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Original Article

Motion capture system: a useful tool to study cyclist's posture

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Abstract
Cycling is one of the most practiced sports in the world, both professionally and an amateur level. Cycling for many kilometers in a training session puts the body under severe metabolic and biomechanical stress. Epidemiological studies have shown that cycling is an activity with a high incidence of overuse injuries and is a sport with the highest absolute number of accidents per year, followed by basketball and football. The study of the cyclist's posture during pedal stroke is crucial in order to better identify not only the biomechanical factors limiting the performance but also those predisposing to the injury. Abnormalities in pelvic movements during cycling are related to improper bicycle fit and related pathologies. Through a Motion Capture System, the gold standard in evaluating biomechanical parameters in sport performance, our purpose aims to investigate the differences in pelvis kinematics during the different phases of the crank cycle.Ten (10) healthy experienced cyclists were collected at different pedaling rates: lower (60 bpm), middle (90 bpm) and higher (120 bpm). Each athlete used his own race bike positioned on a professional cycletrainer. After recording the data, we extrapolated the kinematic parameters of the pelvis. Through statistical analysis we compared the three different pedaling conditions. Our results showed that the lowest swing in the pelvis occurs at 90 rpm. Although this pedaling rate is not the lowest, it represents the safest for injuries' prevention and the most comfortable for the cyclist. Motion capture is therefore a valuable tool for analyzing the kinematics of the pedaling cycle.
Keywords: crank cycle, bike, cyclist, motion capture system, posture

Introduction

Cycling is certainly one of the most popular sports in the world, both professionally and as an amateur(Ascione et al., 2019). Cycling often means, even for amateurs, to move for many kilometers in a training session and therefore undergoing the body to a metabolic and biomechanical stress. This is the reason why cycling is an activity with a high incidence of overuse injury (Holmes et al., 1994; MacAuley, 1996). One of the few scientific paper that has investigated the mechanisms of bicycle related injuries(Silberman, 2013), has highlighted that cycling is the sport with the highest absolute number of accidents per year, followed by basketball and football (Montuori et al, 2019). These injuries involve both professionals and amateurs, including children from 5 to 14 years. Injuries related to cycling can generally be classified as injuries from contact with the bicycle, traumatic and from overuse. The latter are mainly located at the lower limb and involve the soft tissue of the knee, hip and ankle respectively, including acute pain symptoms resolvable with rest (Silberman, 2013). In addition, muscle fatigue during cycling could induce alterations in pedaling technique leading to stress and symptoms in other parts of the kinematic chain (Asplund & St Pierre, 2004).

The bicycle posture imposes a closed kinetic chain movement; three are the main body contact points: the hands to handlebars, the pelvis to the saddle and the feet to the pedals. The effectiveness of pedaling, the terms of performance and anatomical correctness, is influenced mainly by the angles created between the articular segments. These kinematic variables are in turn influenced by changes in pedaling speed, body posture and changes in the positioning of regulating parts of the bicycle. A prevention model is considered useful, but not exhaustive, for the prevention of non-contact injuries is the adaptation of the bike to the anthropometry of the cyclist as well as the improvement of the technique of driving and pedaling. Several studies of video analysis have been carried out (Belfiore et al., 2020; Bini & Carpes, 2017; Di Palma et al, 2016; Di Palma & Tafuri, 2016; Napolitano et al., 2019; Raiola et al, 2015) and to date there are numerous systems of biomechanical video analysis customized for cycling. However, biomechanical studies investigating the organization of lower limb kinematics during the crank cycle remain still few. Moreover, to our knowledge, no study has considered the effects that the increased oscillations of the pelvis at different speed, may have on the lower limb kinematics in terms of alteration of the articular relationships, thus encouraging the non-contact accident. *The pelvis, as a* link between upper and lower body (and as a mobile contact point on the bicycle), must be considered a key element in the cyclist's postural assessment. In fact, asymmetries or overloads in the lower limbs could result from an increase in the pelvis oscillation and this could be responsible for incorrect postures causing back pain or, in the

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worst case, non-contact injuries(Neptune & Hull, 1996). Our study moves specifically to this direction with the aim of investigating, through a sophisticated motion analysis system, the kinematics of the pelvis at different speeds of pedaling.

Materials and Methods

Participants

In this study, we enrolled 10 healthy amateur experienced cyclists. The sample matched for age (30±3 years)and sex (5 male /5 female).

All lower limbs injured subjects or having pain or changes in physiological back structures were excluded. Informed consent was obtained before the experiment.

Motion analysis assessment

The motion analysis assessment was carried out using a stereophotogrammetric system composed by eight infrared camera Qualisys (ProReflex Unit – Qualisys Inc., Gothenburg, Sweden)at 240Hz and 35 sphere-shaped reflective markers, 15 mm in diameter, according to a previously published protocol (Sorrentino et al., 2016; Amboni et al., 2018; Liparoti et al., 2019).

Participants were asked to ride their own bike on a laboratory professional cycletrainer. The study's protocol is composed of three task at different pedaling rates: (1) lower speed at 60 rpm, (2) middle speed at 90 rpm, (3) higher speed at 120 rpm. Each task consisted of a 3-minute period.
In order to identify the geometry and kinematics of pelvis we used the following marker set:right/left anterior iliac crest, right/left posterior iliac crest.In addition, we used two markers on the crank of the bike to identify its cycle. Actually we used a larger marker set (as show in figure 1), but for these study we considered just the markers mentioned above.

Using a previous mathematical model(Agosti et al., 2016; Rucco et al., 2017), we calculated the range of motion (ROM) (defined as the angular excursion of a specific joint in a reference period) of pelvis (P) angle, on frontal, sagittal and transverse plane, in a crack cycle. Specifically, we calculated the distance between the two consecutive events of crank cycle (top dead centre, bottom dead centre). See figure 2 for the definition of crank cycle.

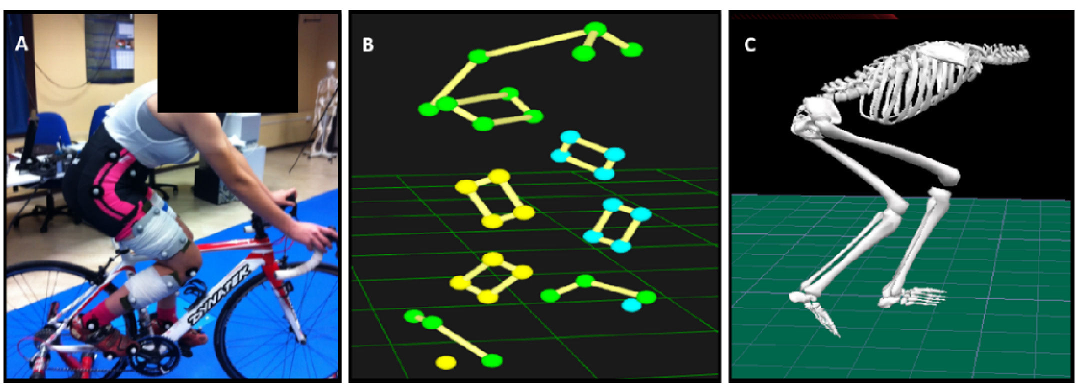

Figure 1: (A) An athlete on his bike, (B) the marker set viewed by infrared cameras, (C) the geometrical reconstruction of body segments.

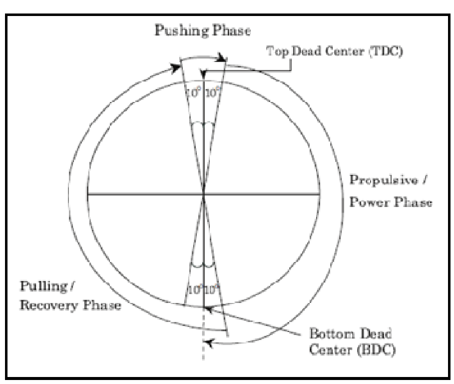

Figure 2: definition of the two-reference event of the crank cycle: top dead centre, bottom dead centre. The three phases of the crank cycle: power phase, recovery phase, pushing phase. Source: (So et al., 2005).

Statistical analysis

The three groups were compared for each variable of interest using repeated measures Anova test. For the significant p values, post-hoc analysis was carried out, using Scheffe correction for multiple comparisons among tasks. All statistical analyses were performed using custom scripts written in Matlab 2018a and the significance level was set to 0.05.

Results

We calculated the range of motion (ROM) of pelvis (P) angle, on frontal, sagittal and transverse plane, in a crack cycle. Specifically, we identify two event occurring in the cycle, TDC and BDC and then we analysed the angular excursion between these two reference instants. Therefore, we defined P1 as the first ROM calculated between TDC and the consecutive BDC, and P2 as the second ROM calculated between BDC and the consecutive TDC. In other words, P1 covers 0-50% of the crank cycle, P2 covers 51-100% of the crank cycle. We found differences among the three conditions only in frontal plane, as summarizedin table 1. Specifically, 90rpm condition differed between both 60 rpm ($p<0.01$) and 120rpm ($p<0.002$).

Condition	P1 (0-50%)	P2 (51-100%)
60 rpm	5.3±0.3	5.2±0.5
90 rpm	4.1±0.2	4.0±0.2
120 rpm	6.4±0.2	6.6±0.7

Discussion

The aim of this study was to analyse the relationship between the pedaling rate and the correct posture of the athlete on the bike. Specifically, using a Motion Capture system, we analysed the kinematic of the pelvis segment, on the three anatomical planes, to identify the best pedaling condition.

The idea was born from the evidence that an incorrect posture on the bike can increase the risk of injury or require greater efforts to keep performance unaltered.Many studies showed thatthe tilting of the pelvis during pedaling depends on the paravertebral muscles, which tend to straighten the trunk, which is kept flexed by the muscles of the upper limbs.The action of the abdominal muscles, which tend to withdraw it during the propulsive phase does not stabilize the pelvis.

Starting from these evidences, we studied the ROM of pelvis angle on sagittal, frontal and transverse plane, in three different condition at different pedaling rates.

Despite we did not find differences in sagittal and transverse plane, we found a lower excursion on frontal plane of P1(ROM of pelvis angle between 0-50% of crank cycle) and P2 (ROM of pelvis angle between 51-100% of crank cycle) in 90rpm condition with respect to both 60 and 120 rpm condition.

On frontal plane, we see the oscillations of the pelvis, during the crank cycle, highlighting the presence of any asymmetries. The presence of these anomalies in the action of the leg can cause wear of the joints and knee pain. Furthermore, an excessive oscillation of the pelvis is a factor that could predispose the subject to low back pain.

Interestingly, a lower swing of the pelvis does not occur when pedaling at a lower rate (60 rpm), but at middle rate (90 rpm). We can speculate about this result, saying that the minor oscillation can be related to some existing evidenceswhich indicate that most competitive cyclists prefer pedaling rates above 90 rpm(Kohler & Boutellier, 2005).The authors hypothesized that this preference of pedaling rate is due to intrinsic properties of the muscle fibers intended which act as a link between muscle strength and the release of heat to shortening velocity.

In conclusion, a correct posture on the bike is essential to prevent injuries. Despite in literature there are many studies focused on the kinematics of lower limbs(Callaghan, 2005), during the crank cycle, very little is known about the important role of pelvis segment. Furthermore, the Motion Capture system is a very useful tool that allows a high-resolution analysis on all three anatomical reference planes, measuring the ROM of the pelvis joint intended as the angular excursion of the segment, during the crank cycle.

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