AN EXAMINATION OF INTRAROWER COORDINATION MOVEMENT COUPLING USING CONTINIOUS RELATIVE PHASE

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The purpose of this study was to identify the coupling relationships between body segments joint angles created in completion of the rowing stroke. A dynamical systems approach utilising continuous relative phase was used to investigate the higher order dynamics of the movement. Five rowers (1 experienced, 4 novice) completed a 2000m row on a RowPerfect ergometer; the kinematics of which were captured using a 200Hz motion analysis system. The results indicate that purely upper limb, and one joint upper-one joint lower limb coupling, show much larger variation than purely lower limb coupling. In particular the knee-elbow coupling relationship differs dramatically between the experienced rower and novices. From a practical viewpoint this coupling relationship should be focused upon to improve the rowing ability of the novice.

KEY WORDS: rowing, kinematic data, coordination, continuous relative phase

INTRODUCTION:

The purpose of this study was to investigate the intrarower coordination during the performance of a 2000m row. Whilst the analysis of interrower coordination between a rowing crew have been carried out (e.g. Hill, 2002), this has not occurred in the case of intrarower coordination. Further, the analysis of rowing technique has focused predominately upon kinetic data (e.g. force curve produced) without examining the kinematic movement characteristics. The objective then is to examine the kinematic data with a view to differentiating between an elite and novice rowers. The identification of the key components of the rowing stroke will allow these components to be used for feedback to the rower in order to improve rowing technique. Rowing can be considered to be an open motor skill which is cyclical in nature. From this perspective it can be compared to the motor skill of walking, or the production of a natural gait pattern. The literature is abundant with evidence of the relevant coordination within gait (e.g. Haddad *et al.*, 2006), but not within rowing. This paper aims to apply this type of analysis to rowing data.

The use of dynamical systems theory (DST) is ever increasing within the analysis of biomechanical and human movement data. It has been reported that the rich dynamical interactions amongst the multiple degrees of freedom during movement may not be adequatly represented using simple parameter – time plots (Hamill, 2006). Consequently, movement coordination and variability has received increasing attention in recent years. Movement coupling, the extent to which two segments are functionally linked during movement (Kurz & Stergiou, 2004), allows the behaviour of two segments to be described by one variable. Relative motion plots such as angle-angle diagrams and phase plane plots provide information about the movement of a segment relative to another segment or relative to angular velocity (Kurz & Stergiou, 2004). However, this data is limited to qualitative interpretation. Further calculations using a technique such as continuous relative phase (CRP) is necessary to determine quantitatively the extent to which two segments are coordinated. Therefore, while the basic kinetics and kinematics of a movement pattern may not change the higher order parameters contain much more information (Hamill, 2006).

The optimisation of the rowing stroke is something that athletes, coaches and sport scientists strive for. Despite the physiological demands of rowing, it is rowing technique (or biomechanics) that can determine the more successful rower from others of similar physiological calibre (Nelson & Widule, 1994). Despite relatively numerious studies the biomechanics of rowing remains poorly understood, although it has previously been reported that certain elements of the rowing stroke must be produced in conjunction with each other. (Zatsiorsky & Yakunin, 1991). Fundamentally, from a biomechanical perspective, the joint kinematics of five major joints in the body can be used to define the performance of the rowing stroke. The coordination aspects within these five major joints is believed by the author to be of major importance and consequently the establishment of the most relevant coordination aspects between them is the key interest in this study.

METHOD:

Data Collection: Five rowers (four novices, one experienced; age 26±4.6 yrs; height 173±5 cm; weight 74±4.3 kg) participated in the study. The participants completed an informed consent form and pre-test questionnaire. Participants were familiarised with the testing procedures and any possible risks were outlined. Ethical approval for this study was obtained from the University Research Ethics Committee. The participants performed a 2000m row on a RowPerfect ergometer (RowPerfect, CARE RowPerfect, The Netherlands). Use was made of the RowPerfect ergometer as the agreement between this type of ergometer and on-water performance has been reported to be excellent (Lyttle *et al*., 2001). This distance was completed in 326±78 strokes. The participants' kinematic data were captured at 200Hz (Motion Analysis Inc, California, USA). Reflective body markers were placed on the fifth metatarsal, lateral malleolus of the tibia, lateral condyle of the femur, greater trochanter of the femur, acromion process, lateral epicondyle of the humerus and styloid process of the ulna. From this five joint angles for the entire movement were identified.

Data Analysis: A measure of performance consistence was calculated for each participant by means of normalised power/stroke dispersion (PSD), using the following equation:

$$PSD = \frac{1}{PS_{MEAN}} \sqrt{\frac{\sum_{i=1}^{N} (PS_i - PS_{MEAN})^2}{n}}$$

Where:

PS_i = power produced for stroke i (W)
PS_{MEAN} = mean power produced for n strokes (W)
n = number of stroke in region of interest

The PSD was used as a measure of consistency of power production by the rower. A constant power production is inherently more efficient. A value approaching zero for PSD indicates a low level of dispersion for the power/stroke values within the region of interest. A value of zero represents the ideal, indicating the rower maintains identical power/stroke output throughout the time or distance investigated.

Data analysis techniques used in DST were performed in this study. This involved angle-angle (AA) diagrams, phase plane (PP) plots, and CRP. Phase angles for each of the respective segment PP plots were utilized to calculate the CRP. CRP was calculated by subtracting the phase angles of the corresponding segments throughout the stance. CRP represented the phasing relationship between the actions of the two interacting segments at every point during the movement. Values close to 0^0 indicated that the two segments moved in phase; values close to 180^0 indicated that the two segments were anti-phase. The CRP curves for each segmental relationship were averaged across movement periods and mean ensemble curves were generated for each subject. To statistically test differences between the CRP curves the mean absolute values of the ensemble CRP curve values (MARP) were calculated by averaging the absolute values of the ensemble curve points. A low MARP value indicated a more in-phase relationship between the interacting segments; a high MARP value indicated that the neuromuscular organisation was more anti-phase. The coordination patterns (MARP values) were then compared to the PSD values in order to assess whether the improved coordination led to an improved consistency. Statistical correlation ($p<0.05$) were carried out using SPSS (V13– SPSS Inc, Illinois, USA).

RESULTS AND DISCUSSION

Graphical qualitative examination of the AA diagrams indicate that several couplings were similar across all subjects (e.g. knee-ankle) but others showed a clear distinction (e.g. knee-elbow) between particular subjects on some couplings. To further extend the analysis phase portraits were drawn up, again for all joint angle coupling combinations. Qualitative analysis of these graphs indicates clear distinctions between subjects for particular joint angle-velocity relationships. The next step of the analysis involved CRP. Whilst rowing requires an in-phase relationship for some joints (e.g. knee-ankle), it requires an anti-phase relationship for others (e.g. knee-elbow; rowing requires extension of the knees and flexion of the elbows during the drive). One basic hypothesis of the DST approach is that CRP variability increases at key transition points in the movement cycle (Kelso, 1995; Van Emmerik & Wagenar, 1996). This is evident in the elite rower (#1) in the hip-knee CRP (Figure 1).

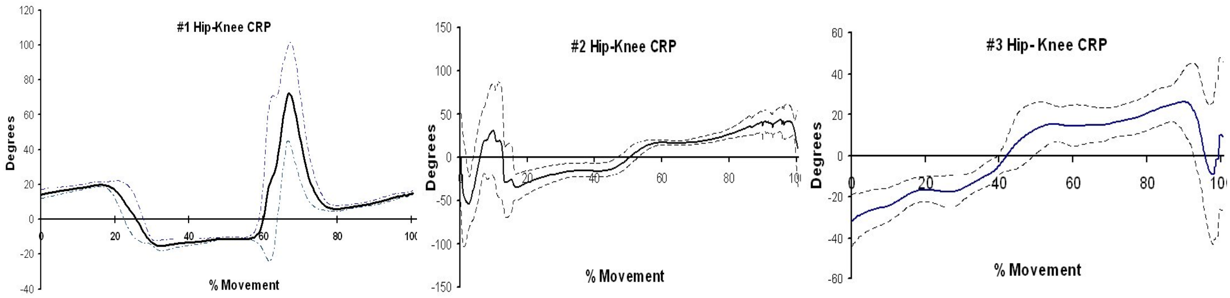

Figure 1: **Comparison of Hip-Knee CRP Angles–subject (#)1,2,3. #1 =expert #2,3 = novice**

Statistical analysis showed positive correlations ($p<0.05$) between MARP values and PSD for the lower body joint couplings (hip-knee, hip-ankle, and knee-ankle), but no significant correlations for any of the upper-lower (shoulder/elbow with hip/knee/ankle) or upper body (shoulder-elbow) couplings. A graphical representation of knee-ankle correlations (Figure 2) and knee-elbow correlations (Figure 3) are presented.

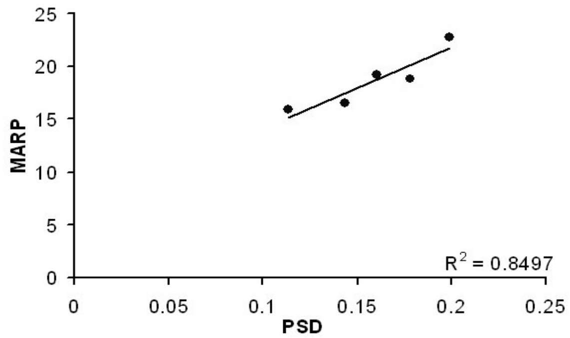

Figure 2: Correlation of knee-ankle MARP and and PSD values for all five subjects

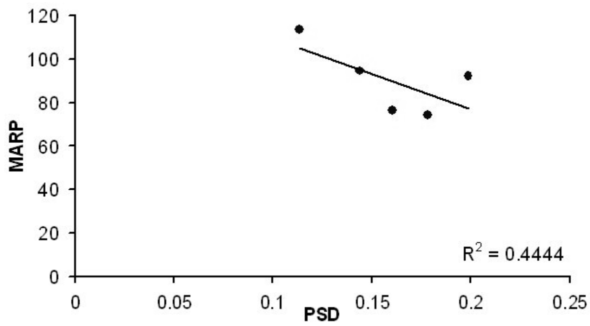

Figure 3 Correlation of knee-elbow MARP and PSD values for all five subjects

The hypothesis that rowing experience would play a role in neuromuscular adaptation was supported in this investigation. Figure 3 portrays the experienced rower having a greater anti-phase movement for knee-elbow coupling. The novice rowers show a lower MARP with varying scores of PSD. Examining Figure 2, the experienced rower, who had an increased average power output, has a decreased PSD and a decreased MARP on lower body couplings, based upon more in-phase movements between body segment joints. This would indicate that the force curves produced from individual segments of the body overlapped. This also allows focus on the length tension relationship of individual muscle fibres. It is known that the length tension relationship follows an inverted U shape and that greatest force is produced at the greatest sacromere overlapping (Brooks *et al.*, 2000). This is true for the muscles involved in both in-phase movements (e.g. knee extensors and hip extensors) and anti-phase movements (e.g. knee extensors and elbow flexors) of the rowing stroke. If the force curves of different body segments occur at the same time then greater force will be produced. From a rowing perspective the position of the oar in the water is paramount. An oar travels an arc centered at the oarlock. A force time curve which focuses the majority of the impulse at the time when the oar is sweeping at 90^0 to the boat is going to result in greater boat velocity, thus providing greater forward propulsion. If each individual body segment is producing its greatest force at different stages the this will not be the case; rather the total force will be spread out over the entire stroke with the resultant loss of forward propulsion as force will be acting perpindicular to the direction of the boat. From a practical view point it is not possible to produce the majority of force at exactly 90^0 and thus it is suggested to produce the majority of the force between 70^0 and 110^0.

CONCLUSION:

Analysis of movement coupling is a relatively new area, which has been examined in a limited number of studies to date. The most appropriate measures to do this are still being investigated. The use of CRP to examine coupling relationships is based on kinematic data obtained across the entire rowing stroke. It is necessary to reduce this information to one variable to quantify it and allow comparisons between groups and individual joints. Future work will focus on increasing the number of elite athletes who produce a greater power output beyond one, and increasing the total number of athletes beyond five. Secondly it will focus on examining the variability within one subject with regards to the CRP as a function of power output. In conclusion coordination is important in the sport of rowing. This is so on a two fold basis. The first is for force production purposes and the summation of forces. The second is for the reduction of time. If the forces are produced together the time will be less and the power will consequently be greater. CRP is one method of analysing coordination. It does so by means of in-phase and anti-phase movements. The biomechanist must identify the type of phase relationship required before comparison and use post hoc examination to differentiate between the ability based upon the results. By using this method one can categorise rowers as elite or non elite. The practical implications of this research are based upon the feedback to the rower to pinpoint areas which are not co-ordinated, and do not portray the required in-phase or anti-phase movement couplings.

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