EXPERTISE AND DISTANCE AS CONSTRAINTS ON COORDINATION STABILITY DURING A DISCRETE MULTI-ARTICULAR ACTION

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The purpose of this study was to identify how coordination variability of the shooting arm varied as a function of interacting task constraints of expertise and shooting distance. Skilled, intermediate and novice male basketball players (n=9 in each group) performed 30 shots from three distances (4.25, 5.25 and 6.25 metres). The dependent variables included shooting performance scores and measures of coordination variability in three joint couplings: wrist-elbow, elbow-shoulder and wrist-shoulder. A main effect for distance was observed for shooting performance, with a reduction in score occurring with increasing distance. Significant main effects for expertise were also apparent for shooting performance together with coordination variability for all three joint couplings. Regression analyses revealed significant, negative relationships between shooting performance and coordination variability for all three joint couplings irrespective of shooting distance. The findings corroborated extant data on changes in movement variability with practice, demonstrating how skilled performers assemble stable movement solutions to satisfy changing task constraints, in contrast to novices and intermediates.

KEYWORDS: basketball shooting, constraint, coordination, expertise, movement variability.

INTRODUCTION: Human movement systems can yield a potential state space of approximately 200 dimensions, consisting of, minimally, 100 biomechanical degrees of freedom, each characterised by two states: position and velocity (Turvey, 1990). This characteristic exemplifies the inherent degeneracy of many neurobiological systems (Edelman & Gally, 2001). Degeneracy relates specifically to how the same functional outcome can be derived from elements that are structurally different (see Tononi *et al.*, 1999). Traditionally, cognitive approaches to the study of human movement professed little function to movement system variability, interpreting it as either neuro-motor or experimental noise. However, dynamical systems theory has helped reconceptualise the role of movement variability suggesting that it can be exploited functionally to satisfy the goals of the task (see Davids *et al.*, 2006). Functional variability allows skilled individuals to adapt to performance perturbations and changing constraints on action, by stabilising successful movement solutions. As a result of this increasing interest in movement system variability, further empirical evidence is required to identify how movement stability changes as a function of changing personal constraints, such as expertise, and task constraints, such as accuracy demands. Currently, there is a lack of clarity on this issue. For example, Button *et al.* (2003) recently reported no clear reduction in variability of phase plane trajectories with increasing skill level during a basketball free-throw task. This finding contrasts with previous work by Darling and Cooke (1987) and Gabriel (2002) who both observed a reduction in variability of movement phase plane trajectories with practice during a rapid elbow flexion and extension task. The reported decrease in movement variability with practice can be attributed to the development of a functionally stable attractor state within the perceptual-motor workspace.
From a dynamical systems perspective, the acquisition of skill is viewed as a process of assembling a stable movement solution to achieve consistent performance outcomes, regardless of changing task constraints (Handford *et al.*, 1997). Changes in task constraints can influence the magnitude of movement variability observed during task performance. For example, Sidaway *et al.* (1995a) quantified both joint amplitude and movement variability during a serial aiming task, and reported a decrease in inter-trial movement variability with a

corresponding reduction in target size. Additionally, Robins *et al.* (2006) reported that skilled basketball players exhibited a reduction in coordination variability with increasing shooting distance. This finding was attributed to the larger margin for error available at closer distances that permitted the use of different movement patterns in obtaining a consistently successful outcome, a phenomenon commonly referred to as motor equivalence. However, there is currently little research on understanding the interactive effects of expertise and distance on coordination variability during performance of multi-articular actions. Therefore, the purpose of this study was to understand the interacting effects of expertise and target distance on coordination variability during a basketball shooting task.

METHODS: 9 skilled (mean (± SD) age of 24.1 ± 4.1 years), 9 intermediate (mean (± SD) age of 21.8 ± 4.1 years) and 9 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 skilled, intermediate or novice using a performance pre-test and a questionnaire indicating previous basketball experience. Before 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 beginning and end of each performance trial. The beginning of each performance trial was defined as the first upward movement of the ball and the end was determined by peak flexion of the wrist. 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 4^{th} 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. Each trial was cropped using the beginning and end points identified from the SONY digital camera and subsequently interpolated to 101 data points using a cubic spline technique. The dependent variables included shooting performance score and coordination variability of the shooting arm using the normalised root mean squared difference technique (NoRMS) proposed by Sidaway *et al.* (1995b). Coordination variability was calculated for the following joint couplings: wrist flexion/elbow extension, elbow extension/shoulder extension and wrist flexion/shoulder extension.

Each dependent variable was subjected to a 3 (expertise) * 3 (condition) analysis of variance (ANOVA) with expertise as the between-individuals factor and condition as the within-individuals factor. Quadratic regression analyses were also conducted to identify the potential relationship between coordination variability for each respective joint coupling and shooting performance score. All assumptions underpinning the use of parametric statistics were tested for and verified. An alpha level of 0.05 was selected to compromise between committing a type I or 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 any of the dependent variables ($p > 0.05$, $\eta^2 < 0.05$).

However, there were significant main effects for expertise for shooting performance and coordination variability for the wrist-elbow, elbow-shoulder and wrist-shoulder joint couplings ($p < 0.0001$, $\eta^2 > 0.59$). Post-hoc tests revealed that both the skilled and intermediate participants performed better than their novice counterparts ($p < 0.04$), and also exhibited less coordination variability for each of the three respective joint couplings ($p < 0.02$). The skilled group also demonstrated less coordination variability at the wrist-shoulder coupling for a distance of 4.25 metres and for all three joint couplings at 5.25 metres when compared to the intermediates ($p < 0.05$). A main effect for distance was also apparent for shooting performance ($p = 0.0001$, $\eta^2 = 0.50$) with a reduction in score occurring with increasing distance regardless of expertise. When plotting shooting performance against coordination variability, the quadratic regression analyses revealed a significant, negative relationship between shooting performance and coordination variability for all three joint couplings irrespective of shooting distance ($p < 0.003$). For instance, regression values of 0.622, 0.586 and 0.539 were found at 4.25 metres for the wrist-elbow, elbow-shoulder and wrist-shoulder joint couplings respectively (see Figure 1). Furthermore, regression values of 0.673, 0.661 and 0.516 (5.25 metres) and 0.36, 0.37 and 0.30 (6.25 metres) were found for the same respective joint couplings at the remaining two distances.

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)	Coordination Variability (NoRMS) Wrist-Elbow Coupling (°)	Elbow-Shoulder Coupling (°)	Wrist-Shoulder Coupling (°)
Expert	4.25	187 ± 17	5.1 ± 1.0	4.5 ± 1.2	4.8 ± 0.7
	5.25	181 ± 14	5.0 ± 1.0	4.6 ± 0.9	4.8 ± 0.9
	6.25	164 ± 8	5.0 ± 1.0	5.1 ± 1.4	5.2 ± 1.3
Intermediate	4.25	151 ± 19	7.0 ± 3.1	6.5 ± 2.4	6.8 ± 2.8
	5.25	142 ± 17	6.6 ± 1.9	6.3 ± 1.6	6.3 ± 2.0
	6.25	125 ± 13	6.1 ± 1.6	5.9 ± 1.3	6.1 ± 1.8
Novice	4.25	128 ± 10	12.4 ± 4.7	10.6 ± 3.7	13.0 ± 4.8
	5.25	118 ± 14	12.0 ± 3.9	10.7 ± 3.2	13.6 ± 5.7
	6.25	103 ± 27	11.3 ± 3.1	9.9 ± 3.0	13.6 ± 6.0

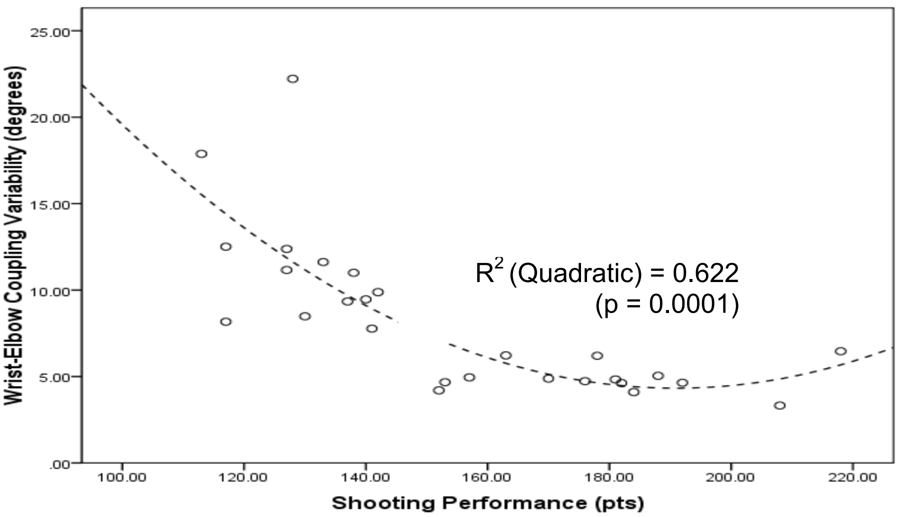

Figure 1: Exemplar regression line identifying the relationship between coordination variability and shooting performance at a distance of 4.25 metres.

DISCUSSION: The purpose of this study was to explore the interacting constraints of expertise and distance-to-target on the stability of movement coordination in basketball shooting. As expected, a reduction in shooting performance score was evident with increasing distance, regardless of expertise. The skilled group also demonstrated significantly higher shooting performance scores than both their intermediate and novice counterparts. More importantly, there was a significant decrease in coordination variability as a function of expertise, irrespective of distance or joint coupling. Specifically, the novice participants displayed significantly more coordination variability than their intermediate and skilled counterparts. The findings of the current study corroborated those reported by Darling and Cooke (1987) and Gabriel (2002) who observed a reduction in the variability of joint kinematics with practice. These findings characterised basketball shooting expertise as the acquisition of stable movement patterns within a perceptual-motor workspace, in which task constraints were altered slowly. It is evident from the current study that skilled participants had acquired more stable motor patterns and could exploit inherent motor system variability functionally to adapt to task constraints. However, novice participants displayed greater variability evident of less stable movement patterns and seemed to be searching the available phase space for a stable task solution, as evidenced by the lack of significant reduction in coordination variability with increasing shooting distance. Ostensibly, this finding seems to contrast with other data of Robins *et al.* (2006) who reported significant reductions in coordination variability with increasing distance. However, this discrepancy between research findings could be explained in two parts. First, differences could be attributed to differences in the measurement of coordination variability i.e. the use of the NoRMS technique in the current study as opposed to the standard deviation of continuous relative phase used by Robins *et al.* (2006). Second, the current study assessed shooting performance on a 1-8 scale whereas Robins *et al.* (2006) standardised success by only including shots awarded 8 points.

CONCLUSION: The findings of this study demonstrated how emerging patterns of coordination are influenced by inherent processes of neurobiological self-organisation, and are governed by the interacting constraints on action. Data showed how functional patterns of movement coordination were stabilised by more skilled performers only as task constraints were changed slowly in a basketball shooting task. Further research is needed to understand the interacting constraints that shape performance of discrete multi-articular actions. Particular attention should be paid to how expertise supports adaptive movement behaviour in more dynamic performance environments.

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