# THE INFLUENCE OF WORK RATE AND CADENCE ON MOVEMENT COORDINATION IN CYCLING

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This study investigated the effect of cycling cadence and work rate on coupling motion in trained male cyclists. Subjects undertook 9 pedalling bouts at various work rates and cadences (120, 210, 300 W at 60, 90, 120 rpm) and intra-limb joint coupling motions were examined using a continuous relative phase (CRP) analysis. The hip/knee (HK) coupling motion was significantly more in-phase during the 90 and 120 RPM trials compared with the 60 RPM trial (recovery phase). Similarly the knee/ankle (KA) coupling motion was significantly more in-phase in the 120 RPM trials than the 60 or 90 RPM trials (propulsive phase). No differences were found between work rate conditions. The results suggest for higher cadences the resulting movement patterns are more stable and consequently more economical. Cyclists should therefore seek to maintain a higher cadence.

**KEYWORDS:** cycling, coordination, cadence, work rate, economy

**INTRODUCTION:** In a kinematic chain the motion of one segment subsequently influences the motion of an adjacent segment, and therefore the study of isolated joints does not effectively capture the complexity of the coordinated motion of components of the body (Bartlett et al., 2007). The consideration of the coupling relationship between segments may therefore be crucial in the analysis of human movement.

There is conflict within the cycling literature regarding the most economical cadence, defined in this study as that which is associated with the lowest metabolic cost at a given work rate. This is due in part to its work rate-dependent nature (Ansley & Cangley, 2009). Li (2004) found as cadence increases there is an added influence of the inertial properties of the limbs, which consequently affects neuromuscular coordination. Changes in the coordination patterns utilised by cyclists as a result of changes to the work rate and /or cadence may therefore have an effect on their economy.

A key component in the analysis of movement coordination is the role of variability within the system under investigation (Wilson et al., 2008). Movement variability is important in skills where the adaptability of complex motor patterns is necessary within dynamic performance environments (Button et al., 2006), enabling athletes to adjust to both intrinsic and extrinsic factors (Bradshaw & Aisbett, 2006). However, in skills where tight task constraints are imposed, such as in cycling, there is likely to be a reduced requirement for flexibility and any variability present in the system may therefore be indicative of an inconsistent performance. In support of this Chapman et al. (2009) concluded that elite cyclists had greater consistency of inter-joint coordination compared with novice cyclists.

The aim of this study was therefore to investigate the affect of the work rate and cadence on the coordination exhibited by trained male cyclists and the subsequent implications for training and competition in terms of adopting the most economical strategy.

**METHODS:** Six trained male cyclists were recruited for the study. All subjects gave written informed consent and were free from injury at the time of the study. Using a two-scanner Cartesian Optoelectronic Dynamic Anthropometer (CODA) motion analysis system three-dimensional kinematic data were collected at a sampling rate of 100 Hz. Exercise was performed on a Monark braked cycloergometer. Twenty-three active markers of 2-mm diameter were attached to the right lower limb and the pelvis. The markers were located on the following anatomical landmarks: 5$^{th}$ metatarsal head, 1$^{st}$ metatarsal head, lateral malleolus, medial malleolus, heel, medial and lateral knee epicondyles, greater trochanters, anterior superior iliac spines, iliac crests and posterior superior iliac spine. The remaining markers were attached to polystyrene plates which were placed on the distal thigh and shank. Each plate contained a cluster of 4 markers. An additional marker was placed on the pedal axis in order to identify individual revolutions.

Subjects undertook 9 pedalling bouts in a randomized order at various work rates and cadences (120, 210, 300 W at 60, 90, 120 rpm). Subjects were instructed to reach the required cadence (visual feedback provided by digital RPM-meter) and maintain this for at least 10 seconds before data recording commenced. Data were recorded for a minimum of 20 s. A minimum of a one minute of recovery was given between trials. For each trial a total of 10 consecutive revolutions within ± 2 rpm of the required cadence were selected for subsequent analysis. A complete revolution was the time from top dead centre (TDC) to subsequent TDC. TDC was defined when the pedal marker reached its maximal value in the z-axis. Visual 3D motion analysis software (C-motion) was used to calculate 3D joint angles according to a method outlined by Grood and Suntay (1983). Prior to this raw coordinate data was smoothed using a fourth order Butterworth digital filter with a cut-off frequency of 8 Hz. The cut-off frequency was selected using Winter's (1990) residual analysis technique. Only sagittal plane data were used for further analysis. The time series of each joint angular position and velocity was assessed on a revolution-by-revolution basis and interpolated to 100 data points using a cubic spline technique. The intra-limb joint coupling motions were assessed for each revolution using a continuous relative phase (CRP) analysis, which was calculated using the angular position and velocity profiles of the relationship between the joint actions (Dierks and Davis, 2007). CRP was assessed for 2 intralimb couplings: ankle plantarflexion/dorsiflexion - knee flexion/extension (KA) and knee flexion/extension - hip flexion/extension (HK). The joint angle and angular velocity data were normalised to the maximum and minimum of the athlete-specific data set according to the procedure presented by Hamill et al. (1999). The CRP time histories for the sagittal plane KA and HK joint couplings were determined by quantifying the difference between the phase angle of the distal and proximal joint at each time interval. CRP describes the relationship between two oscillators in the phase-plane domain. A CRP of 0º indicates in-phase coupling, meaning the phase angles for the two motions are identical, and a potentially stable coupling pattern exists as they are behaving similarly. As the CRP increases from 0º in either a positive or negative direction, the two motions become more out-of-phase and are behaving in a less similar fashion. Individual averaged time histories for the CRP and the associated variation of CRP (CRPv) were determined across all revolutions for each trial using the mean CRP and associated standard deviation (SD) respectively at each time point. Time histories for the group averaged CRP and CRPv were determined as the average across each time point of the individual-specific CRP and within athlete CRP averaged profiles, respectively. This was repeated for each condition. For each coupling, the effects of cadence and work rate (and the subsequent interaction effects) on CRP and CRPv were determined using a 2-way repeated measures ANOVA. Where significant interaction effects were identified, post hoc analyses were employed to examine where the significant differences existed. In addition, differences in CRP and CRPv between the propulsive and recovery phases of the revolution were examined. Significant differences were accepted at $p < 0.05$.

**RESULTS:** No significant differences in CRP or CRPv were found between work rate conditions for either KA or HK. Significant differences in CRP were found between the propulsive and recovery phases for both couplings with a more in phase motion being displayed during the propulsive phase (propulsive *vs* recovery; KA, 27.4º ± 8.9 *vs* 48.5º ± 20.5, $p = 0.000$; HK, 22.5 º ± 6.7 *vs* 32.5º ± 6.8, $p = 0.000$). Significant differences in CRP were also found between the cadences for the HK coupling during the recovery phase with the 60 RPM trial displaying more out of phase motion than either the 90 RPM or 120 RPM trials (36.4º ± 3.5 for 60 RPM *vs* 33.3º ± 3.4 for 90 RPM, $p = 0.030$ and 27.9º ± 13.6 for 120 RPM, $p = 0.026$). Differences in CRP for the KA coupling were found during the propulsive phase only with the 120 RPM trials displaying significantly more in phase motion than either the 60 RPM or the 90 RPM trials (19.2º ± 12.3 for 120 RPM *vs* 30.0º ± 7.1 for 60 RPM, $p = 0.011$ and 33.1º ± 7.4 for 90 RPM, $p = 0.024$). There were no differences in CRPv across the cadence conditions for the HK coupling however in the KA coupling a significantly higher CRPv was displayed during the recovery phase in the 60 RPM trials compared to either the

90 RPM or 120 RPM trials (16.6º ± 7.6 for 60 RPM *vs* 11.6º ± 6.5 for 90 RPM, $p = 0.005$ and 8.9º ± 4.1 for 120 RPM, $p = 0.003$).

**DISCUSSION:** The intra-limb coupling motion of trained male cyclists was quantified for the propulsive and recovery phases of cycle revolutions at three different work rates (120, 210 & 300 W) and three different cadences (60, 90 & 120 RPM). The more out of phase motion of both the KA and HK couplings during the recovery phase suggests a less stable motion than in the propulsive phase as out of phase motion has previously been considered to reflect a less stable coordinative state (Scholz, 1990). When considering the effect of cadence on the CRP, a more out of phase movement pattern was displayed during the 60 RPM trial for the HK coupling (recovery phase) and a more in phase motion was displayed during the 120 RPM trial for the AK coupling (propulsive phases). Both these findings suggest the higher the cadence the more stable the resulting movement pattern. A stable coordinative pattern is able to be maintained despite perturbations to the system (Robertson, 2001) and according to Zanone et al. (2003), the more stable a movement pattern is, the lower the metabolic cost required to maintain the pattern at a given level of stability. This suggests that the coordination patterns exhibited at the higher cadences are more economical. This support for the use of a higher cadence is in agreement with Lucia et al. (2004) who found that for a fixed work rate, economy improves at increasing pedalling cadences and this improvement was attributed to a lower motor unit recruitment. The higher CRPv in the 60 RPM trial for the KA coupling during the recovery phase suggests a less consistent movement pattern and according to van Emmerick and van Wegen (2000) this is a sign of a less stable system. This is consistent with the CRP findings and also suggests that the variability present in the system is not beneficial to performance, something which has previously been suggested by Chapman et al. (2009). The fact that no differences in coupling motion were identified between work rates may be surprising given the significant differences between cadences and the interdependent relationship of work rate and cadence. However, the work rates investigated in this study were limited and greater ranges may be required to identify any differences which exist.

**CONCLUSION:** The results of this study suggest that changes in cadence may result in changes in stability and subsequently the economy for a given coordination pattern. This may have implications for both training and competition. Specifically the results support the use of a higher cadence. In addition, the less stable pattern identified during the recovery phases potentially highlights the need for further consideration of this phase by coaches. This study has been limited to intra-limb coordination however future work investigating inter-limb coordination is advocated.

**REFERENCES:**


Ansley, L., & Cangley, P. (2009). Determinants of optimal cadence during cycling. *European Journal of Sport Science*, *9*, 61-85.

Bartlett, R., Wheat, J., & Robins, M. (2007). Is movement variability important for sports biomechanists? *Sports Biomechanics, 6*, 224-243.

Bradshaw, E.J., & Aisbett, B. (2006). Visual guidance during competition performance and run-through training in long jumping. *Sports Biomechanics*, *5*, 1-14.

Button, C., Davids, K., & Schollhorn, W. (2006). Coordination profiling of movement systems. In K. David, S. Bennet and K. Newell (Eds.), *Movement System Variability* (pp 133-152), Champaign, IL: Human Kinetics.

Chapman, A., Vicenzino, B., Blanch, P., & Hodges, P. (2009). Do differences in muscle recruitment between novice and elite cyclists reflect different movement patterns or less skilled muscle recruitment? *Journal of Science and Medicine in Sport*, *12*, 31-34.

Dierks, T.A., & Davis, I. (2007). Discrete and continuous joint coupling relationships in uninjured recreational runners. *Clinical Biomechanics*, *22*, 581-591.

Grood, E.S., & Suntay, W.J. (1983). A joint coordinate system for the clinical description of three-dimensional motions: Application to the knee. *Journal of Biomechanical Engineering*, *105*, 136-144.

Hamill, J., van Emmerik, R. E. A, Heiderscheit, B. C., & Li, L. (1999). A dynamical systems approach to lower extremity running injuries. *Clinical Biomechanics*, *14*, 297-308.

Li, L. (2004). Neuromuscular control and coordination during cycling. *Research Quarterly for Exercise and Sport*, *75*, 16-22.

Lucia, A., Juan, A. F. S., Montilla, M., Canete, S., Santalla, A., Earnest, C., & Perez, M. (2004). In professional road cyclists, low pedalling cadences are less efficient. *Medicine & Science in Sports and Exercise*, 36, 1048–1054.

Robertson, S.D. (2001). Development of bimanual skill: The search for stable patterns of coordination. *Journal of Motor Behaviour*, *33*, 114-126.

Scholz, J.P. (1990). Dynamic pattern theory – some implications for therapeutics. *Physical Therapy, 70*, 827–843.

van Emmerik, R. E. A., & van Wegen, E. E. (2000). On variability and stability in human movement. *Journal of Applied Biomechanics*, *16*, 394-406.

Wilson, C., Simpson, S.E., van Emmerik, R.E.A., & Hamill, J. (2008). Coordination variability and skill development in expert performers. *Sports Biomechanics*, *7*, 2-9.

Winter, D.A. (1990). Biomechanics and Motor Control of Human Movement ($2^{nd}$ Edition). Wiley, New York.

Zanone, P.G., Monno, A., Temprado, J.J., & Laurent, M. (2001). Shared dynamics of attentional costs and pattern stability. *Human Movement Science*, *20*, 765-789.