THE EFFECTS OF AUGMENTED BIOFEEDBACK ON NOVEL MOTOR-TASK LEARNING

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Biofeedback has been shown to be an influential part of skill acquisition and performance, however, the use of biofeedback for novice, sports specific skill learning has not been assessed. Non-rowers (n=3) performed a 10-minute, novel-rowing task, where joint and rowing ergometer kinematics recorded. Following six non-instructed, subjective reinforcement sessions, participants completed a further six sessions whilst receiving real-time biofeedback. The results show that all subjects changed their rowing technique, moving towards the pattern prescribed by the biofeedback intervention. The elbow remained in greater extension until later in the pull, which induced changes in the temporal aspects of both knee and lumbar spine kinematics.

KEY WORDS: acquisition, feedback, novice, skill, sport

INTRODUCTION: Feedback (Fb) has consistently been shown to be one of the most influential components of motor learning. Feedback can be intrinsic or extrinsic, and the latter can take a number of forms including knowledge of results (KR). Termed biofeedback (BFb), this could include information about motor performance (Newell & Walter, 1981), consisting of various biomechanical parameters (e.g. Fothergill, 2010). The effectiveness of such BFb for the enhancement of gross sport-related skills however, remains questionable and debate remains as to the efficacy of, and the optimal strategies for its provision.
Many inferences as to the effects of Fb have been made from artificial laboratory studies that have used simplified tasks, which cannot be generalised to the learning of complex motor skills (Wulf & Shea, 2002). For example, contrary to findings from studies on simplified tasks (e.g. Schmidt & Wulf, 1997), Wulf *et al.*, (1998) demonstrated that higher frequencies of concurrent Fb during the acquisition of a complex motor task produced increased performance during retention tests compared with lower frequencies. These findings could be due to information processing demands and the cognitive effort required to perform more complex tasks and that situations that require increased cognitive effort may necessitate BFb that reduces the load to more practicable levels. There is a current paucity of research into the effects of concurrent BFb strategies on ecologically valid complex motor skill acquisition, or on the paradigms used for its administration. The aim of this study was to determine the biomechanical changes over time of complete novice performers learning a complex motor skill whilst receiving concurrent BFb. Using rowing as a model task, as it is relatively controlled and cyclical, this information could be used to aid the development of motor learning theories and BFb strategies.

METHODS: Three females were recruited for this study (mean±SD, age 19.7±1.4years, height 167.2±4.7cm, mass 63.6±4.5kg) and provided informed consent. The inclusion criteria were that they were physically active and free from injury, and had no experience of rowing or sculling, ergometer rowing, or any other rowing motion. The participants visited the laboratory on twelve occasions, evenly spaced over 4 weeks. During each visit the participants performed a non-rowing related warm up and then rowed continuously for 10 minutes on a Dynamic ergometer (Concept2, Morrisville, VT). To account for the effects of subjective reinforcement (Winstein & Schmidt, 1990) when encountering a novel task, throughout the first six sessions no rowing instructions or BFb were given. For each of the remaining sessions, real-time BFb was provided for alternate minutes, beginning with the second minute. Kinematic data were obtained from 16 passive, spherical, retro-reflective markers, of 9.5mm diameter, affixed to anatomical landmarks of the ankle, knee, elbow, wrist, hip and shoulder joints, and to the pelvis and the lumbar spine. On the ergometer 15 markers were placed on the handle, foot stretcher, and frame. The ergometer was orientated so that the length of the slider ran along the X-axis towards the feet of the subject, the Z-axis was vertically up and the Y-axis was the cross-product of Z and X (pointing left). Three-

dimensional kinematics of the markers were recorded at a rate of 150Hz using eight Raptor-E and three Raptor-4 Digital Cameras (Motion Analysis Corporation, Santa Rosa, CA) to provide real-time BFb.
All marker identification was completed using Cortex v5.3.1 (Motion Analysis Corporation) and data analysed using MATLAB (R2014b; MathWorks, Natick, MA). Data were smoothed using a zero lag 4^{th} order Butterworth low-pass filter with a cut-off frequency of 7Hz. Two key events were defined as the instants at which the velocity of the centre of the ergometer handle in the X-axis changed from positive to negative (catch), and from negative to positive (finish). These were used to define the 'pull' (catch to finish) and 'recovery' (finish to catch) phases, and the combination of one pull and the following recovery constituted one stroke.
Based on work by Lamb (1989), the pull phase was divided into three sub-phases (I, II, and III), lasting 40, 30, and 30% of the stroke distance, respectively. Movement progress during the pull phase was measured as the percentage of the total stroke length the handle had covered with respect to the foot stretcher. Throughout the first sub-phase of the pull, a light blue dialogue box was displayed giving instruction to produce movement through knee motion; throughout the second sub-phase a darker blue box gave instruction to use spinal motion; and throughout the third sub-phase, a dark blue dialogue box instructed use of elbow motion. To promote the maintenance of a more extended elbow angle and the use of kinematic sequencing, if the angle of the elbow changed to below 130° at any point during either of the first two sub-phases, an orange dialogue box appeared informing the participant that elbow motion was initiated too early. If this occurred, BFb was stopped and only restarted during the next pull. To standardise rowing intensity, subjects rowed at a heart rate between 130-150 bpm (Mackenzie *et al.*, 2009) provided through a FT1 monitor and T31 coded transmitter (Polar Electro, Kempele, Finland). The first ten strokes of the pre-BFb session and the last ten strokes of the post-BFb session (sessions 7 and 12, respectively) were analysed. All further ergometer and joint kinematics were analysed in three dimensions and 3D angles, primarily moving in flexion/extension, were defined for the elbow and knee joints (where 180° was full extension), and the lumbar spine (where >90° was flexion). Data were presented as means and standard deviations, and pre-BFb to post-BFb values were compared using paired t-tests at an alpha level of 0.05 (SPSS v.21 (IBM)).

RESULTS: Between the two sessions all subjects exhibited changes in the kinematics of their rowing technique, most notably in the timing of elbow motion. During the first strokes of pre-BFb, the elbow remained in greater extension for the first 36% of the pull phase before moving into flexion. After the BFb intervention, participants began to move their elbow into flexion later during the pull, at 64% (Figure 1), demonstrating a move towards the pattern prescribed by the BFb intervention.

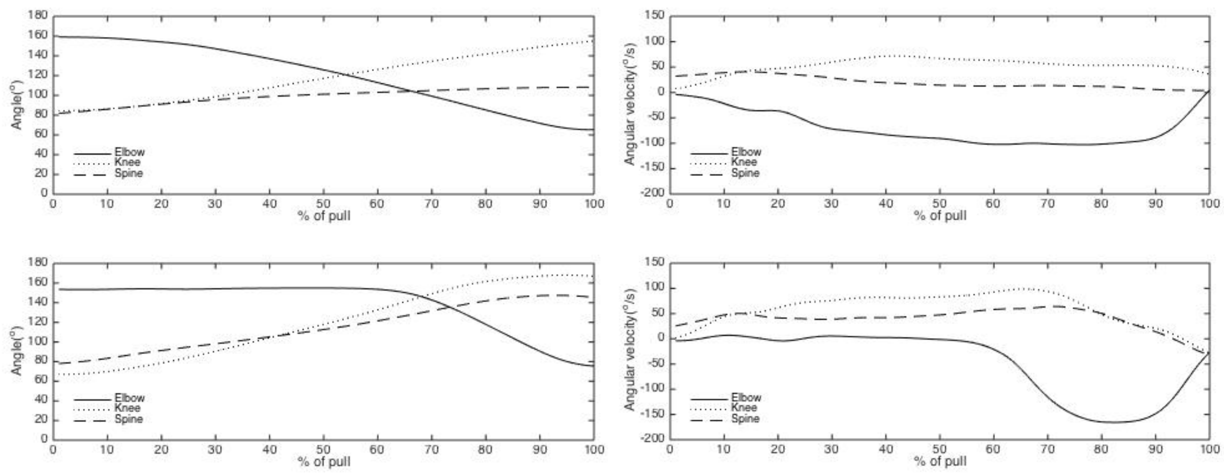

Figure 1: Mean (n=3) elbow, knee, and spine joint flexion-extension angles (left) and flexion-extension angular velocities (right) during the pull of the first ten strokes of the Pre- (top) and last ten strokes of the Post- (bottom) biofeedback sessions.

The angular velocity of elbow motion also demonstrated similar changes. Throughout pre-BFb, flexion angular velocity of the elbow was apparent from the start of the pull, ceasing at 92%. This indicates a contribution from elbow flexion to the resultant velocity of the handle for most of this phase. The cessation of flexion velocity of the elbow did not change post-BFb, however, the BFb intervention did produce a move in the initiation of the elbow flexion angular velocity profile to 56% of the pull, which coincided with the temporal changes adopted in the elbow angle profile. Moreover, this had the effect of increasing the peak flexion velocity produced post-BFb. Despite moving 7° less into extension at the catch, the elbow flexed 14° more at the finish, causing elbow range of motion (ROM) to increase by 7° over the course of the post-BFb session in comparison to the start of pre-BFb (Table 1).

Table 1: Joint kinematics pre- and post-BFb. Data is the mean ± SD for the first ten strokes of pre-BFb and the last ten strokes of post-BFb.

Joint Angle (°)		Pre-BFb	Post-BFb
Knee	C	84 ± 4	70 ± 3*
	F	156 ± 5	169 ± 3*
Spine	C	82 ± 3	78 ± 3
	F	108 ± 3	143 ± 7*
Elbow	C	159 ± 2	152 ± 1*
	F	65 ± 16	51 ± 6*

C=Catch; F=Finish; *Significant change between the first ten strokes of pre-BFb and the last ten strokes of post-BFb.

The changes in elbow kinematics seen here were also accompanied by changes in both knee and lumbar spine kinematics. Both displayed temporal changes in their angle and angular velocity profiles (Figure 1), and in their ROM (Table 1). During pre-BFb, cessation of knee extension velocity occurred at 39% of the pull, which was delayed up until 63% post-BFb, towards the moment that the constraints on elbow motion no longer applied. The knee joint also moved 14° more into flexion at the catch and extended 13° more at the finish. In addition to this, lumbar spine angular velocity began to decline later during post-BFb (33% of the pull) compared to pre-BFb (71% of the pull). Across both sessions, the lumbar spine angle at the catch was not significantly different. However, the spine moved 35° into greater extension at the finish during post-BFb, which contributed to the increase in lumbar spine ROM.

DISCUSSION: All participants adapted the kinematics of their rowing technique, modifying the temporal aspects of each of their knee, spine, and elbow motions towards the pattern prescribed by the biofeedback intervention. As motion of the elbow was most closely constrained by the BFb, it exhibited the greatest temporal changes in its motion, moving more closely towards the target movement pattern, maintaining greater extension until later during the pull (Figure 1). The increase in knee flexion at catch could be attributable to the decrease in elbow extension across both BFb sessions. Alongside decreased elbow extension, a consistent spine angle at the catch infers a greater reliance on movement of the knees at the start of the pull, in line with the demands of the BFb. Also, earlier knee extension, and the delaying of spinal movement (Figure 1), indicates that during post-BFb, participants initiated the pull phase of the rowing motion using their lower limbs, which was followed sequentially by trunk movement, again demonstrating a move towards the pattern set by the BFb intervention. Moreover, this was further exemplified by the temporal changes in the cessation of angular velocity of the knee (63%), spine (71%), and elbow (92%) respectively, giving rise to the development of a kinematic sequence. Such consecutive segment movement has been shown to produce increased power when compared to synchronous segment movement during rowing (Kleshnev & Kleshnev, 1998).
Throughout the pre-BFb session, all participants displayed larger movement variability, especially of the elbow angle at the finish, when compared to post-BFb (Table 1). A decline in the variability of the movement patterns indicates that the BFb intervention gave rise to a

more consistent movement pattern. Moreover, the kinematic differences between the first strokes of the pre-BFb session and the last strokes of the post-BFb session suggest that over the intervention itself there was both adaptation during acquisition of the task and retention and learning of the changes in the kinematics of the technique employed. Furthermore, the changes here also demonstrate the ability of novice performers to attend to, and adapt to, novel, visual, concurrent, BFb interventions while performing a complex, gross-motor task, possibly as a result of BFb being beneficial for reducing the cognitive load of the task and for mediation of task requirements (Wulf & Shea, 2002), especially in the early stages of learning.

CONCLUSION: This study has demonstrated the changes in technique brought about as a consequence of attending to a concurrent BFb intervention and has shown that guidance in the form of concurrent, visual BFb can facilitate the development of novel, complex movement patterns. Moreover, this also had the effect of developing a kinematic sequence in accordance with attempts to match the BFb. These results show clear adaptations towards a prescribed movement pattern, indicating that BFb can be a contributing factor to learning complex, ecologically valid movement patterns. However, investigation into the use of varying concurrent BFb paradigms is warranted, and the scope for combining concurrent with a reduced frequency of BFb during continuous tasks would be worthy of exploration.

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