NEUROMECHANICS OF CYCLING: OPPORTUNITIES FOR OPTIMIZING PERFORMANCE

Sylvain Dorel[1], Vincent Fohanno[2], Mathieu Boucher[3], Guillaume Rao[4]

"Movement, Interactions, Performance" (EA4334), University of Nantes, Nantes, France[1]
Qualisys AB, Gothenburg, Sweden[2]
Sensix Force-Torque Sensors, Poitiers, France[3]
Institut des Sciences du Mouvement E.J. Marey (UMR CNRS 7287), Aix-Marseille University, France[4]

From the very simple (external power output) to the more complex variables (effective force profile, index of effectiveness, specific joint power) up to a neuro-musculo-skeletal integrative approach, we will focus on the following items: a clear definition of each concepts and variables, the tools needed for its accurate measurement and the state of scientific knowledge (and/or illustration) about its potential interest for the cycling performance. The ultimate approach using musculoskeletal models will also be mentioned just to give an idea of the potential interest to use them in a cycling performance enhancement endeavor.

KEY WORDS: power, measurement, effective force, effectiveness, muscle activity, joint torque.

INTRODUCTION: On one hand, the pedaling movement can be considered as relatively intuitive and hence easy to perform by everybody. On the other hand, among coaches, specialists or scientists many still believe and suggest that the "effectiveness" during this task can be improved and therefore can afford to propose some "methods" to train technique in cyclists. The aim of this session is to present different opportunities to measure some biomechanical variables of the cycling task and to discuss about the real benefits and limitations of each of them regarding the performance. In this context, the purpose is to describe the main indexes of the pedaling biomechanics and of the muscle coordination of the lower limbs which can help to characterize the "technical aspect" of pedaling.
This applied session will be organized in different parts alternating talks illustrating biomechanical aspects of pedaling performance and practical demonstrations in real time. Drawing on the expertise of the different speakers, an effort will be made to discuss about i) the practical issues of measurement (and processing) and to a larger extent about ii) the future opportunities for optimizing coordination and performance in this task (especially in sprint cycling). For that, the presentation will provide recent supporting concrete examples regarding the world-class level performance in sprint track cycling.

EXTERNAL POWER OUTPUT, ECOLOGICAL MEASUREMENT AND PERFORMANCE: From the last decade, the overall external power output can be recorded accurately using numerous on-bicycle instrumentations. Several measurement systems have been developed (SRM system, Powertap, Stage, Keo power, Garmin vector…) allowing the continuous recording of the cyclists' power output when riding their own bicycles during training and competition. In submaximal exercise these devices classically allow to express the distribution of power output referring to the aerobic metabolism potential of the athletes (i.e. the intensity of exercise in function of, maximal aerobic power, power at ventilatory or lactate thresholds, or by using the critical power and power profile approach). During maximal sprint cycling, the net power output as well as the corresponding pedaling rate still remain even more useful performance indicators (Martin, Davidson, Pardyjak, 2007) because of the influence of the well-known torque- and power-velocity relationships. Some practical examples of typical time course of power and pedaling rate during elite sprint track cycling competitions will be presented (e.g. 200 flying start performance, personal data). These data will highlight the additional insight into key performance determinants that can be provided especially regarding the optimization of the power profile by taking into account the own athlete's power-velocity characteristics and adapting the choice of the gear ratio. Nevertheless, this type of approach is logically limited as a biomechanical measure because it solely relies on the effective force (or torque) transmitted to the system. Thus, other approaches are needed to give indication of the movement strategy adopted by the cyclist within the crank cycle.

EFFECTIVE FORCE, EFFECTIVENESS AND MUSCLE ACTIVITY: ***From measurement...***
The characteristics of the pedaling task (the constant circular trajectory of the pedals, the mechanical linkage between both left and right cranks constraining an antiphase displacement of both lower limbs) and the involvement of three main joints lead to a specific activation patterns of lower limb muscles (gluteus maximus, quadriceps, triceps surae, hamstrings, see Hug and Dorel, 2009 for review). Associated to this typical muscle coordination, both the magnitude and the orientation of the force on the pedals vary over the crank cycle. The influences of power output, pedaling rate, body position, shoe–pedal interface, or fatigue on the coordination strategies and the biomechanics of pedal forces application have been widely studied in the literature (more extensively in submaximal conditions). The findings of these studies are essential to provide interesting insights in the ability of the neuromuscular system to adapt to these various constraints (Bini and Diefenthaeler, 2009, Dorel, Couturier and Hug, 2009a, Dorel, Drouet, Couturier, Champoux and Hug, 2009b, Hug, Drouet, Champoux, Couturier and Dorel, 2008).

To characterize the biomechanics of force application, it is important to understand that the effective force (i.e., that which acts perpendicular to the bicycle crank and thus drives the crank around in its circle) represents only one component of the total force produced at the shoe/pedal interface. The concept of mechanical effectiveness in cycling (introduced almost twenty years ago, (Ericson and Nisell, 1988, Sanderson, 1991) is directly related to the ability of the subject to efficiently orientate the pedal forces (i.e. so that a great extent of the resultant forces participate to the propulsive action). Therefore, the index of mechanical effectiveness (IE), defined as the ratio between the tangential force component (to the crank) and the total one, has been considered and used as an indicator of cycling skill (see Bini, Hume, Croft and Kilding, 2013).

Many different pedal dynamometers have been described in the literature and some of them were restricted to laboratory use (Boyd, Hull and Woottenet, 1996, Davis and Hull, 1981, Newmiller, Hull and Zajac, 1988) while others recently permit load measurement outside of the laboratory (Drouet, Champoux and Dorel, 2008, Reiser, Peterson and Broker, 2003). Moreover, some commercial device are now available (I-Crankset-2, Sensix, Poitiers) allowing both research and training application. During a practical demonstration of the use of this system, we will present the sensors required to measure the different variables and the software specially dedicated for the acquisition and data post-processing of cycling tests: effective force index of effectiveness profiles, distribution of the force and mean values over specific phases of the crank cycle (downstroke and upstroke), asymmetry and contribution of each leg, real-time feedback of some indexes…

To interpretation… At first sight, these devices provide very interesting perspectives and it is very tempting to expect significant improvement of the effectiveness (and hence the performance) by using this type of feedback. However, the main debatable and exciting issue is actually the influence of expertise and the training status on these different biomechanics indexes. Indeed, it has been suggested several times in the literature that substantial differences exist between subjects regarding their power generation techniques (Gregor, Komi, Browning and Jarvinen, 1991). It's really common to observe coaches, specialists or scientists who propose some “methods” to train technique in cyclists. On the other hand it appears that, for a given intensity–pedaling rate combination, the effective force (or torque) as well as index of effectiveness profile as a function of the crank angle appears to be relatively stereotypical (Sanderson, Hennig and Black, 2000, van Ingen Schenau, van Woensel, Boots, Snackers and de Groot, 1990) with low inter-individual variability (Hug, Drouet, Champoux, Couturier and Dorel, 2008, Mornieux, Stapelfeldt, Gollhofer and Belli, 2008, Sanderson, 1991). Therefore it is proposed to state about the current evidences of the potential link between these parameters and the cycling performance (expertise and training status), especially the controversial link between effectiveness and other parameters such as muscular efficiency or metabolic consumption (Korff, Romer, Mayhew and Martinet, 2007, Zameziati, Mornieux, Rouffet and Belli, 2006). Additionally this part of presentation will report some recent findings regarding the EMG activity and pedaling biomechanics during sprint exercise and will address the potential benefits of these analyses: evaluation of weakness in the crank cycle and realistic prospects to optimize the coordination and effectiveness and hence performance in elite sprint cyclists (Dorel, Guilhem, Couturier and Hug, 2012 and unpublished data).

2D INVERSE DYNAMICS AND SPECIFIC JOINT CONTRIBUTION: From a mechanical standpoint cycling remains a double task: i) moving the leg segments in such a way that the foot moves on a circular trajectory; ii) producing torque at the crank levels. The work produced by the muscles (indirectly reflected by EMG activity) is then transformed into mechanical work at the crank level but also used to move the leg segments (Driss and Vandewalle, 2013, Hull and Jorge, 1985, Kautz, Hull and Neptune, 1994). Therefore it is important to keep in mind that pedal force in cycling can be decomposed into a muscular component due directly to the intersegmental net joint torques and a nonmuscular component due to gravitational and inertial effects.

From measurement and modeling… Biomechanics parameters such as joint kinematics (joint angles, velocities and accelerations) and joint kinetics (joint torques and powers) at the lower limbs are important parameters to quantify the performance and the coordination of the cyclist. The technological and methodological improvements made in the last 20 years allow the researchers to assess these parameters relatively accurately, quickly and easily. This part of the applied session will focus on how the researcher can use the input data from the force sensors and motion capture systems to estimate these parameters. The speech and the practical demonstration using a motion capture system (Qualisys, Gothenburg, Sweden) will be divided into three parts: modelling, inverse kinematics, and inverse dynamics.

Modelling is an important part of the procedure because the accuracy of the defined biomechanical model is directly connected to the accuracy of the outcomes, i.e. joint kinematics and kinetics (Silva and Ambrosio, 2004). Modelling includes the definition of the number of segments, the location of the joint centers and axes of rotation. The lowers limbs are usually modelled as 7 rigid body segments: pelvis, as well as bilateral thighs, shanks, and feet. The feet can be divided in two or more rigid body segments to better cope with the joint anatomy of this segment even though the mobility of these additional joints is highly constrained during cycling due to the rigid aspect of the cycling shoes. The estimation of the joint centers and axes of rotations can be estimated using predictive or functional methods. The functional methods have been introduced to better respect the specific anatomy of each individual (Ehrig, Taylor, Duda and Heller, 2006). Although these methods are becoming more and more popular, it is very difficult to say if they help to better estimate these joint parameters mainly because of the presence of soft tissue artefacts.

To cope with these soft tissue artefacts, inverse kinematics is the procedure to estimate the joint kinematics from the marker trajectories. A large variety of methods exist and are classified as direct, local, or global methods (Fohanno, Begon, Lacouture and Colloud, 2014). Nowadays, global methods are intensively used to estimate the joint kinematics because of its robustness against the presence of marker occlusions and soft tissue artefacts. These methods are interesting because they give directly the joint kinematics using an optimization procedure that best fits the skin marker trajectories and respect the characteristics of the biomechanical model (i.e., the mechanical degrees of freedom).

Inverse dynamics is well known in the biomechanics community and uses inertial parameters, joint/segment kinematics and external forces applied on the system, i.e. on the lower limbs of the cyclist in our case, to estimate the torques and forces produced at each joint. Because the cycling movement is generally considered to occur in the sagittal plane, it is reasonable to apply a two-dimensional inverse dynamic procedure focusing on the joint efforts around the transverse axis.

To interpretations… Compared to the measurement of pedal forces, the inverse dynamic approach is then more realistic i) to understand in much greater detail how the cyclist produces their maximum overall power output ii) to infer the involvement of each muscle groups (extensor and flexors of the hip, knee and ankle) and iii) to interpret the coordination. Ultimately, the information required to better understand in details the pedaling movement would therefore include co-identifying the activated lower limb muscles (and precisely knowing their level/timing of activation) and the joint power distribution across the main joints. The main knowledge about specific joint power distribution during submaximal and maximal cycling is now well established (Elmer, Barratt, Korff and Martin, 2011, Martin and Brown, 2009) but again the question of the link with the involvement (intrinsic properties) of the different muscle groups and the optimization of coordination by training is really challenging. Some recent examples of data recorded to test the influence of local fatigue on the coordination will be presented to underline the strength of this neuro-mechanical approach representing a mean in future studies to better elucidate the role of each of the muscles along the crank cycle.

And futures perspectives with musculoskeletal model… As mentioned before, segmental movements as well as forces at the interface between the human body and the external world are due to muscle forces. However, the muscle redundancy problem (i.e., more muscles than degrees of freedom at the joints) prevents from straightforwardly estimating the muscle forces during motion. Musculoskeletal models aims at overcoming this redundancy issue and can use joint kinematics, external forces, musculoskeletal geometry, muscle-tendon models (i.e., Hill type muscle models), and muscle activations (surface electromyography) as inputs. These models are increasingly used in clinical contexts, but few attempts have been made to use them in a sport and performance enhancement endeavor. The aim of this part of the presentation will be to provide, first some basic overview (and broad descriptions) of the current musculoskeletal models available, and second an example of application of an EMG-Driven model of the lower limb to cycling.

A significant time will be dedicated to questions from the audience. The idea is to discuss about all the directions for future research dealing with pedaling biomechanics and gains in performance. The discussion would also address the benefits and limitations of different other indexes/devices (not mentioned in the presentation) which continue to be developed (sometimes in a commercial manner) and claim to provide useful perspectives to enhance the pedaling technique.

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