The effect of low back pain on neuromuscular control in cyclists

Emile Marineau Belanger[1,2], Dan-Mihai Boon[3,4], Martin Descarreaux[1,2], Jacques Abboud[1,2]

[1]Department of Human Kinetics, Université du Québec à Trois-Rivières

[2]Research Group on Neuromusculoskeletal Disorders (GRAN)

[3]Faculté de biologie-santé parcours neuroscience du mouvement, Université de Paris-Est Créteil

[4] Institut Franco-Européen de Chiropraxie, Campus Paris

Corresponding author

Jacques Abboud

Department of Human Kinetics, Université du Québec à Trois-Rivières

3351, boul. des Forges, C.P. 500, Trois-Rivières, QC G9A 5R7, Canada

819-376-5011 #3783

E-mail: Jacques.abboud@uqtr.ca

Abstract:

This study was designed to identify neuromuscular adaptations of low back pain (LBP) cyclists while cycling, and the impact of a cycling effort on spinal shrinkage. Forty-eight trained cyclists rode their road bike on a smart trainer for 1-hour. Surface electromyography (EMG) recorded muscle activity of the lumbar erector spinae (LES), 3D motion analysis system recorded kinematic of the trunk, and stadiometry measured spinal height. Statistical comparisons were made using repeated measure ANOVAs. The LBP group presented increase in pain levels throughout the effort (p<0.001). A significant group difference was only observed for the thoracic angle (p=0.03), which was more flexed for LBP. The one-hour cycling effort (time effect) significantly increased the trunk flexion (p<0.001) and thoracic flexion (p<0.001) for both groups. Significant lower LES activation (35% less) was observed at the end of the effort for both groups. The effort induced a decrease in MVC (p=0.001) and a decrease in spinal height (p=0.01) for both groups. Neuromuscular adaptations to cycling effort is identified by a decrease in LES EMG amplitude and an increase flexion of the trunk. Adaptation to pain is seen by an increase in thoracic flexion. Despite these adaptations, LBP cyclists could not ride their bike pain-free.

Keywords: Road cycling, EMG, kinematic, stadiometry

Introduction

Low back pain (LBP) is a complex condition with multiple contributors to both pain and associated disability (1). It is the most common musculoskeletal complaint in the world, and the leading cause of years lived with disability (2). LBP is widespread in the population including athletes (2, 3). According to current evidence, the lifetime prevalence of LBP in athletes has been reported to be ranging from 33% to 84% (4).

Although physical activity is associated with a healthier lifestyle, it does not always contribute to a lower prevalence of LBP (5). It is still unclear whether practicing sports has a protective effect or is a risk factor for developing LBP (6-8). In road cyclists, LBP accounts for 15% to 50% of reported injuries (9). Even though 24% to 60% of elite road cyclists report LBP (10-12), only a few studies have explored the mechanism associated with LBP in road cyclists (13-17).

Among those studies, it was observed that cyclists with LBP showed greater lumbar flexion than controls (16). Cyclists with LBP were flexed at 74% of their maximal lumbar flexion, compared to 63% for the control group. In addition, given that a prolonged flexed position increased spinal pressure in the general population (18-20), it was hypothesized that cycling may induce intervertebral discs (IVD) ischemia and altered IVD structure (21). Plus, it has been shown that IVD alteration is associated with the development of LBP (22). However, one study has shown that painless high-volume cyclists have higher IVD height, and better hydration compared to non-sporting referents (23). These results contrast with previous studies suggesting that cycling is a risk factor for developing LBP (21, 24). Therefore, the impact of cycling in LBP athletes on IVD still needs to be further investigated.

Other researchers have studied trunk muscles activities in cyclists with LBP (13-15, 17). For instance, lumbar muscles activity was assessed pre- and post-cycling with electromyography (EMG) in cyclists with and without chronic LBP (14, 17). These two studies showed opposite results regarding muscle fatigue. No myoelectric manifestations of fatigue of the lumbar erector spinae (LES) was observed in the LBP group (14), while the other study revealed muscle fatigue in the same muscle group (17). Another group of researchers assessed the low back muscles activities before and after a cycling task of an average time of 38.5 minutes in a pilot study (15). Their findings showed that the LBP group presented greater asymmetry in the superficial lumbar multifidus activity at both the beginning and end of the effort, which suggests different neuromuscular strategies to perform a cycling task.

Although interesting and innovative at that time, these studies could not benefit from recent advances suggesting that LBP involve complex neuromuscular adaptations of the motor system. According to Hodges and Tucker' pain adaptation model, redistribution of EMG activity between and within muscles represents one of the adaptations to pain (25). The model also proposes that adaptation to pain may imply short-term benefits such as increasing protection of the injured/painful part, but may induce long-term consequences, such as increasing the load, decreasing movement and variability (25). Although studies conducted with cyclists have observed changes in motor activation in the presence of LBP, most studies have focused on efforts of short duration, muscle fatigue occurrence and muscle activity differences before and after the effort. It remains to be determined how the low back muscles' neuromuscular strategies and IVD height adapted in cyclists with chronic LBP during a long cycling effort.

The main aim of this study was to assess the neuromuscular control by considering trunk neuromuscular activity and kinematic during constant and controlled cycling effort in healthy

cyclists versus cyclists with chronic LBP. This study also compared the spinal height difference caused by the cycling effort between both groups. The last aim of this study was to identify the effect of one-hour cycling task on the manifestation of lumbar muscle fatigue between both groups. It was hypothesized that LBP cyclists use different neuromuscular strategies than pain-free cyclists during a cycling effort. Regarding IVD height, because of the prolonged flexion, the height of both groups should decrease after a cycling task.

Materials and Methods

Participants

Twenty-one participants with non-specific chronic LBP and twenty-seven healthy participants with no history of LBP were recruited. Non-specific LBP was determined by the exclusion of other spinal disorders, and refers to a symptom or a syndrome rather than a diagnosis (26). A chiropractor (EMB) screened every cyclist. From the LBP group, exclusion criteria were: Inflammatory arthritis of the axial skeleton, collagenosis, advanced osteoporosis, spinal surgery, neuromuscular disease, malignant tumors, uncontrolled hypertension, infection or any other non-mechanical pain; radiculopathy, progressive neurological deficit, myelopathy, lumbar disc herniation; severe and incapacitating pain limiting the ability to perform the evaluation protocol in the laboratory; pregnancy; congenital heart defects, heart disease, high blood pressure, metabolic diseases which can cause problems with exertion. The inclusion criteria were: suffering from low back pain while cycling for more than 4 months; being able to cycle for at least one hour; having been cycling more than 1000 km per year for more than 2 consecutive years; being an amateur cyclist.

The control group had the same exclusion and inclusion criteria as the LBP group, plus no history of acute/chronic upper or lower back pain in the past 6 months.

The project received approval from the Université du Québec à Trois-Rivières ethics committee for research with humans (CER-19-263-07.22) and all participants gave their written informed consent prior to their participation in the study.

Study design

To identify neuromuscular adaptations to cycling in LBP participants and address the study hypothesis, all participants were involved in one experimental session. At first, anthropometric and sociodemographic data were collected. After, they completed two questionnaires, the modified Oswestry Low Back Pain Disability Index (ODI) (27) to assess LBP-related disability and the Keele Start Back Screening Tool (28) to assess prognostic indicators. Both were in their French, validated versions. Maximal voluntary isometric trunk extension contractions (MVC) and trunk height using a stadiometer were assessed before (baseline assessment) and immediately after the effort (post-effort assessment). Between these measurements, participants rode their own road bike mounted on a smart trainer (Kickr, Wahoo Fitness, Atlanta, USA) for one hour. Participants were instructed not to participate in any heavy training or physical activities 24h before their testing day.

Bicycle Measurements

The distance between the bottom bracket and the saddle, and the distance from the saddle to the handlebar were measured with a measurement tape. Plus, the saddle angle was measured with an inclinometer (Precision: ±0.1°; Johnson, digital angle locator, model 40-6067, Mequon, WI, USA). The cycling fit including saddle angle may have an impact on LBP (29).

Cycling Task

Participants completed the one-hour cycling effort on their own road bike mounted on a smart trainer (Kickr, Wahoo, Atlanta, USA), which measured their pedaling cadence and power output. After a five-minute free warm-up, participants had to keep their hands on their lever hoods for the next 55 minutes. Participants were asked to stay seated for the whole protocol. They were asked to keep a cadence of 80-100 rotations per minute (RPM) (30) and a heart rate between 70% and 80% of their maximal age-predicted heart rate. RPM, with the smart trainer, and the heart rate, with a chest-strapped heart-rate-monitor (HRM-tri and 920 XT smartwatch, Garmin, Olathe, USA), were continuously measured throughout the effort. Feedback from the evaluator was provided if targets were not reached. The Borg scale was used to quantify perceived exertion every 5 minutes during the 60-minute effort (time 0 minute to time 60 minutes for a total of 13 data), with a score ranging from 6 (nothing) to 20 (maximum exertion) (31, 32). Participants had to maintain their Borg's rating of perceived exertion below 17 (very hard). The aim was to recreate a moderate effort during a one-hour ride without reaching exhaustion. LBP intensity was rated every 5 minutes during the 60-minute effort using a visual analogue scale (VAS) (time 0 minute to time 60 minutes for a total of 13 data). VAS was scaled from 0 (no pain) to 10 (worst pain).

Stadiometry

To understand the effect of cycling effort on spinal shrinkage, the external spinal height variation was measured using a stadiometer in a protocol that had been previously validated (33). Participants had to sit on a custom-built seated stadiometer (235 Heightronic Digital Stadiometer, precision: ± 0.1 mm; Measurement Concepts, Quick Medical, Snoqualmie, WA) (Figure 1). The lower limbs were placed on an adjustable footrest so that the ankles were approximately in 10° dorsal flexion, 100° knee flexion, and 100° hip flexion. Hands and forearms were placed on their thighs. A cervical support, tailored to each participant's spine and centered at C4 to C5, was placed

between the custom wooden seat and the spine to maintain spinal alignment. The whole set-up was inclined 5° backward. Participants had to stare at a target positioned at eye level in front of them. Once the participants were correctly positioned on the stadiometer apparatus, the stadiometer head platform was lowered to rest on the top of the subject's head. When sufficient pressure was reached, a sound alert indicated the evaluator to read the measurement. The same evaluator took three repeated measures. This protocol was performed at the baseline assessment (time 0 minutes) and at the post-effort assessment (time 61 minutes).

Figure 1 about here

Maximal Voluntary Contraction

Participants were asked to lay in a prone position on a 45° Roman chair, with the iliac crests aligned with the chair cushion edge. They were then instructed to keep their trunk parallel to the ground. A belt, fixed to the ground and attached to a load cell (Model LSB350; Futek Advanced Sensor Technology Inc., Irvine, CA, USA), was installed over participants' shoulders. Participants were instructed to slowly lift their trunk until they could feel a tension in the belt. From there, they were asked to perform a maximal isometric back extension contraction for at least 5 seconds. Participants had to perform three MVC separated with a minute of rest between each attempt to limit muscle fatigue. Verbal encouragement was provided for each trial. This protocol was performed at the baseline assessment (time 0 minutes) and at the post-effort assessment (time 61 minutes).

Data collection

Electromyography

Right and left LES muscles activity was recorded using four bipolar surface EMG electrodes (Model DE2.1, Delsys Inc., Boston, MA, USA) and sampled at 2048 Hz with a 12-bit

A/D converter (PCI 6024E, National Instruments, Austin, TX, USA). Each pair of electrodes were placed at L1 and L4 level, and the recording sites were prepared according to SENIAM recommendations (34). Electrodes' material was 99.9% Ag, and the inter-electrode distance was fixed at 10 mm. A reference electrode was placed on the right anterior superior iliac spine. The data were collected by LabView (National Instruments, Austin, TX, USA). The bipolar EMG signals were amplified by 1k or 10k. The data was collected for 60 seconds every five minutes, for a total of 12 recordings while cycling (time 5 minutes to time 60 minutes).

Kinematics

Kinematics data were collected by a motion analysis system (Optotrak Certus, Northern Digital, Waterloo, ON, Canada). Light-emitting diodes (LED) were positioned on the left side on five anatomical landmarks: spine of the scapula (sensor 1), anterior superior iliac spine (sensor 2), posterior superior iliac spine (sensor 3), L1 (sensor 4) and T7 spinous processes (sensor 5). The data were sampled at 100 Hz. The data was collected for 60 seconds every five minutes, for a total of 12 recordings while cycling (time 5 minutes to time 60 minutes).

Data Analysis

Every EMG signal from the cycling effort and the MVC were analyzed the same way. Each bipolar EMG signal obtained from the four electrodes was digitally band-pass filtered in the frequency bandwidth 20-450 Hz (2^{nd} order Butterworth filter). Notch filters were also applied to eliminate the 60 Hz power line interference, the 100 Hz kinematics instrumentation interference, and the 240-249 Hz Bluetooth interference and their harmonics (120, 180, 200, 240, 300, 360, 400, 420 Hz). Bluetooth notch filter is based on a pilot study. Root means square (RMS) were calculated on 500 milliseconds windows, with 250 milliseconds overlap. Then, myoelectric signals from each

electrode were normalized using the following methods: MVC and the first cycling effort trial (time 5 minutes). The first normalization technique was used to provide the level of erector spinae muscle activation necessary to perform one hour of cycling. However, chronic LBP participants may perceive the MVC protocol as challenging, and it is increasingly recognized that EMG normalization with this population should be performed using another method (35). Normalization using the first trial was used in our protocol. Therefore, the first EMG recording (time 5 minutes) was removed from the statistical analysis. Only EMG recordings from the 10^{th} to the 60^{th} minutes were considered. For each 60-second trial, the mean and standard deviation of RMS were calculated for each electrode. In addition, to identify the presence of LES muscle fatigue, the median frequency (MDF) was calculated for every 60-second trial of each electrode and MDF slopes from time 5 minutes to time 60 minutes (36).

2D angles were calculated from the 3D coordinates of the LED needed. From five LED sensors, four vectors were created, and three angles were calculated: vector 1 (sensors 1-4), vector 2 (sensors 4-3), vector 3 (sensors 1-5), vector 4 (sensors 2-3); angle 1 (trunk): (vectors 1 and 4); angle 2 (lumbar): (vectors 2 and 4) and angle 3 (thoracic): (vectors 3 and 4). Data were low pass filtered with a cut-off of 5 Hz bandwidth (4^{th} order Butterworth filter). All data were analyzed using the Matlab software (R2021a; MathWorks; Natick, MA, USA).

For the MVC, only the trials with the highest force values from the baseline assessment (time 0 minutes) and from post-effort assessment (time 61 minutes) were kept. Finally, for the stadiometry, the mean of the baseline assessment measures, and the mean of the post-effort assessment measures were calculated.

Statistical Analysis

Normality of distribution for every dependent variable was assessed using visual inspection and the Kolmogorov-Smirnov test. Independent T-tests were performed to determine whether difference exists between LBP and control groups for the anthropometric and sociodemographic data (table 1) and bicycle measurements. The Mann-Whitney U test was performed for variables with non-normal distribution. T-tests were performed on means of the 13 data recordings of pain levels and perceived exertion levels across cycling task. Repeated measures ANOVAs were performed for spinal height and MVC variation to determine the effect of the task (time), group differences and interaction between time and groups. For the EMG data, mean RMS of the 11 data acquisitions for each individual electrodes were analyzed with repeated measured ANOVAs. The first EMG data acquisition was used to normalize the other trials. Only data normalized with the first trial was considered. Repeated measures ANOVAs were also performed for pain level and perceived exertion level for 13 data acquisitions (time 0 minutes to time 60 minutes) to determine the effect of the task (time), group differences and interaction between time and groups. Whenever necessary ANCOVAs were used to control for confounding factors (e.g., significant between-group differences in participants' baseline characteristics). When significant, main effects were decomposed using pairwise comparisons with p value corrected for the number of comparisons using the Bonferroni test. Independent T-tests were performed for each electrode to compare groups from MDF slopes. For all statistical analyses, $p<0.05$ was considered to be statistically significant. Effect size of significant difference were calculated using partial eta-squared (ηp^2; 0.01=small effect; 0.06=medium effect; 0.14=large effect). All analyses were done using SPSS Statistics (IBM Corp. Released 2020. IBM SPSS Statistics for Mac, Version 27.0. Armonk, NY: IBM Corp.)

Results

Table 1 present participants' characteristics. Saddle angle was 2.0 (±1.2°) for the control group compared to 2.3 (±1.6°) for the LBP group; bottom bracket to saddle height was 72.3 (±4.5 cm) compared to 71.1 (±4.4 cm) for LBP; saddle to handlebar length was 65.3 (±5.1 cm) for the control group compared to 65.6 (±4.2 cm) for LBP. No statistical difference was observed between groups for all bicycle measurements: saddle angle (p=0.40), bottom bracket to saddle height (p=0.36), and saddle to handlebar length (p=0.81).

Table 1 about here

Heart rate average was 138 (±12 BPM) for control and 133 (±11 BPM) for LBP; power average on the pedal was 132 (±42 watts) for control and 126 (±43 watts) for LBP; cadence average was 91 (±8 RPM) for control and 92 (±9 RPM) for LBP. No statistical difference was observed for the heart rate average (p=0.20), power average (p=0.64) and pedaling cadence average (p=0.69).

As expected, the VAS pain score was statistically different between group (Figure 2a). A time effect [$F(1,12)=11.34$, $p<0.001$] ($\eta p^2=0.20$), group effect [$F(1,1)=35.23$, $p<0.001$] ($\eta p^2=0.19$), and interaction effect [$F(1,12)=10.71$, $p<0.01$] ($\eta p^2=0.43$) were observed. No pairwise comparisons were made on pain levels since it was not part of the objectives. Only one participant in the control group scored 1/10 for the last 10 minutes of his effort. The Borg's scale score was statistically different across the time [$F(1,12)=114.66$, $p<0.001$] ($\eta p^2=0.72$), but not between groups [$F(1,1)=0.06$, $p=0.80$] nor interaction [$F(1,12)=0.33$, $p=0.98$] (Figure 2b).

Figure 2 about here

Stadiometry

The mean height at baseline assessment was 90.48 (±3.85 cm) and the mean height at post-effort assessment was 90.20 (±4.01 cm) for the control group. The LBP group mean heights were 90.53 (±4.15 cm) before and 90.40 (±4.29 cm) after the cycling effort. There was a time effect [$F(1,1)=6.80$, $p=0.01$] ($\eta p^2=0.13$), yet no group effect [$F(1,1)=0.012$, $p=0.92$], nor interaction [$F(1,1)=0.91$, $p=0.35$] were present.

Maximal Voluntary Contraction

The MVC mean at baseline assessment was 68.71 (±20.09 N) and the MVC mean at post-effort assessment was 65.26 (±22.05 N) for the control group. The LBP group mean MVC were 70.65 (±24.67 N) before and 65.83 (±19.22 N) after the cycling effort. MVC values decreased over time significatively in all participants [$F(1,1)=11.56$, $p=0.001$] ($\eta p^2=0.20$), but there was no group effect [$F(1,1)=0.04$, $p=0.84$], nor interaction [$F(1,1)=0.32$, $p=0.58$].

Kinematics

Kinematics results are illustrated in Figure 3. Three participants were excluded from the kinematics analysis due to technical issues with the sensors during the cycling task. A significant main effect of time has been observed for angle 1 (trunk) [$F(1,11)=4.41$, $p<0.001$] ($\eta p^2=0.09$) and angle 3 (thoracic) [$F(1,11)=3.44$, $p<0.001$] ($\eta p^2=0.08$), while a significant group effect was only observed for the angle 3 (thoracic) [$F(1,1)=5.16$, $p=0.03$] ($\eta p^2=0.11$). The effect of time was not significant for angle 2 (lumbar) [$F(1,11)=0.43$, $p=0.94$] ($\eta p^2=0.01$). No group effect were significant for angle 1 [$F(1,1)=2.09$, $p=0.16$] ($\eta p^2=0.05$) and angle 2 [$F(1,1)=0.43$, $p=0.52$] ($\eta p^2=0.01$). No significant interaction was found for angle 1 [$F(1,11)=0.86$, $p=0.58$] ($\eta p^2=0.02$),

angle 2 [F(1,11)=0.92, p=0.52] (ηp^2=0.02), angle 3 [F(1,11)=0.76, p=0.69] (ηp^2=0.02). The group effect for the angle 3 remained unchanged after controlling for body mass (ANCOVAs).

Figure 3 about here

Electromyography

The results of repeated-measured ANOVAs performed for individual electrodes RMS are illustrated in Figure 4 (figure 4abcd). Eight percent of all trials from EMG recordings were excluded from the analyses because of the too many noise artefacts. RMS decreased significantly over time for all electrodes: L4 left [F(1,10)=2.30, p=0.01] (ηp^2=0.05), L4 right [F(1,10)=9.50, p<0.001] (ηp^2=0.18), L1 left [F(1,10)=16.53, p<0.001] (ηp^2=0.30), L1 right [F(1,10)=6.31, p<0.001] (ηp^2=0.13). No group effect reached statistical significance for any electrodes: L4 left [F(1,1)=0.73, p=0.40], L4 right [F(1,1)=0.28, p=0.60], L1 left [F(1,1)=0.10, p=075], L1 right F(1,1)=0.07, p=0.79]. No interaction effect was statistically significant: L4 left [F(1,10)=0.92, p=0.52], L4 right [F(1,10)=1.41, p=0.17], L1 left [F(1,10)=1.34, p=0.21], L1 right [F(1,10)=0.85, p=0.58]. When EMG data were normalized using the MVC trials, results showed a mean LES activation amplitude (4 locations and throughout the effort) at approximately 4.92 (±3.74%) for the controls and 5.90 (±4.01%) MVC for cyclists with LBP of the first trial. For MDF data, all slopes were positives: L4 left = 0.97 Hz/sec; L4 right = 0.98 Hz/sec; L1 left = 0.34 Hz/sec; L1 right = 0.91 Hz/sec. Independent T-tests showed no difference for MDF slopes between groups for all electrodes: L4 left (t(46)=0.04, p=0.48), L4 right (t(46)=0.47, p=0.68), L1 left (t(46)=1.18. p=0.13), except at L1 right (t(46)=1.06, p=0.02).

Figure 4 about here

Discussion

303 The main objective of this study was to identify and compare trunk neuromuscular
304 strategies during a cycling effort between a group of cyclists with chronic LBP and healthy cyclists.
305 The results of the study showed that the amplitude of lumbar muscles activation (RMS) was similar
306 for LBP and controls cyclists. Participants in both groups decreased their level of muscle activation
307 (RMS) throughout the one-hour cycling effort. MDF slopes were positive for both groups. Those
308 results suggest that no manifestations of muscle fatigue were observed during the task for both
309 groups after the effort. Although the lumbar angle did not change during the cycling effort in either
310 group, the overall trunk and the thoracic angles changed over time for both groups. Cyclists were
311 more flexed at the end than at the beginning of the cycling effort in both angles. The LBP group
312 was less flexed than the control group when considering the thoracic angle only. Even though all
313 cyclists were able to perform the whole one-hour cycling effort, the pain level of the participants
314 with LBP increased throughout the effort. Overall, this suggests that all cyclists presented similar
315 level of muscular activity and different kinematic strategies to perform a one-hour effort on their
316 road bike, yet the LBP group failed in doing so pain free. The difference in kinematics appeared
317 in the thoracic region where no EMG was recorded. In addition, to assess the effect of the one-
318 hour cycling effort on discs loading, spinal height variation was measured. The results showed that
319 spinal height decreases from baseline assessment (time 0 minutes) to post-effort assessment (time
320 61 minutes) in both groups. This result means that the spine of all cyclists sustained a similar load
321 variation during the cycling effort.
322 The measure of spinal shrinkage was assessed since IVD decreased height is one of the
323 first sign of degenerative disk disease (37). One must remember that the measure of the spinal
324 height using stadiometry does not indicate segmental or regional changes. However, previous
325 study showed strong correlation between spinal height measure by stadiometry of the full spine

and lumbar musculoskeletal ultrasonography (33). In the current study, spinal shrinkage, and potentially spinal load changed over the one-hour cycling effort. A very high correlation has already been demonstrated between spinal shrinkage and spinal load for prolonged static posture (38, 39). For dynamic tasks such as cycling, it is unclear whether this correlation exists, but results from a previous study suggest the correlation appears during these tasks (38). Moreover, spinal loads measured during cycling appear to be similar to those assessed during standing, suggesting that a greater decrease in spinal height indicates a greater spinal load in cycling tasks (40). In the present study, a decrease in spinal height was observed in both groups between the baseline and post-effort assessments. The average decrease in spinal height for the control group was 2.8 (±4.8 mm), which is similar to previous findings (38). The LBP group showed less spinal decrease, 1.3 (±6.5 mm), yet no significant difference between groups was observed. As there was no change in the lumbar angle between groups, and stadiometry variations were similar, it could be argued that the lumbar spine of all participants was submitted to similar physical stress throughout the one-hour cycling effort.

The effect of the cycling effort was also observed in the erector spinae maximal strength. No adverse effects were reported due to the MVC protocol. The decrease in MVC between baseline and post-effort assessments in both groups may suggest the presence of low back muscle fatigue (41). However, these results contrast with the positive EMG MDF slopes and a decrease of the erector spinae muscle activity amplitude during the effort. Although MVC using Sorensen protocol was shown to be reliable to detect low back muscle fatigue (42), the decrease in MVC after the cycling effort may be influenced by the presence of lower extremity muscle fatigue. Indeed, there is a decreased MDF observed in the hamstring through time during a Sorensen protocol (43), and the same muscles are needed to complete a cycling task (44). Alternatively, one

could argue that the targeted effort intensity (approximately 13 on Borg's scale of perceived exertion) at the end of the cycling effort was too low to induce muscle fatigue and that central fatigue may have occurred.

In the current study, we found adaptations in the trunk kinematics across the cycling effort. For both groups, trunk and thoracic angles decreased during the cycling effort. It corresponds to a more flexed position towards the end of the cycling effort. Holding the same trunk position might become challenging overtime. Consequently, participants may adapt their position into a more flexed one. This decrease in trunk and thoracic angles may also induce a forward shift in the center of mass. Such shift would decrease the load on low back structures and increase it in the upper limbs (14). Asides, the lumbar angle remained constant throughout the cycling effort, matching previous findings (15). These results suggest participants' trunk was more flexed at the end than at the beginning of the task regardless, the presence or the absence of pain.

Another neuromuscular adaptation we found changes in the neuromuscular control throughout the cycling effort in both groups. The erector spinae muscle activity decreased during the cycling effort for both groups in all four regions (L1 left, L1 right, L4 left and L4 right). Muscle activation had decreased by an average of 35% at the end of the cycling effort compared with the baseline assessment. This adaptation can be supported by the observation of greater trunk flexion during the cycling effort. This change in kinematics could shift the cyclists' center of mass forward, shifting the load from the back muscles to the upper limbs to relieve the lumbar spine. This hypothesis is reinforced by a previous study showing higher muscle fatigue in the biceps brachii of cyclists with LBP than in controls at the end of a cycling effort (14).

In addition to these neuromuscular adaptations, we also showed differences in trunk kinematics between cyclists with LBP and healthy cyclists. The trunk was less flexed in cyclists with LBP than in their counterparts. This more upright position may be related to pain avoidance strategies (25, 45). These results contrast with a previous study that has shown a more flexed position of cyclists with LBP compared to pain-free athletes (16). In the present study, the participants' position was controlled (hands on lever hoods and seated) during the kinematics/EMG recordings, while the participants in Van Hoof's study were allowed to perform the cycling exercise without restriction. This choice was made because the objective was to identify neuromuscular mechanisms to pain adaptation, and not trunk movements. In the present study, a more upright thoracic posture, observed in the LBP group, could be associated to a long-term pain avoidance strategy (25, 45). Indeed, prolonged flexed position of the trunk will stretch viscoelastic structures in the spine, which may increase the risk of spine injury (46, 47). Conversely, the LBP group failed to ride their road bike pain free. With this observation, the current study provides new insights of the long-term consequences of pain adaptations during long duration motor task. These results suggest that part of the adaptation to pain is made by changes in thoracic spine movement.

Contrary to our hypothesis, this study did not reveal a redistribution of muscle activity between electrodes during the task (25). The EMG redistribution might not have been detectable because of the low levels of muscle activation. Redistribution has been observed in erector spinae of LBP participants during more demanding tasks requiring higher muscle activation intensities (48-51). In the current study, while the participants produced moderate power (averaging 1.77 Watt/Kg) on the pedals, low activation levels of the LES were recorded (52). The use of four bipolar electrodes may not be sufficient to detect muscle activity redistribution in comparison to

matrixes of surface electrodes (High-Density surface Electromyography) (53). Although both groups appeared to adopt the same EMG strategies to perform the task, the LBP group reported an increase of pain levels throughout the cycling effort. LBP is a complex condition with multiple contributors (1), and therefore, cyclists with LBP may have developed long-term adaptations such as a decrease in erector spinae contribution and a change in thoracic posture, which allowed them to complete their cycling effort. This study sought to understand neuromuscular adaptations in presence of LBP in cyclists. The decrease in EMG amplitude represents one of many neuromuscular adaptations of low back muscles. The appearance of a plateau (stop in decreasing) at around time 40 minutes might also be another way to adapt to the task. Further study will be needed to understand these phenomena.

One of the strengths of this study is that both groups were similar in their cycling experience. Both groups presented a similar number of kilometers ridden on their bicycle yearly, and the same number of years riding a road bike. However, body mass was statistically different (LBP group being heavier) but ANCOVAs suggested the reported effects were not due to body mass differences. It has been suggested that overweight or obesity is a risk factor of LBP (54, 55). However, to our knowledge, there is no study that has investigated the differences in physiological data (EMG, kinematics, stadiometer) between cyclists of different BMI category. Another strength is that both groups have a similar experience on their road bikes, which leads us to believe that they have the same level of fitness. Both groups presented similar saddle angle, bottom bracket to saddle height and saddle to handlebar length, which suggests that both groups were fitted to their bike similarly. Another methodological consideration is that EMG data were normalized using the first trial, which limit the possibility to compare EMG activity at the beginning of the cycling task. However, normalization with MVC is not recommended with LBP participants (35). Finally, it

should be noted that in the current study, participants experienced low level of pain during the cycling task. It has been shown that the pain intensity in chronic low back pain patients fluctuated in time. People experiencing LBP usually have period of flare-up and period of remission (56, 57). However, even in remission periods, participants suffering of chronic low back pain still present different neuromuscular strategies than pain-free participants. (25, 58). In addition, our results still demonstrated some adaptation to pain. It remained to be determined whether higher level of pain may induce different adaptation to pain in cyclists.

Conclusion

Results showed that a one-hour cycling effort causes trunk neuromuscular changes. Road cyclists present no neuromuscular sign of fatigue in the LES yet decreasing in maximal trunk extension contractions was observed. Cyclists also showed decreasing LES activity during cycling efforts, which may be due to a shift in the center of mass. In addition, a one-hour cycling effort sitting in the same position increases spinal shrinkage, due to increased spinal load. Knowing that increase load may cause damage to the IVD, the road cyclist prolonged flexed position may be a risk factor for disc degeneration and LBP.

In addition, we found that LBP and control cyclists had different kinematics strategies throughout the cycling effort. Cyclists with LBP tend to be less flexed in the thoracic spine than control cyclists, which may indicate a long-term adaptation to the task. Cyclists with LBP seem to develop kinematic strategies to complete prolonged cycling efforts. However, such strategies could not prevent the increase in pain throughout the effort.

Acknowledgments

EMB was supported by Fondation Chiropratique du Québec

Conflict of interest

The authors declare that they have no conflict of interest.

References

1. Hartvigsen J, Hancock MJ, Kongsted A, Louw Q, Ferreira ML, Genevay S, et al. What low back pain is and why we need to pay attention. The Lancet. 2018;391(10137):2356-67.

2. Wu A, March L, Zheng X, Huang J, Wang X, Zhao J, et al. Global low back pain prevalence and years lived with disability from 1990 to 2017: estimates from the Global Burden of Disease Study 2017. Annals of translational medicine. 2020;8(6).

3. Mortazavi J, Zebardast J, Mirzashahi B. Low Back Pain in Athletes. Asian J Sports Med. 2015;6(2):e24718. Epub 2015-06-01. doi: 10.5812/asjsm.6(2)2015.24718.

4. Farahbakhsh F, Rostami M, Noormohammadpour P, Mehraki Zade A, Hassanmirazaei B, Faghih Jouibari M, et al. Prevalence of low back pain among athletes: a systematic review. Journal of back and musculoskeletal rehabilitation. 2018;31(5):901-16.

5. Jacob T, Baras M, Zeev A, Epstein L. Physical activities and low back pain: a community-based study. Medicine and science in sports and exercise. 2004;36(1):9-15.

6. Baker RJ, Patel D. Lower back pain in the athlete: common conditions and treatment. Primary care. 2005;32(1):201-29.

7. Kaartinen S, Aaltonen S, Korhonen T, Rottensteiner M, Kujala UM, Kaprio J. Cross-sectional associations between the diversity of sport activities and the type of low back pain in adulthood. European journal of sport science. 2020;20(9):1277-87.

8. Heneweer H, Staes F, Aufdemkampe G, van Rijn M, Vanhees L. Physical activity and low back pain: a systematic review of recent literature. European Spine Journal. 2011;20(6):826-45.

9. Dettori NJ, Norvell DC. Non-traumatic bicycle injuries : a review of the literature. Sports Med. 2006;36(1):7-18. Epub 2006/02/01. doi: 10.2165/00007256-200636010-00002. PubMed PMID: 16445308.

10. Clarsen B, Krosshaug T, Bahr R. Overuse injuries in professional road cyclists. Am J Sports Med. 2010;38(12):2494-501. Epub 2010/09/18. doi: 10.1177/0363546510376816. PubMed PMID: 20847225.

11. Barrios C, Bernardo ND, Vera P, Laiz C, Hadala M. Changes in sports injuries incidence over time in world-class road cyclists. Int J Sports Med. 2015;36(3):241-8. Epub 2014/11/08. doi: 10.1055/s-0034-1389983. PubMed PMID: 25376727.

12. Callaghan MJ, Jarvis C. Evaluation of elite British cyclists: the role of the squad medical. British Journal of Sports Medicine. 1996;30(4):349-53.

13. Balasubramanian V, Jagannath M, Adalarasu K. Muscle fatigue based evaluation of bicycle design. Appl Ergon. 2014;45(2):339-45. Epub 2013/05/08. doi: 10.1016/j.apergo.2013.04.013. PubMed PMID: 23647886.

14. Balasubramanian V, Jayaraman S. Surface EMG based muscle activity analysis for aerobic cyclist. J Bodyw Mov Ther. 2009;13(1):34-42. Epub 2009/01/03. doi: 10.1016/j.jbmt.2008.03.002. PubMed PMID: 19118791.

15. Burnett AF, Cornelius MW, Dankaerts W, O'Sullivan P B. Spinal kinematics and trunk muscle activity in cyclists: a comparison between healthy controls and non-specific chronic low back pain subjects-a pilot investigation. Man Ther. 2004;9(4):211-9. Epub 2004/11/04. doi: 10.1016/j.math.2004.06.002. PubMed PMID: 15522646.

16. Van Hoof W, Volkaerts K, O'Sullivan K, Verschueren S, Dankaerts W. Comparing lower lumbar kinematics in cyclists with low back pain (flexion pattern) versus asymptomatic controls--field study using a wireless posture monitoring system. Man Ther. 2012;17(4):312-7. Epub 2012/03/23. doi: 10.1016/j.math.2012.02.012. PubMed PMID: 22436688.

17. Srinivasan J, Balasubramanian V. Low back pain and muscle fatigue due to road cycling—An sEMG study. Journal of Bodywork and Movement Therapies. 2007;11(3):260-6.

18. Callaghan J, McGill S. Low back joint loading and kinematics during standing and unsupported sitting. Ergonomics. 2001;44(3):280-94.

19. Gerke DA, Brismée J-M, Sizer PS, Dedrick GS, James CR. Change in spine height measurements following sustained mid-range and end-range flexion of the lumbar spine. Applied ergonomics. 2011;42(2):331-6.

20. Owens SC, Brismée J-M, Pennell PN, Dedrick GS, Sizer PS, James CR. Changes in spinal height following sustained lumbar flexion and extension postures: a clinical measure of intervertebral disc hydration using stadiometry. Journal of manipulative and physiological therapeutics. 2009;32(5):358-63.

21. Marsden MaS, Martin. Lower back pain in cyclists: A review of epidemiology, pathomechanics and risk factors. International Sportmed Journal. 2010;11:216-25.

22. Cheung KM, Karppinen J, Chan D, Ho DW, Song Y-Q, Sham P, et al. Prevalence and pattern of lumbar magnetic resonance imaging changes in a population study of one thousand forty-three individuals. Spine. 2009;34(9):934-40.

23. Belavy DL, Quittner M, Ridgers ND, Ling Y, Connell D, Trudel G, et al. Beneficial Intervertebral Disc and Muscle Adaptations in High-Volume Road Cyclists. Med Sci Sports Exerc. 2019;51(1):211-7. Epub 2018/08/30. doi: 10.1249/mss.0000000000001770. PubMed PMID: 30157104.

24. Rostami M, Ansari M, Noormohammadpour P, Mansournia MA, Kordi R. Ultrasound assessment of trunk muscles and back flexibility, strength and endurance in off-road cyclists with and without low back pain. J Back Musculoskelet Rehabil. 2015;28(4):635-44. Epub 2014/11/14. doi: 10.3233/bmr-140559. PubMed PMID: 25391328.

25. Hodges PW, Tucker K. Moving differently in pain: a new theory to explain the adaptation to pain. Pain. 2011;152(3 Suppl):S90-8. Epub 2010/11/23. doi: 10.1016/j.pain.2010.10.020. PubMed PMID: 21087823.

26. Cedraschi C, Robert J, Goerg D, Perrin E, Fischer W, Vischer T. Is chronic non-specific low back pain chronic? Definitions of a problem and problems of a definition. British journal of general practice. 1999;49(442):358-62.

27. Vogler D, Paillex R, Norberg M, de Goumoens P, Cabri J. [Cross-cultural validation of the Oswestry disability index in French]. Ann Readapt Med Phys. 2008;51(5):379-85. Epub 2008/05/27. doi: 10.1016/j.annrmp.2008.03.006. PubMed PMID: 18501463.

28. Bruyere O, Demoulin M, Beaudart C, Hill JC, Maquet D, Genevay S, et al. Validity and reliability of the French version of the STarT Back screening tool for patients with low back pain. Spine (Phila Pa 1976). 2014;39(2):E123-8. Epub 2013/10/11. doi: 10.1097/brs.0000000000000062. PubMed PMID: 24108286.

29. Salai M, Brosh T, Blankstein A, Oran A, Chechik A. Effect of changing the saddle angle on the incidence of low back pain in recreational bicyclists. Br J Sports Med. 1999;33(6):398-400. Epub 1999/12/22. doi: 10.1136/bjsm.33.6.398. PubMed PMID: 10597848; PubMed Central PMCID: PMCPMC1756210.

30. Lucia A, Hoyos J, Chicharro JL. Preferred pedalling cadence in professional cycling. Medicine and science in sports and exercise. 2001;33(8):1361-6.

31. Chow R, Wilmore J. Continuing Medical Education: The Regulation of Exercise Intensity by Ratings of Perceived Exertion. Journal of Cardiac Rehabilitation. 1984;4(9):382-7.

32. Chen MJ, Fan X, Moe ST. Criterion-related validity of the Borg ratings of perceived exertion scale in healthy individuals: a meta-analysis. Journal of Sports Sciences. 2002;20(11):873-99. doi: 10.1080/026404102320761787.

33. Poortmans V, Brismee JM, Poortmans B, Matthijs OC, Dugailly PM, Sobczak S. Assessment of Lumbar Spine Height Following Sustained Lumbar Extension Posture: Comparison Between Musculoskeletal Ultrasonography and Stadiometry. J Manipulative Physiol Ther. 2016;39(8):586-93. Epub 2016/09/18. doi: 10.1016/j.jmpt.2016.07.003. PubMed PMID: 27637322.

34. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. Journal of electromyography and Kinesiology. 2000;10(5):361-74.

35. Besomi M, Hodges PW, Clancy EA, Van Dieën J, Hug F, Lowery M, et al. Consensus for experimental design in electromyography (CEDE) project: Amplitude normalization matrix. Journal of Electromyography and Kinesiology. 2020;53:102438.

36. Phinyomark A, Thongpanja S, Hu H, Phukpattaranont P, Limsakul C. The usefulness of mean and median frequencies in electromyography analysis. Computational intelligence in electromyography analysis-A perspective on current applications and future challenges. 2012:195-220.

37. Cinotti G, De Santis P, Nofroni I, Postacchini F. Stenosis of lumbar intervertebral foramen: anatomic study on predisposing factors. Spine. 2002;27(3):223-9.

38. Van Deursen L, Van Deursen D, Snijders C, Wilke H. Relationship between everyday activities and spinal shrinkage. Clinical Biomechanics. 2005;20(5):547-50.

39. Wilke HJ, Neef P, Caimi M, Hoogland T, Claes LE. New in vivo measurements of pressures in the intervertebral disc in daily life. Spine. 1999;24(8):755-62.

40. Rohlmann A, Zander T, Graichen F, Schmidt H, Bergmann G. Spinal loads during cycling on an ergometer. Plos one. 2014;9(4):e95497.

41. Enoka RM, Duchateau J. Muscle fatigue: what, why and how it influences muscle function. The Journal of physiology. 2008;586(1):11-23.

42. Coorevits P, Danneels L, Cambier D, Ramon H, Vanderstraeten G. Assessment of the validity of the Biering-Sørensen test for measuring back muscle fatigue based on EMG median frequency characteristics of back and hip muscles. Journal of Electromyography and kinesiology. 2008;18(6):997-1005.

43. Plamondon A, Trimble K, Lariviere C, Desjardins P. Back muscle fatigue during intermittent prone back extension exercise. Scandinavian journal of medicine & science in sports. 2004;14(4):221-30.

44. So RC, Ng JK-F, Ng GY. Muscle recruitment pattern in cycling: a review. Physical therapy in sport. 2005;6(2):89-96.

45. Hodges PW, Smeets RJ. Interaction between pain, movement, and physical activity: short-term benefits, long-term consequences, and targets for treatment. The Clinical journal of pain. 2015;31(2):97-107.

46. Pope MH, Goh KL, Magnusson ML. Spine ergonomics. Annual review of biomedical engineering. 2002;4(1):49-68.

47. Solomonow M. Neuromuscular manifestations of viscoelastic tissue degradation following high and low risk repetitive lumbar flexion. Journal of Electromyography and Kinesiology. 2012;22(2):155-75.

578 48. Falla D, Gizzi L, Tschapek M, Erlenwein J, Petzke F. Reduced task-induced variations in
579 the distribution of activity across back muscle regions in individuals with low back pain. PAIN®.
580 2014;155(5):944-53.

581 49. Sanderson A, Martinez-Valdes E, Heneghan NR, Murillo C, Rushton A, Falla D. Variation
582 in the spatial distribution of erector spinae activity during a lumbar endurance task in people with
583 low back pain. Journal of anatomy. 2019;234(4):532-42.

584 50. Martinez-Valdes E, Wilson F, Fleming N, McDonnell S-J, Horgan A, Falla D. Rowers with
585 a recent history of low back pain engage different regions of the lumbar erector spinae during
586 rowing. Journal of science and medicine in sport. 2019;22(11):1206-12.

587 51. Abboud J, Nougarou F, Page I, Cantin V, Massicotte D, Descarreaux M. Trunk motor
588 variability in patients with non-specific chronic low back pain. Eur J Appl Physiol.
589 2014;114(12):2645-54. Epub 2014/09/01. doi: 10.1007/s00421-014-2985-8. PubMed PMID:
590 25173095.

591 52. Turpin NA, Costes A, Moretto P, Watier B. Upper limb and trunk muscle activity patterns
592 during seated and standing cycling. Journal of sports sciences. 2017;35(6):557-64.

593 53. Falla D, Gallina A. New insights into pain-related changes in muscle activation revealed
594 by high-density surface electromyography. Journal of Electromyography and Kinesiology.
595 2020;52:102422.

596 54. Shiri R, Falah-Hassani K, Heliövaara M, Solovieva S, Amiri S, Lallukka T, et al. Risk
597 factors for low back pain: a Population-Based longitudinal study. Arthritis care & research.
598 2019;71(2):290-9.

599 55. Zhang T-T, Liu Z, Liu Y-L, Zhao J-J, Liu D-W, Tian Q-B. Obesity as a risk factor for low
600 Back pain. Clinical spine surgery. 2018;31(1):22-7.

601 56. Costa N, Smits EJ, Kasza J, Salomoni SE, Ferreira M, Hodges PW. Low Back Pain Flares:
602 How do They Differ From an Increase in Pain? The Clinical Journal of Pain. 2021;37(5):313-20.

603 57. Stanton TR, Latimer J, Maher CG, Hancock MJ. How do we define the condition 'recurrent
604 low back pain'? A systematic review. European Spine Journal. 2010;19(4):533-9.

605 58. Hodges PW. Pain and motor control: from the laboratory to rehabilitation. Journal of
606 Electromyography and Kinesiology. 2011;21(2):220-8.

607

608 Figure 1: Schematic representation of the custom-built seated stadiometer set-up. Participants'
609 footrest height and cervical spine support were adjusted to their height.
610
611 Table 1: Participants' baseline characteristics and PROMs: This table presents demographics and
612 PROMs of the participants. LBP, low back pain; cm, centimeter; kg, kilogram; Km, kilometer;
613 ODI, Oswestry Disability Index; SD, standard deviation; NA = No answer; PROMs, patient-
614 reported outcome measures, * < 0.05, *p*-value based on T-test for height, body mass, pain scale
615 and Borg's scale, *p*-value based on Mann-Whitney U test for age, Km on bicycle/year and year on
616 bicycle
617
618 Figure 2: Evolution of pain and perceived exertion during cycling effort based on repeated
619 measures ANOVAs results. The black line represents the LBP group and the gray line the control
620 group. Circles and triangles represent the mean, and vertical bars show the standard deviation. The
621 time axis (X-axis) is divided in 13, which represents the baseline assessment (time 0 minutes) to
622 the last data acquisition (time 60 minutes). 2a represents the VAS pain score throughout the cycling
623 effort (0 = no pain; 10 = worst pain ever). 2b represent the Borg's scale score for perceived exertion
624 (6 = nothing; 20 = maximal exertion). For 2b, every pairwise comparisons were significative
625 except for trials: (5-6), (5-7), (6-7), (7-8), (8-9), (9-10), (9-11), (9-13), (10-11), (10-12), (10-13),
626 (11-12), (11-13), (12-13).
627
628 Figure 3: Evolution of kinematic angles during the cycling effort based on repeated measures
629 ANOVAs results. The black line represents the LBP group and the gray line the control group.
630 Circles and triangles represent the mean, and vertical bars show the standard deviation. The time

axis (X-axis) is divided in 12, which represents the first acquisition (time 5 minutes) to the last data acquisition (time 60 minutes). The Y-axis shows angle in degree.

Figure 4: Evolution of EMG activation amplitude (RMS) during cycling effort, based on repeated measures ANOVAs. The black line represents the LBP group and the gray line the control group. Circles and triangles represent the mean and vertical bars shows the standard deviation. The time axis (X-axis) is divided in 11, representing the time 10 minutes (second data acquisition) to time 60 minutes (the last data acquisition). Time 5 minutes (the first data acquisition) is not displayed since it has been used to normalize the other data acquisitions. The Y-axis shows percentage of activation normalized on first trial as 100%. 3a represents the mean RMS normalized of electrodes placed at L1 left; 3b represents the mean RMS normalized of electrodes placed at L1 right; 3c represents the mean RMS normalized of electrodes placed at L4 left; 3d represents the mean RMS normalized of electrodes placed at L4 right. * < 0.05, *p*-value based on pairwise comparisons.