

# Gait Analysis before and after Cycle Training Using a 3D Pedal System

## Analýza chůze před a po tréninku na bicyklu vybaveném 3D Pedal systémem

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### ABSTRACT

#### PURPOSE OF THE STUDY

In this pilot study, gait analysis was performed before and after training with a 3D pedal system (BIUS1), in order to clarify whether these differences are detectable by gait analysis after a short period of training.

#### MATERIAL AND METHODS

Two female and three male subjects were included in a prospective case-control pilot study. The patient and training characteristics were determined. Objective measurement data of the gait were obtained by using a three-dimensional motion analysis system with six infrared cameras and three force plates before and after training with the 3D pedal system.

#### RESULTS

The mean age was  $36.7 \pm 8.7$  years and the subjects had a BMI of  $21.8 \pm 2.4$  kg/m<sup>2</sup>. The training time per year was an average of  $36.0 \pm 11.2$  days, with a training workload of  $511.4 \pm 36.7$  km.

For time-distance parameters, improvements for the left and right side were obtained for cadence and cycle time after training. In total, there was a reduction in hip abduction angle, and an increase in hip inward rotation, knee outward rotation, and range of the frontal knee angle.

#### CONCLUSIONS

Changes in parameters in the gait analysis after a short training interval demonstrate that a 3D pedal system is suitable to produce changes in the gait pattern detectable by gait analysis. Training effects on the supposedly weaker left side can be explained after a brief application of the BIUS1 system.

**Key words:** cycle training, 3D pedal system, gait analysis.

### INTRODUCTION

Up to 85% of injuries in competitive cycling are reported to be atraumatic. Most commonly, they result from overloading and poor posture. The most common localizations are the knee, neck, shoulder, hands, gluteals, and perineum (3). Different studies have investigated injury patterns under different sitting positions and pedal mechanics (9, 17). With regard to injuries in the area of the lower limbs, the knee joint is most frequently affected as a result of the medialized force transmission (11, 13, 14). At the same time, studies have shown that professional cyclists can compensate better than untrained cyclists. García-López et al. could show that professional cyclists have a better pedalling technique (i.e. higher positive impulse proportion) than elite and club cyclists when pedalling at 200 W or more. This is due to the lower minimum torque during the upstroke (less negative torque values) and the kinematic differences in ankle (increased ROM) (8, 10).

In addition to direct mechanical strain, coordinative processes with activation of additional muscle groups play roles in the manifestation of such injuries. Thus, it has been shown electromyographically that activities of the *quadriceps femoris* muscle and the posterior thigh muscles depend on the crank angle. The vastus muscles show the highest activation during the first quadrant of the pedal cycle, whereas the posterior thigh muscles show loading peaks during the second quadrant (1). However, when the performance limit was reached with fatigue of the *vastus medialis* and *lateralis* muscles, a recruitment of additional muscle groups was observed (5).

Axes, lever lengths and moments are largely dependent not only on saddle position but also on pedal position. Since the position of the hip, knee and ankle changes relative to the pedals during rotation, the function of fixed pedals can only represent a good compromise.

Therefore, a dynamic pedal system was designed (BIUS1, Fig. 1), which changes its position during loading. The BIUS1 allows for a leg axis with an externally open angle of 170–175°, so that the loading axis runs more or less centrally through hip, knee and ankle. The feet are not parallel to each other, as in classical pedals, but show an opening angle of 30°. The track width is adjusted individually. In the case of standard pedals, the main loading zone is on the outer edge of the foot (10), whereas it is in the midfoot area in the BIUS1 pedal. The aim is to facilitate use of the adductors in addition to the iliopsoas muscle during flexion. In extension, the iliotibial tract and the *gluteus medius*, as well as the quadriceps muscle and the ischiocrural musculature, should come into effect.

In addition to optimization of force development, the aim is to recruit additional muscle groups in order to reduce one-sided loading and, thus, atraumatic injuries in amateur cycling.

Gait analysis makes it possible to determine even small changes in the gait pattern as a surrogate parameter of protective posture and coordination. It permits, by measurement of numerous parameters, a differentiated analysis of the gait image, and allows conclusions to be made on if the neuromuscular system has changed by a specific intervention or therapy (12). The gait analysis parameters can be measured directly (e.g. speed, step length, cadence, joint range of motion, and ground reaction force) as well as calculated using these data based on biomechanical models (e.g. acting joint moments and power). Motion analysis is a commonly employed method for diagnosis and documenting clinical improvement, which has been used in a number of small studies, but recently has been suggested as a “conceptual basis for application of real-time movement feed-back” and a strategy for the design of new interventions (4).

A change of motion pattern by using a new pedal design is expected to change gait parameters by influencing the neuromuscular system and should therefore be detected by means of gait analysis.

Therefore, the objective of the present pilot study was to clarify whether this pedal concept can be used to change the gait pattern of active amateur cyclists.

## MATERIAL AND METHODS

Five subjects took part in the prospective case control study of the BIUS1 pedal system. The subjects underwent gait analysis before (pre) and after (post) training with BIUS1. The age of the five subjects (three male and two female) was  $36.7 (\pm 8.7)$  years and their BMI was  $21.8 \pm 2.4 \text{ kg/m}^2$ . Thus, all of the subjects were of normal weight and were recreational cyclists, but were using conventional pedals. Their annual training time was on average  $36.0 \pm 11.2$  days, at a training workload of  $511.4 \pm 36.7 \text{ km}$ .

The details of the study were explained to the subjects to obtain their written consent. This study was conducted with the approval of the local Ethics Committee of the Friedrich-Schiller University Jena EA 4960-10/16.

The gait analysis was carried out with the motion analysis system 3D Vicon (Vicon, Oxford, GB) using 10 infrared cameras (Bonita 10, image rate 200 Hz) and 3 force plates. One of these was from Kistler (Kistler Instrumente AG, Winterthur, Switzerland), and two were from AMTI (AMTI, Watertown, USA). For data acquisition and treatment, the program “Nexus V.2.1” was available, and for evaluation the program “Polygon V.4.1” (Vicon, Oxford, GB). As a model, “Plug in Gait” (PIG) – which was integrated into Nexus – was chosen.

The persons were each labelled with 17 markers over anatomically defined guiding points (Spina iliaca anterior superior, sacrum, trochanter major, thigh, knee lateral (*epicondylus femoralis lateralis*)).

tibia lateral (left proximal, right distal), hock (*malleolus lateralis*) and heel. Each on both sides with the exception of *sacrum*) foot (2<sup>nd</sup> metatarsal)). The local co-ordinates of the markers during the gait are covered, recorded and displayed graphically by means of the model. The persons have to complete the gait analysis by finishing a run of approximately 12 m, a distance over which they must in each case completely meet a force plate with one foot. The persons had to take over this distance long enough, until 10 usable trials are accomplished.

By means of gait analysis, a double step is analysed (phase between two heel treads of the same foot). The step cycle is divided into the stance phase (“touchdown”

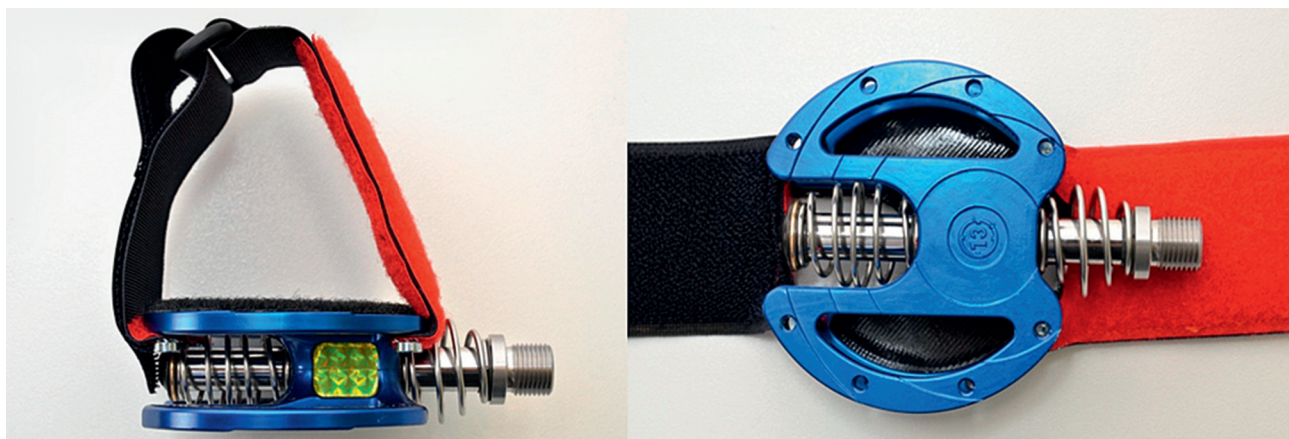


Fig. 1. BIUS 1 in frontal and transversal view.

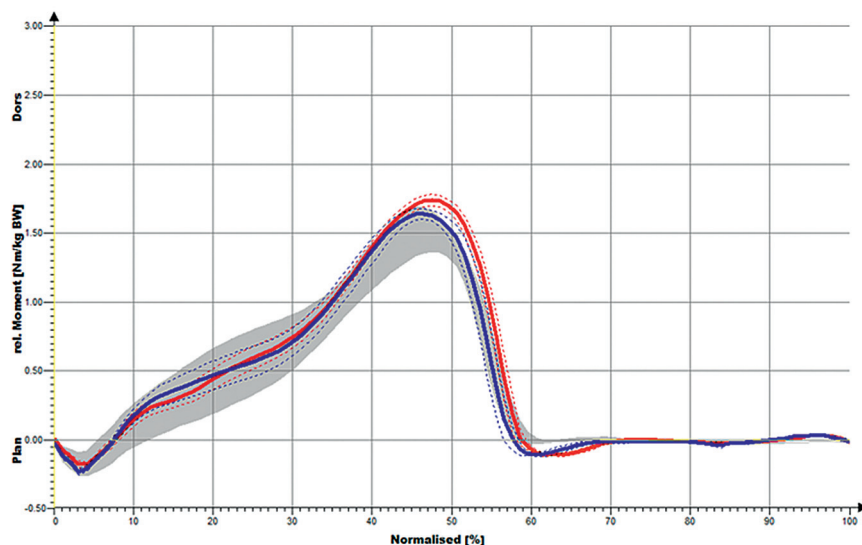


Fig. 2. Example of a relative ankle course for the sagittal ankle moments (shaded in grey: comparative values from a healthy group; red: left side; blue: right side).

and “toe off”), and the swing phase (“toe off” and touchdown”). By that movement, the stance phase covers about 60% of the gait cycle. In order to be able to compare the right and left foot immediately, the values are normalized, i.e. the values for the stance phase of both feet are put on top of each other (15).

With the instrumental gait analysis system, parameters can be recorded in three planes. For evaluation, the relevant maximum or minimum values of the curves were considered, as well as the relevant ranges between them (angles, moments, and power) (15, 16).

1. Time-distance parameters (all parameters were also calculated as relative variables (related to body height), except for the stance phase) cadence, double support, cycle time, stance phase, step length, gait velocity.
2. Ground reaction forces  $x$ ,  $y$  and  $z$  components.
3. Angles (in sagittal, frontal, and transversal planes) pelvic, hip, knee, and ankle angles in all three planes.
4. Relative moments related to body weight (in sagittal, frontal, and transversal planes) relative hip, knee, and ankle moments in all three planes.
5. Power relative to body weight relative hip, knee, and ankle power.

The statistical evaluations were performed with the program IBM SPSS Statistics Version 19. The values of the parameters determined pre and post were tested for significant differences by using a Wilcoxon test.

Further, means of the gait parameters were determined and the percentage deviation of the values determined before (measurement value) and after training (nominal value) were calculated.

## RESULTS

The investigation was carried out without complications. For the time-distance parameters, improvements for the right and left side were obtained in the t-test for cadence and cycle time after training. The cadence increased

from 119.4 to 122.6 steps/min ( $p = 0.043$ ) and the relative cadence increased from 0.86 to 0.88 steps/min/m ( $p = 0.043$ ).

The cycle time declined significantly from 1.01 to 0.98 s ( $p = 0.043$ ) and the relative cycle time declined from 2.34 to 2.27 s/m ( $p = 0.043$ ).

No differences were determined for the joint angles of the hip, knee or ankle. An increase of 0.18 to 0.2198 Nm/kg BW ( $p = 0.043$ ) was seen for the relative ankle moment on the left side in the sagittal plane.

A typical relative moment (related to body weight) for the sagittal ankle moments (plantar flexion/dorsal extension) is shown in Fig. 2. The maximum for plantar flexion occurred at about 3.5% of the gait cycle.

Differences in joint power of hip and ankle were also found for the

left side (hip power increased from 1.79 to 1.96 W/kg BW ( $p = 0.043$ ), while ankle power increased from 4.82 to 5.27 W/kg BW ( $p = 0.043$ )).

Numerous effects of the BIUS1 application on performance were seen, but they were different between the right and left side. Taken together, there was a reduction in the frontal hip angle (abduction), and an increase in hip rotation (inward), in knee rotation (outward), and range of the frontal knee angle.

## DISCUSSION

The main result of the present study was that a dynamic pedal system is suitable to produce changes in gait pattern that are detectable by gait analysis.

For all subjects, the right leg was found to be the take-off leg and, thus, the left was the weaker leg. Since all participants were already active amateur cyclists before the study, asymmetries in the gait parameters determined between the right and left leg can be accounted for by the differences in training conditions between the two sides (8, 10).

After brief application of BIUS1, training effects on the supposedly weaker left side can be explained by the changes in kinematics resulting from the dynamic pedal system. This is suggested by the significant improvements in performance in the area of the left ankle and the left hip. This may also have led to the increases in cadence, and a dynamic pedal probably results in more even training of the right and left lower limb.

The hypothesis may be put forward that, in contrast to the conventional pedal, the BIUS1 pedal system establishes coordination strategies between muscle groups to provide relief, not only using extensor and flexor muscles of the leg, as confirmed in other studies (5). After only a short training interval, early fatigue and contractures could be prevented. The inclusion of different muscle chains may increase endurance and counteract contractures, thus



preventing injury (9, 17). The extended range of movement with the participation of additional muscle groups may lead to improved endurance and metabolic supply, which, according to previous investigations, plays a central role (7). Attempts have been previously made to establish different pedals with translational motion, but without using gait analysis to investigate the effects on the entire lower limb. Here, the behaviour and performance of different muscle groups during cycling was examined using a camera and force transducer on the pedal (6). Attempts have also been made to align the various components such as saddle and pedals differently (2, 10). Here, further processes for improving training were established. Biomechanical analyses have shown that professional cyclists can achieve a better result and improved performance as a result of better pedalling technique (i.e. higher positive impulse proportion) (8). Therefore, the next objective might be to demonstrate the effect of 3D pedals in professional cyclists. In addition to this, it should be tested whether this technique can be applied effectively in the field of rehabilitation.

## CONCLUSIONS

The present study points out the short-term effect of the investigated pedals on gait pattern. This result may have some impact on sports medicine and rehabilitation. From a scientific point of view the data may serve as basis to conduct further investigations using a prospective randomized study design.

*We did not receive any benefits directly or indirectly from commercial parties.*

*The study was approved by the local Ethics Committee of the Friedrich-Schiller University Jena EA 4960-10/16.*

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