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KINETIC PROPERTIES AND EMG ACTIVITY OF NORMAL AND OVER-SPEED PEDALING IN TRACK SPRINT CYCLISTS: A CASE STUDY

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Track sprint cycling requires unique skills. We investigate the pedaling kinetics and muscle coordination of a male track sprinter (170cm, 65kg, peak power 1513W) to see if they differ from that of a non-sprinter, and if the subject's own technique vary from normal riding to an under-load maximal cadence sprint. Two trials were collected using 3D motion capture technology. EMG signals of 8 leg muscles were recorded. Joint torque and power of each trial were calculated using a subject specific musculoskeletal model, with realistic pedal forces as input to our dynamic simulation. Flexion torque appears at the knee during its extension, different from the non-sprinters. Joint torque and power appears similar for both trials, but 6 of the 8 muscles showed differences in EMG patterns. These findings could potentially benefit the evolvement of training methods.

KEY WORDS: track cycling, match sprint, cadence, inverse dynamics, modeling.

INTRODUCTION: In track cycling, typically reported cadences for sprinting events range from the 127rpm in a 1-kilometer time trial (Craig & Norton, 2001), to the 140~155 range in world-class athletes (Craig & Norton, 2001; Dorel et al., 2005) during the flying 200-meter qualification race for a match sprint; numbers that differ hugely from the typical 90rpm range observed in road racing (Lucia, Hoyos, & Chicharro, 2001). Such nature calls for a "smooth" pedaling technique. Practical reasoning among coaches is that with smoother pedal strokes, there is less effort "wasted" in the bouncing, twitching and weaving movements, and that a calm upper body provides a more solid base to deliver power from. And from a mechanical stand point, huge fluctuations in the pedaling torque could contribute to jerky propulsion, thus overly deforming components such as the tires, causing loss of energy; moreover, forces that are applied on the non-tangential direction of the traveling pedal spindle would create substantial external forces to the rider, excessively moving his body causing him to overly maneuver the bicycle. And while this same analogy applies also to the road, the differences in power magnitudes might be the sole reason why these movements were not commonly observed or discussed in road racing. According to data from both track (Dorel et al., 2005; Gardner, Martin, Martin, Barras, & Jenkins, 2007) and road (Lucia et al., 2001), the resolved tangential pedal forces in a track sprint (typical peak power 1500~2000 Watts at 125~130rpm) are around 4 to 5 times of that during a road race (typical sustained power 300~400W at 70~90rpm). Assuming similar techniques, the redundant (non-tangential) forces must also be 4 to 5 times greater for track sprinters, leading to far greater instability.
Modeling simulations regarding this special branch of competition are relatively scarce. Force-measuring pedals as such utilized by Childers (2011) have considerably large mass and rotational inertia, which could generate excessive loads under high pedaling rate. In fact very few of the simulation studies were done at near 140rpm; so their conclusions might not apply to track sprinting. Our study therefore looks to resolve these issues, and to investigate the possible differences between maximal and submaximal pedaling rates.

METHODS: The pedaling movements of a male amateur track racer (height 170cm, weight 65kg, peak power 1513W, personal best flying 200 11.19 seconds) on the a Arion Al13 rollers (Elite Cycling, Italy) were captured for both maximal (MaxC) and submaximal (SubC) pedaling cadences using a 3D motion capture system (Motion Analysis Corporation, CA) at 250Hz. EMG signals of 8 muscles on the right leg (gluteus maximus GM, bicep femoris BF, semitendinosus ST, vastus medialis VM, rectus femoris RF, vastus lateralis VL, satorius SA and tensor

fasciae latae TFL) were collected. The subject's own road bicycle was used to allow power measurement and to quickly alter transmission ratios. Power output was measured with a wheel-based portable power meter (PowerTap Elite+, CycleOps, WI). The subject first posed for a static trial. After conducting personal pre-race warm up routine on the rollers, the subject then did an under load rev out (MaxC) for 10 seconds using a ratio of 48.86 gear inches, reaching a peak of 400W. After recovery, the subject switched to 119.25 gear inches and rode a sustained 400W (SubC) for 10 seconds. Motion data from the static trial were used to scale a generic musculoskeletal model (Hamner et al., 2010) in OpenSim (Delp et al., 2007). Inverse kinematics was then conducted to investigate joint angles.
Due to the unique nature of the sprint events, we've hypothesized that sprint cyclists apply a constant, left-right combined crank torque throughout the pedal stroke, and exert forces only on the tangential direction. A separate experiment on the same subject was performed to further decompose the torque into contributions from left and right cranks (Figure 1).

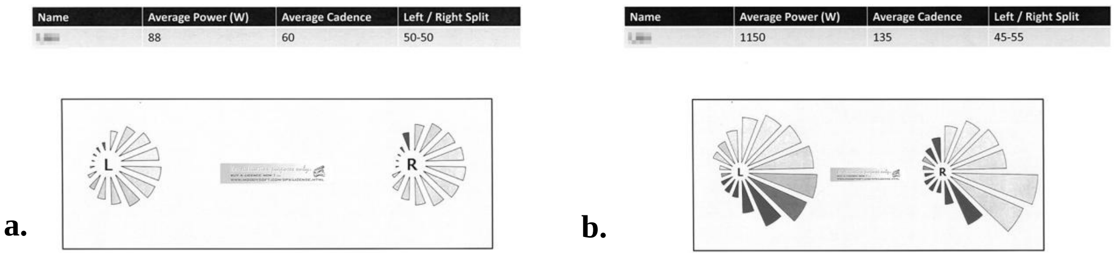

Figure 1: Left and right foot power of a) submaximal and b) maximal pedalling. Bars indicate magnitudes; white means 100% positive work and black would have meant 100% negative work. The greys indicate there are force components along the axial direction.

Based on the hypothesized torque profile, we were able to construct virtual force data as input to our simulation in OpenSim (figure 2). In figure 2a, the pedaling forces were arranged into correct phase angles (left one rotated 180°); 2b, the left and right graphs overlapped; 2c, we could simplify the combined forces in 2b by adding up the overlapped magnitudes and forming an outer circle, inscribed by smaller ones; and in 2d, the regions below and above the sine wave indicates the magnitudes of pedaling forces exerted by the right and left foot, respectively. The forces are along the tangential direction of the pedal stroke.

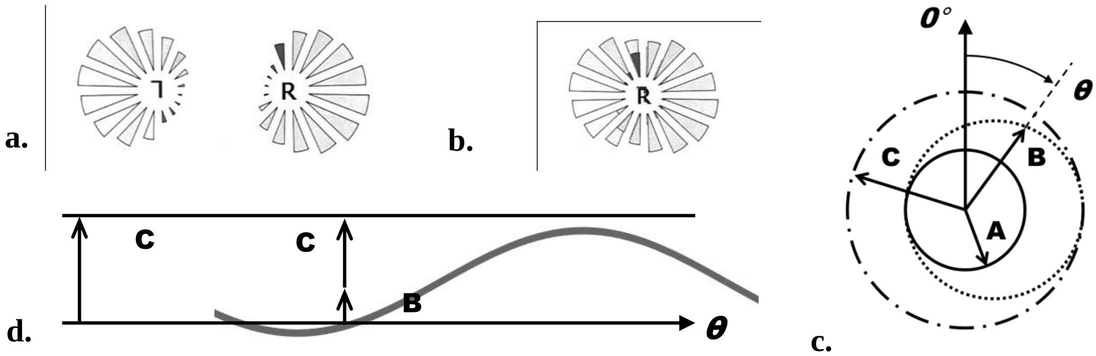

Figure 2: Construction of the virtual force input.

With this idealized profile, the resultant torque is now constant, eliminating pulsative forward propulsion. This profile is adopted for input data of both the MaxC and SubC; the combined pedaling force values (value "C – A" in Figure 2d) having been set at 100 and 200 N respectively, approximated according to the power and cadence data. Joint torques and power were calculated using inverse dynamics for each trial. EMG data for each muscle was low-pass filtered at 5 Hz and averaged for all complete strokes during a trial, and normalized to its maximum value acquired from all complete strokes within that trial.

RESULTS AND DISCUSSION: The EMG pattern of each muscle is shown in figure 3. Notice that in GM, the MaxC pattern shows earlier activation and later deactivation than SubC, in line with the simulation of Vercruyssen and Brisswalter (2010). However, in MaxC of RF, TFL and SA, activation and deactivation are both earlier; whiles in BF, ST, VL and VM, the activation is earlier bur deactivation remains remarkably in-phase. On closer inspection of the motion data, it seemed there's an earlier plantar flexion of ankle for the MaxC trial compared to SubC; the rider also moved forward on the bike and flared-out the elbows. Taken together, it came clear that the apparent "earlier plantar flexion" was actually a result of closed chain movement and earlier knee extension.

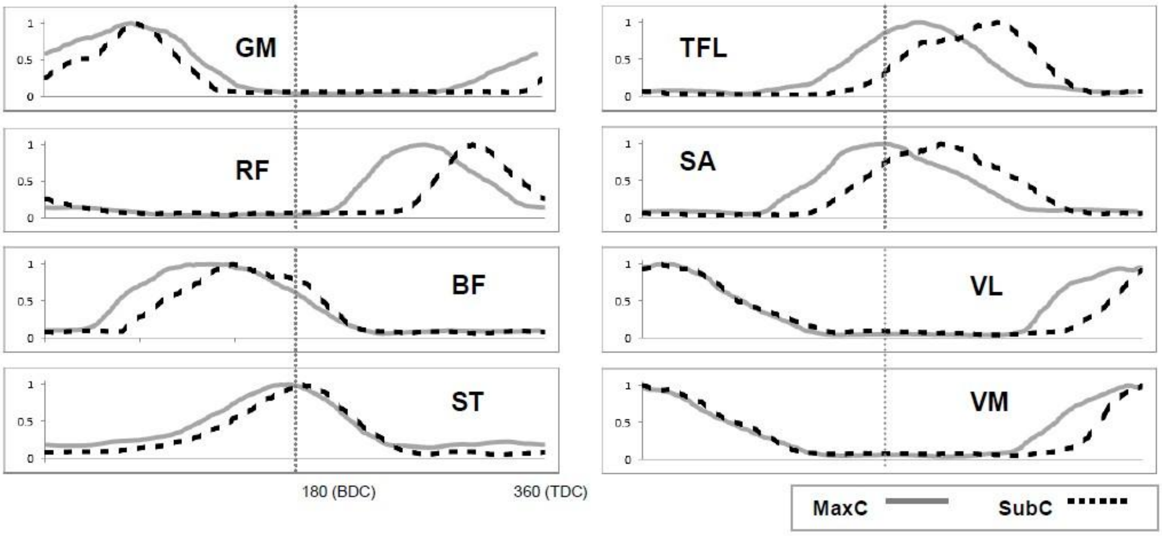

Figure 3: EMG patterns of the two trials. TDC: top dead centre, BDC: bottom dead centre.

For both trials, the biarticular muscle RF is activated near the end of a pedal stroke and clearly acts as a hip flexor. Interestingly, the other two of the quadrucep group, VL and VM, were not really activated during the whole down stroke; rather, they get turned on while nearing the top of the stroke and are already switched off at around 3 o'clock of the stroke. The ST muscle is activated opposite to VL and VM; the agonist-antagonist relationship evidently displayed. The other hamstring muscle BF however, does not show the same pattern as the ST; it's activated at a bit after 0°, and starts to shut down when the pedal is at 180°, showing the partial function of a hip extensor. Hence neither should be counted as the sole representation for the hamstring muscle group when conducting EMG studies. The SA and TFL also appear to be activated on the up stroke while they're traditionally considered as lateral knee stabilizers. This might pose a new way of investigating hip flexion in cycling.

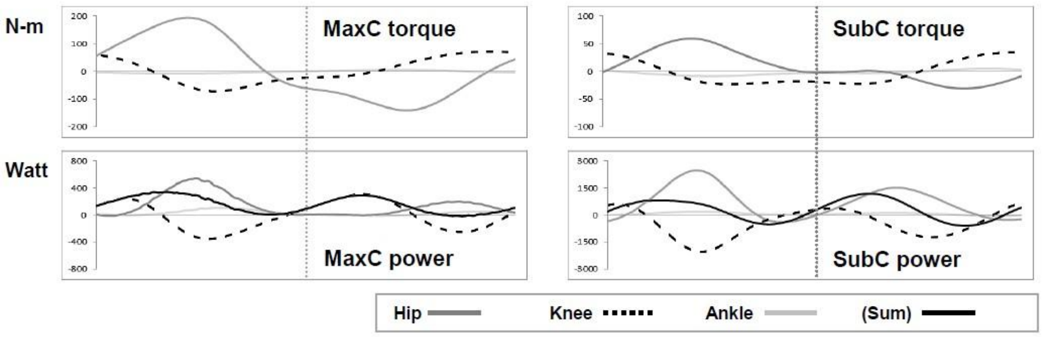

Figure 4: Joint torque and power of the MaxC (left) and SubC (right).

Finally, the inverse dynamic results in figure 4 showed that a flexion torque happens at the knee joint during knee extension, which contradicts with previous studies conducted on road cyclists, mountain-bikers or endurance track riders (Childers, 2011; Martin & Brown, 2009). The hip joint provides most of the average power, which concurs with these previous studies, but it also provides significant power on the upstroke (during hip flexion), something these studies didn't demonstrate. Differences between MaxC and SubC are not apparent.
For both MaxC and SubC trials, the negative knee power and positive hip power were presented during the down-stroke phase. The negative power seemed counterintuitive; however, Gregor et al. (1985) has reported this phenomenon and attributed it to the fact that the reaction pedal force vector passing in front of the knee joint. Our finding highlights the role of the hamstrings in transferring mechanical energy between two adjacent joints. In addition, the fact that such energy transfer exists in both trials might indicate that through rigorous training, the control strategy adopted for track sprints are actually transferred into submaximal riding. (Note: Although the power output for SubC and MaxC are identical, the lower muscle contraction velocity made SubC nowhere near an all-out effort.)

CONCLUSION: For track sprint cyclists, the hip joint power seems to dominate the pedaling action in both maximal and submaximal cadence. A knee flexion torque occurred when the knee is extended, which results in negative power output. It could be that the unique demand and training methods adopted by track sprint cycling caused the riders to develop a pedaling technique that is different from road cyclists to minimize their center of mass movement. SA and TFL play the role of hip flexors and are thus vital prime movers that have to be considered while designing a strength training program. The pedaling skills developed from high-speed, maximal efforts could carry over to submaximal riding; yet whether this strategy is metabolically efficient remains to be seen. The EMG patterns between the two cadences however still present dissimilarities, therefore assistive pedaling drills should not be composed of no-load maximal rev-outs only; drills closer to the 140~155rpm range should also be applied to prevent distortion in neuromuscular control.

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