DEFINING KEY KINEMATIC VARIABLES OF THE OVERARM THROW DURING LEARNING: A MOTOR CONTROL PERSPECTIVE

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This study aimed to investigate changes in technique during a period of learning, in line with three key models of motor learning: Components Model (Roberton & Halverson, 1984), Bernstein's (1967) observations of freezing and freeing, and Newell's (1985) stages of learning model. Ten participants with no specific non-dominant arm throwing experience completed a longitudinal learning study. Full body kinematic data was collected at 200 Hz using an automated 3D motion capture system. Results were analysed in line with the key models of motor learning (Roberton & Halverson, 1984; Bernstein, 1967; Newell's 1985). All the models identify key change point with a session in between each other, therefore, producing support for the idea of a collective variable in motor 'control'. From an applied perspective the Roberton and Halverson (1984) model provide a useful tool to aid practitioners.

KEYWORDS: motor control, motor learning, biomechanics, throwing.

INTRODUCTION: Overarm throwing action is a fundamental movement and is the vehicle used in this study to understand the greater issue of motor control and development in whole body actions. To support models of motor learning, considerable research has focused on identifying the series of stable states in technique that occur when performing motor tasks, and change during practice. Three key models that capture technique change during whole body movement such as overarm throwing are highlighted within the literature. Specifically, the Components Model (Roberton & Halverson, 1984), Bernstein's (1967) observations of freezing and freeing and Newell's (1985) Coordination, Control and Skill model of learning.
In order to further understand technique changes during learning, there is a need to apply the models to whole body movements that are ecologically valid (Ko, Challis & Newell, 2003). Biomechanics of throwing have been investigated (Stodden et al. 2006), however little is known about technique changes during the learning of overarm throwing movement (Kernodle & Carlton, 1992; Southard, 2011). Therefore, the purpose of this study was to investigate changes in technique during a period of learning non-dominant overarm throwing action, in line with three key models of motor learning.

METHOD: Ethical approval was gained from the host University Ethics Committee. Ten participants completed 9 training sessions over 3 consecutive weeks (4 female, 6 males; 22±2 years, 1.71±10, and 73±14 kg). Participants were asked to complete a series of dominant and non-dominant overarm throws. To meet inclusion criteria, participants were not participating in throwing based activity, had a clear dominant hand as determined by Oldfield's (1971) Edinburgh handedness inventory, and were free from musculoskeletal injury that would hinder throwing action. Bilateral kinematics data (200 Hz) was collected using CODA motion (Charnwood Dynamics Ltd, UK) with active makers located on the right and left lateral side of: 3rd metacarpal, radial and ulnar styloid process, forearm, lateral epicondyle of the elbow, shoulder joint at the centre of rotation, xiphoid process, greater trochanter, thigh, femoral condyle, tibia, lateral malleolus, calcaneus and 2nd metatarsal. The propulsion phase of throwing action was interpolated to 101 data points. Repeated measures analysis of variance was used to quantify differences between discrete variables across learning sessions. Statistical significance was set a priori to ($p < 0.05$) data collection with Bonferroni corrections applied for multiple comparisons. Mauchly's test was used to determine the sphericity assumption; and was corrected according to the Greenhouse–Geisser procedure if violated. The Components Model (Roberton & Halverson, 1984) was used to provide quantitative analysis of the data. Range of motion of key joint was quantified to establish if individuals had increased (freed) range of motion or decreased (frozen) range of motion in line with Bernstein (1961) observations. The centre of mass and wrist joint movement were coupled and provided a collective variable in which to observe the coordination of the system through vector coding analyses in line with Newell (1985) stages of learning.

RESULTS AND DISCUSSION: Participants progressed through the action levels of the Components Model (Table 1). From Session 6 onwards the majority of participants were categorised as action level 3 (70%) or 4 (30%) for step, action level 2 (20%) or 3 (80%) for the trunk, action level 2 (30%) or 3 (70%) for the humerus and action level 2 (30%) and 3 (70%) at the forearm. No-one was categorised as action level 1. The number of participants who moved from one action level to another was small. This could be due to lateral transfer from prior knowledge and experience of dominant overarm throwing.

Table 1: Developmental action level from Session (S) 1 Session to Session 9.

		Non-dominant arm throws								
Segment	Action level	S1	S2	S3	S4	S5	S6	S7	S8	S9
		Number of participants in each level for a given session								
Step	1									
	2	1	1	1						
	3	9	9	9	8	8	7	7	7	7
	4				2	2	3	3	3	3
Trunk	1									
	2	8	6	6	4	3	2	2	2	2
	3	2	4	4	6	7	8	8	8	8
Humerus	1									
	2	6	5	5	4	4	3	3	2	2
	3	4	5	5	6	6	7	7	8	8
Forearm	1									
	2	6	5	5	4	4	3	3	3	3
	3	4	5	5	6	6	7	7	7	7

Range of motion of key joints was increased (freed) over a period of learning (Fig. 1). Changes in range of motion either occurred gradually over the learning period or as a sudden shift taking place between session 4 to session 5, although the timing and configuration of joint freeing was individual specific. Freeing of the lower extremities occurred to a greater extent than the upper extremities enabling greater movement of the centre of mass; this indicates that the organisation of the segment involved within overarm throwing action is important during the initial stages of learning. The freeing of the centre of mass and lower extremities eludes to the idea that stability and balance was favoured over the skill action (Verhoeven & Newell, 2016). With the environmental constraints being met prior to the task constraints as task stability was favoured over movement ability.

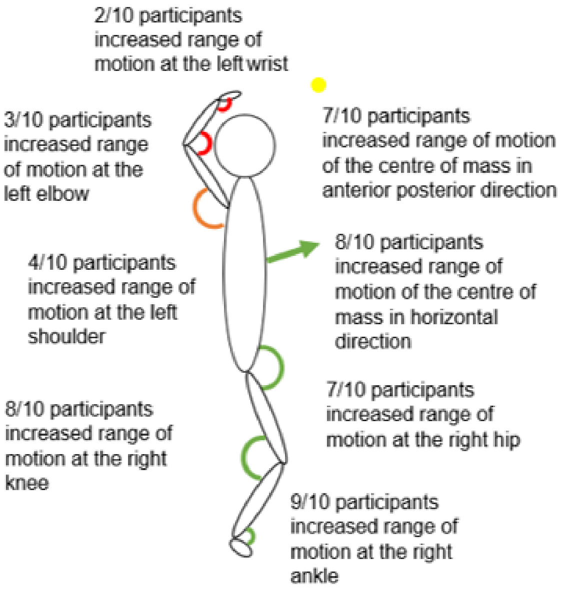

Figure 1: Number of individuals who achieved increased degrees of freedom at key kinematic joints over a period of learning.

Following a period of practice, 7 of 10 individuals (PT01, PT03, PT04, PT05, PT06, PT08, and PT09) experienced significant increase in coordination variability. While 3 of 10 participants experienced decrease in coordination variability (PT02, PT07, and PT10). PT07 showed no signifiant change. Coordination variability was not consistent during the learning period. Increased variability was present for 4 out of 10 participants, however, 9 out of 10 participants more closely resembled dominant arm baseline trail by the end of the learning period (Table 2). Suggesting that individuals had obtained the appropriate set of relative motions required for the first stage of learning for this task (Newell, 1985).

Table 2: Coordination variability of vector coding angle for centre of mass and wrist coupling coordination in the anterior posterior direction over time ($p < 0.05$ indicated by *). Table 2 shows average variability for non-dominant arm trials from S1 – S9 and dominant arm trails from S7 of data collection.

Average coordination variability of the centre of mass and wrist joint (°)			
Participant	Non-dominant throw S1	Non-dominant throw S9	Dominant throw S7
PT01*	5.14	53.31	19.51
PT02*	31.15	30.33	30.81
PT03*	18.84	30.23	37.00
PT04*	32.71	64.50	41.80
PT05*	60.41	66.57	71.23
PT06*	23.52	52.33	48.83
PT07	41.01	23.07	18.89
PT08*	30.64	42.58	42.68
PT09*	11.60	24.53	36.06
PT10*	41.75	13.91	30.98

The results from this study show that all models capture key change point in technique and mutually support the use of all three model and their ability to identify key technique change during learning. From a theoretical perspective the Components Model (Roberton & Halverson, 1984) and Bernstein (1967) freeing arguably provides support for the collective variables idea. Interestingly, despite being from different theoretical perspectives all three models identify key points of transition in technique. Of particular interest is how the Components Model (Roberton & Halverson, 1984) and Bernstein (1967) freeing support the collective variable idea proposed by Newell (1985) which is based on the theoretical proposition that motor 'control' is associated with an overall system dynamics rather that the control of individual degrees of freedom as proposed by Adam (1971) and Schmidt (1975) computing approach.

CONCLUSION: This study has shown developmental changes in non-dominant overarm throwing can be captured through current models of motor learning. From an applied perspective the mutual support provided by these models means we can favour the most useful. Therefore, the Roberton and Halverson (1984) components model approach provides us with a qualitative and generalizable method that can provide practitioners with a framework to assess and progress technique. Greater understanding of how technique changes during learning to throw has the potential to underpin learning interventions for individuals who have suffered a loss in motor control function. In addition, this knowledge would highlight key areas of focus during teaching and aiding sport practitioners, sports coach's and school teachers.

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