EFFECTS OF IMPOSED CYCLE FREQUENCY TRAINING ON THE HEAVE AND PITCH PHASE RELATIONSHIPS IN UNDULATORY UNDERWATER SWIMMING

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This study compared the effects of training at a self-selected preferred cycle frequency (PF) with an identical imposed cycle frequency (IF) on the heave and pitch phase relationship in undulatory underwater swimming (UUS), to examine the effects of frequency imposition on coordination. Kinematic data were recorded from 16 skilled swimmers performing maximal UUS prior to and during 4-weeks UUS training at either their PF or an IF set at their preferred frequency, with weekly testing sessions and final retest session 2-weeks post training. No differences in maximal swimming velocity were found. No differences were found in heave and pitch phase relationship between training groups. Further research is required to establish the efficacy of heave and pitch coupling as an effective measure of UUS behaviour in skilled swimmers.

KEY WORDS: Training, Coordination, Performance.

INTRODUCTION: The importance of movement frequency to an overall understanding of coordinated action and skilled movement cannot be understated, whether it is the frequency of an end-effector (global) or the component frequencies of various (local) subsystems which are coupled within a coordinative structure. The frequency (relative or otherwise) of movement has been used as a means to classify, predict and/or determine the efficacy and efficiency of the movements produced (Swaine & Reilly, 1983; Van Emmerik, *et al.,* 1989; Neptune & Hull, 1999). Primarily, imposed cycle frequencies have been utilised, as a control variable, with manipulations used to perturb the coordinative structure(s) of a *system*, to assess the short term impacts on the stability and topological dynamics of the resultant movement behaviour in a self-organising system (Smoll & Schulz, 1978; Carson *et al.,* 1999; Semjen, 2002). Previous research has also examined the efficacy of imposed frequencies for training (Sparrow et al.,1999; Van Emmerik *et al.,* 1989), suggesting that the preferred cycle frequencies (self-selected and imposed) represented the most effective ways in which performance/learning was optimised, compared to learning at higher and lower imposed cycle frequencies. However, the majority of research into the efficacy of training/learning via an imposed frequency has not typically employed imposed frequencies which are equivalent to the performer's preferred cycle frequency, the exception being Van Emmerik *et al.,* (1989). Importantly, there is a dearth of research which has specifically examined the effect of frequency imposition, i.e. the effects on coordination and performance of the act of 'imposing' (and training at) a cycle frequency identical to a performer's preferred cycle frequency. Without a thorough understanding of the effects of the act of imposition of a cycle frequency identical to performers own preferred cycle frequency, future studies could not fully explain and/or delineate the effects of imposing higher or lower cycle frequencies on changes in performance and coordination. Maximal undulatory underwater swimming (UUS) velocity is produced via the sequenced oscillations of sections of the body creating bends along its length, generating an undulatory wave and transferring momentum to the water to produce a propulsive impulse (McHenry *et al.*, 1995). The movements employed to generate the propulsive forces required for UUS, act simultaneously to produce a large proportion of the resistive forces (active drag) experienced (Ungerechts, 1984). Connaboy *et al.* (2011) have shown that the cycle frequency of the end-effector in skilled swimmers performing maximal UUS are very reliable. This could suggest that the coordination which occurs at this cycle frequency may be optimised to produce the maximal UUS performance. Previous research into undulatory locomotion in aquatic animals (Hertel, 1966; Anderson *et al.* 1998) proposed that the phase relationships between the heave motions and pitch angle oscillations act to determine and control the propulsive performance of the caudal aspects of the swimming body. A pitch angle of zero signifies that the axis of the end-effector is parallel to the path of progression of the swimmer, effectively minimising drag encountered by the end-effector, although negating the generation of an effective propulsive impulse (Fish & Rohr, 1999). Anderson *et al.* (1998) suggested that the relative-phase relationship between the heave and pitch of the end-effector is critical to the maximisation of an effective propulsive force and simultaneously the minimisation of active drag, with an optimal phase angle difference of 75° reported. Given the importance of heave and pitch phase relationship in the production of effective UUS locomotion, it would appear as an appropriate initial choice in the search for an order parameter to encapsulate the behaviour of the skilled UUS system, to examine the effects and efficacy of the imposition of cycle frequency identical to the swimmers own preferred cycle frequency. In this instance, are any improvements associated with training at a preferred cycle frequency a consequence of the ability to freely adopt a cycle frequency and search the perceptual-motor workspace from cycle to cycle, or is it the initial benefit contained/represented in the individuals, already established preferred cycle frequency of the skilled swimmer? The aim of the present study was to compare the effects of training at a preferred cycle frequency (PrefGp) and an imposed preferred cycle frequency (ImpGp) on the heave and pitch phase relationship in maximal UUS in skilled age-group swimmers.

METHODS: Sixteen (8 male/8 female) national age-group competitive swimmers (Mean±SD: Age 16.0±1.4 years, Height 171.9±9.1cm, Mass 63.7±12.1kg) from the '*Elite*' squad of a local swimming club were analysed. Participants had a minimum of 5 years competitive swimming experience (7.01±1.7years), and had competed in a national age-group final. The participant selection criteria were established to ensure a level of UUS which would be representative of a 'skilled' swimmer. Prior to undertaking the study, ethical approval was granted from the local University ethics committee. Informed consent was obtained from each participant. The participants' mean preferred UUS cycle frequencies were established following an initial familiarization session (Connaboy *et al.,* 2011). Participants were randomly assigned to either the PrefGp or ImpGp and performed 3 trials of PF and IF UUS in each testing session. The IF was imposed using an electronic metronome (Sportspacer$^{\mathrm{TM}}$). Participants completed an initial testing session (S0) immediately prior to the commencement of training, and a further 4 sessions (S1-S4) at weekly intervals during the training period. A retest (RT) was completed 2-weeks post training. Training consisted of 3x40min sessions per week, incorporating 5 undulatory drills. The PrefGp performed the drills at a self-selected frequency and the ImpGp performed the drills at an IF set at their initial PF using the Sportspacer$^{\mathrm{TM}}$. The 2D kinematics were analysed from the digitised motions of the wrist, shoulder, hip, knee ankle and 5th metatarsal phalangeal joint (MPJ) centres. Heaving motions were calculated as the vertical, quasi-sinusoidal motions of the end-effector (ankle joint). Pitch angle was calculated as the segment angle of a line between the joint centre of the ankle and the 5th MPJ, relative to the path of the swimmer. To examine between session variability in continuous relative phase (CRP), ensemble curves of the six cycles (representing either PF or IF from a testing session) were produced for each participant, as the mean from the six CRP curves. Two methods were employed to analyse any changes in the CRP data between testing sessions. The mean absolute relative phase (MARP) angle over a complete kick cycle was calculated to examine discrete between session variations in heave and pitch CRP segment couplings. Discrete measures of the variability of the ensemble CRP curve for each individual were then calculated as the root mean square error (RMSE) for the six ensemble curves for each condition. A measure of the average (maximal) swimming velocity (max*U*) was included to monitor changes in UUS performance. Separate three-way (Groups x Frequency tested x Session) repeated measures ANOVA were conducted, to analyze the MARP and RMSE of the heave and pitch CRP, and max*U* achieved by the skilled swimmers.

RESULTS: There were no statistically significant main or interaction effects for max*U* across the training and retest period. For the MARP of the heave and pitch CRP there was a significant main effect for Session (*F* (2.06,10)=32.06, *p*=0.001) with a large effect-size statistic (η^2=0.696), showing a significant difference (*p*<0.05) between S0 and S2, S3, S4 and RT and also RT and S2, S3, and S4. The MARP heave and pitch angle increased in both PF and IF for both training groups, with mean MARP heave and pitch angle increasing from S0 (119.9) through to S4 (124.5) before dropping slightly in the RT session (123.9). However, there were no significant differences for either the Frequency tested x Session (*p*=0.684) or Group x Frequency tested x Session (*p*=0.780). There was a significant heave and pitch angle RMSE main effect for Session (*F* (2.88,10)=7.90, *p*=0.001), with a large effect-size statistic (η^2=0.361) and also a significant interaction effect for Group x Session (*F* (2.88,10)=3.41, *p*=0.028) with an medium effect-size statistic (η^2=0.196). Repeated contrasts revealed significant differences (*p*<0.05), by Session between S0 and S3 and between RT and S0, S1, S2 and S3. There was a general trend of decreased RMSE in both PF and IF for the PrefGp across S1 to S4 (Figure 1). The ImpGp showed fluctuations across the testing and training session with an initial increase in PF heave and pitch angle RMSE over S0 to S2 before decreasing in S3, increasing to the highest levels in S4, before decreasing again at RT. No significant interaction effect was found in heave and pitch angle RMSE for either Frequency tested x Session (*p* =0.192) or Group x Frequency tested x Session (*p* =0.618).

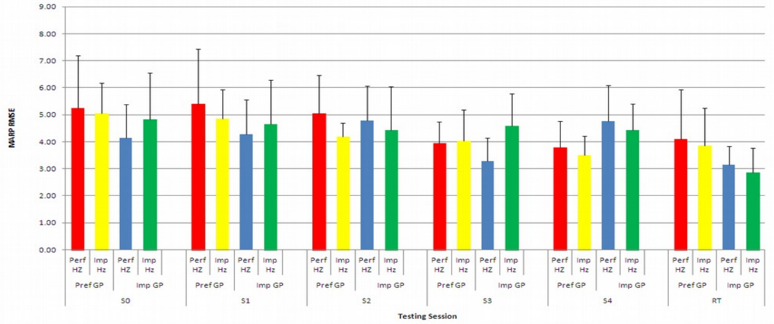

Figure 1. Root Mean Square Error for Heave and Pitch angle Continuous Relative Phase across testing sessions (S0-S4 and RT) for preferred and imposed frequency UUS by training group

DISCUSSION: Four weeks training in either the PrefGp or ImpGp did not result in any change in max*U.* Either the training period and/or the 3xweek training stimulus were insufficient to cause any changes / improvement in UUS performance within the skilled swimmers tested. However, there were changes in MARP and RMSE across the training and RT period. While MARP was found to increase across the training period, this increase was similar for both training groups and at both the PF and IF tested. The MARP was found to be beyond the 75° value for heave and pitch phase coupling proposed by Anderson *et al.* (1998) as optimal for propulsion. Though MARP is a discrete measure of the relative phase relationship and does not provide information regarding the changes in value of CRP throughout the UUS cycle, the heave and pitch phase coupling were consistently higher than the 75° optimal value throughout the UUS cycle. The morphological limitations of the human anatomy in conjunction with the cycle frequencies adopted when attempting to maximise UUS may act to limit the achievement of this optimal coupling within the UUS cycle in comparison to highly adapted aquatic animals. Furthermore, as a consequence of training (irrespective of group) the MARP was shifting away from the proposed optimal 75° relationship, suggesting that the skilled swimmer may be preferentially optimising another aspect(s) of coordination to maintain max*U*. The RMSE was found to decrease between S0 and the RT, indicating a reduction in the variability of the coordination of the heave and pitch CRP and suggesting continued practice at either PF or IF increases the stability of the heave and pitch phase coupling. The population examined in the present study is unlike those previously analysing the effects of training at a movement frequency on coordination/performance, as those have concentrated on the novice/intermediate to skilled transition (Sparrow et al.,1999; Van Emmerik *et al.,* 1989). Little emphasis has been focused on the further optimisation of skilled performers. Unlike novice/intermediate performers, skilled performers in cyclical activities are classified by having achieved a high level of performance and a very reliable cycle frequency (Connaboy *et al.,* 2011). Therefore, the efficacy of continued practice at a preferred cycle frequency (PF or IF) to further improve performance may be questioned, as practice may only serve to reinforce already established coordination pattern(s). Continued improvements in performance may require adaptations in coordination, and as the both PF and IF do not perturb the coordination sufficiently enough to improve max*U*, then a possible interpretation is that the maximal performance contained/represented in the individuals, already established preferred cycle frequency is not further enhanced by repeated practice.

CONCLUSION: Further research is required to establish whether there are other order parameter(s) which encapsulate UUS behaviour better than heave and pitch CRP and whether training at an IF outside of the PF can perturb coordination resulting in increased max*U* in skilled swimmers.

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