Original Article

# The relationship between free-throw accuracy and performance variables in male wheelchair basketball players

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## ABSTRACT

We investigated the relationship between the free-throw accuracy and performance variables among fourteen elite male wheelchair basketball players. Participants performed 20 basketball free-throws. Basketball performance variables were the phases of the pre-shoot routine: (a) time taken, (b) minimum angle when taking the ball back, (c) angle at ball release, (d) angular displacement during the forward arm swing, and (e) angular velocity at ball release on the elbow, shoulder, and hip. A significant negative correlation was observed between the free-throw accuracy and mean pre-shot time, suggesting that participants with a shorter pre-shot time showed a higher free-throw accuracy. In addition, a significant negative correlation was found between the free-throw accuracy and variability of angular velocity of the hip at the time of ball release, indicating that the consistency of hip movement is an important factor in free-throw accuracy. In contrast, there were no relationship between the free-throw accuracy and player's classification point defined as International Wheelchair Basketball Federation, and experience of wheelchair basketball. These data suggest that the routine duration and trunk movement are related to free-throw accuracy in wheelchair basketball.

**Keywords:** Shoot; Athlete; Routine; Kinematics.

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## INTRODUCTION

Wheelchair basketball is played all over the world and is known as a para sport among people with physical disabilities. Athletes with various physical disabilities due to conditions such as spinal cord injury, amputations, post poliomyelitis sequelae, and cerebral palsy join teams to play wheelchair basketball (Santos et al., 2017). All players are assigned based on their trunk movement and stability, which is classified between 1.0 and 4.5 as a regulation of the International Wheelchair Basketball Federation (IWBF). This classification value represents the players "*playing points*" on the court. At any time during a game, the total points of the five players must not exceed 14.

To date, studies have focused on several factors of wheelchair basketball, such as shooting accuracy (Fay et al., 2013), game-related statistics (Valandewijick et al., 2004; Gómez et al., 2014), trunk function (Saltan & Ankarali, 2017; Santos et al., 2017), anthropometry (Cavedon et al., 2015), physical fitness test (Marszałek et al., 2019), and visual control training (Oudejans et al., 2012). In addition, several studies examined kinematic data on free-throw shooting in wheelchair basketball (Goosey-Tolfrey et al., 2002; Malone et al., 2002; Numome et al., 2002; Schwark et al., 2004; Eltz et al., 2015; Hanks & Oliver, 2018). Free-throw shooting skill and accuracy are important for all wheelchair basketball players as well as regular basketball players, irrespective of age, sex, position, and playing points. The free-throw shooting differs from other shots, such as 2-point, and 3-point shots, because players can throw with no pressure from opponents. However, free-throw shooting requires different techniques in wheelchair basketball player, compared with regular basketball players, since wheelchair basketball players shoot from a seated position to the same rim height. Therefore, scientific evidence may be useful to improve their performance. In previous studies, for example, Malone and colleagues (2002) showed that players with low points tended to release the ball from a lower height, with a greater velocity and release angle. Schwark and colleagues (2004) reported the optimal speed and angle of release of the ball for the free-throw in wheelchair basketball. However, after a thorough literature search, factors affecting the free-throw accuracy in wheelchair basketball remain unclear.

The present study focused on three factors based on previous findings in regular basketball. The first was the start timing of each phase in the free-throw motion (i.e., routine timing). Some previous studies in regular basketball showed the importance of the pre-shot routine (Gayton et al., 1989; Lonsdale & Tam, 2008; Ogawa et al., 2019). However, no studies have examined the relationship between the free-throw accuracy and start timing of each phase during the routine in wheelchair basketball. The second was kinematics of the elbow, shoulder, and upper torso joints during the free-throw motion. Previous studies in regular basketball players recorded the kinematics of the lower limbs during free-throws (Mullineaux & Uhl, 2010; Khlifa et al., 2013; Ogawa et al., 2019). Wheelchair basketball players can use only the power of their upper limbs and trunk for shooting, and not that of the lower limbs. An understanding of the characteristics of kinematics of the free-throw in wheelchair basketball is important. The third factor was the variability in the angle and timing for each joint in the free-throw motion. A previous study showed that regular basketball players with a smaller variability of angular displacement of the elbow at ball release had a higher free-throw accuracy (Ogawa et al., 2019). We considered that the variability in the angle and timing for each joint was also related to free-throw accuracy in wheelchair basketball. Focusing on these factors, we investigated the relationship between the free-throw accuracy and performance variables among fourteen elite male wheelchair basketball players. We hypothesized that wheelchair basketball players with higher accuracy would show different routine timing and kinematics and less variability relative to those with lower accuracy.

## MATERIALS AND METHODS

### *Participants*

Fourteen male participants (mean age: 26.9 years, range: 18-36 years) participated in the present study. The thirteen participants were right-handed and one participant was left-handed. All participants had competed in an international event in the last three years. The characteristics of each participant are listed in Table 1. All participants had previously received an official homologation of their functional classification levels according to the IWBF regulations. In the present study, the player classification ranged from 1.0 to 4.0. This study was approved by the Ethical Committee of Nara Women's University (Approval Number: 17-17). Experiments were conducted in accordance with the Declaration of Helsinki. All participants gave their informed consent to participate in the study.

Table 1. The characteristics of each participant.

| Subject | Age | Experience (yr) | Classification point | Free-throw score |
|---|---|---|---|---|
| F | 22 | 12 | 1 | 39 |
| A | 27 | 10 | 1 | 52 |
| G | 20 | 6 | 1.5 | 37 |
| C | 25 | 7 | 1.5 | 41 |
| B | 29 | 6 | 1.5 | 44 |
| I | 31 | 10.5 | 2 | 46 |
| J | 31 | 13 | 2 | 48 |
| H | 33 | 9 | 2 | 50 |
| D | 24 | 4 | 2 | 52 |
| E | 36 | 14.5 | 2.5 | 26 |
| K | 18 | 6 | 2.5 | 45 |
| N | 25 | 10.5 | 3 | 54 |
| M | 27 | 7 | 3.5 | 46 |
| L | 29 | 9 | 4 | 43 |

### *Measures*

Participants performed 20 basketball free-throws at the basket while remaining behind a free-throw line (diameter: 0.45 m, length: 3.05 m), following the regulations of the international wheelchair basketball federation. The experiment was conducted in a national training centre with a regulation-size court. Participants were asked to shoot at the usual timing after the flashing of a light, which was set at the right in front of participants on the floor. A practice session with several trials was performed before recordings in order for participants to warm up and become familiar with the conditions. All participants used the same basketball. The free-throw shooting movement was recorded at 300 Hz using two high-speed video cameras (EX-F1, CASIO COMPUTER Co., Ltd., Tokyo, Japan). Camera 1 was set approximately 4 m to the right of the right-handed player's shooting position (Figure 1A). Camera 2 was placed approximately 9 m to the right perpendicular to the plane of ball motion in order to record the ball trajectory from ball release into the basket (Figure 1B). Four reflective markers were attached to the body of each participant: the right hand (styloid process of the ulna), right shoulder (acromion), right elbow (lateral epicondyle of the humerus), and right hip (upper greater trochanter). For the left-handed player, these settings were reversed. The markers were attached to participants using double-sided adhesive tape prior to data collection. Data were digitized and analysed using Frame Dias V (DKH Co., Tokyo, Japan). Two-dimensional coordinates were obtained by Direct Linear Transformation (DLT). The X-axis was directed from the free-throw line to the basket goal, and the Z-axis indicated a vertical upward direction (Figure 1A). The time period for the analysis of the free-throw movement was from the onset of the light flashing to ball release. The timing of ball release was defined as the first frame when the ball was not in contact with the player's hand.

***Analysis***

Regarding performance data, the participants earned 0 to 3 points for each shot according to the following criteria: 3 points for swishing the shot (not hitting any part of the rim), 2 points for making the shot after hitting the rim, 1 point for hitting the rim but not making the shot, and 0 points for completely missing the rim or hitting the backboard first. Based on this evaluation, the total score of 20 trials (i.e., 60 points in total) was defined as the free-throw score (Table 1). Then, we analysed the bivariate correlation between the free-throw score and player's classification points, and experience of wheelchair basketball. This analysis was performed after checking data for a normal distribution using the Kolmogorov-Smirnov test. If a normal distribution was confirmed, Pearson's correlation was calculated. If non-parametric data were found, Spearman's correlation was analysed.

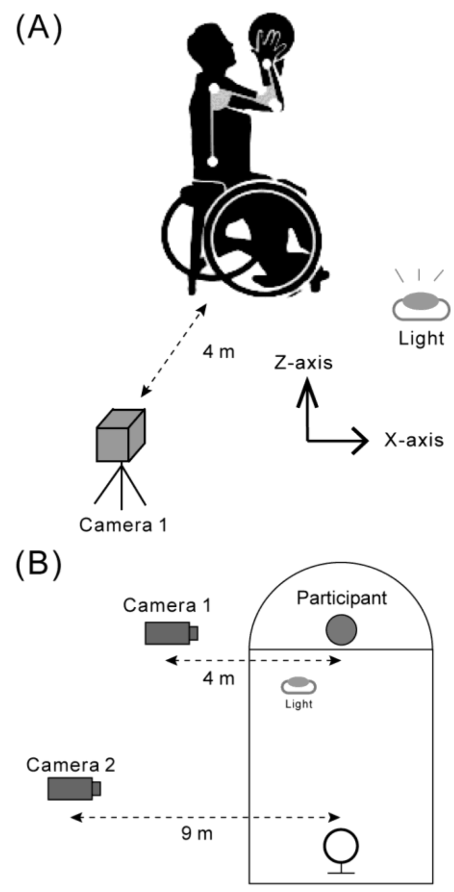


Figure 1: (A) Experimental set-up for recording the time period and kinematic data using camera 1. (B) Experimental set-up for recording the ball trajectory from ball release into the basket goal using camera 2.

The time period and variability for the pre-shot routine were calculated from the onset of the light flashing to the minimum angle during the backswing (Phase 1) and shooting (ball release) (Phase 2). We also defined the whole movement duration (Phase 3) from the onset of the light flashing to ball release (Figure 2). In data for each phase, final values were the average of 20 throws. Variability among 20 throws was the standard deviation (SD). Intraclass correlation coefficients (ICCs) were calculated to show the reliability of each phase.

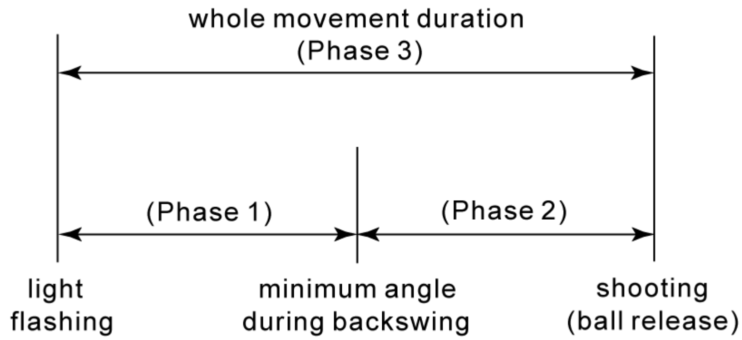


Figure 2: Schema for the time course of the pre-shoot.

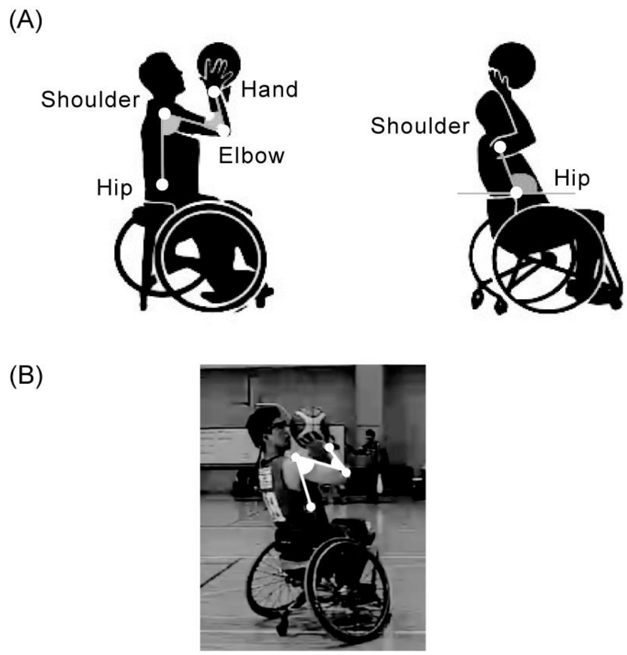


Figure 3: (A) Left: Markers attached to the hand, elbow, shoulder, and hip. Right: Definition of the hip angles. (B) An example of the actual frame in a representative participant.

Regarding kinematic data, the minimum angle of the elbow during the backswing was defined as the smallest angle during the backswing. The angles at ball release for the elbow, shoulder, and hip were defined as the angle of the frame at ball release. The angle of the hip was defined as the angle from the horizontal line to shoulder (Figure 3). Angular displacement of the elbow during the forward swing was defined as the angle of the range from the minimum angle during the backswing to the angle at ball release. Angular velocity at ball release was calculated based on the values for the angular displacement and time period. Final values were the average of 20 throws. Movement variability among 20 throws with these angles and timings was calculated as SDs. ICCs were calculated to demonstrate the time period for the pre-shot routine. ICCs were also calculated to show the reliability of kinematic data for the minimum angle during the backswing, the angle at ball release, angular displacement during the forward swing, and angular velocity at ball release in the elbow, shoulder, and hip angle. We analysed the bivariate correlation between the free-throw accuracy and data on the time period and variability of the pre-shot routine, and kinematic data. After extracting significant factors correlated with the free-throw accuracy, a stepwise multiple regression analysis was conducted to examine the relative contribution of variables to the explained variance of free-throw accuracy. All analyses were performed with SPSS Advanced Models 22.0 for Windows. Significance was set at $p < .05$.

## RESULTS

Regarding the characteristics of each participant, we analysed the relationship between the free-throw scores and player's classification points, and experience of wheelchair basketball. However, there were no significant correlations among them (Table 1).

### *Performance data*

ICCs for 'Phase 1', 'Phase 2', and 'Phase 3' are listed in Supplementary Table 1. As a result of examining the inter-trial reliability, high ICCs were observed in 'Phase 1' and 'Phase 3'.

We analysed the bivariate correlative relationship between the free-throw score and mean time period, and between the free-throw score and variabilities of the time period at each phase. Significant negative correlations for mean time period were observed in Phase 1 ($r = -0.726$, $p < .01$) and Phase 3 ($r = -0.725$, $p < .01$) (Figure 4).

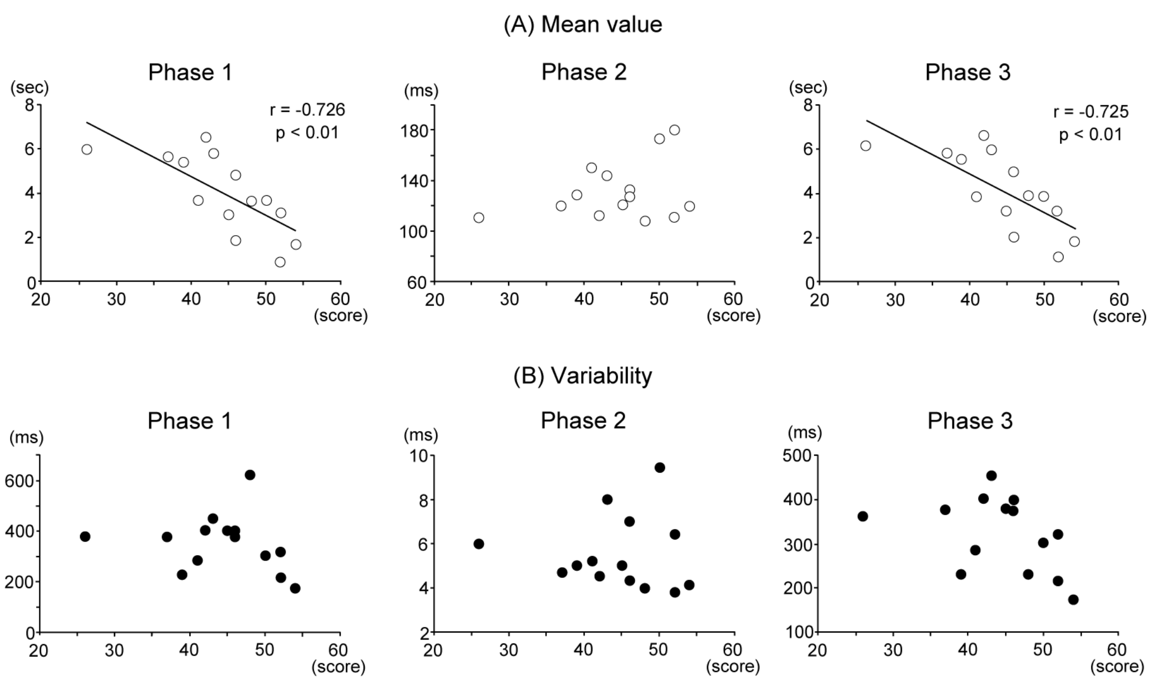


Figure 4: (A) Correlation between mean values and the free-throw score in each phase of the pre-shoot. (B) Correlation between variabilities and the free-throw score in each phase of the pre-shoot.

### *Kinematic data*

The ICCs of each variable for the elbow, shoulder, and hip are listed in Supplementary Table 1. Table 2 shows a correlation matrix for performance variables among the elbow, shoulder, and hip. Significant correlations were observed between the minimum angle of the elbow during the backswing and angle at ball release of the shoulder (r = 0.702, $p < .01$), and angular velocities at ball release of the elbow (r = -0.537, $p < .05$) and hip (r = -0.631, $p < .05$). Significant correlations were observed between the angles at ball release of the elbow and shoulder (r = 0.713, $p < .01$). Significant correlations were observed between the angle at ball release of the shoulder and angular velocities at ball release of the elbow (r = -0.556, $p < .05$) and shoulder (r = -0.662, $p < .05$). Significant correlations were observed between the angle at ball release of the hip and angular velocities at ball release of the shoulder (r = -0.647, $p < .05$) and hip (r = -0.763, $p < .01$). Significant correlations in the angular velocity at ball release were noted between the elbow and shoulder (r = 0.804, $p < .01$), elbow and hip (r = 0.647, $p < .05$), and shoulder and hip (r = 0.670, $p < .05$).

Data on values and variabilities at each angle and angular velocity are listed in Table 3. We analysed the bivariate correlative relationship between the free-throw score and mean value, and variabilities in each angle and angular velocity. There was a significant correlation between the free-throw accuracy and variability of angular velocity at ball release of the hip (r = -0.540, $p < .05$). No significant correlations were noted in other performance variables.

Table 2. Correlation matrix for performance variables among elbow, shoulder, and hip.

| | | **(A)** | **(B)** | | | **(C)** | **(D)** | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Elbow** | **Elbow** | **Shoulder** | **Hip** | **Elbow** | **Elbow** | **Shoulder** | **Hip** |
| (A) | Elbow | | 0.528 | 0.702 ** | 0.232 | -0.094 | -0.537 * | -0.485 | -0.631 * |
| (B) | Elbow | | | 0.713 ** | 0.170 | 0.074 | -0.367 | -0.337 | -0.317 |
| | Shoulder | | | | 0.355 | -0.046 | -0.556 * | -0.662 * | -0.471 |
| | Hip | | | | | 0.336 | -0.417 | -0.647 * | -0.763 ** |
| (C) | Elbow | | | | | | -0.159 | 0.012 | -0.345 |
| (D) | Elbow | | | | | | | 0.804 ** | 0.647 * |
| | Shoulder | | | | | | | | 0.670 * |
| | Hip | | | | | | | | |

*(A): Minimum angle during backswing, (B): Angle at ball release, (C): Angular displacement during forward swing, (D): Angular velocity at ball release. *p < .05; **p < .01.*

Table 3. Mean values and variabilities of performance variables for the elbow, shoulder, and hip, and the r value of correlations with the free-throw score.

| | **Value** | | **Variability** | |
|---|---|---|---|---|
| **Minimum angle during backswing (°)** | | | | |
| Elbow | 50 (14) | r = -0.349 | 1.4 (0.4) | r = -0.266 |
| **Angle at ball release (°)** | | | | |
| Elbow | 136 (9) | r = -0.009 | 3.6 (1.1) | r = -0.382 |
| Shoulder | 106 (11) | r = -0.437 | 2.2 (0.8) | r = -0.430 |
| Hip | 105 (5) | r = -0.031 | 1.4 (0.6) | r = -0.207 |
| **Angular displacement during forward swing (°)** | | | | |
| Elbow | 77 (22) | r = -0.169 | 3.3 (0.7) | r = -0.500 |
| **Angular velocity at ball release (°/s)** | | | | |
| Elbow | 923 (109) | r = -0.018 | 45 (14) | r = -0.280 |
| Shoulder | 437 (140) | r = -0.320 | 26 (11) | r = -0.436 |
| Hip | 94 (48) | r = -0.064 | 14 (6) | r = -0.540 * |

*Note: Data are expressed as mean (SD). *p < .05.*

Then, we performed stepwise multiple regression analysis to identify predictors of free-throw scores. We used data on mean values of the time period in Phases 1 and 3, and variability of angular velocity at ball release of the hip. In the first analysis for predictors, because VIF in the meantime period of Phase 1 was greater than 10, we deleted these data for stepwise multiple regression analysis. As the results, the mean time period in Phase 3 ($\beta$ = -0.725) was identified as a significant predictor of free-throw scores in wheelchair basketball ($R$ = 0.725, $R^2$ = 0.525).

## DISCUSSION

The present study investigated relationships between the free-throw accuracy of wheelchair basketball and performance variables among elite male wheelchair basketball players. No significant correlations were observed between the free-throw scores and player's classification points, and experience of wheelchair basketball, suggesting that classification points and experience of wheelchair basketball are not directly associated with the free-throw accuracy. Malone and colleagues (2000) also reported that the free-throw accuracy was not related to a player's classification in the Sixth Gold Cup World Wheelchair Basketball Championship held in 1994, being consistent with our findings. However, we found that some important factors in kinematic data during the pre-shot routine were related to the free-throw accuracy.

It is known that the free-throw accuracy is associated with elbow-wrist angle-angle coordination variability in multi-joint kinematics before ball release in regular basketball (Mullineaux & Uhl, 2010). Our correlation matrix showed some significant correlations among the elbow, shoulder, and hip (Table 2). For example, the angular velocity at ball release was significantly correlated among the elbow, shoulder, and hip, indicating the significance of coordination in the upper limbs and trunk at ball release.

The time period from the onset of the light flashing to the minimum angle during the backswing (Phase 1) and whole movement duration (Phase 3) were significantly correlated with the free-throw scores (Figure 4). On the other hand, the time period from the minimum angle during the backswing to ball release (Phase 2) was not correlated. These findings were not consistent with a standard motor control principle, "*the speed-accuracy trade-off*". Common sense tell us that as we move more rapidly, we become more inaccurate in terms of the goal we are trying to achieve (Schmidt, & Lee, 2004). Our findings suggest that the players with a higher free-throw accuracy started preparation for the shoot-set earlier and showed a more coordinated and rapid motion sequence than those with a lower accuracy. The free-throw conditions in the present study clearly differed from shooting during real games, but based on our findings, a quick tempo may be related to the free-throw accuracy. A similar result was observed among collegiate regular female basketball players (Ogawa et al., 2019). Taking these findings into consideration, irrespective of wheelchair or regular basketball, national or collegiate levels and male or female, basketball players with a higher free-throw accuracy might have already prepared for shooting before the light flashes or the ball is passed from the referee.

Then, we have to consider why a short routine duration rather than a long routine duration plays an important role in improving free-throw accuracy. We hypothesized that brain activity associated with an externally triggered movement (i.e., short routine duration) is appropriate and stable for aiming objects. In contrast, a long routine duration might be related to internally triggered movement, found in several sport motions such as the golf swing, weightlifting, and darts. This hypothesis may be supported by the findings of previous studies using neuroimaging and neurophysiological methods. Previous studies reported differences in human brain activity between externally and internally triggered movements (Deiber et al., 1999; Jenkins et al., 2000; Sakamoto et al., 2009). For example, Jenkins and colleagues (2000) using positron emission tomography

 

(PET) showed that activated brain regions were larger in internally triggered movement than in externally triggered movement, including the basal ganglia, dorsolateral prefrontal cortex, insula, and posterior parietal cortex. This notion may be related to the difficulty of motor control in internally triggered movement.

Another factor affecting the free-throw accuracy was the variability of angular velocity at ball release of the hip (Table 3). This indicates that players with a smaller variability of angular velocity of the hip at ball release had a higher free-throw accuracy. Santos and colleagues (2017) showed that the trunk strength and balance differed among various classes of wheelchair basketball players, while Saltan & Ankarali (2017) reported no relationship between classification levels and trunk stabilization or sitting balance. These studies focused on the role of trunk stabilization in functional classification levels for wheelchair basketball players. Thus, this is the first study to show that the consistency of hip movement may be an important factor associated with the free-throw accuracy rather than trunk stabilization in wheelchair basketball. This may be supported by the findings of Hanks & Oliver (2018). They recorded surface electromyography from the lumbopelvic-hip complex, lower extremity, and upper extremity musculature during the free-throw, and showed greater activation of latissimus dorsi among players with than without disabilities during the free-throw. They suggested that wheelchair basketball players with disabilities used the lumbopelvic-hip complex.

Using factors related to the free-throw accuracy, we also performed stepwise multiple regression analysis to identify predictors of free-throw scores and found that the mean time period in Phase 3 ($\beta = -0.725$) was a significant predictor of free-throw scores in wheelchair basketball. Based on this result, we should emphasize the importance of a short routine period for wheelchair basketball players in order to improve the free-throw accuracy.

As limitations of the present study, since we used 2D coordinates with DLT, data on the free-throw were available on a sagittal plane. Therefore, if data based on 3D coordinates are analysed, further findings may be elucidated. Moreover, the present study focused on the data from elite wheelchair basketball players. Thus, if we compare the data with amateur players, new findings may be obtained. We did not analyse the data showing a difference between successful and unsuccessful trials, since participants performed only 20 free-throws. For example, participants achieved a shooting accuracy of 90% after only 2 unsuccessful trials and 18 successful trials. In addition, some factors, such as a participant's condition and luck, may be included in data on only 20 free-throws. Therefore, many shooting trials are needed to clarify more detailed mechanisms affecting the free-throw accuracy. Finally, the more detailed knowledge would be obtained if we can examine the data during actual games. Further studies are needed to clarify these issues.

## CONCLUSIONS

The present study investigated the relationship between the free-throw accuracy and performance variables in elite male wheelchair basketball players. Our findings suggest that wheelchair basketball players with a high accuracy show a shorter routine timing and more consistent hip movement than players with a low accuracy. The present results may help wheelchair basketball players to improve their performance and be applicable to actual practice.

## AUTHOR CONTRIBUTIONS

M.N., M.F., and H.N. conception and design of the research; All authors performed experiments; S.S., M.O, and H.N. analysed the data; M.N., M.F., and H.N. interpreted the results of the experiments; S.S., and H.N. prepared figures; S.S., M.N., M.F., and H.N. drafted the manuscript.

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**DISCLOSURE STATEMENT**

No potential conflict of interest was reported by the authors.

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## ANEXE I

Supplementary Table 1. 95% confidence intervals (CI) for each performance variable.

| | |
|---|---|
| **Performance** | |
| Phase 1 | 0.887 (0.792-0.958) |
| Phase 2 | 0.198 (0.079-0.487) |
| Phase 3 | 0.961 (0.921-0.987) |
| **Minimum angle during backswing** | |
| Elbow | 0.990 (0.979-0.997) |
| **Angle at ball release** | |
| Elbow | 0.875 (0.767-0.956) |
| Shoulder | 0.967 (0.932-0.990) |
| Hip | 0.912 (0.824-0.972) |
| **Angular displacement during forward swing** | |
| Elbow | 0.925 (0.823-0.975) |
| **Angular velocity at ball release** | |
| Elbow | 0.858 (0.740-0.950) |
| Shoulder | 0.966 (0.930-0.990) |
| Hip | 0.888 (0.783-0.964) |