CHANGES IN COMPENSATORY VARIABILITY AS A FUNCTION OF TASK EXPERTISE AND DISTANCE DURING BASKETBALL SHOOTING

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The purpose of this study was to identify how compensatory control of the shooting arm changed under the interacting constraints of task expertise and shooting distance. Expert, intermediate and novice male basketball players (n=10 in each group) performed 30 shots from three distances (4.25, 5.25 and 6.25 metres). The dependent variables included shooting performance together with variability of the wrist, elbow and shoulder joints at the instant of ball release. A significant main effect for expertise was observed for both shooting performance and shoulder joint variability at ball release. No significant main effects for expertise were found for either wrist or elbow joint variability at release. Quadratic regression analyses revealed greater compensatory control of the shooting arm for the expert participants compared to their intermediate and novice counterparts. The level of compensatory control shown also persisted with increasing shooting distance regardless of level of expertise. Findings are harmonious with existing data on movement variability during dynamic throwing tasks, specifically demonstrating how expert performers exploited variability in a functional manner to satisfy the constraints of the task.

KEYWORDS: basketball shooting, dynamical systems theory, expertise, movement variability.

INTRODUCTION: The advent of dynamical systems theory in the movement sciences has helped sports biomechanists to better understand the role of variability within human movement systems (e.g. Bartlett *et al.*, 2007). Dynamical systems theory attributes a functional role for movement variability in task performance whereby coordination patterns emerge through the cooperative behaviour of multiple biomechanical degrees of freedom. Cooperative system behaviour is realised through the acquisition of coordinative structures that promote interdependency between joints of the human movement system (see Davids *et al.*, 2003). Bootsma and Van Wieringen (1990) initially postulated the idea of compensatory variability whereby joints in a kinematic chain interact in a functional manner to preserve invariance in the performance outcome. Empirical support for compensatory variability has been reported for postural control mechanisms (Ko *et al.*, 2003) and dynamic throwing tasks (Kudo *et al.*, 2000; Button *et al.*, 2003; Muller and Sternad, 2004; Robins *et al.*, 2006). Robins *et al.* (2006) reported that expert basketball players exhibited a proximal to distal increase in movement variability along the kinematic chain at the instant of ball release. It was further argued that the wrist, elbow and shoulder joints acted in a cooperative fashion to facilitate successful shooting performance. Further support for compensatory variability appeared in work by Button *et al.* (2003) who observed that the joint-space variability of elbow and wrist motion during a basketball free-throw increased towards the end of the action, compared to the initial movement phase. Elevated joint-space variability was suggested to be indicative of motor system flexibility allowing for compensatory adjustment between important release parameters i.e. angle, height and speed of release. However, no formal assessment of compensatory control was conducted by either Button *et al.* (2003) or Robins *et al.* (2006).

Using an index of coordination for release parameters (ICRP), Kudo *et al.* (2000) observed that with 150 trials of a ball-throwing task, release parameters were complementarily coordinated and the degree of coordination increased as a function of practice. Kudo *et al.* (2000) proposed that the change in compensatory variability could be explained by functional interdependencies between joints and not merely by traditional explanations such as neuro-motor noise or random processes (see Faisal *et al.*, 2008). Therefore, the purpose of this study was to build upon existing research pertaining to basketball shooting by formally addressing how compensatory variability might change as a function of both task expertise and shooting distance.

METHODS: 10 expert (mean (± SD) age of 24.1 ± 4.1 years), 10 intermediate (mean (± SD) age of 21.8 ± 4.1 years) and 10 novice (mean (± SD) age of 26.8 ± 2.8 years) male basketball players provided voluntary informed consent to participate in the study. Each participant was categorised as an expert, intermediate or novice using a performance pre-test (adapted from Vickers, 1996) and a questionnaire indicating previous basketball experience. Prior to data collection, all procedures were approved by the University's ethics committee. Participants completed 30 shots from each of three distances: 4.25 metres (equating to the free-throw line), 5.25 metres and 6.25 metres (equating to the three-point line). A counterbalanced design was implemented to minimise potential order effects. For each of the 30 trials shooting performance was assessed using a 1 - 8 scoring scale (adapted from Landin *et al.*, 1993). A score of 1, for example, signified missing the ring and backboard completely whereas a score of 8 was recorded when the ball entered the basket without contacting either the hoop or the backboard.

Kinematic data were collected using an eight-camera motion analysis system sampling at a frequency of 200 Hz (Motion Analysis Corporation, Santa Rosa, CA). Twenty five 12.7 mm retro-reflective markers were attached to appropriate anatomical landmarks and used to define 4 body segments: the trunk, upper arm, lower arm and hand. A SONY TRV950E digital camera, sampling at 25 Hz, was linked to the motion analysis system to identify the instant of ball release. Ball release was defined as the first frame in which the basketball left the participant’s hand. The shutter speeds of both the motion capture system and SONY digital camera were set to 1/1000s. The raw three-dimensional coordinate data were filtered using a zero lag 4th order Butterworth filter with the cut-off frequency selected at 6 Hz. The three-dimensional joint coordinate system angles for the wrist, elbow and shoulder joints were then generated using Visual 3D version 3.79 (C-Motion Inc., MD, USA). Due to the planar nature of the basketball shot, only movements within the sagittal plane were considered for further analysis i.e. flexion / extension. The dependent variables of interest included shooting performance score together with wrist, elbow and shoulder joint angles at release. Movement variability for each of the three joints at release was also calculated.

Each dependent variable was subjected to a 3 (expertise) * 3 (distance) analysis of variance (ANOVA) with expertise as the between-subjects factor and distance as the within-subjects factor. Further quadratic regression analyses were performed using a multiple single-individual approach to identify the potential relationship between interacting joints along the kinematic chain i.e. identification of potential covariance between joint angles at release. All assumptions underpinning use of parametric tests were tested for and verified ($p > 0.05$). An alpha level of 0.05 was selected to compromise between committing a type I and type II error. Inferential statistics were also supplemented with measures of effect size (η^2) to quantify the meaningfulness of the differences.

RESULTS: The mean (± SD) values for each dependent variable as a function of both expertise and shooting distance are presented in Table 1. There were no significant expertise * distance interactions for shooting performance, nor elbow or shoulder variability at release ($p > 0.05$, $\eta^2 < 0.09$). A significant expertise * distance interaction was found, however, for wrist variability at release ($p = 0.05$, $\eta^2 = 0.26$). Post-hoc comparisons revealed that the intermediate participants possessed significantly greater variability of the wrist at release for shots at 5.25 metres compared to the other two shooting distances ($p = 0.05$, $\eta^2 = 0.33$).

Significant main effects for expertise were also found for shooting performance ($p = 0.0001$, $\eta^2 = 0.83$) and shoulder variability at release ($p = 0.03$, $\eta^2 = 0.25$). Specifically, both expert and intermediate participants were found to perform better than their novice counterparts, with the expert group also outperforming the intermediate group. Finally, novices exhibited

greater variability at the shoulder joint at release than the intermediate group ($p = 0.05$). Interestingly, no differences were observed for shoulder joint variability at release between expert and novice participants ($p > 0.05$). No other significant main effects were observed for either expertise or distance for any of the other dependent variables ($p > 0.05$, $\eta^2 < 0.09$).
Quadratic regression analyses revealed significant relationships between the wrist, elbow and shoulder joint angles at release for expert, intermediate and novice participants ($p < 0.05$). However, the magnitude of the relationship changed markedly with respect to level of expertise. For instance, the mean regression values at a distance of 4.25 metres for experts ranged from 0.7 – 0.9, whereas the mean regression values for intermediates and novices ranged from 0.5 – 0.7 and 0.4– 0.6 respectively (see Figure 1). It is important to note that these range values were similar to those observed at 5.25 and 6.25 metres, indicating that the strength of the relationship between interacting joints persisted with increasing distance.

Table 1 Mean (± SD) values for each dependent variable of interest as a function of both expertise and shooting distance.

Expertise	Shooting Distance (m)	Shooting Performance (pts)	Movement Variability at Release (°) Wrist Angle	Elbow Angle	Shoulder Angle
Expert	4.25	187 ± 17	12.3 ± 4.1	8.2 ± 2.4	3.4 ± 1.2
	5.25	181 ± 14	9.5 ± 2.4	8.2 ± 1.9	3.4 ± 0.8
	6.25	164 ± 8	10.1 ± 1.0	8.1 ± 1.5	3.6 ± 1.1
Intermediate	4.25	151 ± 19	8.8 ± 3.4	6.3 ± 1.3	2.8 ± 1.2
	5.25	142 ± 17	11.9 ± 4.4	7.4 ± 1.2	3.5 ± 1.7
	6.25	125 ± 13	9.1 ± 2.1	7.5 ± 1.7	3.2 ± 1.5
Novice	4.25	128 ± 10	8.4 ± 2.3	7.2 ± 2.0	4.8 ± 2.4
	5.25	118 ± 14	8.9 ± 3.5	8.7 ± 3.8	5.3 ± 2.8
	6.25	103 ± 27	9.2 ± 3.3	7.1 ± 2.2	5.7 ± 2.4

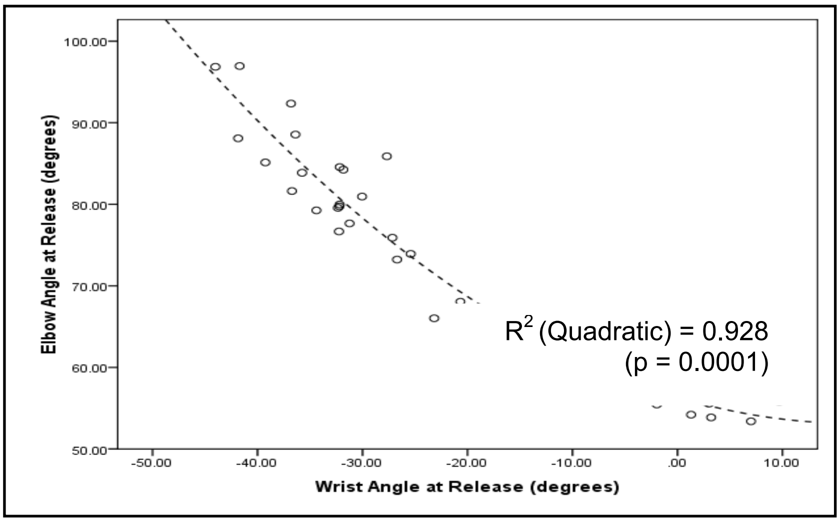

Figure 1: Relationship between wrist and elbow angle at release for an exemplar expert participant at a distance of 4.25 metres.

DISCUSSION: The purpose of this study was to identify how compensatory variability changed as a function of both task expertise and shooting distance. Experts were found to perform significantly better than both intermediate and novice participants across all three shooting distances. A proximal to distal increase in movement variability was also exhibited along the kinematic chain at ball release regardless of level of expertise. Interestingly, no significant differences with regards to expertise were found for wrist or elbow joint variability at release. In addition, no significant differences were observed for shoulder joint variability at release between the expert and novice participants. Quadratic regression analyses did, however, reveal heightened compensatory control for expert participants compared to their intermediate and novice counterparts. The findings of the current study supported previous research pertaining to dynamic throwing tasks (Kudo *et al.*, 2000; Button *et al.*, 2003). Specifically, Kudo *et al.* (2000) observed that with 150 trials of a ball-throwing task, release parameters were complementarily coordinated and the degree of coordination increased as a function of practice. The findings of the current study provided additional support for the functional role of movement variability during discrete multi-articular actions. Expert performers demonstrated evidence of cooperative behaviour between joints of the shooting arm whereby errors in execution of the proximal joints i.e. the shoulder joint, can be offset by compensatory adjustments at more distal joints i.e. the wrist joint. Both intermediate and novice performers, however, displayed variability that was less functionally related to performance, due to weak adaptation to the constraints of the task. The variability displayed by novices in particular could be interpreted as neuro-motor noise or random processes (Faisal *et al.*, 2008), or perhaps even the exploration of potential solutions within the perceptual-motor workspace. Importantly, the data also suggested that sports biomechanists should be cautious when drawing conclusions regarding performance based purely upon the magnitude of discrete movement variability scores. When possible, more formal assessments of compensatory control strategies should be employed (see Kudo *et al.*, 2000; Muller and Sternad, 2004).

CONCLUSION: The findings of this study suggested that compensatory control develops with task expertise and persists as task constraints change, e.g., increased shooting distance in throwing tasks. Therefore, sports biomechanists should give further consideration to the function as well as the magnitude of movement variability during precision aiming tasks such as basketball shooting. Future research should explore how compensatory variability can be used to facilitate successful performance in different experimental paradigms.

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