INVESTIGATING THE RELATIONSHIP BETWEEN MOVEMENT VARIABILITY, SKILL ACQUISITION AND ADAPTABILITY

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Facilitating adaptability is a role attributed to movement variability. The aim of this investigation was to track changes in movement variability during the learning of a novel task where adaptability was expected to be present. A contextual interference design was implemented with sample entropy and vector coding used to quantify joint and coordination variability respectively. Those exposed to high contextual interference performed significantly better and were more adaptable. Significant decreases in coordination variability were found during the learning process for all participants. The more adaptable group also exhibited higher coordination variability at key points providing some support for previous hypotheses on the interaction between, skill acquisition and adaptability. Results have implications for practitioners working in skill acquisition.

KEY WORDS: contextual interference, variability, vector coding, entropy, surrogate.

INTRODUCTION: Movement variability describes variation in movement patterns from one task repetition to the next. One of the functions attributed to movement variability is facilitation of adaptability of an individual to changing environmental and/or task constraints (Bartlett, Wheat, & Robins, 2007). This functional movement variability is considered a characteristic of highly skilled individuals (Button, MacLeod, Sanders, & Coleman, 2003; Wilson, Simpson, van Emmerik, & Hamill, 2008) whose variability profile is thought to change during task learning. For example, a U-shaped curve has been hypothesised to characterise coordination variability, where the highest and lowest skilled display increased variability while those in intermediate stages have their variance constrained (Wilson et al., 2008). This pattern correlates with the changes in degrees of freedom proffered by Bernstein (1967). However, there have been few longitudinal investigations offering empirical support for these hypotheses. As such, the aim of this study was to investigate changes in joint level and coordination variability across the learning of a novel discrete task. Use of contextual interference design (Brady, 2004) is expected to elicit motor skill acquisition and adaptability allowing exposition of any relationship between this adaptability and movement variability. It is thought this study could provide information impacting the understanding and tracking of skill acquisition in sport related tasks.

METHODS: The data for this study were collected during the learning of a novel, discrete task (overarm throwing with the non-dominant hand) under contextual interference conditions. Twenty informed and consenting adult males [22.2 (3.3) years; 179.4 (6.5) cm; 78.1 (9.1) kg] were randomised into either a low contextual interference (LowCI) or high contextual interference (HighCI) group. Each participant attended nine sessions. Each session consisted of a pre-test, four blocks of practice throws and a post-test. Session nine also including a transfer test (novel targets). In all sessions the seated (to constrain movement to the upper body) participant was asked to throw a tennis ball as accurately as possible toward the centre of a target projected on a cloth screen seven metres away. Targets were uniform in size and changed location depending on treatment group and session component (Figure 1; Table 1). Participants performed 16 throws at each pre-, post- and transfer test (Taylor et al., 2016).

Data collection equipment are reported in Taylor et al. (2016) with the addition of a digital video camera (120 Hz) to detect ball impact. Three-dimensional (3D) marker trajectories from the pre-test of sessions one, three, five, seven and nine were filtered using 4^{th} order low pass Butterworth filter with a 12 Hz cut off. Three 3D joint rotations (elbow flexion/extension, shoulder internal/external rotation, wrist flexion/extension) were calculated from the trajectory data. A radial error score determined throw accuracy at the pre-test of session one (pre-test), the post-test of session nine (post-test) and the transfer-test of session nine (transfer-test). This score was calculated using the digitised pixel distance of the ball centre from the target centre, divided by the target radius. A lower score describes a more accurate throw.

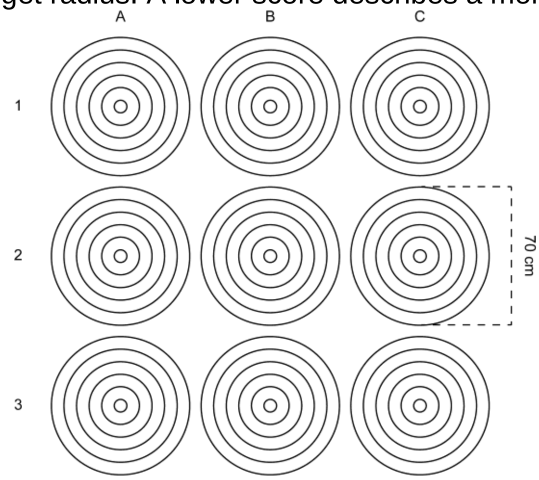

Figure 1: Grid of targets used in this investigation.

Table 1: Task flow for sessions 1–9 for each group.

	Low Contextual Interference	High Contextual Interference
Warm up	Self-selected number of throws ~2 mins	Self-selected number of throws ~2 mins
Pre-test	16 throws at target 2B	16 throws at target 2B
Rest	3 minutes	3 minutes
Practice blocks	4 blocks of 10 throws at target 2B (1 min rest between blocks)	4 blocks of 10 randomised throws at targets 1B, 2A, 2C, 3B (1 min rest between blocks)
Rest	3 minutes	3 minutes
Post-test	16 throws at target 2B	16 throws at target 2B
Rest	5 minutes (session 9 only)	5 minutes (session 9 only)
Transfer-Test	4 x 4 throws at randomised novel targets 1A, 1C, 3A, & 3C (session 9 only)	4 x 4 throws at randomised novel targets 1A, 1C, 3A, & 3C (session 9 only)

The presence of deterministic dynamics in a representative sample of the collected data (640 trials) were tested for using surrogate methods to ensure observed variability was due to changes in motor control and not stochastic (noise) elements. Surrogates were generated using a method developed for discrete data and compared to collected data using sample entropy (Taylor et al., 2016). To avoid the effect of variable data length on the outcome of entropy estimates, and to a facilitate calculation of coordination variability, trial data were interpolated to 101 data points. Joint angle variability was calculated using sample entropy estimates across the 16 trials per session of each included rotation. Vector coding coupling angles ($-180° \leq \gamma \leq 180°$) were derived for the shoulder/elbow and elbow/wrist joint couplings using the method described by Heiderscheit, Hamill, and van Emmerik (2002). Circular statistics (Batschelet, 1981) were used to calculate the standard deviation of each joint coupling at each percentage of movement time across all trials for each participant in each session. Coordination variability was quantified as the mean of the resultant 100 standard deviation values. Dependent variables of interest were screened for normality and other relevant assumptions before appropriate statistical testing. Changes in radial error score (across pre-, post- and transfer-tests) within and between groups were analysed using dependent and independent t-tests, respectively. Differences between entropy content of observed data and their respective surrogates were assessed using the Mann Whitney U test. Differences in entropy joint variability and coordination variability of the included joint couplings across sessions and between groups were investigated using two-way mixed ANOVAs. Where appropriate, follow up t-tests were used. Significance was set at $p < 0.05$ and where possible, effect sizes (Cohens *d*, partial η^2 and *r* where $r = \frac{Z}{\sqrt{N}}$) were calculated.

RESULTS: The LowCI ($p < 0.05$, $d = 0.73$) and HighCI ($p < 0.01$, $d = 1.44$) groups both significantly improved performance from pre- to post-test. The High CI group also performed better in the transfer-test compared to the pre-test ($p < 0.01$, $d = -0.16$). There was no difference in throwing performance of the LowCI and HighCI groups at pre-test ($p = 0.51$, $d = -0.31$). However, at both post- ($p = 0.03$, $d = 0.96$) and transfer-tests ($p < 0.01$, $d = 1.36$) the HighCI group performed significantly better than the LowCI group.

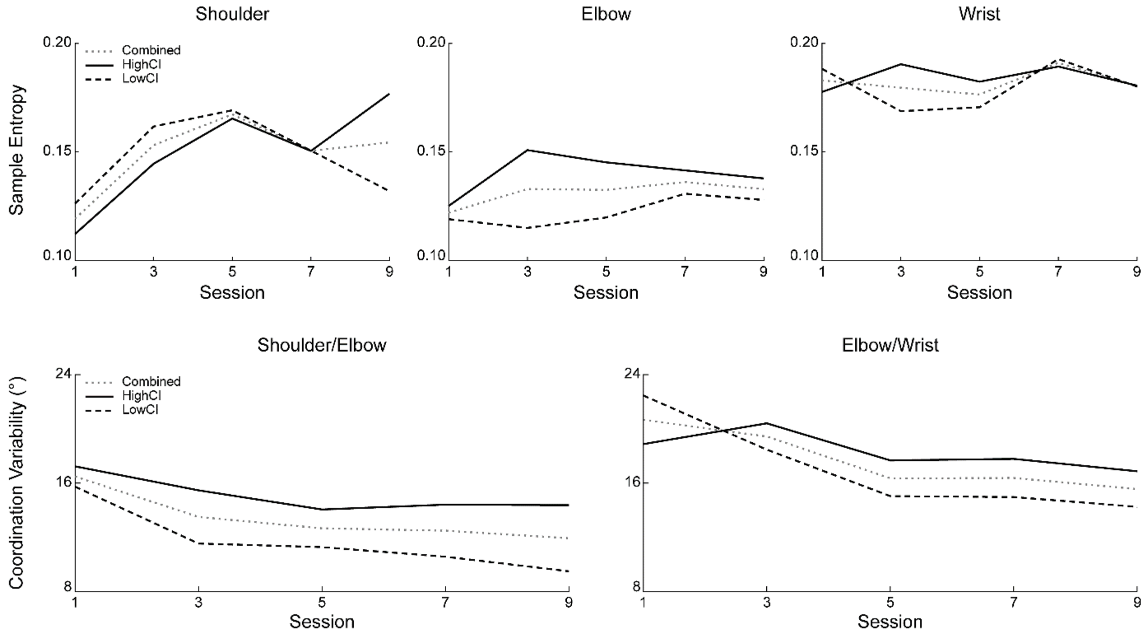

Figure 2: HighCI, LowCI and combined group mean joint and coordination variability across sessions

Deterministic dynamics were confirmed as observed data sample entropy estimates were all significantly lower than their respective surrogates ($p < 0.01$, $r \leq -0.63$). Results from mixed ANOVAs indicated no significant interaction between groups and sessions on sample entropy estimates from the three joint rotations or the coordination variability of the two joint couplings ($p \geq 0.24$, $0.02 \leq$ partial $\eta^2 \leq 0.08$). The main effect of group was non-significant ($p \geq 0.08$, $0.01 \leq$ partial $\eta^2 \leq 0.163$) for all sessions combined. Group difference across sessions for Shoulder/Elbow coordination variability approached significance ($p = 0.08$) with a large effect size ($\eta^2 = 0.163$). The main effect of sessions indicated a significant decrease in coordination variability with large effect size ($p \leq 0.02$, partial $\eta^2 \geq 0.158$) for both joint couplings. Specifically, sessions five, seven and nine all displayed significantly lower coordination variability compared to session one ($p < 0.05$). Furthermore, the coordination variability displayed by the HighCI group was greater than the LowCI group for both joint couplings. This difference was significant with large effect for the Shoulder/Elbow coupling ($p = 0.02$, $d = -1.20$), insignificant with medium effect for Elbow/wrist ($p = 0.31$, $d = -0.47$).

DISCUSSION: The principal finding of this investigation was the significant decrease in coordination variability of the Shoulder/Elbow and Elbow/Wrist joint couplings within the context of skill acquisition and performance improvement. It has been previously hypothesised that coordination variability would describe a U-shaped curve (Wilson et al., 2008) as an individual progressed from novice to skilled. While this U-shape is not present in the current data, the results do not necessarily preclude this hypothesis. The linear decrease trend in the data is possibly driven by the relatively large variability observed in session one, perhaps indicative of the exploration strategies described by Bernstein (1967). Furthermore, while participants were more skilled at the completion of the intervention than they were at the beginning, they could not be classified as experts. As such if they were to continue practice it is possible that coordination variability may begin to rise again in line with the U-shaped hypothesis. Indeed, an increase in coordination variability from the better performing HighCI group is present from session five to nine which may lend further support to this.
The greater amount of coordination variability displayed by the HighCI group at session 9, significantly so for the Shoulder/Elbow coupling, is also important in this context. The HighCI

group performed significantly better in the transfer test than the LowCI group, in line with a large body of evidence on the contextual interference effect (Brady, 2004), indicating enhanced ability to adapt to new task constraints. Facilitating adaptability in skilled movement is one role that has been hypothesised for movement variability previously (Bartlett et al., 2007) by enabling compensatory coordination (Bootsma & van Wieringen, 1990). That the HighCI group was able to more effectively adapt to the changed task constraints while displaying greater coordination variability may support this.
Contribution of individual joint motion to changes in coordination variability in the current investigation is not immediately apparent. It was interesting that variability at the joint level increased from session one to session nine, in contrast to previous work (Button et al., 2003). However, non-significant statistical results limit most speculation regarding this. When considering trends in the joint variability data it was worth noting that the wrist displayed the greatest variability but the least change across the sessions. The wrist can act as highly flexible final effector of ball release characteristics, which may explain the elevated variability similar to that seen in racquet/bat sports (Sheppard & Li, 2007). If so, then it appears it performs this role at a similar level throughout skill acquisition. The spike in shoulder variability in the HighCI group at session nine was also of note. Again, this was not a significant change, but could be related to the increase in the coordination variability of Shoulder/Elbow coupling in this group in this session. Qualitatively, the researchers noted the higher performing participants adopting a technique with greater contributions from shoulder internal rotation. This could provide avenues for future investigation of these phenomena.
The results of this study provide potentially impactful knowledge to those involved in applied roles where skill acquisition is of importance. There has been a dearth of longitudinal investigations into the phenomena of movement variability and this study provides unique information on the changes that occur in movement and coordination variability during motor learning. It also adds further evidence to the understanding that high contextual interference environments enable enhanced skill acquisition and adaptability of novel tasks (sports related yet with constrained degrees of freedom in this instance). Combined, this knowledge provides practitioners with variables that could be tracked across skill acquisition to determine progression and information on how best to design the learning process to optimise success.

REFERENCES:

Bartlett, R., Wheat, J., & Robins, M. (2007). Is movement variability important for sports biomechanists? *Sports Biomechanics, 6*(2), 224-243. doi:http://dx.doi.org/10.1080/14763140701322994

Batschelet, E. (1981). *Circular statistics in biology*. New York, NY: Academic Presss.

Bernstein, N. A. (1967). *The coordination and regulation of movements*. Oxford, UK: Pergamon Press.

Bootsma, R. J., & van Wieringen, P. C. W. (1990). Timing an attacking forehand drive in table tennis. *Journal of Experimental Psychology: Human Perception and Performance, 16*(1), 21–29. doi:http://dx.doi.org/10.1037//0096-1523.16.1.21

Brady, F. (2004). Contextual interference: A meta-analytic study. *Perceptual and Motor Skills, 99*(1), 116-126. doi:http://dx.doi.org/10.2466/pms.99.5.116-126

Button, C., MacLeod, M., Sanders, R., & Coleman, S. (2003). Examining movement variability in the basketball free-throw action at different skill levels. *Research Quarterly for Exercise and Sport, 74*(3), 257-269. doi:http://dx.doi.org/10.1080/02701367.2003.10609090

Heiderscheit, B. C., Hamill, J., & van Emmerik, R. E. A. (2002). Variability of stride characteristics and joint coordination among individuals with unilateral patellofemoral pain. *Journal of Applied Biomechanics, 18*(2), 110-121.

Sheppard, A., & Li, F.-X. (2007). Expertise and the control of interception in table tennis. *European Journal of Sport Science, 7*(4), 213-222. doi:10.1080/17461390701718505

Taylor, P. G., Small, M., Lee, K.-Y., Landeo, R., O'Meara, D. M., & Millett, E. L. (2016). A surrogate technique for investigating deterministic dynamics in discrete human movement. *Motor Control, 20*(4), 459 - 470. doi:http://dx.doi.org/10.1123/mc.2015-0043

Wilson, C., Simpson, S. E., van Emmerik, R. E. A., & Hamill, J. (2008). Coordination variability and skill development in expert triple jumpers. *Sports Biomechanics, 7*(1), 2-9. doi:http://dx.doi.org/10.1080/14763140701682983