REAL-TIME FEEDBACK OF PEDAL FORCES FOR THE OPTIMIZATION OF PEDALING TECHNIQUE IN COMPETITIVE CYCLING

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INTRODUCTION:

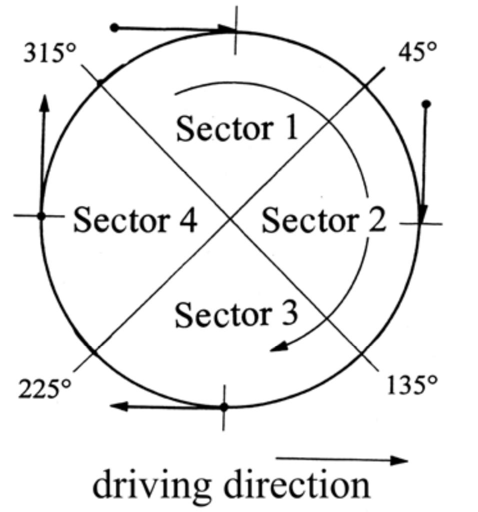

Fig. 1. Sub-dividing the pedal cycle in four 90°-sectors
Sector 1 = Area of the top dead center
Sector 2 = Push-down phase
Sector 3 = Area of the bottom dead center
Sector 4 = Pull-up phase

In competitive road cycling the balance between the daily intake of energy through the digestive tract and the daily demands on the body to generate energy can limit performance. An increase in performance, that is an increase in the effectiveness of converting energy expended into speed, can be achieved through improved pedaling technique. The force applied to the pedal can be resolved into two components, namely the radial force, which works in the direction of the pedal arm, and the tangential force, which always lies tangentially to the circle being described by the pedal. It is only the tangential forces which contribute to the turning of the crank, while the radial forces have no effect on propulsion. From the physics point of view, therefore, the ideal situation when riding a bicycle is to exclusively generate constant tangential forces (Fig. 1). It is, however, questionable, from the physiological point of view, whether such an application of forces is possible or even desirable. Evolution has dictated that the quadriceps femoris is stronger, because of the effect of earth's gravitation, than the muscles which oppose it on the rear-side of the thigh. As a result, a greater force is generated during the push-down phase (sector 2), when the pedal is moving downward, than when the pedal is moving upward (sector 4). Here forces acting counter to the forward movement are observed, working against the turning direction of the crank, due to incomplete release of pressure on the pedals.

METHODS: The pedal forces are recorded by triple-axis piezo force measuring elements, which are integrated into LOOK-compatible cycle pedals, which resolve the three dimensionally operating forces being applied into their vectorial components, virtually without crosstalk. Furthermore, the crank and pedal angles were recorded by continuous rotatory potentiometers in order to be able to mathematically resolve the resulting pedal force into its tangential and radial components. The measurements were recorded and processed on-line using a PC. Trials were conducted on a treadmill which offered the possibility of varying the angle of incline as well as the speed. In addition, a method was developed which allowed feedback to the athlete about the pedal forces he was generating so that he could deliberately influence them and could also compare in his mind the actual forces which he was generating with those which he subjectively kinesthetically felt were being generated. The feedback occurred in real-time via a monitor screen. A polar representation on the PC monitor was chosen in order to come as close to natural movement characteristics during pedaling as possible, where the actual values of the forces were presented in a 360° circle according to the position of the crank. In this form it was possible to present the tangential force, the radial force and the efficiency (tangential force/resultant pedal force) for both pedals simultaneously. 12 competitive road cyclists each took part in a 30 minute trial, which was split into three 10 minute sessions. The first five minutes of each session were spent cycling without feedback, while during the second five minutes one of the above-mentioned parameters was fed back over the monitor screen. The output of the trial participants was 200 Watts at a pedaling speed of 60 rpm.

RESULTS:

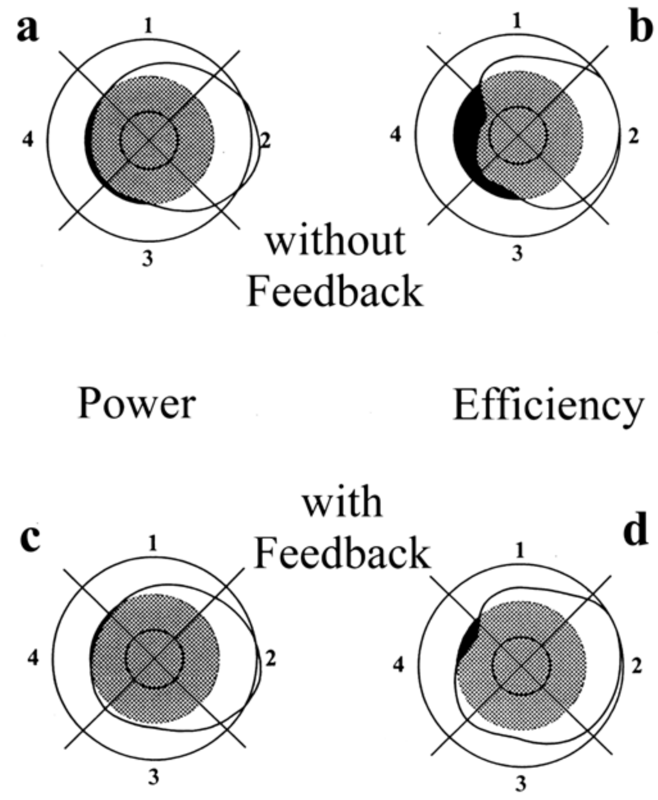

Fig. 2.
Power and efficiency during cycling without and with feedback
white=positive values black=negative values
Power: Outer circle=250W Inner circle=-250W
Efficiency: Outer circle=00% Inner circle=-100%

When the values for all of the subjects are averaged and the values for the three intervals without feedback are compared to those with feedback (Fig. 2) the results show that, as expected, without feedback the forward propulsion forces (a) were generated in the push-down phase (Sector 2), while in the pull-up phase (Sector 4) negative forces hindering forward propulsion were observed due to incomplete release of pressure on the pedals. The type of presentation corresponds to the screen presentation during the feedback. The forces applied during the pull-up phase are relatively low so that the effect is magnified when the efficiency (b) is considered rather than the tangential force components. It is only in the push-down phase that the pedal forces being applied are converted into almost 100 % into forward propulsion. While using feedback (c) it becomes obvious that the forward propulsion generated during the push-down phase can be reduced corresponding to the degree of absence of forces in the pull-up phase. Forward propulsion now occurs in the whole of Sector 3, even if this is only at a low level. A similar picture arises concerning the effectiveness during the whole crank revolution (d). This improves significantly from 50 % to 60 % ($p<0.05$).

A differentiated view arises when the phases without feedback are grouped together and compared with feedback phases divided up according to the sectors and the parameters being fed back (Fig. 3). The dependent variable is the efficiency in the respective sector (the sum of the tangential forces in the sector/sum of the total pedal forces in the sector).

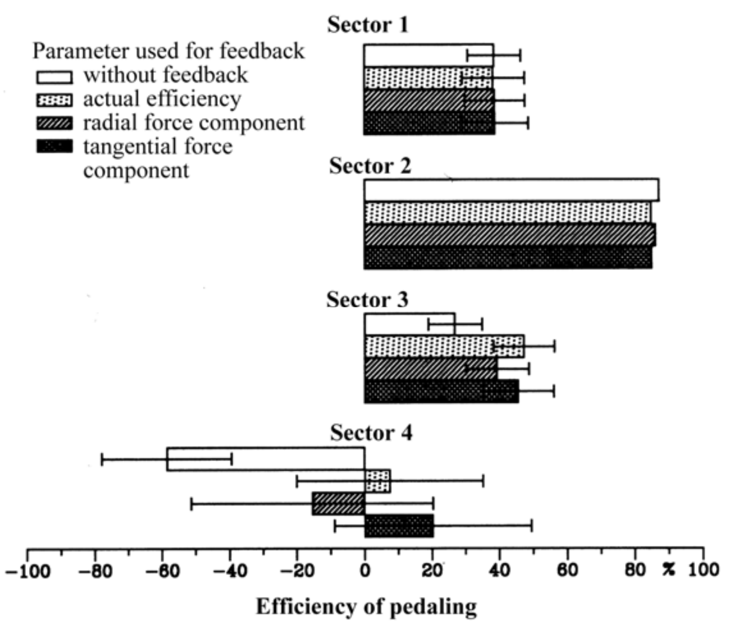

Fig. 3. Efficiency during cycling without feedback and with different parameters displayed in the feedback session (mean ±95%-CI)

A tendency exists for the feedback of efficiency and tangential forces to bring better results than the feedback of radial forces, which is more difficult to reduce. While no significant effect is to be observed due to feedback in sector 1, a reduction of efficiency of 2 % occurs in sector 2, a figure which is to be statistically confirmed, since there was such a low variance around this average value. In sectors 3 and 4 the average increase in efficiency over the three parameters which were fed back was 15 % and 62 % respectively. The lowest improvements were recorded during the pull-up phase where the radial force was being fed back.

DISCUSSION: The modification of pedaling technique which leads to the increased use of pedaling forces to propel a bicycle forward, achieved by feeding back visual information in real-time, looks promising. The cycling athletes taking part in the trials were all of the opinion that the feedback of pedal forces gave them a new feeling for their pedaling movements. A regular use of feedback during training was desired. The reduction in the forward propulsion hindering forces in the pull-up phase was greater than for other investigations (McLean, 1988, Sanderson, 1987), which is probably due either to the fact that only recreational cyclists participated in those investigations, or that the visual feedback was not in real-time but rather after some delay (averaging the values of a number of turns of the pedals). The quantitative improvements are in the same order of magnitude as for other investigations where lost power was fed back acoustically during feedback training lasting a number of weeks (Dittrich, 1989). Further possibilities for using feedback could be:

1. The development of a model technique for cycling. Here, however, it is necessary to simultaneously observe the physiological efficiency. Moreover, it is necessary that the muscles of the athletes can adjust to the demands made by the new conditions. A longitudinal section with about 3 or 4 feedback units per week over 3 months would be the basic prerequisite for this.
2. The feedback over a monitor screen offers beginners the possibility of learning more quickly about general structures of pedaling and making a comparison in the mind between the forces they subjectively feel are being generated and the forces actually being generated.
3. An improvement in inter-muscular coordination could be the main emphasis for the advanced athlete. He could develop measures for controlling particular groups of muscles during the crank revolution.
4. Direct computer screen monitoring of pedaling technique offers the trainer the possibility of helping the athlete to find the best sitting position on the bicycle which brings the highest forward propulsion efficiency. One could also mention the possibility of developing verbal commands for controlling pedaling technique. This, above all, could be tailored to a particular athlete who is being trained.

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