

Influence of difference in view of goal on shooting performance and muscle synergy

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Published online: January 31, 20223

(Accepted for publication January 15, 2023)

DOI:10.7752/jpes.2023.01013

Abstract:

Problem Statement: Muscle synergy differs between scored and missed shots during free-throw shooting that is, four synergies during a scored shot and three synergies during a missed shot. The synergy of a missed shot functions similarly to the synthesis of two synergies during a scored shot to transfer energy from the lower to the upper limb. However, whether or not a difference in the view of goal influences muscle synergy remains unclear. Therefore, this study investigated synergy during basketball free-throw shooting and compared the synergies of five positions. **Approach:** Six male collegiate basketball players (age: 20.2 ± 0.8 years; height: 1.74 ± 0.03 m; weight: 63.7 ± 4.5 kg; duration of playing basketball: 9.7 ± 2.3 years). The distance from all shooting positions to the goal was the same as the free-throw distance. The study used a wireless electromyographic system to measure 16 muscle activities during free-throw shooting and analyzed three success and failure shots in each position to extract the synergies using non-negative matrix factorization. **Results:** The difference between the success and failure shots was the number of synergies. The study extracted four and three synergies during the success and missed shots, respectively, in each position. Additionally, the synergies remained the same despite the different positions. **Conclusion:** These results are in agreement with those of a previous study and suggested that the view of the goal did not influence the factor of success or failure shots if the distance from the shooting positions to the goal remained the same. Thus, understanding not only the evaluation of success or failure of a shot but also its potentially located muscle synergy can aid in the improvement of shooting performance.

Key Words: non-negative matrix factorization, basketball, free-throw shooting, electromyography

Introduction

Human physical behavior is the result of the coordinated activity of various muscles, and this muscle coordination is represented by synergy. This activity is divided into synergy (to indicate which muscle is working in coordination with other muscles) and activity pattern (to determine when synergy is used in the movement). Using synergy analysis, scholars report that synergy differs according to the level of competition; therefore, identifying synergy is essential for improving sports performance (Cheung et al., 2020; Kristiansen et al., 2016; Matsunaga et al., 2017a, 2018; Matsuura et al., 2020; Sawers et al. 2015; Vaz et al., 2016). Additionally, a longitudinal investigation of muscle synergy for the same players demonstrates that synergy changes with the improvement in competitiveness (Matsunaga, 2022a). Muscle synergy is also used in the field of disability prevention and rehabilitation. For instance, fatigue changes muscle synergies and causes disfunction or injuries (Matsunaga et al., 2017b, 2019, 2021a, 2021b; Matsuura et al., 2022; Sato et al., 2019; Smale et al., 2016). These findings suggest that evaluating muscle synergy is a useful method for sports education.

In target sports, the constant repetition of the same action is crucial for improving performance. Button et al. (2003) conducted a biomechanical study on basketball and reports that the shooting movement becomes increasingly constant with the increase in the level of competition. As a result, maintaining a constant movement of the ball is equally important (Nakano et al. 2020). Additionally, synergy during free-throw shooting differs between success and failure shots (Matsunaga et al., 2022b). According to these studies, the lack of constant movement influences performance decline.

Alternatively, Keetch et al. (2008) propose different success rates for shots taken at the same distance and from different angles. The finding suggests that the view of the goal influences physical control; thus, one can infer that the view of the goal also influences sports performance. Considering that when it comes to swish shots should have similar success rates regardless of the angle from which they are taken, given that the same movements are performed. However, Keetch et al. (2008) only investigate shooting success rates and overlook physical behavior.

Therefore, the current study focuses on visibility and compares synergies during free-throw shooting from the same distance but different shooting positions. It hypothesized that a change in visibility or shooting position will result in a decrease in shooting success rate and a change in synergy.

Materials & methods

Subjects

The study recruited six male collegiate basketball players (mean $\pm$ standard deviation [SD]: age: 20.2 ± 0.8 years; height: 1.74 ± 0.03 m; weight: 63.7 ± 4.5 kg; duration of playing basketball: 9.7 ± 2.3 years). All participants were right-handed. The ethics committee of our university approved the study (2018-18b). All subjects read and signed an informed consent prior to participation.

Data measurement

Before the measurement, we defined the 0° position as the shooting position on the right side of the goal, where the ball moves parallel to the backboard. The 90° position was in front of the goal and intended for a normal free-throw shot, and the 45° , 135° , and 180° positions were defined using the same method. The distance from the shooting position to the basket goal for each position was set at the same distance.

After warm-up, the participants performed free-throw shooting in the 90° position. The measurement in the 90° position ended when we measured the data at least five times for the scored and missed shots. The participants then performed free-throw shooting from four positions. The measurement of each position was performed randomly and ended when we measured the data at least five times for the scored and missed shots. The activity of 16 muscles was recorded using an electromyography (EMG) system (SS-EMGW-HMAG, SPORTS SENSING Co., Ltd, Japan) at 1,000 Hz. Prior to attaching the EMG system, the skin was disinfected with alcohol. The EMG system was attached to the right side of the pectoralis major, deltoid anterior fiber, serratus anterior, latissimus dorsi, triceps brachii, biceps brachii, extensor carpi radialis, flexor carpi ulnaris, rectus abdominis, external oblique, internal oblique/transversus abdominis, lumbar erector spinae, gluteus maximus, rectus femoris, biceps femoris, and gastrocnemius muscles, as adapted from Perotto (2014). The study used a high-speed camera (LUMIX DC-GH5S, Panasonic Co., Japan) to confirm the timing of the start and finish of the free-throw shooting motion. The measuring frequency of the high-speed camera was 200 Hz and was synchronized with the EMG system.

Data analysis

The study analyzed three scored and missed free-throw shots in each position. Data were randomly selected from among the those without measurement error or signal noise. The timing of the start and finish of the free-throw shooting was defined as the *beginning of the knee extension movement* and *immediately after the ball release*, respectively. A custom MATLAB (MATLAB R2020, MathWorks, Inc., USA) code was used to analyze EMG data. First, raw data were low-pass filtered at 20 Hz and full-wave rectified. They were then interpolated to 201 time points. Next, we extracted muscle synergies (Lee et al., 2001; Hug, 2011; Hug et al., 2010; Torres-Oviedo et al., 2006) and compared synergies (Cheung et al., 2012) using the following Formula:

$$\mathbf{E} = \mathbf{WC} + \mathbf{e}; \text{ Formula 1}$$

$$\min_{\mathbf{W}, \mathbf{C}} \|\mathbf{E} - \mathbf{WC}\|_{\text{FRO}}, \text{ Formula 2}$$

where $\mathbf{E}$ is the initial matrix, $\mathbf{W}$ represents muscle synergy, $\mathbf{C}$ denotes the activation pattern, and $\mathbf{e}$ stands for the residual error matrix. Formula 2 indicates that matrix “ $\mathbf{e}$,” which is calculated using Formula 1, reaches a minimum. The subscript FRO refers to the Frobenius norm. We used the updated rules of Lee and Seung (1999). Global and local variance (VAF) values were then calculated. Global VAF was calculated on the basis of the findings of previous studies:

$$\text{Global VAF} = \left(1 - \frac{\sum_{i=1}^p \sum_{j=1}^p (\mathbf{e}_{i,j})^2}{\sum_{i=1}^p \sum_{j=1}^p (\mathbf{E}_{i,j})^2}\right) \times 100 [\%]; \text{ Formula 3}$$

$$\text{Local VAF} [m] = \left(1 - \frac{\sum_{j=1}^p (\mathbf{e}_{m,j})^2}{\sum_{j=1}^p (\mathbf{E}_{m,j})^2}\right) \times 100 [\%], \text{ Formula 4}$$

where i increases from 1 to 16, and j increases from 1 to 201. We selected the least number of synergies that filled for global VAF $> 90\%$ and local VAF $> 75\%$.

To compare $\mathbf{W}$, the study calculated for the scalar product (SP) as follows:

$$\text{SP} = \frac{\mathbf{W}_\alpha \cdot \mathbf{W}_\beta}{\|\mathbf{W}_\alpha\| \|\mathbf{W}_\beta\|} \quad (0 \leq \text{SP} \leq 1), \text{ Formula 5}$$

where $\mathbf{W}_\alpha$ and $\mathbf{W}_\beta$ denote arbitrary $\mathbf{W}$. The SP for the use of cosine coefficients can assess the similarity of $\mathbf{W}$. We defined synergy as similar if the SP was > 0.75 . We calculated the SP between the 90° and other positions. These formulas were adapted from Matsunaga et al. (2022b).

Statistical analysis

The study employed SPSS Statistics v.25 (IBM Japan Co., Ltd., Japan) for statistical analyses. Wilcoxon’s t-test was used to compare the success rate of free-throw shooting between the 90° and other positions. The α -level was set at 0.05.

Results

Table 1 presents the success rate of free-throw shooting. The results indicate no significant difference in the success rate of free-throw shooting from other positions compared with the 90° position. Tables 2 and 3 demonstrate the global and local VAFs of each position. Based on these findings, the study extracted four and three synergies from the scored and missed shots, respectively, in each position.

Table 1. Comparison of the success rate of free-throw shooting between the 90° and other positions.

position	median success		p	
	rate (%)	compared to 90°	effect size	
0°	51.4	0.462	0.30	
45°	61.3	0.343	0.39	
90°	55.0	-	-	
135°	58.6	1.000	0.00	
180°	45.0	0.343	0.39	

Table 2. Relationship between number of synergies and global VAF (%)

		position	number of synergies during set shot			
			n=1	n=2	n=3	n=4
Global VAF (%)	scored shot	0°	69.2 ± 18.2	77.3 ± 18.9	90.1 ± 18.6	93.8 ± 9.5
		45°	83.2 ± 16.6	88.9 ± 17.7	88.8 ± 17.6	98.1 ± 1.0
		90°	81.4 ± 18.7	86.3 ± 16.4	95.4 ± 7.6	98.3 ± 1.6
		135°	75.0 ± 8.1	85.3 ± 10.8	96.7 ± 1.6	97.5 ± 2.0
		180°	78.5 ± 17.5	86.6 ± 15.8	95.6 ± 4.7	98.1 ± 1.8
	missed shot	0°	62.0 ± 31.2	80.1 ± 9.9	94.4 ± 5.3	
		45°	81.2 ± 8.3	84.5 ± 10.7	96.5 ± 3.4	
		90°	87.2 ± 12.1	90.6 ± 11.8	94.6 ± 5.4	
		135°	66.0 ± 25.5	86.9 ± 8.9	93.8 ± 6.6	
		180°	68.8 ± 21.7	80.8 ± 20.1	92.0 ± 9.7	

Table 3. Relationship between number of synergies and local VAF (%)

PM: pectoralis major, Del: deltoid, SA: serratus anterior, LD: latissimus dorsi, TB: triceps brachii, BB: biceps brachii, ECR: extensor carpi radialis, FCU: flexor carpi ulnaris, RA: rectus abdominis, EO: external oblique, IO/TrA: internal oblique/transversus abdominis, ES: erector spinae, Gmax: gluteus maximus, RF: rectus femoris, BF: biceps femoris, and GC: gastrocnemius

	position	number of synergies	PM	Del	SA	TB	BB	LD	ECR	FCU	RA	EO	IO/TrA	ES	Gmax	RF	BF	GC
Local VAF (%)	scored shot	0°	n=3	82.1	98.0	93.8	93.5	89.7	72.6	96.9	94.9	82.6	86.6	91.0	85.8	84.0	64.8	88.2
		0°	n=4	78.1	90.3	88.2	89.6	82.0	80.9	89.6	90.1	83.3	79.4	85.9	78.6	82.5	77.7	84.4
		45°	n=3	88.3	98.5	93.6	95.7	92.7	86.9	94.1	96.2	91.3	86.6	89.8	85.6	85.1	83.8	85.7
		45°	n=4	90.2	98.1	94.8	96.4	93.5	87.2	93.7	96.7	93.7	91.4	93.6	88.0	88.5	92.5	93.3
		90°	n=3	74.5	96.1	89.9	96.1	81.7	87.7	91.9	90.2	75.7	84.1	94.5	83.6	73.4	82.6	89.4
		90°	n=4	84.1	95.5	95.0	89.2	90.9	91.1	94.1	95.2	86.4	89.0	93.4	84.9	76.4	85.5	94.1
		135°	n=3	89.0	95.1	92.2	96.1	73.3	88.1	93.3	96.3	82.5	92.2	77.2	79.8	73.8	89.8	92.8
		135°	n=4	91.9	94.5	95.1	95.0	75.5	87.9	86.7	96.4	82.2	94.3	81.3	84.6	83.9	88.5	91.4
	missed shot	180°	n=3	77.7	97.7	93.8	96.8	92.7	74.3	95.1	94.6	87.8	90.9	92.5	63.0	79.6	80.9	90.2
		180°	n=4	78.6	96.4	89.7	93.3	91.6	78.7	92.0	93.4	83.2	88.0	89.5	77.4	74.9	87.8	91.4
		0°	n=2	64.8	97.6	93.1	95.1	76.8	67.5	89.1	87.9	92.6	87.6	78.3	70.7	77.4	65.5	74.7
		0°	n=3	82.3	97.5	95.7	96.9	91.3	79.6	94.9	92.9	93.8	92.3	92.9	90.4	83.4	84.0	93.2
		45°	n=2	85.3	97.0	88.6	94.3	90.0	79.8	88.0	94.3	77.3	63.3	90.3	71.5	75.6	71.4	69.0
		45°	n=3	87.4	98.0	96.6	96.1	91.2	88.4	92.7	95.1	89.1	79.6	91.8	79.3	87.9	89.4	90.6
		90°	n=2	77.1	96.6	91.3	95.2	80.8	87.9	85.7	91.7	74.1	82.2	83.9	77.8	71.9	89.4	91.7
		90°	n=3	78.1	95.5	91.6	95.3	89.7	88.8	93.8	91.6	76.2	81.9	90.7	83.9	87.5	87.8	88.2
	135°	n=2	75.3	96.4	90.0	90.9	89.8	83.3	80.9	93.4	75.7	82.9	77.1	66.3	82.4	68.4	81.6	77.0
		135°	n=3	87.2	97.3	95.1	93.2	90.6	90.3	83.0	96.5	86.2	85.7	85.7	78.8	89.5	86.1	86.7
		180°	n=2	78.9	93.3	87.6	92.9	75.2	76.6	83.7	90.8	77.6	78.3	82.1	60.6	75.6	69.0	79.8
		180°	n=3	85.3	96.9	90.9	97.2	89.3	84.2	93.7	98.4	80.0	82.4	89.7	87.6	83.0	88.7	87.4

Table 4. Comparison of SP in the scored shot between the 90° and other positions.

The synergy was the same as that in the 90° position when the SP was >0.75.

		position	#1	#2	#3	#4
SP	scored shot	0°	0.847	0.857	0.931	0.974
		45°	0.836	0.750	0.857	0.989
		135°	0.909	0.563	0.913	0.989
		180°	0.679	0.804	0.763	0.991
	missed shot	0°	0.791	0.821	0.975	
		45°	0.936	0.771	0.986	
		135°	0.810	0.715	0.983	
		180°	0.781	0.822	0.985	

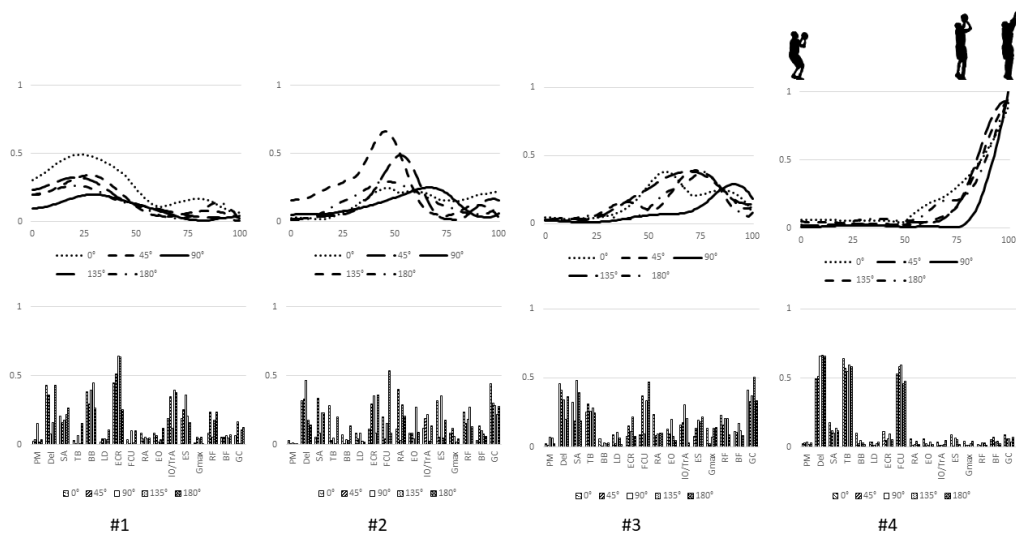


Fig. 1 Extracted synergies during the scored shots in each position

Upper row: activation pattern of synergies; lower row: extracted synergies

PM: pectoralis major, Del: deltoid, SA: serratus anterior, LD: latissimus dorsi, TB: triceps brachii, BB: biceps brachii, ECR: extensor carpi radialis, FCU: flexor carpi ulnaris, RA: rectus abdominis, EO: external oblique, IO/TrA: internal oblique/transversus abdominis, ES: erector spinae, Gmax: gluteus maximus, RF: rectus femoris, BF: biceps femoris, GC: gastrocnemius

Fig. 1 illustrates the synergies of the scored shots in each position, and Fig. 2 depicts the synergies of the missed shots in each position. Additionally, Table 4 displays the SP between the 90° and other positions, the majority of which indicated values that exceed 0.75.

Discussion

The study compared muscle synergies among the five shooting positions during free-throw shooting. The result demonstrated that synergies were similar due to the shooting positions.

First, the success rate of each position was similar compared with the 90° position. This result contradicts the study hypothesis. The 0° and 180° positions are more difficult than the other positions, because there is not the backboard behind. Keetch et al. (2008) reported that the success rate of free-throw shooting from several positions, excluding the 90° position, was lower than that at the 90° position. Despite this finding, the study found no difference in the shooting success rate, which indicates that the shooters could shoot a certain distance in all positions.

Second, the number of synergies during the free-throw shooting differed due to success or failure. This result was the same as that recorded by Matsunaga et al. (2022). The #1 had the function of shoulder flexion to set the ball, #2 was intended for lower limb extension, #3 denoted upper limb extension, and #4 stood for palmar flexion to release the ball during successful free-throw shooting. Next, #1 and #3 of the failed free-throw shooting performed the same functions as those of #1 and #4 of the successful free-throw shooting. However, #2 of the failed free-throw shooting represented lower and upper limb extensions at the exact timing. Matsunaga et al. (2022) reported that this error in timing influences the success or failure of free-throw shooting.

Third, the majority of SP exceeded 0.75 among the 90° and other positions; therefore, the majority of synergies were the same regardless of position. In other words, free-throw shooting remained the same from all positions. This result also rejected the study hypothesis. Keetch et al. (2008) reported that the success rate of free-throw shooting decreased from a different distances or angles compared with the free-throw. Therefore, the view of the goal may influence certain types of shooting. However, the current study found that synergies were similar among the positions. Thus, it suggested that the view of the goal does not influence the shooting movement at the shooting distance. Additionally, the view of the goal did not influence the success or failure of free-throw shooting.

This study has its limitations. It assessed only synergy; however, not only by synergy but also body movement (Miller, 2002; Button et al., 2003), aerodynamics, and biomechanics between the ball and hoop (Hung et al., 2004; Kartiko et al., 2019; Mullineaux et al., 2010) influence the success or failure of free-throw shooting. Particularly, data were determined only by whether free-throw shooting was a success or failure. Thus, the study inferred that eliminating the biomechanical influence between the ball and hoop would have been possible if the swish shot alone was also analyzed. For these reasons, future research should consider several factors. Conversely, few studies examined the synergy between the view of the goal and sports performance. Therefore, the current study is a valuable one on the basis of this perspective.

Conclusions

This study investigated and compared muscle synergies during free-throw shooting from several shooting positions and different views of the goal. The results implied that the synergies remained the same across positions if the distance from the shooting positions to the goal was the same. Alternatively, the number of synergies differed between the scored and missed shots in each position; the study extracted four and three synergies for the scored and missed shots, respectively. Among them, the synergy of the missed shot functioned similarly to the synthesis of two synergies of the scored shot to transfer energy from the lower to the upper limb. Moreover, the success rate of shooting remained the same across positions. These findings indicated that motor control through synergy influenced the success or failure of free-throw shooting instead of the view of the goal. Therefore, understanding not only the success or failure of a shot but also its potentially located muscle synergy will aid in the improvement of shooting performance.

Data Availability

No. The data will be used in a future study.

Conflicts of Interest

The authors declare no conflicts of interest.

Funding

This work was supported by JSPS KAKENHI Grant Number 19K20078.

Author Contribution

Material preparation and data collection and analysis were performed by Naoto Matsunaga and Tomoki Oshikawa. The first draft of the manuscript was written by Naoto Matsunaga, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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