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Intra-individual Movement Variability within the 5 m Water Polo Shot

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Abstract

The purpose of this study was to explore movement variability of throwing arm and ball release parameters during the water polo shot and to compare variability between successful (hit) and unsuccessful (miss) outcomes. Seven injury free, sub-elite, females completed 10 trials of the 5 m water polo penalty shot. Intra-individual coefficient of variation percentage (CV%) values were calculated for elbow and wrist angular displacement, wrist linear velocity and ball release parameters (height, angle and velocity). Coordination variability (elbow/wrist angular displacement) was calculated as the CV% of the mean cross-correlation coefficient. Elbow and wrist displacement variability decreased to 80% of throwing time then increased toward release. Wrist linear velocity variability reduced toward release. Individual CV% values ranged between 1.6 – 23.5% (all trials), 0.4 – 20.6% (hit) and 0.4 – 27.1% (miss). Ball release height and velocity variability were low (< 12%; all trials) while release angle variability was high (>27%; all trials). Cross-correlation results were inconclusive. Roles of the elbow and wrist in production of stable ball release height and velocity and control of the highly variable release angle in the water polo shot are discussed and suggested for further study. Optimal levels of variability warrant future investigation.

Keywords: coordination, cross-correlation, variance, coefficient of variation, movement outcome

Word Count: 1996

Introduction

Historically, movement variability has been described as evidence of random noise within the neuromuscular system. It was hypothesized this ‘noise’ may result in an inability to convey consistent directions to working muscle and seen as deleterious.[1] However, functional roles including facilitating consistent movement outcomes and adapting to changeable task and environmental constraints are now being attributed to movement variability.[2] The phenomena has been investigated within numerous applied settings including table tennis,[3] tennis,[4,5] golf,[6] basketball[7,8] and baseball.[9] Movement variability within water polo remains un-researched. Yet, the lack of a fixed base of support and constant perturbation of the environment by defenders within the sport may provide a unique setting to assess movement variability.

In addition to quanitifcation, interactions between variability and other elements including movement outcome are beginning to be investigated. Significant differences have been demonstrated between elements of basketball shooting, including coordination variability, for successful and unsuccessful shots.[8] Understanding differences in movement variability relative to movement outcome may improve understanding of any functional limit to movement variability. For example, a threshold of variability may exist which is functional, facilitating performance and even reducing injury risk, but beyond which these elements are compromised.[2,7] Therefore, the purpose of this study was to explore variability of throwing arm kinematics, coordination and ball release parameters during the 5 m water polo shot. Furthermore, to describe any interactions between variability and movement outcome.

Methods

Participants

Seven injury-free participants (21.1 ± 2.7 years, 168.8 ± 5.4 cm, 76.0 ± 9.0 kg) were recruited from the highest grade of recreational women's water polo in Sydney (Australia). While sub-elite, it was expected the skill level in this sample would adequately suit the exploratory nature of this study, providing guidance for further research. The project was approved by the University human research ethics committee and all participants provided informed consent.

Data collection

Data from the 5 m penalty (rule WP 23.4)[10] were collected in an indoor laboratory. To maintain ecological validity participants threw from within a commercial water tank (1.90 m diameter; 1.60 m high, water level 1.55 m) providing sufficient volume to perform the action unimpeded. Following a self-directed warm up (arm ergometer) participants practiced the task until indicating they were confident with the protocol. Participants performed 10 trials aiming at a 25 cm^2 target painted centrally on an imitation water polo goal mounted at water level.

Kinematic data were captured using six Vicon optoelectronic cameras (250 Hz) and Vicon Nexus software using the fourteen marker, unilateral, "Vicon Upper Limb Model" (Vicon, Oxford Metrics, Oxford, UK). Two-dimensional (2D) to three-dimensional (3D) reconstruction and calibration error was less than 0.35 root mean square pixel distance. To reduce false marker reconstructions caused by splash, participants were asked to begin the movement with their throwing arm above the water line. Ball release parameters were quantified from 2D videography (250 Hz; Fastcam PCI R2; Photron USA, San Diego, CA, USA) and shot outcome was qualitatively evaluated from separate 2D footage (50 Hz; Sony

Handycam, Sony, Tokyo, Japan). A shot was considered ‘successful’ if half or more of the ball impacted within the target.

Data Analyses

Elbow and wrist flexion/extension angles were calculated from motion capture data. Wrist linear velocity (2D) was taken from anterior-posterior (y-axis) displacement of the lateral wrist marker on the throwing hand. Time series were normalized from first movement of the wrist toward the target (0%) to the point of maximal wrist linear velocity (100%). Ball release was manually digitized (one researcher) using Peak Motus (Vicon, Oxford Metrics, Oxford, UK) and release height (above water level), angle (to the horizontal) and 2D resultant velocity (one frame post release) calculated. High intra-tester digitizing reliability was determined using; (1) intraclass correlation (ICC) 3.1 [r(27) = .998, $p < .001$], (2) dependent t-tests [t(28) = 0.662, $p = .514$], (3) effect sizes[11] (0.006) and (4) mean differences (as a percentage) ± 95% limits of agreement[12] (0.026 ± 2.0%).

[Table 1 about here]

Following qualitative assessment of the 3D kinematic data, 17 trials were excluded based on obscured or incomplete reconstructions. The number of shots analyzed for limb kinematics for each condition are contained in Table 1. Ball release footage of all 10 trials were available for all participants and were submitted for analysis. Intra-individual coefficient of variation percentage (CV%; $SD/\bar{X} \times 100$) values were calculated for all participants for each accuracy condition. To profile of variability changes across the movement, angular displacement and wrist linear velocity CV% were calculated at 20, 40, 60, 80 and 100% of movement time. Individual values were collapsed to produce group mean variability values. Intra-individual ball release CV% for each condition and variable were calculated. Cross correlation of elbow and wrist angular displacement at periodic lags of ±10% of throwing time was performed as a measure of coordination between the two variables. Coordination variability was calculated as the CV% of the mean peak correlation coefficient. Consistent with the literature, a CV% value of less than 10% was considered to represent low variability across all variables.[12] Due to the exploratory nature of this investigation, and reduced statistical power owing to small sample and trial sizes, the analyses employed no inferential statistics, instead using qualitative comparisons to highlight areas of interest and guide future research.

Results

Group mean elbow and wrist angular displacement at release were 133.7° ± 8.2° and 122.7° ± 20.6° respectively. Elbow displacement group mean variability began low (7.8 – 8.2%) and decreased through 80% of throwing time then increased to higher variability at release (9.4 – 16.4%; Figure 1). Wrist angular displacement variability was low throughout the movement (1.0 – 7.3%) with decreasing values through to 80% of throwing time followed by a slight increase at release (Figure 1). Group mean variability in linear velocity of the wrist began high (21.9 – 29.2%), increased slightly from 20 – 40% then decreased toward release where variability was low (4.7 – 6.0%; Figure 1). Qualitatively, group mean angular displacement appears lower for successful than unsuccessful shots, particularly at release (Figure 1). Alternatively, group mean wrist linear velocity variability was higher for successful shots early in the throw; however, there was little difference between the three conditions near release (Figure 1). The individual behavior of variability relative to shot outcome is illustrated by the sample kinematic plots in Figure 2. Individual variability values ranged between 1.6 – 23.5% (all trials), 0.4 – 20.6% (hit) and 0.4 – 27.1% (miss) for limb kinematic variables. There was no apparent relationship between individual variability and hit/miss ratio. All individual variability patterns reflected groups mean trends presented in Figure 1.

[Figure 1 about here]

[Figure 2 about here]

Group mean ball release velocity, angle and height in the current study were 13.07 ± 1.71 m/s, 5.8° ± 2.7° and 0.59 m ± 0.05 m respectively. Intra-individual variability values for release velocity (1.5 – 6.3%) and height (0.5 – 49.2%) were generally low. Release angle variability (6.5 – 191.1%) was predominantly high (Figure 3). However, as the mean release angle was 5.8° these CV% values should be interpreted with consideration of the measures limitations as the mean approaches zero.[12] Similar to limb kinematic variability, ball release variability appeared lower for successful compared to unsuccessful shots.

[Figure 3 about here]

Cross correlation (Table 2) displayed no clear trends with four participants (1 – 4) having strong correlations between elbow and wrist while three (5 – 7) reported relatively weaker values. Four participants produced their strongest correlations with a positive time lag in the range of 4 – 10% of throwing time, one with neutral lag and one with a negative lag (-2%). Similarly, coordination variability displayed no clear trends across participants.

[Table 2 about here]

Discussion

This study aimed to explore intra-individual variability within 5 m penalty water polo shooting and to compare variability profiles of successful and unsuccessful shots. Variability appeared to reduce throughout the throw with increases near release for joint displacement variables. Apparently lower variability values were observed for successful compared to unsuccessful shots. Coordination analysis produced no clearly identifiable pattern. Group mean ball release velocity was lower than mean values previously reported for male water polo players of 16.5,[13] 19.7,[14] and 25.3 m/s.[15] However, CV% values for ball release velocity (2.1 – 5.4%) were comparable to other values reported for water polo (5.5%)[15] and baseball

(1.78 – 7.27%).[9] Group mean elbow angular displacement at release (122.7° ± 20.6°) was in the lower end of the range of values previously reported (122° - 158°).[14,16-18] Wrist angular displacement at release (133.7° ± 8.2°) was lower than previously reported values for female players 148°.[17] This may be attributed to differences in the skill level of participants and/or the use of maximal wrist linear velocity as the endpoint of the movement in the current study. Another consideration is that participants in this study were asked to begin their shots with their arm elevated above the water. While this is similar to some postures adopted during shooting in open play, it was not the regular starting position for most participants.

The varied inter-participant coordination variability results may stem from several factors. The sample used may be of insufficient size to produce a clear trend in correlation strength or variability. However, similar inter-participant differences have been reported in basketball free throw shooting.[8] Another explanation may be variable skill level. Decreased variability in coordination of the elbow and wrist has been reported for higher skilled participants, also in basketball.[7] While all participants came from the same grade, this competition does not have the same consistency of skill found in higher tiers of competition, particularly Australian national league and international competitions.

The apparent reduction in variability close to the critical point of release warrants additional investigation. Similar phenomena have been previously described for the critical point of impact in sports involving ball striking.[3,4] Variability of ball release height and velocity and wrist linear velocity at release were all low. That elbow and wrist displacement variability was lowest at 80% of movement time followed by an increase at release may suggest a proximal to distal control of the movement, particularly as wrist displacement variability was low and failed to increase to the same magnitude of the elbow. While CV% values for release angle were generally high (≥27.6% for all trials combined), absolute SD values were small (≤3.5°). This could suggest this variable acts as a final, sensitive, determinant of ball trajectory similar to vertical bat and racquet orientation at impact in table tennis[19] and tennis[5] respectively, which are reported as determinants of shot success. This may indicate a dual role for the elbow and wrist during the water polo shot. First, to coordinate early in the throw to produce consistent release height and velocity. Second, to provide final adjustment of release angle in order to produce a successful outcome, resulting in increased variability. This may be further supported by the time lag observed in elbow-wrist coordination which has also been reported in basketball shooting.[7] Further research is required to support this hypothesis.

While elbow and wrist displacement and wrist linear velocity variability increased toward release for all conditions (all, hit, miss) there was a consistent trend for lower variability values in successful than unsuccessful shots (mean 0.7% and 2.1% lower respectively). This trend was also evident within ball release variables. Button et al.[7] suggested that basketball players may employ an optimal ‘bandwidth’ of variability which allows them to adapt to unique task and environmental constraints. That unsuccessful movements were associated with higher levels of movement variability in the present study may provide some evidence that a similar phenomenon exists within water polo. Players may employ variability to adapt to game constraints and produce a successful shot. However, if motor fluctuations exceed an ‘optimal bandwidth’ then the motor system may not be able to correct any errors quickly enough to produce an accurate shot. This hypothesis warrants further examination within water polo, other sports and movement patterns. Furthermore, superior performance in higher skilled participants has been shown to be characterized by decreased movement variability at critical points within a movement.[6,9,19] If higher skilled athletes can produce more successful movement outcomes, it suggests they may be able to operate within functional limits of movement variability more consistently. The interaction between movement variability, skill level, skill acquisition and movement outcome should continue to be investigated to further identify and/or confirm the concept of optimal or functional variability limits within the motor system.

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Figure 1: Mean coefficient of variation percentage patterns for combined (All) successful (Hit) and unsuccessful (Miss) trials for elbow angular displacement, wrist angular displacement and wrist linear velocity

Figure 2: Hit and miss mean (solid) plus and minus one standard deviation (dotted) curves for participants 3 and 7 for joint angular displacement and wrist linear velocity variables

Figure 3: Coefficient of variation percentage values for combined (All) successful (Hit) and unsuccessful (Miss) trials for ball release velocity, release angle and release height

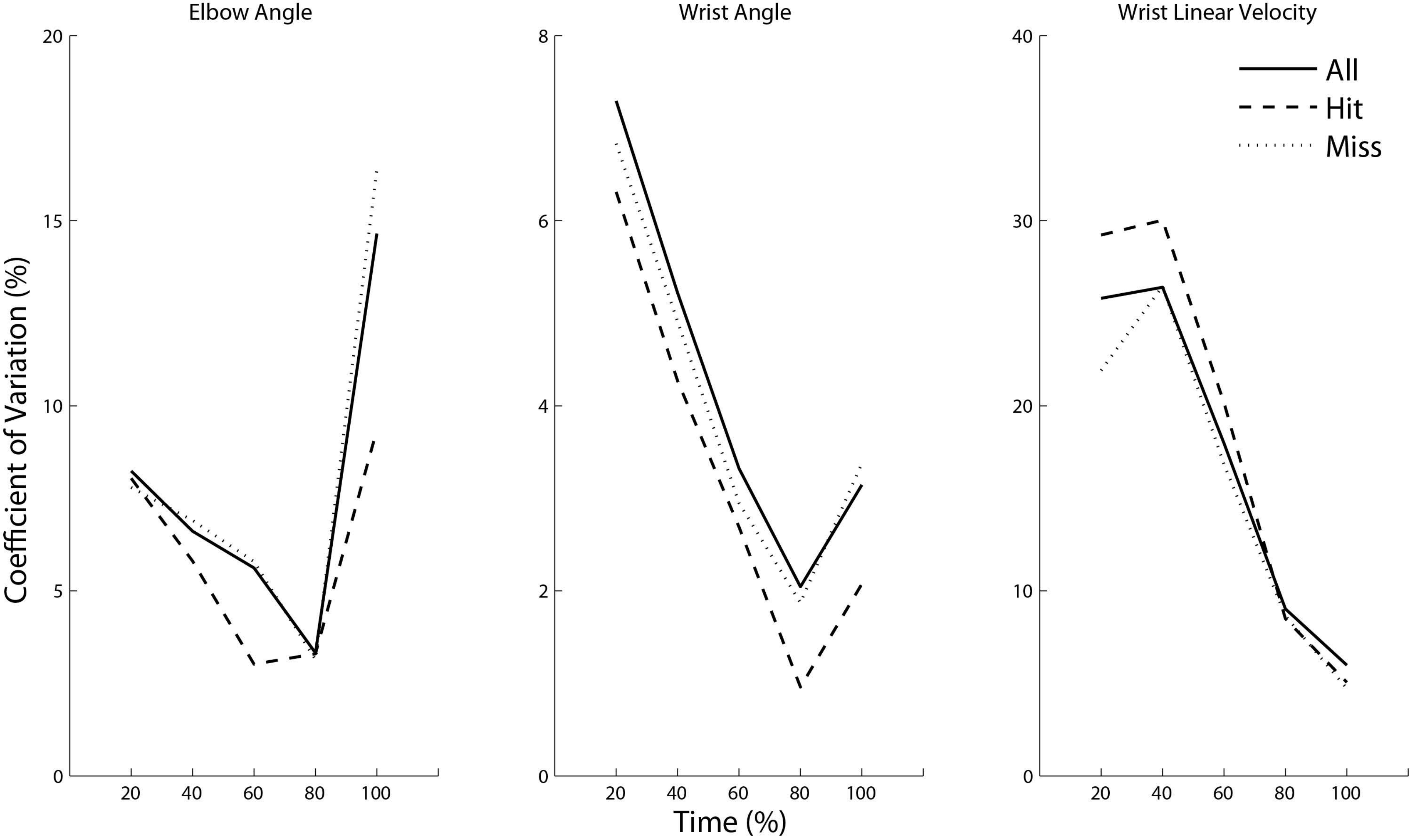
Table 1: Number of trials for which coefficient of variation percentage values (CV%) were calculated for participants 1 – 7 across all three conditions

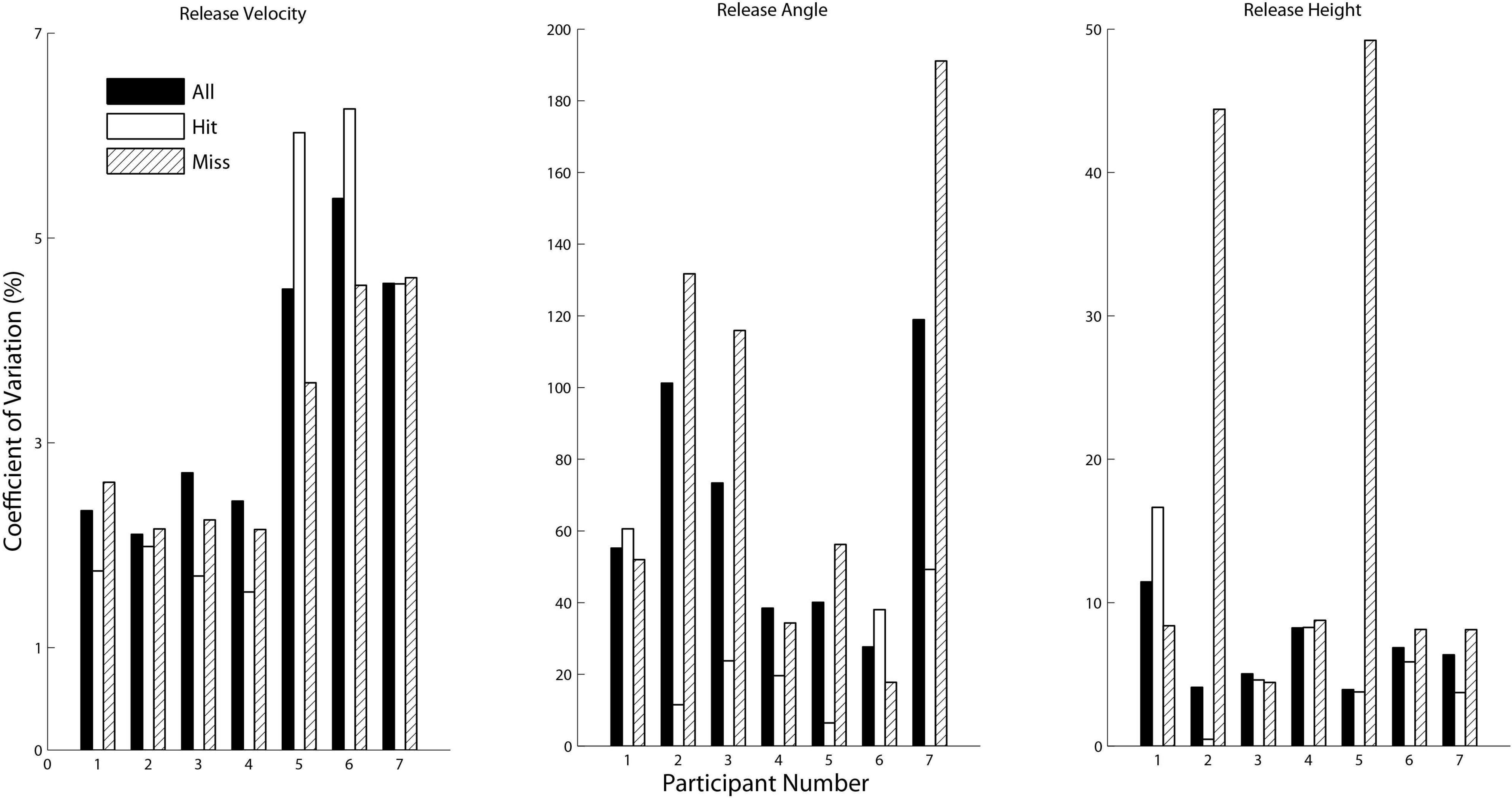
	All	**Hit**	**Miss**
1	7	3	4
2	9	2	7
3	8	4	4
4	8	2	6
5	7	3	4
6	4	-	3
7	10	5	5

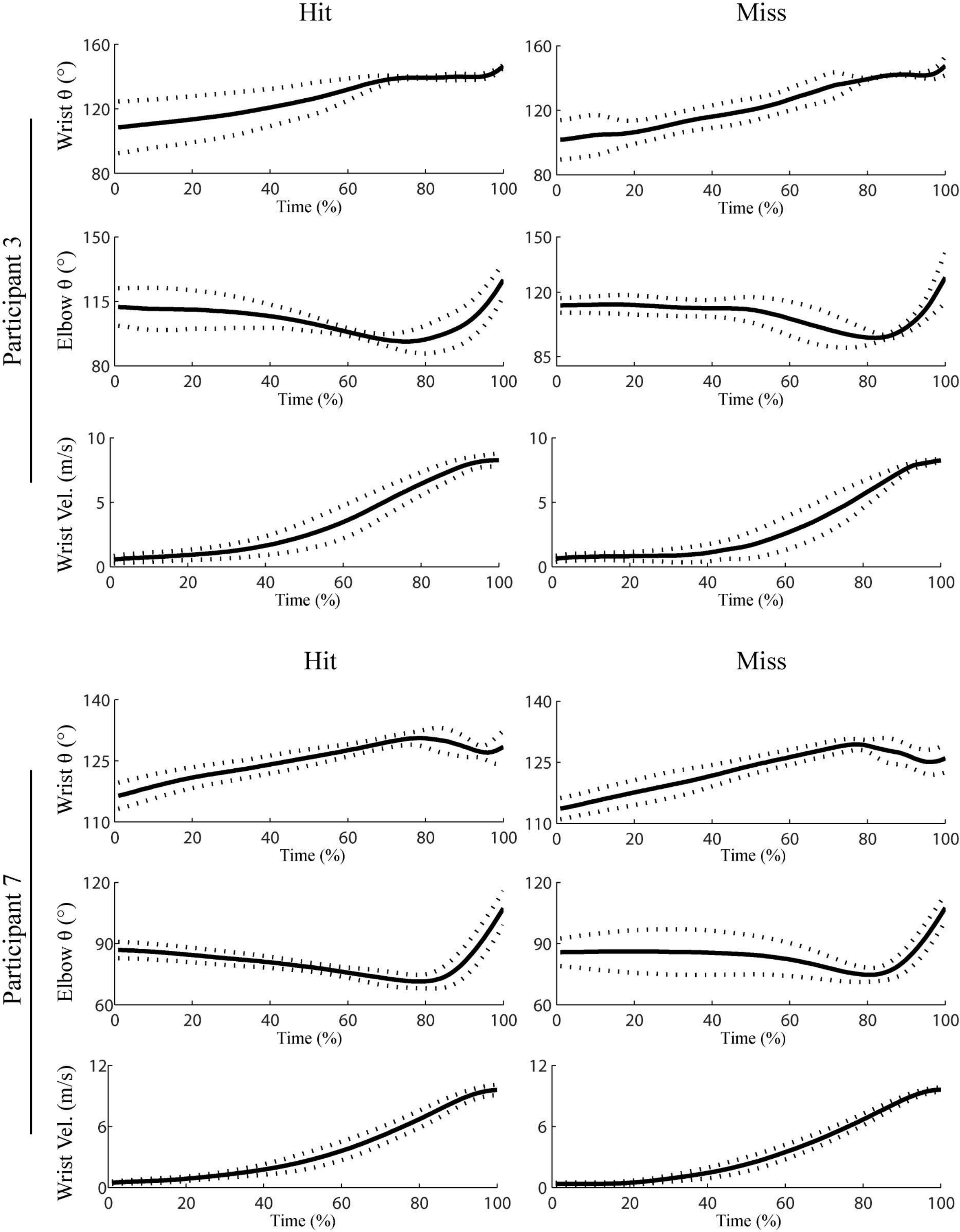
Note. Participant 6 only produced one successful shot and as such no CV% was calculated. Differences between sample sizes of hit and miss categories should be considered when interpreting results

Table 2: Peak mean cross correlation coefficient (Max r) and coefficient of variation (CV%) results for participants 1 – 7 for combined (All) successful (Hit) and unsuccessful (Miss) trials

	All		**Hit**		**Miss**	
	Max r	**CV%**	**Max r**	**CV%**	**Max r**	**CV%**
1	.871	14.0%	.910	4.4%	.842	16.8%
2	.773	7.7%	.806	3.5%	.764	8.4%
3	.711	24.3%	.644	32.8%	.748	23.9%
4	.856	9.6%	.862	9.4%	.854	10.5%
5	.183	187.8%	.240	108.7%	.392	29.6%
6	.325	29.6%	-	-	.312	36.4%
7	.459	48.6%	.522	41.7%	.399	58.1%


Elbow Angle
Wrist Angle
Wrist Linear Velocity
All
Hit
Miss
Coefficient of Variation (%)
Time (%)
20
15
10
5
0
8
6
4
2
0
40
30
20
10
0
20
40
60
80
100


Release Velocity
Release Angle
Release Height
All
Hit
Miss
Coefficient of Variation (%)
Participant Number
0
1
3
5
7
20
40
60
80
100
120
140
160
180
200
10
30
50
1
2
3
4
5
6
7


Hit
Miss
Participant 3
Wrist θ (°)
160
120
80
Elbow θ (°)
150
115
80
120
85
Wrist Vel. (m/s)
10
5
0
Time (%)
0
20
40
60
80
100
Participant 7
Wrist θ (°)
140
125
110
Elbow θ (°)
120
90
60
Wrist Vel. (m/s)
12
6
0