COORDINATION DURING INITIAL ACQUISITION OF THREE-BALL JUGGLING

Adam J. Strang and L. James Smart

Miami University, Oxford, Ohio, United States

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INTRODUCTION: Bimanual coordination is critical for the performance of a number of continuous skills (e.g., walking, running, drumming, etc.). However, relatively little is known about how such coordination is developed and maintained. In the current study researchers sought to address this issue by examining coordination changes in bilateral elbow motion during initial acquisition of three-ball cascade juggling. Elbow motion was assessed using a set of both traditional (Average Amplitude; *Avg. Amp*) and more recently developed *nonlinear* time-series analyses (Approximate Entropy; *ApEn* – a measure of *complexity* within a single time series, and Average Mutual Information; *AMI* – the amount of information *shared* between two time-series) (Abarbanel, 1996; Pincus, 1995). It was hoped that together these analyses would lend new insights about bimanual coordination in continuous skills that could be used to develop more sophisticated biomechanical models of human movement and/or advance general motor theory

METHODS: Eighteen college-aged students underwent twelve supervised training sessions (three sessions per week for four weeks, each session lasting approx. 45 minutes) during which participants received juggling instructions provided by experimenters (Finnigan et al., 2002). Once able to achieve ten consecutive tosses participants began to undergo three experimental trials at the end of the next nine training sessions where elbow motion (relative elbow flexion in degrees) was recorded at 140 Hz for the fist 7-sec of each trial where participants were instructed to complete 'as many juggling tosses in a row as possible'. Elbow motion was recorded from electronic sensors placed bilaterally on the upper arms (midpoint between acromion process and cubital fossa) and forearms (midpoint between cubital fossa and ulnar styloid) using a magnetic tracking system (Flock of Birds, Ascension, Inc.) interfaced and digitized with MotionMonitor Software® (v. 7.72). All elbow data were then analyzed with *ApEn, Avg. Amp*, and *AMI* using custom Matlab code. All dependent measures (including number of successive tosses) were averaged across all three experimental trials for each training session where elbow data were recorded.

RESULTS AND DISCUSSION: Participants saw significant improvements in juggling performance with training. $F(8,136)=11.36$, $p<.01$ (Fig.1).

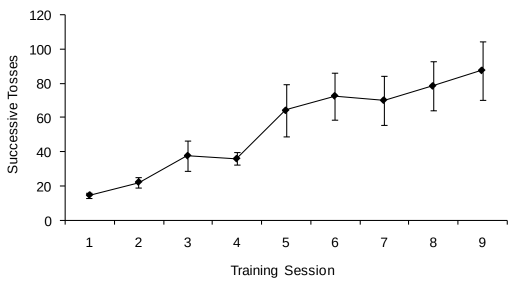

Figure 1. Mean ± standard error (SE) tosses completed in a row during experimental trials

Participants also showed a significant increase in *ApEn*, $F(8,272)=3.98$, $p<0.01$, accompanied by a decrease in *Avg. Amp*., $F(8,272)=7.17$, $p<0.01$ (collapsed across dominant/non-dominant limbs) (Fig. 2). These findings indicate that as training progressed elbow motion became confined to an increasingly smaller range (as indicated by a steady decrease in *Avg. Amp*), but the movement pattern within that range became more *complex* (as indicated by an increase in *ApEn*).

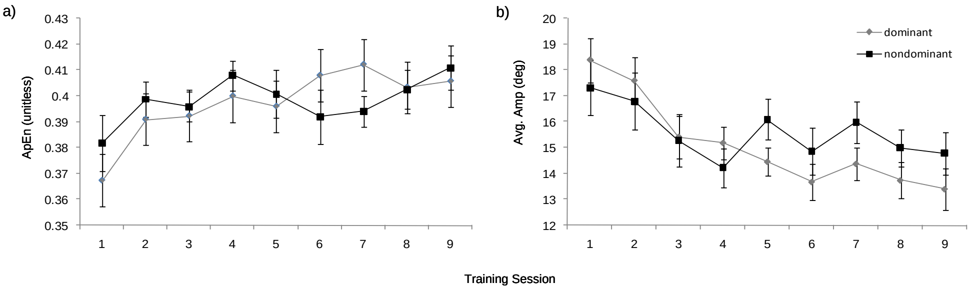

Figure 2. Mean (SE) *ApEn* (a) and *Avg. Amp* (b) for successive training days

Finally, participants showed a progressive decrease in *AMI* with training, *F*(8,136)=6.43, p<0.01 (Fig. 3). This finding indicates that the amount of information *shared* between two limbs was steadily decreasing. This was interpreted to reflect decreased congruence in movements of the two limbs.

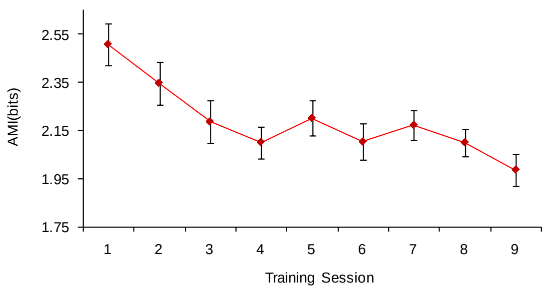

Figure 3. Mean (SE) AMI values for successive training days

CONCLUSION: The analyses used in this study successfully revealed a number of unique features in bimanual coordination during initial acquisition of three-ball juggling. For intra-limb coordination results showed that elbow motion became more confined, but also more *complex*. Might this reflect the steady development of a coordination that exhibits flexibility in one dimension (movement pattern) and stability on another (range of motion)? Assessment of inter-limb coordination showed that movements of dominant and non-dominant limbs were had become less congruent with training. This finding might indicate that control over the two limbs was progressively becoming more independent and could be hinting at the possibility that each limb has a different role to play in the coordination of this skill? In anecdotal observations experimenters noted that towards the end of the training some participants seemed to be using their dominant limb to set the tempo for juggling and the non-dominant limb to make adjustment and corrections for inconsistencies with each toss. At present more work is needed to replicate these findings and investigate possibility that different limbs may have independent roles to play in bimanual coordination in juggling as well as other bimanual skills (e.g., running and walking gait).

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