

Effects of Pedal Type and Pull-Up Action during Cycling

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Key words

- pedalling effectiveness
- feedback
- net efficiency
- muscular recruitment

Abstract

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The aim of this study was to determine the influence of different shoe-pedal interfaces and of an active pulling-up action during the upstroke phase on the pedalling technique. Eight elite cyclists (C) and seven non-cyclists (NC) performed three different bouts at 90 rev·min⁻¹ and 60% of their maximal aerobic power. They pedalled with single pedals (PED), with clipless pedals (CLIP) and with a pedal force feedback (CLIPFBACK) where subjects were asked to pull up on the pedal during the upstroke. There was no significant difference for pedalling effectiveness, net mechanical efficiency (NE) and muscular activity

between PED and CLIP. When compared to CLIP, CLIPFBACK resulted in a significant increase in pedalling effectiveness during upstroke (86% for C and 57% NC, respectively), as well as higher biceps femoris and tibialis anterior muscle activity ($p < 0.001$). However, NE was significantly reduced ($p < 0.008$) with 9% and 3.3% reduction for C and NC, respectively. Consequently, shoe-pedal interface (PED vs. CLIP) did not significantly influence cycling technique during submaximal exercise. However, an active pulling-up action on the pedal during upstroke increased the pedalling effectiveness, while reducing net mechanical efficiency.

Introduction

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The cycling movement is powered by the legs by applying forces to the pedals. Therefore, theoretically, the shoe-pedal interface can have an effect on this cycling movement in addition to muscular activity of the lower leg and mechanical efficiency. Compared to single pedals, using toe-clips (surrounding the forefoot for a better foot-pedal connection) has been reported to increase knee flexor muscle activity during the upstroke phase of the pedal [6,26]. For instance, Ericson et al. [6] reported that recreational cyclists significantly increased muscular activity of the rectus femoris and biceps femoris during submaximal cycling with toe-clips, caused likely by a pull-up action. Tate and Shierman [26] described, for one cyclist, higher tibialis anterior and biceps femoris activity. These results were somewhat different from those reported by Jorge and Hull [9] who reported, during submaximal cycling by experienced cyclists, a higher muscle activity level for knee flexors and extensors (up to 133% and 67%, respectively, for some regions of the crank cycle) when cycling with soft shoes, compared to cy-

cling shoes with cleats and toe-clips. However, few data have been reported concerning submaximal cycling with clipless pedals [4]. These authors described, on four triathletes, less electromyographic activity when cycling with clipless pedals (providing a rigid fixation of the shoe on the pedal surface) compared to pedals with toe-clips. Moreover, shoe-pedal interface seemed to influence the oxygen uptake [10,11]. Indeed, Lafortune and Cavanagh [10] reported, with non-cyclists, significant lower oxygen uptake during submaximal cycling with metal surface pedals with cleated shoes and toe-clips compared to rubber surface pedals and leather soled shoes. Lavoie et al. [11] reported that cyclists and non-cyclists reached higher values of maximal oxygen uptake when cycling with stirrups than without. On the contrary, Lafortune and Cavanagh [10] reported that shoe-pedal interface seemed not to influence the pedalling effectiveness. However, these authors did not investigate clipless pedals. Inasmuch as these studies differed in the pedalling conditions (i.e., pedalling intensity and cadence, types of shoe and pedal, tested population), no consensus was found on any consistent

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Table 1 Main physical and physiological characteristics (mean \pm standard deviation) of both groups. MAP and $\dot{V}O_{2\text{peak}}$ represent the maximal aerobic power and the peak oxygen uptake, respectively and HR_{max} the maximal heart rate. Mileage represents the number of kilometres ridden in a year

	Height (m)	Mass (kg)	MAP (Watts)	$\dot{V}O_{2\text{peak}}$ ($l \cdot \text{min}^{-1}$)	HR_{max} ($\text{beat} \cdot \text{min}^{-1}$)	Mileage (thousand km)
Elite cyclists (n = 8)	1.80 \pm 0.06	68 \pm 4*	457 \pm 15*	4.8 \pm 0.3*	183 \pm 7	19.6 \pm 4.5
Non-cyclists (n = 7)	1.80 \pm 0.04	79 \pm 10	387 \pm 31	4.1 \pm 0.5	185 \pm 9	

* Elite cyclists significantly different from non-cyclists, $p < 0.05$

effect of shoe-pedal interface. Thus, it remains difficult to identify influence of the shoe-pedal interface during submaximal cycling. Therefore it is of interest to conduct an analysis of the influence of the shoe-pedal interface on pedalling biomechanics, by investigating pedal kinetics, mechanical efficiency and muscular activity when cycling with single pedals versus modern clipless pedals. It was hypothesised that the better shoe-pedal fixation provided by the clipless pedals commonly used by cyclists would allow them to pull up on the pedal routinely during the upstroke phase.

When compared to non-cyclists, experienced cyclists were reported to have more knee flexor muscle activity during the upstroke phase of the pedal, simultaneously relieving the knee extensors during the downstroke phase during submaximal cycling [25]. As a result, experienced cyclists showed less pedal forces during the downstroke phase. This change in pedal forces production could imply a better mechanical efficiency, as these authors reported less oxygen uptake in the elite group than in the non-cyclist group for pedalling cadence above 75 revolutions per minute at 200 Watts.

Thus, if increasing knee flexor muscle activity during the upstroke phase would be relevant to relieve extensor muscles during the downstroke phase of the pedal in order to achieve less pedal forces and oxygen uptake, we hypothesised that an active pull-up action would improve the pedalling effectiveness and the muscular efficiency. To test this second hypothesis, feedback of the cyclists pedalling technique could be used to control the pull-up action. This methodology has been used by Sanderson and Cavanagh [22] who succeeded in modifying the pedal force application in the pedalling sector where the subjects get the representation of their pedalling pattern. Therefore, using this feedback technique could provide a good insight in understanding the impact of pulling up on the pedal during the upstroke phase.

Thus, the aim of this study was to determine the influence of the shoe-pedal interface, as well as an active pulling-up action during the upstroke phase on the pedalling mechanics, the mechanical efficiency and the muscular activity during submaximal cycling.

Methods



Subjects

Eight elite cyclists (C) and seven non-cyclists (NC) volunteered to participate in this study. Prior to the test, their informed consent was obtained. Elite cyclists held, at minimum, a status A men's licence of the German cycling federation (from C to A, dependent on official race ranking) or had a former UCI professional status (GS 1–3). Non-cyclists were physically well trained but had no regular cycling activity and no experience in riding with clipless

pedals. The main physical and physiological characteristics for both groups are presented in **Table 1**.

Protocol

Subjects conducted the tests on two days separated by at least 48 hours. During the first visit, they performed a cycling incremental test until exhaustion. This test started with a 5-minute warm-up at 100 Watts with a fixed pedalling cadence of 90 revolutions per minute ($\text{rev} \cdot \text{min}^{-1}$). Power output was then increased each minute by 30 Watts (C beginning with 200 Watts; NC beginning with 130 Watts) until the subject could not maintain the pedalling cadence of $90 \pm 2 \text{ rev} \cdot \text{min}^{-1}$. The rationale for this cadence selection was to make sure that elite cyclists would ride close to a cadence they would freely choose [12], as this group would be more sensitive to an unusual pedalling cadence compared to non-cyclists. During this incremental test, elite cyclists rode with clipless pedals and their own cycling shoes while non-cyclists used single pedals without any toe-clips and their own tennis shoes. The rationale for this was to prevent subjects from being perturbed by a shoe-pedal interface that would be different from what they are used to. After having recovered from the incremental test, the non-cyclists performed a riding period with clipless pedals. They rode at $90 \text{ rev} \cdot \text{min}^{-1}$ for as long as any discomforts due to this unusual riding condition had totally disappeared, usually about 20 minutes.

During the second test, both groups completed a 3 minute 30-second bout, where oxygen uptake at rest level ($\dot{V}O_{2\text{rest}}$) was measured while subjects remained sitting stationary on the ergometer. This was followed by a warm-up period of five minutes performed at $90 \text{ rev} \cdot \text{min}^{-1}$ up to 200 Watts. Then subjects performed, in a randomized order, three 3 minute and 30-second bouts at $90 \text{ rev} \cdot \text{min}^{-1}$ and at a power output corresponding to 60% of the maximal aerobic power (MAP) defined during the first visit. This power, which represented 274 ± 9 and 232 ± 18 Watts for C and NC, respectively, ensured aerobic conditions and limited fatigue. The three bouts differed in the pedalling conditions, i.e., cycling with simple pedals without any toe-clips (PED) where tennis shoes were worn, with clipless pedals (CLIP) and with clipless pedals with feedback (CLIPFBACK). Before each cycling bout, a minimum of a one-minute period of rest was given to the subject to provide enough time to change pedals and shoes. For PED and CLIP, no instruction in the way of pedalling was given to the cyclists, thus ensuring the subjects to pedal in such a manner that they would express their natural pedalling pattern. During CLIPFBACK, cyclists were asked to keep the tangential force positive during the upstroke phase which inevitably forced subjects to pull up on the pedal during this phase. A continuous visual feedback of the tangential pedal force was depicted on a monitor positioned in front of the rider. The feedback representation was a circle which was oriented with the top dead centre (TDC) being at the top. This arrangement made it

relatively easy for the subject to recognise the downstroke and upstroke phases. The circle was scaled according to a theoretical unloaded crank revolution, which allowed subjects to know if they were applying a positive tangential force. In order to understand the cycling condition with feedback better, all cyclists tested it during the warm-up period until they understood the way they had to pedal to complete this task. It is worth noticing that this task was easily and quickly understood by all riders. During the entire protocol, elite cyclists used their own pedals and shoes and adjusted the ergometer according to the dimensions of their bicycle. The non-cyclists were supplied with shoes and pedals and investigators adjusted the ergometer in order to place these subjects in the best position and configuration.

Apparatus

Pulmonary gas exchange was measured breath-by-breath using a computerised system (Oxycon Pro, Erich Jaeger, Höchberg, Germany), which has already been validated in the literature [19]. This apparatus gave us instantaneous output of the pulmonary gas exchange variables. The oxygen consumption ($\dot{V}O_2$ in $l \cdot \text{min}^{-1}$) and the carbon dioxide production ($\dot{V}CO_2$ in $l \cdot \text{min}^{-1}$) were determined from the gas analyser system calibrated prior to the test with gases of known concentrations. The respiratory exchange ratio (RER) was determined from these two parameters.

Both right and left cranks of the electro magnetically braked SRM ergometer (Schoberer Rad Messtechnik, Welldorf, Germany) were equipped with the Powertec[®] pedal forces measurement system (O-tec, Bensheim, Germany). This device, where the pedal is screwed on, is based on two orthogonal sensor systems, which determine the magnetic field variations (Hall-Effect) as a result of force application. With these two orthogonal sensor systems, both tangential and radial pedal force components were measured with an error of less than 1% and 2%, respectively. The accuracy and validity of the Powertec[®]-System have been described in the literature [23]. A magnetic switch was used as position signal for the left pedal top dead centre. The crank length was 0.1725 m.

Electromyographic (EMG) signals from six superficial muscles of the right lower limb (Vastus Medialis, VM; Tibialis Anterior, TA; Gastrocnemius Lateralis, GL; Biceps Femoris, BF; Rectus Femoris, RF and Gluteus Maximus, GMax) were recorded using bipolar surface-EMG (EISA, University of Freiburg, Freiburg, Germany). Before applying pre-gelled Ag-AgCl surface electrodes (Blue Sensor, Ambu, Ballerup, Denmark) (inter-electrode distance: 3 cm), a skin impedance below 5 k Ω was ensured by shaving, sanding and cleaning the skin to remove surface epithelial layers.

Signals from the Powertec[®]-System, position switch and EMG channels were sampled at 1000 Hz on a personal computer via an analog/digital data-acquisition card (DAQ-6023E, National Instrument, Austin, TX, USA).

Calculations and analysis

During the second test, oxygen uptake ($\dot{V}O_2$), forces applied on the right pedal and the muscular activity of the right lower limb were recorded for 30 seconds in the third minute.

The net mechanical efficiency (NE), defined, for instance, by Gaesser and Brooks [7], was calculated over the last 30-s interval as the ratio between the mechanical work accomplished (corresponding to the product between the mechanical power output, directly obtained from the SRM ergometer, and the time) and the metabolic work expended above that at rest, obtained indirectly

from $\dot{V}O_2$ and the energy equivalent of one litre of oxygen based on RER values [14].

Right-side pedal forces and EMG signals were analysed during 30 consecutive crank revolutions. These signals were divided into 30 segments, from TDC to TDC, and then normalised. Then pedal force signals were low-pass filtered (Butterworth 4th order with no phase lag) with a cut-off frequency of 25 Hz and averaged. Angular impulse (integration of the torque-time curve expressed in N.m.s) during the positive and negative phases (I+ and I-, respectively) was calculated. Positive and negative phases represented crank angle values where crank torque was positive and negative, respectively. As asymmetry between right and left pedal forces was not related to either the strongest or the kicking leg and as this could be a variable from day to day [5], measuring one pedal rather than the other had no rationale. We decided arbitrarily to select the right leg.

The following equations were used to calculate the pedalling effectiveness of the right pedal as the percentage of the applied linear impulse that was used to generate angular impulse in three different crank angle (θ) intervals, i.e., the whole pedal revolution (IE₃₆₀) during the downstroke phase (IE_{DOWN}) and during the upstroke phase (IE_{UP}) according to Zameziati et al. [27]:

$$IE_{360} = \frac{\int_0^{2\pi} F_E(\theta) \cdot d\theta}{\int_0^{2\pi} F_{TOT}(\theta) \cdot d\theta} \cdot 100 \quad (1)$$

$$IE_{DOWN} = \frac{\int_0^{\pi} F_E(\theta) \cdot d\theta}{\int_0^{\pi} F_{TOT}(\theta) \cdot d\theta} \cdot 100 \quad (2)$$

$$IE_{UP} = \frac{\int_{\pi}^{2\pi} F_E(\theta) \cdot d\theta}{\int_{\pi}^{2\pi} F_{TOT}(\theta) \cdot d\theta} \cdot 100 \quad (3)$$

where F_E and F_{TOT} represented the tangential pedal force and the total applied pedal force, respectively, assessed as the components of the right pedal, during the whole pedal revolution for IE₃₆₀, during the downstroke phase for IE_{DOWN} and during the upstroke phase for IE_{UP}.

Time normalised EMG signals were rectified, averaged and finally integrated. The integrated EMG (iEMG) of the different muscles for PED and CLIPFBACK were normalised to CLIP.

Statistics

Student's *t*-test for unpaired groups was used to compare the physical and physiological characteristics of the riders and also the power output corresponding to 60% of MAP for C vs. NC groups. A two-factor (group \times pedalling condition) ANOVA with repeated measures on pedalling condition was used to test for main effects of group and pedalling condition as well as the interaction effect for kinetic parameters, the $\dot{V}O_2$, NE and the iEMG data. When the ANOVA revealed a significant effect, a Scheffe's post hoc test followed. A significance level of 0.05 was used for all statistical procedures.

Results



The power output level corresponding to 60% of the maximal aerobic power was significantly higher for the elite group than for the group of non-cyclists (274 vs. 232 Watts; $p < 0.001$).

Table 2 Influence of the three pedalling conditions on the positive and negative angular impulses (I+ and I-, respectively), pedalling effectiveness (IE₃₆₀, IE_{DOWN} and IE_{UP} represent the pedalling effectiveness during the whole pedal revolution, during the downstroke phase and during the upstroke phase, respectively), oxygen uptake ($\dot{V}O_2$) and net efficiency (NE) for both elite cyclists (C) and non-cyclists (NC)

	Elite cyclists			Non-cyclists		
	Pedal	Clipless	Clipless feedback	Pedal	Clipless	Clipless feedback
I+ (N.m.s)	24.3 ± 1.3	24.2 ± 1.7	22.1 ± 1.8*	22.6 ± 2.4	22.4 ± 2.1	19.8 ± 2.0*
I- (N.m.s)	- 3.4 ± 1.1	- 2.9 ± 1.2	- 1.4 ± 0.6*	- 5.0 ± 2.1	- 5.2 ± 2.4	- 3.0 ± 1.5*
IE ₃₆₀ (%)	47.4 ± 4.5	49.7 ± 6.5	59.7 ± 7.6*	39.2 ± 6.2	39.0 ± 7.2	50.7 ± 5.9*
IE _{DOWN} (%)	71.6 ± 2.4	72.4 ± 2.6	76.3 ± 4.5*	68.9 ± 1.2	68.8 ± 2.0	79.7 ± 7.2*
IE _{UP} (%)	- 28.1 ± 6.5	- 21.1 ± 13.0	2.4 ± 14.1*	- 35.6 ± 7.9	- 37.2 ± 9.8	- 17.3 ± 13.2*
$\dot{V}O_2$ (L·min ⁻¹)	3.5 ± 0.3	3.4 ± 0.3	3.7 ± 0.2*	3.1 ± 0.3	3.1 ± 0.3	3.2 ± 0.3*
NE (%)	26.0 ± 2.3	26.5 ± 1.8	24.0 ± 1.2*	24.7 ± 2.1	25.0 ± 2.0	24.2 ± 2.3*

* Clipless feedback condition significantly different from pedal and clipless conditions, p < 0.05

Table 3 Influence of the three pedalling conditions on the integrated EMG (iEMG) values of the six different muscles normalised to the clipless condition for both elite cyclists and non-cyclists groups

	Elite cyclists			Non-cyclists		
	Pedal	Clipless	Clipless feedback	Pedal	Clipless	Clipless feedback
Vastus medialis	100 ± 13.2	100	89.7 ± 17	101 ± 9.4	100	85 ± 15.4
Tibialis anterior	80 ± 15.9	100	167 ± 87.1* £	101 ± 18.7	100	260 ± 138* £
Gastrocnemius lateralis	112 ± 19.8	100	123 ± 52.3	119 ± 15.2	100	166 ± 94.8
Biceps femoris	102 ± 16.5	100	172 ± 80.3* £	102 ± 20.2	100	339 ± 183* £
Rectus femoris	75.1 ± 20.1	100	110 ± 31.8*	95.1 ± 15.9	100	182 ± 124*
Gluteus maximus	111 ± 7.7	100	91.7 ± 22.8	96.1 ± 14.8	100	104 ± 16.8

* Clipless feedback condition different from the pedal condition (p < 0.05); £ Clipless feedback condition different from the clipless condition (p < 0.05)

Moreover the mass (p < 0.019), MAP and also the peak oxygen uptake (p < 0.001) were significantly different between C and NC (Table 1). Mean ± standard deviation values of the different kinetic parameters (I+, I-, IE₃₆₀, IE_{DOWN}, IE_{UP}), $\dot{V}O_2$ and NE quantities are presented in Table 2, and those for iEMG parameters in Table 3.

Pedalling condition effects

The two-factor ANOVA showed a significant pedalling condition influence on the different kinetic parameters and $\dot{V}O_2$ (p < 0.001), as well as NE (p < 0.002). The Scheffe's post hoc test revealed CLIPFBACK to increase significantly IE₃₆₀ and IE_{DOWN} (p < 0.001) as well as $\dot{V}O_2$ (p < 0.006) while I+, I-, IE_{ASC} (p < 0.001) and NE (p < 0.008) were reduced. When compared to CLIP, these variations represented a 22% and 32% increase in IE₃₆₀ for C and NC, respectively. CLIPFBACK also increased IE_{DOWN} of 5.5% and 16% and decreased IE_{UP} of 86% and 57% for C and NC, respectively. A 9% and 12% decrease in I+ was observed for C and NC, respectively, while both groups decreased I- of about 40%. Finally, when cycling in the feedback condition, an 8.1% and 3.3% $\dot{V}O_2$ increase for C and NC, respectively and a decrease in NE (9% for C and 3.3% for NC) was calculated. However, none of these dependant variables differed significantly between PED and CLIP.

The influence of the pedalling condition is further described in Fig. 1. Indeed, CLIPFBACK enabled all athletes to modify their pedalling pattern, as F_E decreased during both downstroke and upstroke phases. Moreover, this figure highlighted the difficulty for subjects to fully realize the feedback condition, as they could not pull up enough to generate a positive F_E during the whole upstroke. Furthermore, this graph depicted the lack of difference

in the pedal forces application between PED and CLIP for both C and NC groups as reported in Table 2.

Table 3 shows a significant main effect of the pedalling condition on the muscular activity of BF and TA (p < 0.001) as well as RF (p = 0.033) muscles. The clipless feedback condition increased significantly BF and TA muscle activity compared to PED and CLIP (p < 0.001) while RF demonstrated higher activity in CLIPFBACK compared to PED (p = 0.036).

Group and interaction effects

The two-factor ANOVA revealed a significant main group effect for I+, I-, IE₃₆₀, IE_{UP}, $\dot{V}O_2$ and for the integrated activity of GMax (p < 0.05). NE was not influenced by the group factor (p = 0.581). Moreover, an interaction effect between group and pedalling condition was found for IE_{DOWN} and the integrated activity of BF (p < 0.05).

Discussion

The major findings of this study are twofold. Firstly, shoe-pedal interface did not influence the pedalling pattern during submaximal cycling. Secondly, cyclists could change their technique by actively pulling up during the recovery phase. However, doing so impaired their mechanical efficiency.

Concerning the influence of the shoe-pedal interface, the lack of difference between the pedals without toe-clips and clipless pedals is somehow surprising. Indeed none of the kinetic quantities, $\dot{V}O_2$, NE and iEMG parameters showed any differences between PED and CLIP, even for elite cyclists who are used to cycling with clipless shoe-pedal systems. Mean values for NE were

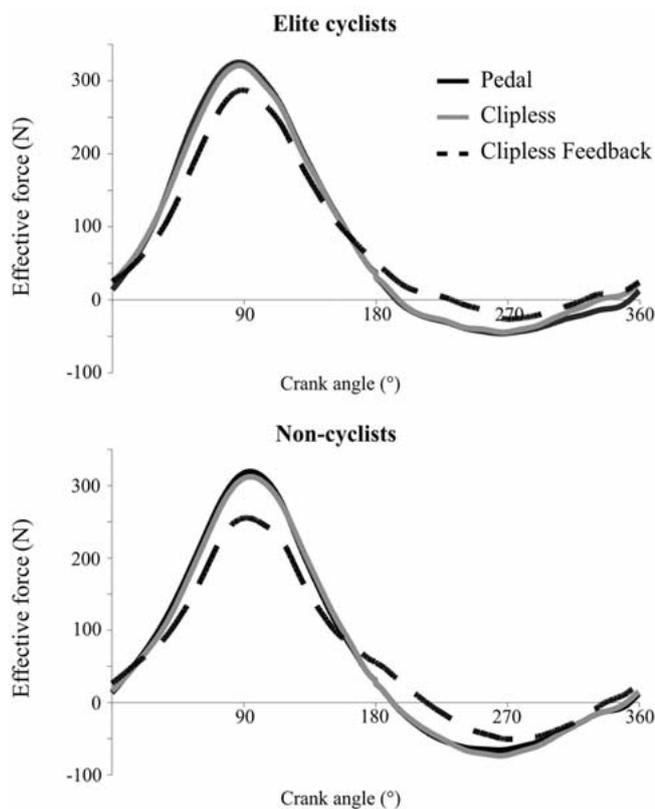


Fig. 1 Right effective pedal force during one crank revolution at 60% of the maximal aerobic power and 90 rpm for the three different pedalling conditions (Pedal: simple pedals without toe-clips; Clipless: clipless pedals; Clipless Feedback: clipless pedals with feedback). Data were averaged on all subjects for each elite cyclists and non-cyclists group. The standard deviations have been purposely omitted for better clarity.

in agreement with that presented in the literature for comparable cadence and power output [1]. Angular impulses were also in agreement with values reported by Sanderson and Black [21] according to the power output discrepancies. Mean IE_{360} values were comparable to that presented in the literature [10,18,20], as well as for mean IE_{DOWN} [3].

The lack of discrepancy between pedals without toe-clips and clipless pedals is in contradiction with results presented in the literature. Lafortune and Cavanagh [10] reported a lower oxygen uptake when pedalling with toe-clips compared to single pedals. In the literature, muscular activity alterations have been reported when using different shoe-pedal interfaces [4,6,9,26]. However, the first authors [4] did not have enough subjects to determine significant effects, while Tate and Shierman [26] measured only muscle activity duration. Finally, except for Cruz and Bankoff [4], other authors used pedals made of obsolete materials and pedal fixation systems. Hence, such results may no longer be valid when investigating modern shoe-pedal interfaces (e.g., clipless pedals). Thus it seems that wearing clipless pedals did not influence mechanical efficiency, pedalling mechanics or muscular activity and that elite riders are not further able to take advantage of clipless pedals during submaximal cycling in a laboratory testing. However, wearing clipless pedals could be advantageous in other cases, where the link between the foot and the pedal provided by the fixation could be necessary, e.g., during maximal cycling, cycling up hills, or any condition where maximal power is required. Indeed, Capmal and Vandewalle [2] have shown a greater power output during all-out sprints with toe-clips than

without, while Hintzy et al. [8] reported a significant increase of the maximal values of force, velocity and power output when clipless pedals were used during all-out ergometer sprints. The cycling intensity chosen in the present study, corresponding to 60% of PMA, ensured that subjects remained in aerobic conditions. However, at this power output, it might be that cyclists did not need to use a possible pedalling technique related to the pull-up action when pedalling with clipless pedals. Therefore, it would be interesting to investigate in the future the effect of power output on the pedalling mechanics with particular focus on the possible pull-up action at higher power output.

When cycling with clipless pedals and feedback, the positive angular impulse during the downstroke and the negative angular impulse during the upstroke phase decreased (● Fig. 1). Moreover, this condition modified all the mechanical parameters for elite riders and non-cyclists. This strongly confirms the influence of force-feedback during the cycling movement on pedal forces obtained by Sanderson and Cavanagh [22]. It is worth noticing that modifying the upstroke phase (44% variation in I^-) did not lead to an angular impulse alteration in the same proportion during the downstroke phase (9 to 12%). This is further underlined when looking at the muscular activity, as the significantly higher iEMG of the biceps femoris, tibialis anterior and rectus femoris muscles (working as knee flexor muscle, ankle dorsal-flexor muscle and hip flexors, respectively) during the upstroke phase did not allow other muscles to modify their activity during the downstroke phase (e.g., no knee extensor muscles relief). Thus, even if the better IE_{DOWN} observed could lead to a better mechanical efficiency [15], a greater muscular activity and a better IE_{UP} during the upstroke phase could be associated with greater stress and therefore an increase in the energetic cost. Indeed, cycling with clipless pedals and feedback altered the metabolic and mechanical efficiency quantities. Elite cyclists might have a specific individual pedalling pattern, due to their high training volume, so that any induced pedalling pattern alteration (e.g., an active pulling-up action) would likely impair their physiological response. However, non-cyclists reached a higher IE_{DOWN} increase (16% vs. 5% for elite) but did not increase their oxygen consumption in the same proportion (3.3% vs. 8.1% for elite). Therefore, it can be hypothesised that letting non-cyclists trained with the feedback condition would allow them to improve their pedalling effectiveness without significant alteration of their oxygen consumption and net mechanical efficiency. This hypothesis would speak in favour of the use of clipless pedals, as this type of foot-pedal interface would be required for such training, despite the lack of clipless pedals advantages during submaximal cycling without feedback found in the present study.

The influence of the group factor on the different parameters cited in the results was likely due to the absolute power output discrepancy between the elite cyclists and the non-cyclists, except for net mechanical efficiency, which could still be compared at the same relative intensity. Thus, the lack of any significant difference in net mechanical efficiency between elite riders and non-cyclists indicated that cycling experience did not influence the net mechanical efficiency during submaximal cycling. This result was in agreement with conclusions already reported by other authors in the literature [13,16,17,24]. The interaction effect found for IE_{DOWN} and the integrated activity of the biceps femoris were likely due to a relatively greater increase of these parameters with CLIPFBACK observed in the non-cyclists group compared to the elite cyclists group.

One limitation of the present study was the choice of the shoe-pedal interface during the incremental test. Elite cyclists and non-cyclists did not use the same interface (i.e., clipless and single pedals without any toe-clips, respectively). Even if this ensured both groups to cycle with pedal types they are used to, the lack of foot-pedal connection could have minimised the maximal oxygen uptake for the non-cyclists [11]. Hence, one could argue that the maximal aerobic power and therefore the submaximal level corresponding to 60% MAP could be inaccurate for the non-cyclists compared to the elite riders. Although this would unlikely change the results concerning the influence of the shoe-pedal interface, it remains questionable if it might have affected the comparability of the results of the two groups. Nevertheless, the influence of possible impairment of the maximal oxygen uptake for non-cyclists during the incremental test could have been lower than the effect caused through not being used to clipless pedals.

In conclusion, shoe-pedal interface did not have any influence on either the mechanical efficiency, the pedalling mechanics or the muscular activity during submaximal cycling. Feedback based on pedal forces representation could be used to develop a new pedalling pattern, characterised by an enhanced active pulling-up action during the upstroke phase. Subjects benefited from this pulling-up action by increasing their pedalling effectiveness, but this new pedalling pattern was associated with an impairment of the mechanical efficiency. Finally, cycling experience did not appear to influence the mechanical efficiency.

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