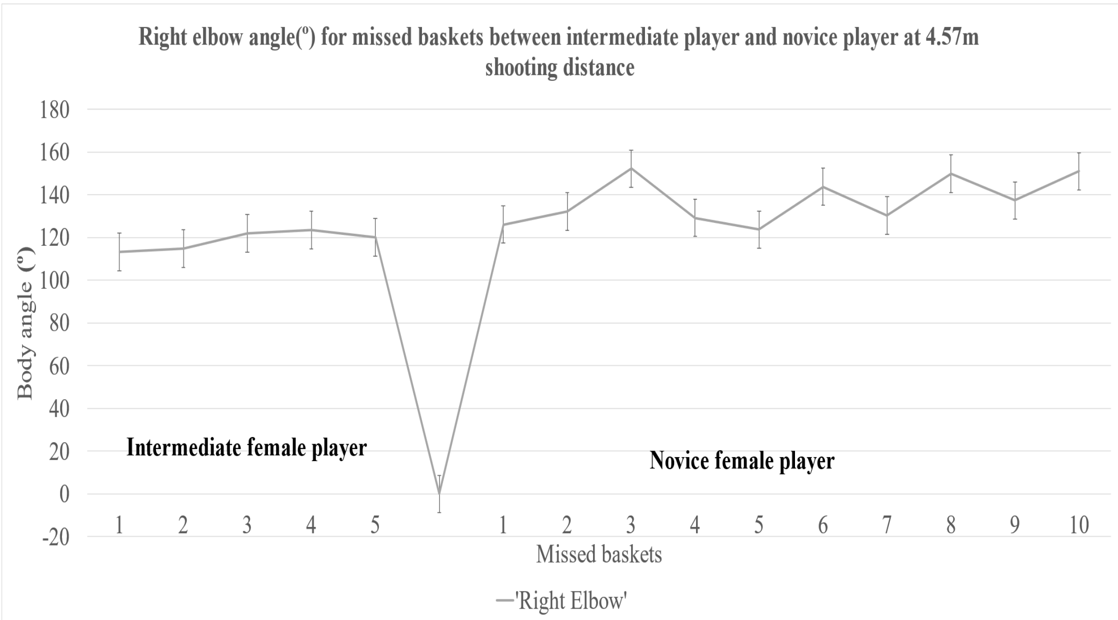


Fig. 5. Comparison on right elbow angle between intermediate and novice female player for missed baskets

Figure 6 compared the intermediate and novice female players' left hip angles at a shooting distance of 4.57 m. As noted previously, because the novice female player could not make any successful shots, the only possible comparison was the missed baskets. The intermediate female player's average left hip angle was 81.3°, while the novice female player's average left hip angle was 77.7°. This indicated a 5.0% difference.

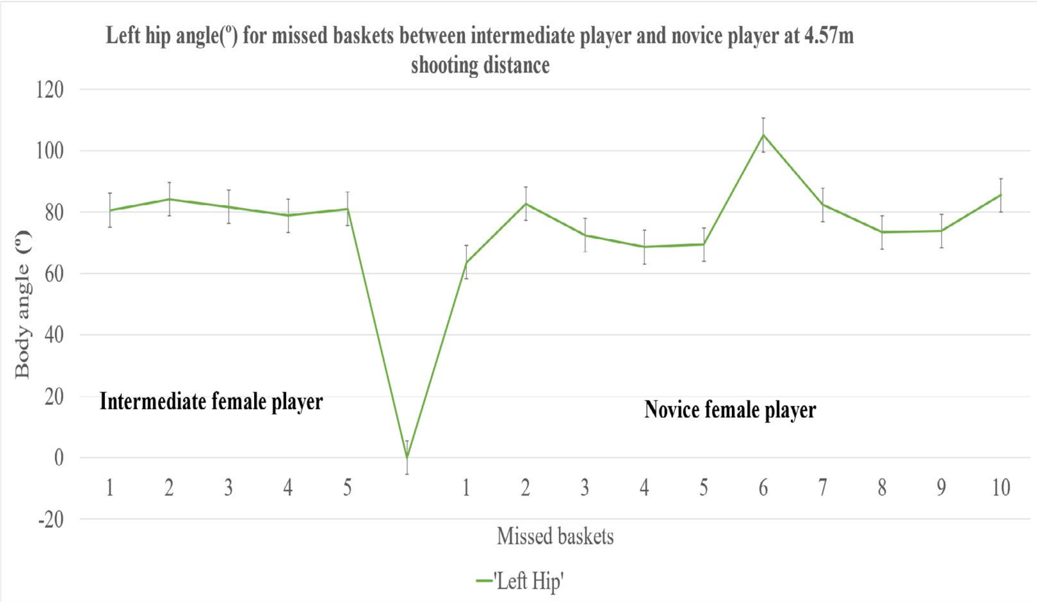
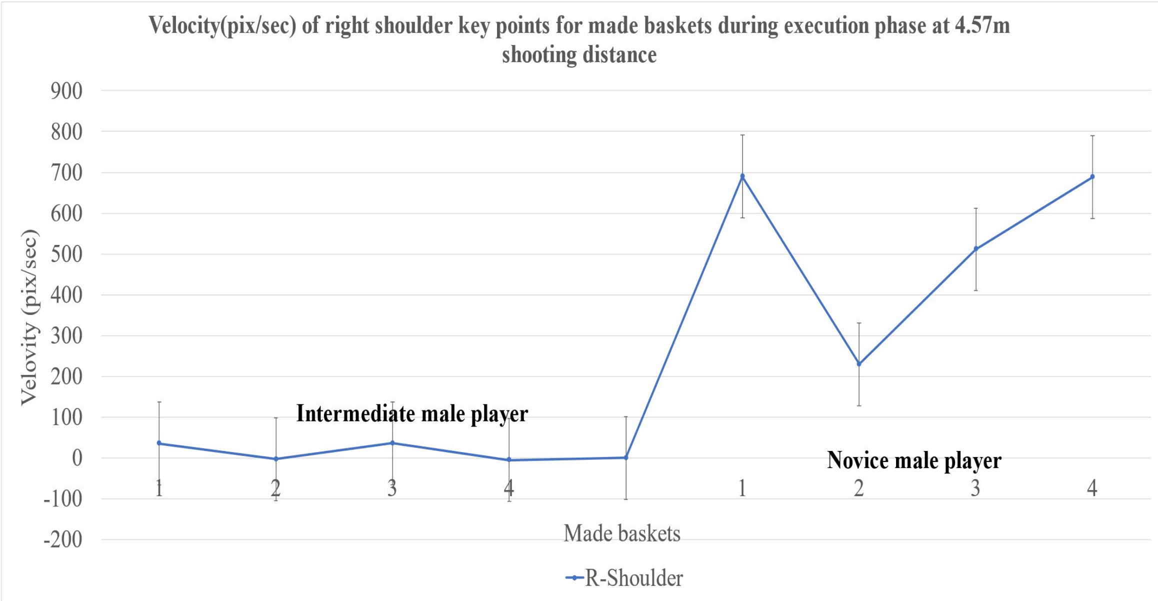
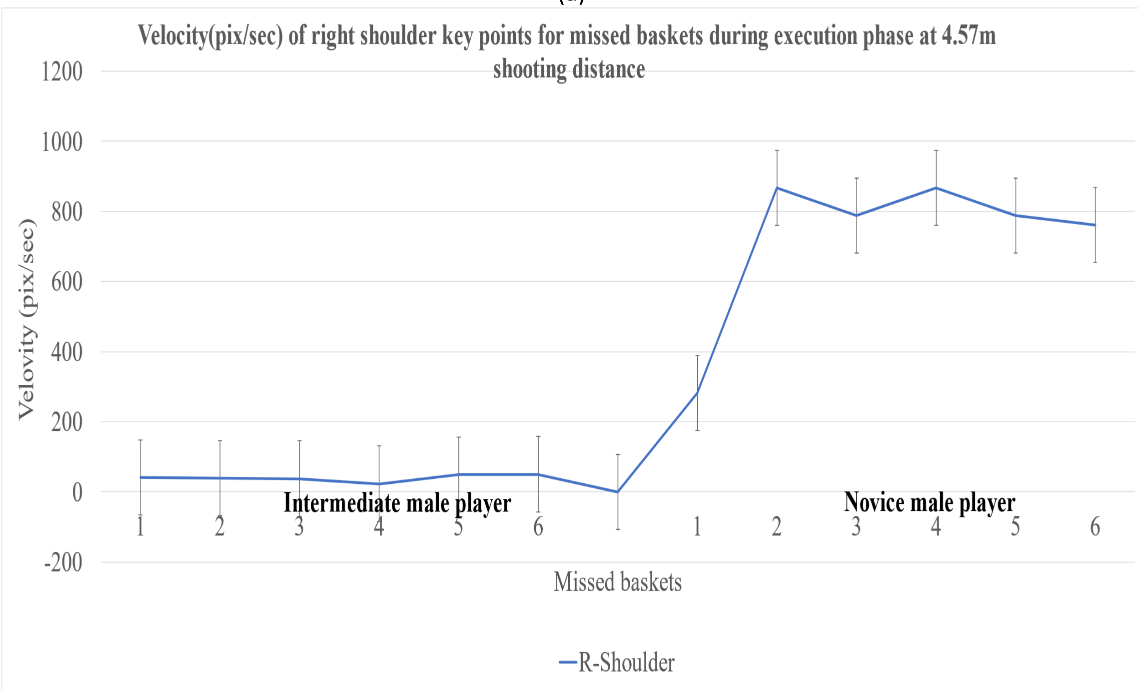


Fig. 6. Comparison on left hip angle between intermediate and novice female player for missed baskets

Figure 7 compared the intermediate and novice male players' right shoulder velocity at a 4.57 m shooting distance. The rest of the variables and biomechanical parameters, on the other hand, showed no significant difference. In the case of made baskets, the average right shoulder velocity for the intermediate male player was 16.0 pix/sec. In comparison, the novice player has an average right shoulder velocity of 529.6 pix/sec. This indicated a 3219% difference in right shoulder velocity between the two players for made baskets. In the case of missed baskets, the average right shoulder velocity for the intermediate male player was 40.4 pix/sec, while that of the novice male player was 725.3 pix/sec. This also indicated a massive difference of 1696.0% in the velocity of the right shoulder between the two players. However, this finding suggested that the novice male player tended to shoot faster than the intermediate male player. Furthermore, this supported findings from previous research which suggested that each basketball player would have different personal techniques to achieve the same goal [5,20].



(a)



(b)

Fig. 7. Comparison on right shoulder velocity between intermediate and novice male player

4. Conclusions

In conclusion, this paper determined the quantitative aspect of shooting analysis using a marker-less motion capture system and the relationship between the biomechanical parameters of body angles and right upper limb velocity with the shooting performance. Although OpenPose Demo 1.7.0 only had 2-dimensional (2D) skeletal recognition, there is still a quantitative biomechanical aspects capable of performing shooting analysis. The MATLAB code-generated numeric datum of body angle and joint velocity have assisted with statistical testing. According to the statistical test (independent *t* test), the biomechanical parameter in body angle of the right elbow and left hip for the intermediate female player, as well as the right shoulder and left hip for novice male player, had a significant difference towards shooting performance at a 4.57 m shooting distance. Furthermore, the statistical test for the velocity of the right upper limb indicated that only the right shoulder of the intermediate male player showed a significant difference in the shooting performance at 4.57 m. These findings indicated a measurable difference that can be used to determine which biomechanical parameters would contribute to shooting performances.

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