COORDINATION VARIABILITY ASSOCIATED WITH ATTENDENCE TO A LONGITUDINAL REDUCING BIOFEEDBACK SCHEDULE

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The aim of this paper was to assess skill exploration via coordinated variability (CoordVar) during attendance to a longitudinal, reducing biofeedback (BFb) intervention. Novices (n=15 BFb; n=15 Control) were introduced to a lunge touch task. Visual BFb were given on the timing and magnitude of rear leg kinematics. A modified CI2 method (CI2area) was used to quantify CoordVar for rear leg joint couplings. Coefficient of variability was used to quantify CoM horizontal velocity as performance variability (PerfVar). Linear regression 95% confidence intervals were compared between groups to assess changes over time. The BFb group demonstrated increasing CoordVar as a response to the BFb, with all participants showing no change in PerfVar. This highlights the potential for CoordVar to identify the effectiveness of BFb provision by practitioners.

KEYWORDS: Kinematics, Kinetics, Motor Learning, Skill Development, Performance

INTRODUCTION: It has been proposed that biofeedback (BFb) can enhance the development of motor skills by guiding skill exploration (Lauber et al., 2013). While BFb has guiding properties, too much feedback can lead to dependency and block autonomous exploration processes (Guidance hypothesis; Salmoni et al., 1984). Frequent and concentrated BFb schedules have shown successful performance modifications (e.g. Mononen et al, 2003), but are time and resource intensive, and can lead to BFb dependency. A reducing BFb schedule, where the provision of feedback and contact is reduced over time, can help to negate these effects (Mulloy et al., 2017). Furthermore, much of the research underpinning how individuals interact with feedback originates from simple tasks with limited degrees of freedom, thus limited complexity. Complex skills involve the interaction of multiple segments, joints and musculature as occurs in many sporting movements, therefore there is a need to better understand how we can aid in complex skill development. Previous research has shown the effectiveness of BFb to develop whole limb movement in a lunge touch task, with changes occurring early on (Mulloy et al., 2017). However, little is known about the coordinated exploration strategies used underpinning these changes when applying BFb. These can be explored through an analysis of coordination variability.

Coordination variability (CoordVar) of joint coupling provides an insightful paradigm to analyse and assess an individual’s skill exploration strategies and could be a useful tool to assess the effectiveness of BFb provision and the translation of theory to practice in an ecologically valid setting. Traditionally viewed as inherent noise within the motor system, a concurrent perspective highlights the functional role of movement variability in maintaining a consistent performance outcome (Mullineaux & Ulh, 2010). The notions of freezing and freeing CoordVar underpins Bernstein’s (1967) stages of learning. Further work by Newell et al. (1985) suggests that individual stages of learning emerge through searching for a coordinative movement, gaining control with a stable pattern, and then later emerging as skilled where the performer is able to use and manipulate environmental constraints. This also allows for system flexibility to achieve a more consistent performance outcome. Indeed, early research has shown how skill learning can manifest at more proximal joints, with distal joint variability allowing for corrections of mistakes that emerge earlier in the kinematic chain (Robins et al., 2006). Additionally, understanding individual responses to BFb is of great importance, particularly through a longitudinal research design. Analysis of CoordVar, therefore, could be used to identify stages of learning during BFb interventions.

The aim of this paper was to assess the CoordVar of the rear leg in a complex skill with attendance to a longitudinal reducing BFb schedule. It was hypothesized that 1) BFb would encourage greater CoordVar over a 6-month period, 2) CoordVar would be greater in the more distal segment coupling, and 3) Performance variability would not change.

METHODS: With Institutional ethical approval, 30 participants were randomly grouped into BFb (n=15; mean ± SD; BFb; age: 26 ± 5 yrs, height: 1.71 ± 0.08 m, mass: 67.4 ± 10.8 kg) or control (n=15; age: 24 ± 4 yrs, height: 1.71 ± 0.10 m, mass: 70.1 ± 14.9 kg). Participants visited the laboratory on six occasions over a six-month period structured as a faded schedule with increasing duration between each visit (e.g. 24 hours up to 12 weeks). During the first week participants attended three sessions, spaced 24-48 hours apart where they were introduced to a novel lunge task, and then returned for single visits at 4-6, 12 and 23 weeks. Each visit comprised of multiple blocks of six lunges.

The aim of the lunge task was to use a 20 cm long pointer to strike a 15 x 15 cm target placed 1.5 leg lengths away from the front foot in the lunge “on guard” start position. During the first three blocks of visit one participants practiced three blocks of ‘self-learning’ following instruction on the starting positon. Each foot was on an individual force plate, with the front foot pointed toward the target, with the rear foot perpendicular to the target. Elbows were tucked in, with the participant crouching to 130° of flexion at the rear knee. Participants were instructed to propel their body forward as quickly as possible, and strike the target centre. Within 10s of each lunge, the intervention group then received BFb on the magnitude and timing of rear leg hip, knee and ankle maximal angular extension velocity for three blocks of BFb. The BFb was displayed as a bar-chart with a colour system used to identify joint sequencing (green signifying correct proximo-distal sequencing; red identifying joints that were out of sequence). Participants were requested to beat previous personal bests with each lunge. All subsequent sessions comprised of one block of retention lunges (no BFb) followed by three blocks of BFb. Following the intervention week, participants returned at 4-6 (blocks 15-18) and 12 weeks (blocks 19-22), and then for a final retention session at 26 weeks (block 23).

Kinematic data were collected using 12 Raptor cameras sampling at 150 Hz and Cortex v5.3 software (Motion Analysis Corporation, Santa Rosa, CA), Kinetic data were sampled at 1500 Hz through two piezoelectric force plates (Kistler, Switzerland). Thirty 12.5 mm retro reflective markers were placed on lateral anatomical landmarks of the whole body, with four additional markers placed on the target, and three on the hand-held pointer. 3D joint angles were calculated for the rear leg hip, knee and ankle. To determine a performance output, the integral horizontal of the force trace from onset of movement was calculated and divided by body mass to provide centre of mass velocity (CoM_{Vel}). CoordVar of joint angular velocity couplings were quantified using a modification of the CI2 technique (Mullineaux, 2017). This method was modified to extract the ‘area’ encompassed by the 95% confidence interval (95%CI) and is denoted as CI2area. The CI2area was calculated for each joint angular velocity coupling time point, and for each block (e.g. 6 data point cluster) during the propulsive phase of movement (onset of rear leg resultant force >10% BW, to take off defined as the first point that differentiated resultant force returned to 0N).

To determine change in CoordVar across the 26 weeks, a simple linear regression was fitted to the group mean CI2area for both joint couplings ($CV_{Gradient}$), and 95%CI of the control group slopes were also calculated (95%CIslope). Simple linear regressions were then used at an individual level to determine if BFb had led to an increase in joint coupling variability by assessing if the individual regression slopes overlapped the 95%CIslope. Performance variability (PerfVar) was quantified using the coefficient of variability of the CoM_{Vel} at both the individual and group level ($PV_{Gradient}$), and also compared to control group 95%CIslope.

RESULTS: As a group the BFb showed an increase in the CI2area over time in both the hip-knee ($CV_{Gradient}$: 0.7 BFb vs. -0.9 control), and knee-ankle joint coupling variability ($CV_{Gradient}$: 3.14 BFb vs. -0.24 control), relative to the control group. This increase was larger in the more distal joint coupling of the knee-ankle (Figure 1). Group PerfVar, as a measure of task performance, was unchanged over the 6-months in both groups ($PV_{Gradient}$: BFb -0.01 vs. control 0.00).

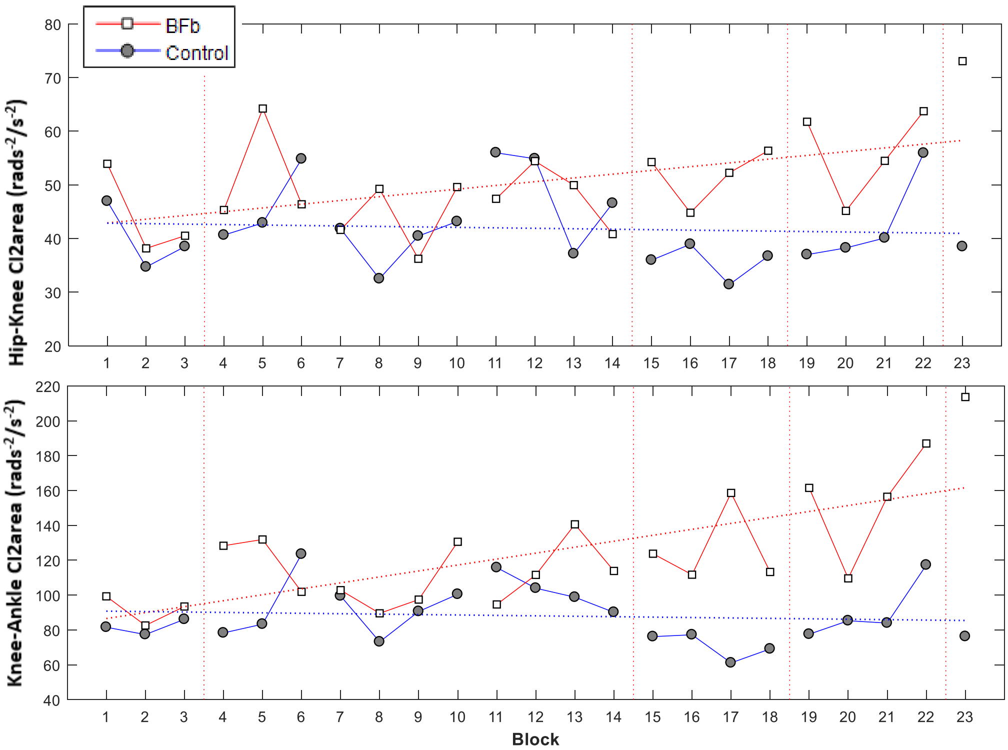

Figure 1. Hip-knee (top) and knee-ankle (bottom) coupling CI2 area variability profiles for BFb and Control groups over 23 blocks, spanning 26 weeks. The horizontal red dotted lines separate between sessions (Self learning, Intervention, 4-6 weeks, 13 weeks and 26 weeks. Dashed lines are simple linear regressions fitted to each group.

On an individual level, 7 out of 15 BFb participants showed greater increases in hip-knee coupling variability throughout the reduced schedule biofeedback intervention than the control group (95%CIslope lower bound, -1.79; upper bound, 1.21), while 9 out of 15 BFb individuals showed a greater increase in knee-ankle variability than the control group (95%CIslope lower bound, -0.55; upper bound to 0.48). PerfVar did not alter over time for almost all participants, with only two of the BFb group's $PV_{Gradient}$ exceeding the control group 95%CIslope (0.26 and 0.21 for each participant; control lower bound, -0.11; upper bound, 0.12).

DISCUSSION: The use of CI2area was able to highlight the exploration of the lunge skill in novices. CoordVar remained constant in the control group yet continually increased with the intervention group receiving reducing biofeedback over a 6-month period. The BFb appears to guide skill exploration (Lauber et al., 2013). This continual exploration is in line with Bernstein's (1967) stages of motor learning, with participants freeing the coordinated degrees of freedom to continually explore task execution. This is also in line with concepts observed by Newell (1985) in that the BFb group were organising the system to adhere to constraints, but had not fully gained control of the complex motor skill to organise a stable pattern. In this respect, the guidance hypothesis was negated, as the BFb guided participants to explore a movement pattern, but ensured that they were not dependent on it once the BFb was removed, as shown with no significant alterations in CoordVar at the retention blocks. BFb variability increased as a group, whereas the CoordVar remained constant in the control group who were free to self-explore in finding their own motor pattern. Linear statistics were used, as visually it is clear that the CoordVar increased linearly, which highlights participants remained in a functional state of technique exploration. However, questions arise as to when this increase would plateau, or reduce, as prescribed in Bernstein (1967), and Newell's (1985) theoretical frameworks, and those of reaching a stable attractor state. These suggest that CoordVar would decrease when a skill was mastered, but would still allow functionally variable interactions to maintain a stable and successful performance outcome. It can be postulated that the volume of BFb (which totaled around six hours per individual) kept the BFb individuals in a continual state of exploration. Therefore, perhaps more BFb would have helped to solidify learning without effects of dependency (e.g. Mononen et al, 2003). Positively, throughout the entirety of the BFb driven skill exploration, the performance output variability (PerfVar) remained consistent in both groups. With only two of the BFb group's $PV_{Gradient}$ exceeding the control group 95%CIslope with minor gradient changes. The group variability changes, paired with successfully altered kinematics in previous research of this task (Mulloy et al., 2017) show that BFb is an effective method to modify technique, with participants exploring this BFb information to identify coordination patterns which satisfy task outcomes.

The individual results highlight that there are varied individual responses to BFb interventions. Relative to the control hip-knee CI2area over the 6 months, 7 out of the 15 BFb group individual's $CV_{Gradient}$'s were greater than 95%CIslope of the control group. Almost half of the BFb group explored the rear leg propulsion pattern by increasing hip-knee coupling exploration strategies. In addition, 9 out of 15 BFb individuals had knee-ankle coupling $CV_{Gradient}$'s which exceeded the 95CI%slope of the control group. This, paired with the greater CI2area block values, shows that the knee-ankle joint coupling was perhaps the more favoured joint coupling exploration strategy. This is in line with previous research underpinning whole limb sequential coordination strategies, with the more distal joints offering a compensatory strategy for movement errors in more proximal segments (Robins et al., 2006; Mullineaux and Ulh, 2010). Looking at both joint couplings across individuals, it appears that the same individuals (n=6) with greater hip-knee coupling variability also had greater knee-ankle coupling variability. This also seems to suggest that certain individuals have greater CoordVar, which may be as a strategy in response to the BFb. This could warrant further investigation in future research to individualise BFb approaches, and also to focus BFb on more easily manipulated joints.

CONCLUSION: This investigation highlighted that the provision of BFb guided and directed skill exploration, but without altering performance consistency. This novel longitudinal approach adds evidence to the functional nature of coordination variability to better satisfy task demands during practice. In future, to assess effectiveness of feedback provision, coordination variability paradigms may offer insight that is of use to the applied practitioner. Specifically, exploring coordination variability could potentially identify the stages of learning during individual skill development cycles, further enhancing training and skill development.

REFERENCES:

Bernstein, N. 1967. *The Coordination and Regulation of Movements*, New York: Pergamon Press

Lauber, B., Keller, M., Leukel, C., Gollhofer, A., & Taube, W. (2013) Specific interpretation of augmented feedback changes motor performance and cortical processing. *Experimental Brain Research*, 227, 31-41.

Mononen, K., Viitasalo, J. K., Konttinen, N., & Pertti, E. (2003) The effects of augmented kinematic feedback on motor skill learning in rifle shooting. *Journal of Sports Sciences,* 21 (10), 867-876.

Mullineax, D. R., & Uhl, T. (2010). Coordination-variability and kinematic of misses versus swishes of basketball free throws. *Journal of Sports Sciences,* 28 (9), 1017-1024.

Mulloy, F., Mullineax, D.R., & Irwin, G. (2017) Longitudinal manipulation of the kinematic chain using a reducing biofeedback schedule. *Proceedings of the 35th International Conference of Biomechanics in Sports,* 35(1).

Newell, K. (1985). Coordination, control and skill. *Advances in Psychology,* 27, 295-317.

Robins, M. T., Wheat, J., Irwin, G., & Bartlett, R. (2006) The effect of shooting distance on movement variability: A new theoretical perspective for neurologic physical therapy. *Journal of Neurologic Physical Therapy,* 30, 120-129.

Salmoni, A. W., Schmidt, R. A., & Walter, C. B. (1984). Knowledge of results and motor learning: A review and critical reappraisal. *Psychological Bulletin*, 95, 355–386.