THE EFFECTS OF CONCURRENT BIOFEEDBACK ON ROWING PERFORMANCE

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The aim of this study was to assess the effects of concurrent biofeedback (BFb) on the ability of skilled rowers to modify the relative motions of their elbow and knee joints during ergometer rowing. Over 2 weeks, BFb (*n*=7) and control (*n*=7) participants completed two maximal rowing tasks (pre-intervention; transfer) separated by three submaximal rowing sessions supplemented with BFb for the BFb group. Pre-intervention to transfer session patterns showed increased elbow extension and knee flexion in the early phases of the pull, which was a move towards the pattern advocated by the BFb intervention. Although these alterations were not universal, BFb appears to be a useful training aid for those further from the target movement pattern.

KEY WORDS: feedback, skilled, sport

INTRODUCTION: Successful biofeedback (BFb) interventions with skilled athletes in a variety of sports exemplify its use not only for the initial acquisition of complex motor skills, but also for their refinement. Few studies have assessed the use of BFb with skilled rowers, despite their ability to attend to both visual and auditory BFb (e.g. Anderson *et al*., 2005; Schaffert & Mattes, 2015). Furthermore, there is limited research on the adaptation of coordination patterns through BFb in complex, sports specific tasks. The aim of this study was to assess the effects of concurrent BFb on the ability of skilled rowers to adapt the coordination of their elbow and knee joints. This information would inform consideration of the incorporation of such BFb into training regimes.

METHODS: Fourteen participants were recruited for this study (sex; m=7, f=7; mean ± SD; age, 22 ± 3 years; height, 170 ± 9 cm; mass, 74 ± 8 kg) and provided informed consent. Inclusion criteria were that participants were free from injury; had ergometer rowing experience of at least one year; were regularly training and competing at the time of the study; and had an ergometer 2000 m time-trial personal-best faster than 8 min 30 s. Each participant was randomly assigned to either an experimental group that received concurrent BFb on their rowing technique (BFb; *n*=7, m=3, f=4), or a control group that did not (Con; *n*=7, m=4, f=3). Participants visited the laboratory on five separate occasions, evenly spaced within two weeks of the first session. During each visit, participants rowed continuously for five minutes on a Dynamic ergometer (Concept2, Morrisville, VT).

During sessions 1 (pre-intervention; Pre-int) and 5 (Transfer), participants rowed at maximal volitional effort, with the aim to row as far as possible, whilst no technique instruction or BFb were provided. For sessions 2 to 4, participants rowed at a sustained target stroke rate (SR) equivalent to 60% of their maximal capacities, determined as percentages of the mean SR calculated over the first maximal effort session. During these intervention sessions, concurrent BFb was given to the BFb group using custom written Sky script (Cortex, Motion Analysis Corporation (MAC), Santa Rosa, CA). The modality and content of the BFb intervention was based on that of Gorman *et al*. (2015). The pull phase of the rowing stroke was divided into three sub-phases (I, II, and III), lasting 40, 30, and 30% of the pull distance, respectively. Throughout sub-phase I, a light green dialogue box was displayed giving instruction to produce movement through knee motion; throughout sub-phase II, a darker green box gave instruction to use spinal motion; and throughout sub-phase III, a dark green dialogue box instructed use of elbow motion. To promote the maintenance of a more extended elbow angle, if the elbow angle flexed to below 130° at any point during either of the first two sub-phases a red 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. At all times the current SR was displayed in the dialogue boxes. The concurrent BFb was provided intermittently for alternate 30-second periods, beginning 30-seconds after the start of the trial. The Con group received no BFb.

Kinematic data were obtained from 16 passive, retro-reflective markers, of 9.5 mm diameter, affixed over anatomical landmarks of the ankle, knee, hip, wrist, and shoulder joints, and to the pelvis and lumbar spine. On the ergometer, 15 markers were placed on the handle, foot stretcher, and frame. Three-dimensional kinematics of the markers were recorded at 150 Hz using eight Raptor-E and three Raptor-4 digital cameras (MAC). All marker identification was completed using Cortex v5.3.1. (MAC) and data analysed using MATLAB (R2015b; MathWorks, Natick, MA). Data were smoothed using a zero-lag, 4th order Butterworth low-pass filter with a cut-off frequency of 7Hz. The first 10 strokes immediately after the midpoint of the Pre-int and Transfer sessions were analysed for ergometer kinematics and 3D elbow and knee angles (where 180° was full extension). Data for each pull-phase were normalised with respect to time through cubic-spline interpolation to 101 data points, and were offset-normalised by subtracting the mean value of each joint angle time-series from each data point of that series.

Bivariate analysis of the elbow and knee joints for each of the 10 strokes for both sessions of each participant was conducted using the 'CI2' method (Mullineaux, 2017). Confidence intervals (CI) of 95% were calculated at each data point. Joins between consecutive pairs of CI created convex quadrilaterals, the overlap of which (at the same time or ±5 frames as a time-lag) indicated where the two sessions were similar. The overlaps of CIs were plotted by group (e.g. Figure 1b), and temporal agreement for group CI overlap periods indicated similarities and differences in the changes between Pre-int and Transfer strokes for a given participant. Two participants (BFb P4; Con P1) were chosen for presentation.

RESULTS: Between 0-33%, 55-77%, and 94-100% of the pull, BFb P4 demonstrated both a spatial and temporal change in the dynamics of their elbow and knee motions, as exemplified by the periods of no overlap (white) of the Pre-int and Transfer sessions elbow-knee angles plot (Figure 1c). These alterations to the stroke indicate an increased elbow angle from the catch, alongside increased knee extension over the same period, and demonstrates a clear move towards the demands of the BFb intervention. Furthermore, the BFb also had the effect of increasing the flexion of the knees at the catch, and the flexion of the elbows at the finish, which possibly caused an increase in the displacement of the ergometer handle.

The BFb intervention appeared to promote changes in movement patterns primarily during sub-phase I of the pull; i.e. no overlap occurred between approximately 20-35% of the pull for three of the BFb participants (Figure 1d). Over the same period (20-35%), no participant in the Con group showed differences in their rowing stroke, as spatial and temporal movement pattern similarities were apparent between both Pre-int and Transfer sessions (Figure 1b). Con P1 demonstrated no change in the relative motions of the elbows and knees through the pull, with the exception of the first 7% (Figure 1a). Similarly, differences in the pull phases of the Con group were most apparent over the first 10%. This coincided with between-session dissimilarities of some participants in the BFb group. Variances at the start of the stroke were thus independent of group. Responses to the BFb varied across individuals. Despite promoting changes to the stroke over sub-phase I of the pull phase, the BFb intervention did not influence the elbow-knee relationship for four of the seven participants (solid lines; Figure 1d). The remaining three BFb participants demonstrated a total of between 17-63% difference in the rowing strokes between sessions. Furthermore, differences in the stroke were apparent during sub-phases II and III of the pull for some of the Con participants (Figure 1c). Two Con participants showed a total of <90% similarity, which indicated some degree of variation in the rowing stroke between the sessions.

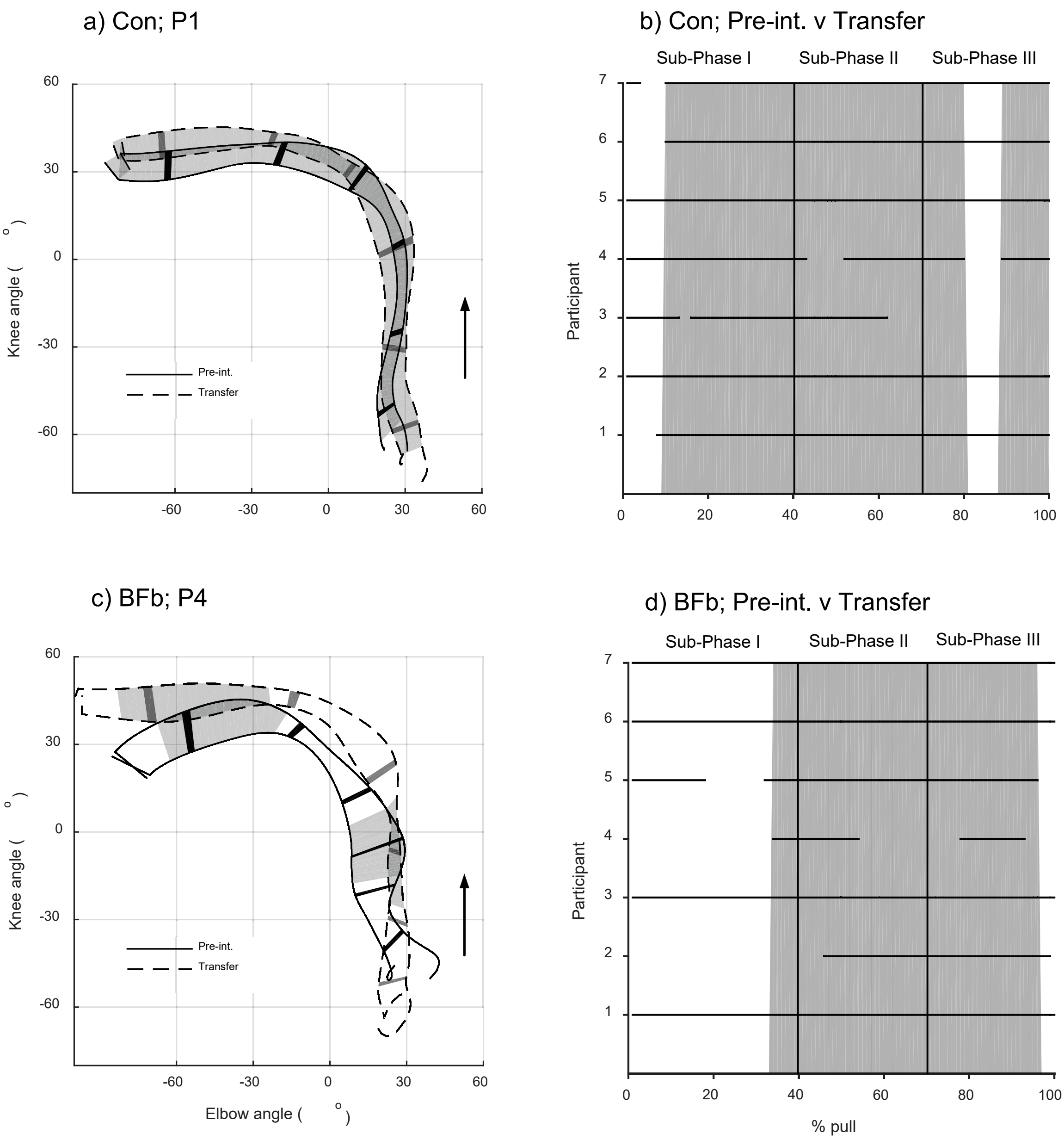

Figure 1. Elbow-knee angles bivariate plots for selected control (a; Con; P1) and biofeedback (c; BFb; P4) participants, for pre-intervention (Pre-int) v Transfer sessions. Solid and dashed lines represent the 95%CI for respective sessions. Time-periods of overlap are shaded (light or medium-light grey) and periods of non-overlap are white. Highlighted quadrilaterals represent intervals 15% of the normalised pull for Pre-int (black) and Transfer (medium-dark grey) sessions, which illustrate temporal alignment between series. Arrows in (a) and (c) indicate movement from the catch towards the finish. Minimum values are elbow flexion and knee flexion. Figures (b; Con) & (d; BFb) show periods of CI overlap for each participant, by group, for Pre-int v Transfer session. Shaded regions indicate where more than five participants for Pre-int v Transfer sessions overlapped, and vertical lines represent transition between pull sub-phases. Data were from catch to finish (0 to 100%-pull phase).

DISCUSSION: To assess if BFb is a useful training aid to improve skilled performance, concurrent BFb was provided to accomplished rowers. Results showed that whilst attending to concurrent, visual BFb, the pull phase of the rowing stroke can be successfully altered, as participants developed a movement pattern that was congruent to that promoted by the BFb. This was characterised by modification of the coordinated motions of the elbow and knee joints. During the Transfer session, participants who responded to the BFb demonstrated delayed elbow flexion during sub-phase I, and a greater reliance on the lower limbs to subsequently initiate the pull and accelerate the ergometer system (Figure 1c).

Alterations to the movement pattern were retained in to the Transfer session, where both the BFb was removed and there was a change in the SR. This indicates that changes made at a low SR were successfully maintained whilst rowing at maximal intensity, and maintained when BFb was unavailable to guide the movement pattern. This shows not only an acquisition effect of the BFb, but also an adaptability of the newly learnt movement pattern. The BFb therefore aided the production of a movement pattern that was not specific to the conditions under which it was acquired.

Although variation in Pre-int to Transfer movement patterns were promoted by the BFb for some participants, BFb on the coordination of knee, spine, and elbow motions may be of importance to certain individuals, as the coordination did not change for some participants (Figure 1d). As some of these more proficient performers were capable of producing a movement pattern that was similar to that of the BFb during Pre-int, the content of this intervention may not have been specific or applicable enough for use with all skilled rowers. As rowing technique varies individually, there are potentially no optimal parameters that all rowers should exhibit (Lamb, 1989). Only those who were initially further from the BFb pattern during Pre-int showed differences into the Transfer session, similar to the successful application of a comparable BFb intervention with novice rowers (Gorman *et al*., 2015). However, those participants who could still use the BFb appeared to do so effectively.

Future directions should investigate the purported guidance effects of BFb through comparison of the movement patterns from the last intervention session to Pre-int and Transfer sessions. A measure of the responses to the BFb at lower exercise intensity, and potential variations of that pattern during subsequent maximal rowing, would elucidate the effectiveness of this BFb intervention and the ability of skilled rowers to attend to concurrent, coordination-based BFb. The application of this BFb intervention at higher proportional SRs may increase the specificity of this BFb training and reduce possible guidance effects. Additionally, comparison with other methods such as verbal coaching or video feedback would further clarify the effectiveness of the BFb.

CONCLUSION: The application of concurrent BFb was successful in altering the coordinated motions of the elbow and knee joints of some skilled rowers, yet was not effective for all rowers. The intervention was detectable by CI2 if initial movement patterns were further from the desired movement pattern. Absences of change could be due to the application of this BFb intervention with skilled rowers, who were already close to the target movement pattern prior to the intervention. BFb appears to be a useful tool as a training aid, however the content and design of the BFb would benefit from individualised settings.

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