RELATIONSHIP BETWEEN CYCLING MECHANICS AND CORE STABILITY

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ABSTRACT. Abt, J.P., J.M. Smoliga, M.J. Brick, J.T. Jolly, S.M. Lephart, and F.H. Fu. Relationship between cycling mechanics and core stability. J. Strength Cond. Res. 21(4):1300-1304. 2007.—Core stability has received considerable attention with regards to functional training in sports. Core stability provides the foundation from which power is generated in cycling. No research has described the relationship between core stability and cycling mechanics of the lower extremity. The purpose of this study was to determine the relationship between cycling mechanics and core stability. Hip, knee, and ankle joint kinematic and pedal force data were collected on 15 competitive cyclists while cycling tethered on a high-speed treadmill. The exhaustive cycling protocol consisted of cycling at 25.8 km·h⁻¹ while the grade was increased 1% every 3 minutes. A core fatigue workout was performed before the second treadmill test. Total frontal plane knee motion (test 1: 15.1 ± 6.0°; test 2: 23.3 ± 12.5°), sagittal plane knee motion (test 1: 69.9 ± 4.9°; test 2: 79.3 ± 10.1°), and sagittal plane ankle motion (test 1: 29.0 ± 8.5°; test 2: 43.0 ± 22.9°) increased after the core fatigue protocol. No significant differences were demonstrated for pedaling forces. Core fatigue resulted in altered cycling mechanics that might increase the risk of injury because the knee joint is potentially exposed to greater stress. Improved core stability and endurance could promote greater alignment of the lower extremity when riding for extended durations as the core is more resistant to fatigue.

KEY WORDS. alignment, injury, overuse

INTRODUCTION

Core stability has received considerable attention with regards to functional training in sports. Anecdotally, core strengthening has been adopted by the athletic community and clinical professionals both for performance enhancement as well as injury prevention (17), with particular focus related to strengthening the abdominal, paraspinal, and gluteal muscles (11). The core not only provides stability to the spine while controlling movement at the torso, but also affords greater leverage for upper and lower extremity motion and force development (9).

Specific to cycling, the core provides the foundation from which force is generated (10). The core muscles maintain the neutral pelvic position on the bike when the anterior and posterior muscle components are equally balanced. On the basis of orientation and attachment of the psoas muscle on the lumbar spine, pelvic stabilization and resistance to fatigue are critical to maintain the natural curve of the spine as well as provide the leverage from which the psoas and gluteal muscles contract when a greater power output is required (8). Although the lack of core stability would appear to have the greatest influence on the back, lower extremity alignment could also be affected as the foundation from which power is generated becomes compromised (2).

Appropriate bike fitting is critical to prevent injuries such that consistent lower extremity alignment is adopted throughout the pedal stroke (1). Decreased core strength however, could artificially induce malalignment of the lower extremity in an effort to maintain a given power output. Furthermore, the combined effect of lower extremity malalignment, excessive cadence, and increased riding volume or intensity could increase the risk of injury (1). The typical cyclist, with an average cadence of 90 revolutions per minute, will pedal between 16,000 and 21,000 revolutions during a typical 3-4-hour ride and upwards of 33,000 for a 6-hour ride. The repetitive motion of cycling and the fixed position of the pelvis and feet require efficient movement patterns to avoid excessive stresses being applied to the musculoskeletal structures of the lower extremity (6). Although the relationship between core stability and back injury in cyclists has been studied (3), no research that we are aware of has examined the role of core stability in maintaining lower extremity alignment during cycling. The core is often described according to the perspective of the investigator (17). For the purpose of this study, the core will refer to the main anterior and posterior lumbo-pelvic stabilizing muscles. The purpose of this study was to determine the relationship between cycling mechanics and core stability. It was hypothesized that diminishing core stability would result in altered cycling mechanics and pedal force application.

METHODS

Experimental Approach to the Problem

A within-subject, repeated measures design was used to determine changes in lower extremity joint kinematics and pedaling forces as a result of compromised core stability. Subjects reported for 3 sessions (1 training, 2 testing) throughout the study. Sessions were separated by a minimum of 1 week to ensure full recovery and prevent potential confounding results on subsequent tests. An initial training session was provided to introduce subjects to testing methods. Subjects performed an incremental ramp cycling protocol during test 1. Test 2 required the subjects to complete a precore fatigue isokinetic test, core fatigue workout, postcore fatigue isokinetic test, and a repeat of the incremental ramp protocol performed during test 1.
Subjects
Fifteen competitive cyclists (age: 34.5 ± 9.8 years; height: 1.77 ± 0.11 m; mass: 76.3 ± 11.1 kg) participated in this study. Subjects were members of local road cycling teams with a road race classification of category 2-4 on the basis of racing experience and accumulated finishing place points by the U.S. Cycling Federation. Subjects provided written informed consent before participation in accordance with the university Institutional Review Board. Subjects who reported a history of musculoskeletal injury within the previous 3 months or participated in a core strengthening program (2 or more times per week for 6 weeks before study enrollment) on a regular basis were excluded.

Procedures
Training Session. Subjects were provided a separate training session to become familiar with the testing procedures and, specifically, riding on the treadmill (Woodway ELG; Woodway USA, Waukesha, WI). Proper gear ratio was determined during the training session to ensure subjects were able to maintain the desired pace with a cadence of 90–95 revolutions per minute. This would be the gear ratio that subjects would ride during the testing sessions.

Incremental Ramp Protocol—Test 1 and Test 2. One week after the training session, subjects reported for test 1. Linear and circumferential anthropometric measurements of the dominant lower extremity were recorded for each subject. Spherical reflective markers (diameter 0.025 m) were placed at designated anatomical landmarks previously described by Vaughan et al. (16). Two additional markers were positioned at the most lateral aspect of the pedal in line with the pedal spindle and approximately 4.5 cm inferior to the pedal spindle marker. Raw coordinate data were collected with the Peak Motus 3D Motion Analysis System (software version 7.1; ViconPeak Inc., Centennial, CO) interfaced with 8 high-speed (120-Hz) optical cameras (Pulnix Industrial Products Division, Sunnyvale, CA). Dependent kinematic variables included total frontal and sagittal plane motion of the hip and knee and total sagittal plane motion of the ankle. Intraclass correlation coefficients (ICCs) and standard error of measurement (SEM) were previously calculated within our laboratory for test-retest reliability of all kinematic measurements (ICC 0.843–0.957; SEM 0.97–1.89°).

Raw force data (1,200 Hz) were collected with the use of custom-designed pedals constructed from silicone strain gauge force transducers (ATI Industrial Automation, Apex, NC) and Shimano Pedaling Dynamics (SPD) pedals (Shimano, Osaka, Japan). A local coordinate system was created on the bicycle, with the origin positioned on the seat tube, 5 cm inferior to the seat tube–top tube junction. Two additional markers were positioned on the down tube at the same vertical height as the origin marker and the center of the head tube. The local y-axis was calculated as the vector between the seat tube and down tube markers, whereas the x-axis was formed by the vector between the seat tube and head tube markers. The cross product of the x- and y-axes was used to calculate the z-axis. Dependent variables included power phase effective force, recovery phase effective force, total gross work, total net work, positive work, and negative work. Power phase was defined as the time period that corresponded to 0–180° of the pedal stroke, and recovery phase was defined as the time period that corresponded to 180–360° of the pedal stroke. Coefficient of variation for pedal force data has been previously determined within our laboratory to be 18.3–24.4%. Coefficient of variation for work data has been previously determined within our laboratory to be 20.7–23.2%.

Subjects rode their own bikes and wore their own cycling shoes with SPD cleats (Shimano, SM-SH51) to ensure natural position within the SPD pedal (Shimano, PD-M520). Subjects were provided a 10-minute warm-up before data collection. The treadmill protocol for test 1 and test 2 consisted of riding untethered on a high-speed treadmill at 25.8 km·h⁻¹. The treadmill elevation was increased in 1% increments every 3 minutes until exhaustion. Subjects were required to maintain the same gear ratio, cadence, and hand position throughout the test while remaining seated. A total of 7 pedal cycles were collected during the final 30 seconds of each stage, with the middle 3 trials being used for data analysis.

Isokinetic Torso Rotation Test—Test 2. The Biodex System 3 Multi-Joint Testing and Rehabilitation System (Biodex Medical Inc., Shirley, NY) was used to validate core fatigue following the core fatigue workout by determining the changes in torque, work, and power after the exercise circuit. Subjects were seated in an upright position with their popliteal space approximately 6 cm from the edge of the seat of the chair. The torso rotation attachment was aligned with the long axis of the spine and lowered to contact the subject’s chest approximately 4 cm below the level of the clavicles. Practice trials were provided to ensure patient understanding and familiarity. Subjects were instructed to perform maximal intensity, concentric isokinetic axial torso rotations at 120°·s⁻¹ for 3 minutes without pacing. Right and left rotational data were averaged for peak torque, total work, average power, maximum repetition total work, and average peak torque per repetition.

Core Fatigue Workout—Test 2. Subjects performed a 32 minute circuit of 7 exercises designed to target core stabilizer muscles in multiple planes of motion. Each subject completed 4 consecutive sets of the exercise circuit, performing each exercise for 40 seconds and resting for 20 seconds. The exercise circuit consisted of the following exercises: seated upper torso rotations with medicine ball, static prone torso extension with medicine ball, supine lower torso rotations with medicine ball, incline sit-ups with weighted plate, lateral side bend (performed bilaterally) with weighted plate, rotating lumbar extension with weighted plate, and standing torso rotations with weighted pulley resistance.

Immediately after the exercise circuit, subjects performed a second isokinetic torso rotation test to verify fatigue of the core musculature. On completion of the post-exercise isokinetic test, subjects performed a second incremental cycling treadmill test as described for test 1.

Data Reduction. Raw coordinate data were filtered with a fourth-order Butterworth filter with an optimal cutoff frequency (7). All of the kinematic calculations were performed in the Kincalc module of the Peak Motus software package and based on Vaughan et al. (16). Raw force data were filtered with a fourth-order Butterworth filter with an optimal cutoff frequency (7). The filtered coordinate and analog data were then exported to a custom-designed LabView (version 6; National Instruments, Austin, TX) program to calculate the joint kinematic and pedal force data of interest.

Initially, the pedal markers were converted to the lo-
A significant decrease (30.0–43.3%) in peak torque, total work, average power, maximal repetition total work, and average peak torque was demonstrated after the core fatigue workout, confirming the effect of the core fatigue workout to induce fatigue. Isokinetic torso rotational data are presented in Table 1.

**RESULTS**

For all analyses, statistical significance was set a priori at p < 0.05. Significant prefatigue/postfatigue differences (p < 0.05) are reported at the final stage as subjects self-terminated the test because of exhaustion. Termination of test 1 and test 2 were completed within the same stage within subjects (5 ± 1%). Total frontal plane knee motion and total sagittal plane knee and ankle motion increased (13.4–54.3%) after the core fatigue protocol, indicating greater extraneous motion throughout the pedal stroke. Kinematic data are presented in Table 2.

Because of variability in completion of the incremental ramp protocol between subjects, kinematic and force data are reported at the final stage as subjects self-terminated the test because of exhaustion. Termination of test 1 and test 2 were completed within the same stage within subjects (5 ± 1%). Total frontal plane knee motion and total sagittal plane knee and ankle motion increased (13.4–54.3%) after the core fatigue protocol, indicating greater extraneous motion throughout the pedal stroke. Kinematic data are presented in Table 2.

No significant differences were demonstrated for any pedal force or work data. Pedal force and work data are presented in Table 3.

**DISCUSSION**

The purpose of this study was to determine the relationship between cycling mechanics and core stability. The results of this study only partially supported our hypotheses. Specifically, several of the kinematic variables were altered after the core fatigue workout, whereas the pedal force and work variables remained unchanged. Collectively, these results would suggest compensatory kinematic adaptations to maintain a given power output.

Knee pain remains one of the most commonly diagnosed pathologies in cyclists, with factors such as bicycle fit, improper training, and anatomical abnormalities identified as contributors to injury (6). Considering the fixed pelvis and feet positions, the knee acts as the fulcrum of the thigh and shank, at which point excessive stresses are likely to be absorbed. Cycling mechanics typically involve a pistonlike, symmetrical motion of the legs for power generation and smooth rolling transition between the contact points of the patellofemoral joint (4, 5). Disrupted tracking of the patella could result in wearing on the posterior surface of the patella because of excessive...
frontal plane motion of the knee. As identified in this study, disruption of core stability resulted in greater total frontal plane knee motion and altered the cyclical, aero-
dynamic position of knees near the top tube with a greater
greater knee flexion after the pedal bottom. The subjects also
described a combination of greater total sagittal
plane knee motion and total sagittal plane ankle motion. The adopted sagittal plane knee motion pattern could have been a compensatory adaptation as a result of an-
ting to increase the leverage of the foot against the ped-
al. The lack of core stability might amplify the influence of the other factors (strength imbalances, flexibility defi-
cits, heavy gear selection, large accumulation of miles) that are known to contribute to knee pathology, particularly as cyclists continue to ride for durations of sev-
eral hours with altered mechanics of the lower extremity.

The application of pedaling forces has been previously
studied in normal and prolonged cycling conditions. The typical pedaling stroke is separated into the effective (force application perpendicular to crank
arm) and ineffective (force application parallel with crank
arm) components. By partitioning the application of
pedaling forces into the respective components, inefficient
force patterns can be identified, particularly as the feet
transition through the top and bottom of the pedal stroke. Inefficent force patterns include persistent inferior
vertical force at the bottom of the pedal stroke and in-
sufficient superior forces during the recovery phase as the
top of the pedal stroke approaches.

The role of core stability and subsequent changes in
pedaling forces has received limited attention. Sanderson
and Black (14) demonstrated an improvement in pedaling
effectiveness during the power phase coupled with a re-
duction in pedaling effectiveness during the recovery
phase as a result of prolonged cycling. The authors con-
tended that the increased power phase effective force was a
compensatory mechanism to offset the diminished ef-
fective force during the recovery phase (14). The lack of
changes in pedaling forces, specifically during the recov-
ery phase, was somewhat surprising considering our hy-
pothesis that disrupting core stability would result in a
reduction in pedaling effectiveness during the recovery
phase. The lack of differences between test 1 and test 2
for positive work, negative work, net work, and gross
work was also not expected. On the basis of our hypoth-
eses, improved pedaling efficiency would have been dem-

Practical Applications

The introduction of a core fatigue workout altered the me-
chanics of the lower extremity during cycling while pedal
force application remained unchanged. Prolonged cycling
with altered lower extremity mechanics as a result of a
fatigued core might increase the risk of overuse injury
from malalignment. Cyclists should integrate a year-
round core conditioning program into current training to
promote lower extremity alignment while cycling. Al-
though cycling is primarily a sagittal plane activity, a
core conditioning program should incorporate both sag-
ittal and frontal plane exercises. Strengthening the core
muscles could enhance the stability of the founda-
tional leverage from which the cyclist generates power,
and increasing the endurance of the core muscles could
promote core stability maintenance.
REFERENCES


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