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Communication

Effects of Anaerobic Fatigue Induced by Sport-Specific Exercise on Postural Control in Highly-Trained Adolescent Road Cyclists

Bartosz Zając [1,*], Anna Mika [2,*], Paulina Katarzyna Gaj [3] and Tadeusz Ambroży [4]

1 Laboratory of Functional Diagnostics, Central Scientific and Research Laboratory, University of Physical Education, 31-571 Kraków, Poland
2 Institute of Clinical Rehabilitation, University of Physical Education, 31-571 Kraków, Poland
3 Cracow Academy of Track-and-Field Sports, 31-511 Kraków, Poland
4 Institute of Sport Science, University of Physical Education, 51-571 Kraków, Poland
* Correspondence: bartosz.zajac@awf.krakow.pl (B.Z.); anna.mika@awf.krakow.pl (A.M.); Tel.: +48 508-116-286 (B.Z.); +48 12-683-11-34 (A.M.)

Abstract: The aim of this study was to evaluate whether and how anaerobic fatigue induced by sport-specific exercise affects the postural control of highly-trained adolescent road cyclists. Twenty-three male athletes, aged 15–18 years, were included in the study. Postural control was assessed using the pedobarographic platform (bipedal upright stance, sequentially, with eyes open (EO) and closed (EC) for 60 s each, with a 30 s interval), before and 3 min after a 30 s all-out effort performed on the ergometer. The results showed significant increases in the 95%-confidence ellipse area (*p*-value 0.000 and 0.001 for EO and EC, respectively), as well as centre-of-pressure (CoP) range displacement in the anteroposterior (*p*-value 0.000 for both EO and EC) and mediolateral (*p*-value 0.011 and 0.001 for EO and EC, respectively) planes. In addition, a significant decrease in CoP mean sway frequency was observed (*p*-value 0.000 and 0.001 for EO and EC, respectively), but no changes were noted in CoP mean velocity (*p*-value 0.316 and 0.670 for EO and EC, respectively). In our study, it has been indicated that anaerobic fatigue induced by sport-specific exercise deteriorates postural control in adolescent cyclists. Moreover, cycling training may affect the quality of postural corrective reactions occurring in response to anaerobic fatigue.

Keywords: postural control; body sway; anaerobic fatigue; cyclists; sport-specific exercise

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1. Introduction

Road cycling is one of the most extreme endurance sports. Professional road cyclists typically train ~20 h per week and cover ~600 km a week [1]. The longest 1-day race in men's cycling can be up to 300 km while the longest multiple-stage races can last up to 21 days. The most demanding competitions are so-called grand tours in which athletes compete for 21 days (>3000 km) with only 2 days dedicated to rest in between [2]. Interestingly, in the course of such a long-lasting competition, work intensity may by very high. The percentage of the total flat race time spent by professional cyclists at an intensity below 70%, between 70 and 90%, and above 90% of maximal oxygen uptake averages approximately 70, 25, and 5%, respectively [2]. During races, ~20–70 accelerations take place, exceeding maximal aerobic power [3]. Moreover, male elite cyclists may generate power exceeding 1200 W (17 W $\times$ kg^{-1}) during final sprints [4]. In addition, data have indicated that the younger category of competition may be even more intense than the elite in terms of internal intensity [5]. Apart from huge training and race loads, road cycling is also a very demanding sport on the postural control system due to the presence of various external destabilising factors related to the course of training or competition with which the cyclist's body must cope in order to avoid falls, for example, winding roads of various pavements [6], high speed [7], a large number of rivals, and variable weather conditions [2].

The human body in the upright bipedal standing position is constantly swaying due to the inability of the neuromuscular system to maintain constant muscular tension [8] as well as the presence of physiological destabilising factors such as body liquid movements, heart work, and respiratory muscular contraction [9,10]. Despite this, the human body is able to maintain a vertical projection of the centre of gravity within the base of support due to the operation of the postural control system. The quality of postural control may be quantified by registering the trajectory of the centre of pressure (CoP) using force platforms, which track the point of application regarding ground reaction forces resultant under the feet present during upright standing [11]. The resulting signal, called the stabilogram, provides various parameters describing postural control quality such as positional parameters (e.g., 95%-confidence ellipse area [EA], distance between extreme points of the stabilogram (range) in anteroposterior [AP_R] and mediolateral [ML_R] planes, as well as AP_R/ML_R ratio), dynamic parameters (e.g., CoP mean velocity [MV] calculated as path length divided by time of measurement), and frequency parameters (e.g., CoP mean frequency [MV] defined as the rotational frequency, considering the total CoP length as a trajectory around a circle with a radius equal to the mean distance) [11].

Generally, exercises that solicit a large part of body musculature (general exercise)—for instance, cycling—cause the aggravation of postural sway due to increased cardiac and breathing rhythm as well as intensified body liquid flow [12]. Moreover, general exercise generates fatigue which affects postural control by decreasing the quality of input sensory information and its integration, as well as output motor command efficiency. The crucial exercise parameters influencing the size of postural sway aggravation and postural control deterioration are intensity and duration. A large acid–base imbalance due to the dissociation of lactic acid produced into lactate and hydrogen is typical for high-intensity, short-term exercises. In contrast, low-intensity, long-term exercise may cause elevated body temperature, dehydration, muscle damage, and/or the depletion of glycogen storage [13]. In addition, the size of postural control deterioration may depend on exercise type, intensity of proprioceptive stimulation, forms of muscle contraction, and the activation of muscle fibres [14].

There are many reports in which it is suggested that fatigue deteriorates postural control. Some authors studied in different populations the influence of various fatiguing protocols in terms of energetic background (aerobic [15,16] or anaerobic [17–21]), and exercise type (general [16,22,23], or local [24–26]) in different populations. However, in only a number of works are the effects of sport-specific fatiguing protocols shown with regard to athletes' postural control [13]. To the best of our knowledge, there are no studies in which the impact would be evaluated of anaerobic fatigue induced by sport-specific exercise on adolescent road cyclists' postural control. These athletes are exposed to both large amounts of fatigue of various etiologies (on this basis, of anaerobic background) and various external factors hindering postural control. We hypothesize that the combination of these factors may induce changes in the operation of postural control in response to anaerobic fatigue. Therefore, the aim of this study was to evaluate whether and how anaerobic fatigue induced by sport-specific exercise has an impact on the efficiency of postural control in highly-trained adolescent road cyclists.

2. Materials and Methods

2.1. Study Design

Postural control was assessed with eyes open and closed before and 3 min after an effort carried out on a cycle ergometer. We decided to perform the second assessment after 3 min to reduce aggravation of body sway related to post-effort hyperventilation and tachycardia. Moreover, the somatic measurements and data on the training experience were collected. The course of the study was presented in Figure 1. All measurements were performed by experienced researchers between 10:00 a.m. and 4:00 p.m. at an ambient temperature of 20 ± 1 °C and relative humidity of 40 ± 5%. Participants were asked to remain well-hydrated, to refrain from consuming alcohol or any stimulants for at least 24 h before testing, and not to engage in strenuous exercise at least 48 h prior to testing. Each participant was familiarised with the measurement procedure. The study was approved by the Bioethics Committee at the Regional Medical Chamber in Kraków (No. 249/KBL/OIL/2021). All procedures were carried out in accordance with Helsinki Declaration.

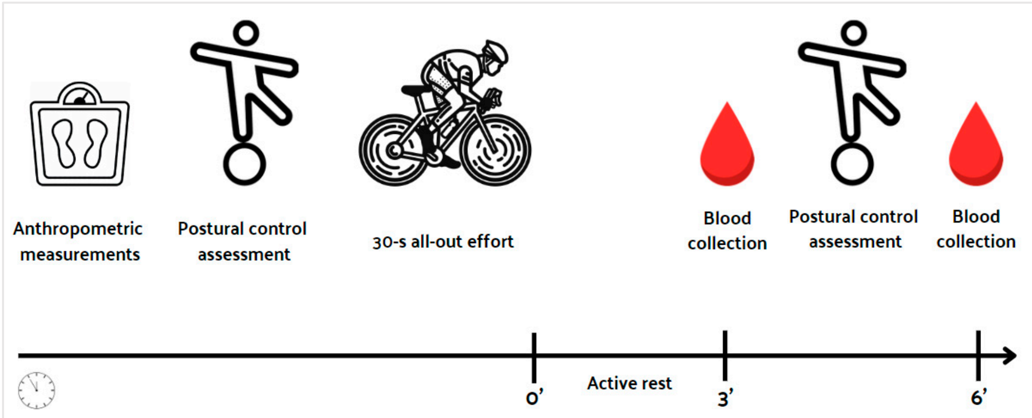

Figure 1. The course of the study.

2.2. Participants

The study evaluated 23 male cyclists recruited from among students of the Sport Championship School in Cycling in Poland. Sample size was calculated using G*Power 3.1.9.6 software (input parameters: two tails, effect size 0.6, α 0.05, power 0.7). Main characteristics of the cyclists are showed in Table 1. The inclusion criteria were: (i) progression of biological development—minimum 3rd pubic hair stage on Tanner's Scale [27]; (ii) "highly-trained/national" sports level according to [28] participant classification framework for research in sports sciences; (iii) having a current certificate from a sports medicine doctor regarding the ability to practice road cycling. The exclusion criteria were: (i) age above 18 years, (ii) postural control disorders identified in the past, (iii) health condition making it impossible to perform the tests. The participants and their legal guardians were informed about the research protocol in detail and gave their written informed consent to participate in the study.

Table 1. Main characteristics of the studied cyclists.

	Median (Q_1–Q_3)	Minimum	Maximum	CQV (%)
Age [year]	16 (15–17)	15	17	6.3
TE [year]	5 (3–6)	1	8	30.0
BH [cm]	178.5 (174.0–180.5)	167.5	192.0	1.8
BW [kg]	63.2 (60.1–67.6)	52.6	82.2	5.9
BMI [kg × m^{-2}]	20.3 (19.2–21.0)	17.8	25.2	4.5
LBM [kg]	53.4 (51.0–57.3)	43.9	67.1	5.9
BF [kg]	9.8 (8.7–12.2)	6.5	15.1	17.9
BF [%]	15.5 (14.5–17.9)	11.1	19.7	11.0

Q_1–Q_3—1st and 3rd quartiles; CQV—coefficient of quartile variation; TE—training experience; BH—body height; BW—body weight; BMI—body mass index; LBM—lean body mass; BF—body fat.

2.3. Somatic Assessment

Body height (BH) was determined with stadiometer seca 213 (seca gmbh & co., kg, Deutschland) with 1mm accuracy. Body weight (BW), body fat (BF), and lean body mass (LBM) were determined with multi-frequency (5 kHz/50 kHz/250 kHz) MC 780 MA device (Tanita, Japan), using the bioelectrical impedance method [29]. At baseline, feet and hands of the athletes and electrodes were sanitized and cleaned. Body mass index (BMI) was calculated in following manner: BW in kilograms ÷ BH in metres squared.

2.4. Postural Control Assessment

The evaluation of postural control was performed using the FreeMED Posture Base pedobarographic platform (Sensor Medical, Italy) with a sampling frequency of 400 Hz, recording movement of CoP in 2-dimensional space. The platform was supported by FreeStep v.1.3.34 software using a low-pass filter to remove any artefacts below 10 Hz. Before initiating measurements, the subject was familiarised with the measuring equipment and test procedure. The measurement was carried out in a quiet room, barefoot, in a standing position, with feet parallel to the width of the pelvis and upper limbs hanging freely along the body [30]. During the measurement, the subject stood on the platform motionless, sequentially, eyes open and closed for 60 s each, with a 30 s interval [30]. The following variables of postural control were analysed: 95%-confidence ellipse area (EA), CoP range displacement in the anteroposterior (AP_R) and mediolateral (ML_R) planes, AP_R/ML_R ratio, CoP mean velocity (MV), and CoP median frequency (MF).

2.5. Fatiguing Protocol and Biochemical Analysis

The effort was performed on the Cyclus 2 ergometer (RBM elektronik-automation GmbH, Germany) with the athlete's own bike installed (the same on which he trained and competed in the race). The ergometer was calibrated in accordance with the manufacturer's recommendations. Before the effort, the participant performed a 5 min warm-up with a load totalling 1.2% of body mass. The pedalling rate during the warm-up equalled 90 rpm. During the final 3–5 s of the second and fourth minutes of the warm-up, the athletes carried out maximal accelerations. Two minutes after the warm-up, the maximal 30 s all-out effort with stationary start was performed. The resistance applied during the test was set at 10% body weight [31]. At the "go" command, the task of the subject was to obtain the highest-possible pedalling rate as quickly as possible and then maintain it in a seated position until the end of the effort (with strong verbal encouragement). During the effort, peak power, time to obtain peak power, mean power, and minimal power were registered. Fatigue index was calculated in the following manner: ((peak power $-$ minimal power) $\div$ (peak power)) $\times$ 100% [32]. After effort, cyclists were pedalling 2 min without load with frequency 50–60 rpm. During the 3rd and 6th minutes following the effort, 20 µL of blood were collected by medical staff from the fingertip for measurement of blood lactate concentration (BL) with the Super GL2 device (Dr. Müller Gerätebau GmbH, Freital, Germany), employing the enzymatic amperometric electrochemical technique. The analyser was calibrated before each series of obtaining samples.

2.6. Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics 26. Changes in postural control variables were evaluated with the paired-sample *t*-test or the Wilcoxon signed-rank test, depending on consistency of the variables' distribution with normal distribution, which was examined using Shapiro–Wilk test. Level of statistical significance was set at <0.05. The effect size (ES) for the paired *t*-test samples was calculated via dividing the mean difference by the standard deviation of the difference, while for the Wilcoxon signed-rank test, it was calculated through dividing the z-value by the square root of the observation number [33]. ES was interpreted as small (<0.3), medium (0.3–0.5), or large (>0.5) [33].

3. Results

3.1. Somatic Indices

Table 1 shows the main characteristics of the study's cyclists.

3.2. Fatiguing Protocol and Biochemical Response

The kinetic values obtained during the effort as well as BL concentrations from the third and sixth minutes after the effort are presented in Table 2.

Table 2. Kinetic data collected during the effort and BL concentration after its completion.

	Median (Q_1–Q_3)	Minimum	Maximum	CQV (%)
Peak power [W]	910 (851–983)	710	1232	7.3
Peak power [W × kg^{-1}]	14.2 (13.4–15.6)	13.4	15.6	7.7
Time to peak power [s]	3.30 (2.50–3.80)	1.00	7.40	19.7
Mean power [W]	716 (671–774)	553	894	7.1
Mean power [W × kg^{-1}]	11.4 (10.6–11.5)	10.3	12.6	4.1
Minimal power [W]	535 (466–579)	419	658	10.8
Minimal power [W × kg^{-1}]	8.2 (7.8–8.8)	6.3	8.8	6.0
Fatigue index [%]	41.2 (37.6–46.8)	31.0	56.0	10.9
Blood lactate 3′ [mmol × L^{-1}]	12.9 (12.0–14.0)	9.8	16.0	7.7
Blood lactate 6′ [mmol × L^{-1}]	11.9 (10.6–13.3)	8.6	15.1	11.3

Q_1–Q_3—1st and 3rd quartiles; CQV—coefficient of quartile variation.

3.3. Postural Control Indices before and after Effort (Eyes Open)

After the effort, significant increases were registered in EA (large ES), AP_R (large ES), and ML_R (small ES), as well as a decrease in MF (large ES). AP_R/ML_R ratio and MV did not change significantly (small effect size) (Table 3).

Table 3. Postural control indices before and after the effort (eyes open).

	Before	After	Difference (%)	*p*-Value	ES
EA [mm^2]	92.2 (56.6–125.6) CQV: 37.8%	250 (151–670) CQV: 63.2%	231.2 (79.2–564.1)	0.000 *	0.59
AP_R [mm]	12.0 (10.6–16.1) CQV: 20.6%	25.7 (18.7–45.3) CQV: 41.6%	110.9 (24.7–323.1)	0.000 *	0.93
ML_R [mm]	10.8 (8.6–14.3) CQV: 24.9%	17.8 (10.9–25.6) CQV: 40.1%	44.3 (−0.82–188.7)	0.011 *	0.28
AP_R/ML_R	1.07 (0.82–1.57) CQV: 31.4%	1.42 (1.12–1.96) CQV: 27.3%	12.3 (−11.7–114.5)	0.136	0.10
MV [mm × s^{-1}]	10.7 (9.1–12.3) CQV: 15.0%	10.6 (10.1–11.7) CQV: 7.3%	1.8 (−7.2–37.7)	0.315	0.04
MF [Hz]	1.11 (0.95–1.26) CQV: 14.0%	0.80 (0.72–0.87) CQV: 9.4%	−21.3 (−33.0 to −10.9)	0.000 *	1.09

Data are expressed as median (with 1st and 3rd quartiles); EA—95%-confidence ellipse area; AP_R, ML_R—CoP range displacement in the AP and ML planes; AP_R/ML_R—ratio of AP_R and ML_R; MV—CoP mean velocity; MF—CoP mean frequency; *p*-value—probability of Type I error; * statistically significant difference; ES—effect size; CQV—coefficient of quartile variation.

3.4. Postural Control Indices before and after Effort (Eyes Closed)

After the effort, significant increases were registered in EA (medium ES), AP_R, and ML_R (in both cases, large ES), with a relatively greater increase in the AP_R, as well as decrease in MF (medium ES). MV did not change significantly (small ES) (Table 4).

Table 4. Postural control indices before and after the effort (eyes closed).

	Before	After	Difference (%)	*p*-Value	ES
EA [mm^2]	90.8 (42.9–291.3) CQV: 74.3%	265 (158–761) CQV: 65.6%	181.7 (−12.5–657.5)	0.001 *	0.49
AP_R [mm]	10.2 (8.4–21.2) CQV: 43.2%	30.2 (21.0–40.8) CQV: 32.0%	141.3 (38.7–276.2)	0.000 *	1.08
ML_R [mm]	12.3 (9.3–15.5) CQV: 25.0%	17.0 (12.6–29.5) CQV: 40.1%	77.7 (1.8–114.0)	0.001 *	0.82
AP_R/ML_R	1.09 (0.70–1.5) CQV: 36.4%	1.66 (1.11–2.16) CQV: 32.1%	46.6 (−11.8–141.1)	0.026 *	0.50
MV [mm × s^{-1}]	11.9 (9.6–13.5) CQV: 16.9%	11.6 (10.3–12.4) CQV: 9.3%	2.3 (−10.0–25.4)	0.670	0.01
MF [Hz]	1.14 (1.04–1.26) CQV: 9.6%	0.87 (0.78–0.96) CQV: 10.3%	−21.1(−29.0 to −9.3)	0.000 *	0.80

Data are expressed as median (with 1st and 3rd quartiles); EA—95%-confidence ellipse area; AP_R, ML_R—CoP range displacement in the AP and ML plane; AP_R/ML_R—ratio of AP_R and ML_R; MV—CoP mean velocity; MF—CoP mean frequency; *p*-value—probability of Type I error; * statistically significant difference; ES—effect size; CQV—coefficient of quartile variation.

4. Discussion

The main finding of this study is that anaerobic fatigue induced by sport-specific exercise deteriorates postural control in highly-trained adolescent road cyclists. What is also of significance in this research is that deterioration of postural control was visible as an increase in the positional parameters of body sway (EA, AP_R, and ML_R) as well as a decrease in MF, but not a change in MV. To best of our knowledge, this is the first study in which the effect was examined of anaerobic fatigue induced by sport-specific exercise on postural control in adolescent road cyclists.

In our study, anaerobic fatigue induced a significant increase in the majority of positional body sway parameters (i.e., EA, AP_R, and ML_R), both with eyes open and closed. It was only the AP_R/ML_R ratio with eyes open that did not increase substantially after the effort. Similar changes were also observed by other authors when anaerobic fatiguing protocols were used: the Wingate Anaerobic test (young judokas [17]; 13-year-old alpine skiers [18]); repeated sprint ability test among soccer players [19]; U19 basketball players [20]); and the Bosco protocol (recreationally trained volunteers [21]). All these protocols linked (beyond the anaerobic background) the involvement of a large number of muscles (general exercise type) mainly in the lower extremities. Therefore, the probable explanation for postural control disturbances may be that high-intensity general exercise such as cycling, running, or jumping deteriorates the quality of sensory information (proprioceptive, visual, vestibular, and plantar cutaneous inputs) and/or their integration, while potentially decreasing the efficacy of the muscular system [34–36]. Metabolic products diminish the facilitation of muscle spindle afferents and thus reduce the efficiency of the myotatic loop during postural regulation. Windhorst [37] specifies that the action of the chemosensitive group III and IV muscle afferents reduces the motor resolution in response to any input, which might lead to less efficient control and reduced motor output accuracy. Another explanation may be the decrease of lower limb muscle strength (the median fatigue index registered in our study was 41.2%). Dickin and Doan [38] and Harkins et al. [39] reported that the decrease in the strength of the ankle or knee musculature as a result of fatigue significantly disturbed postural control, and manifested in increased EA, AP_R, as well as ML_R. Another important aspect which should be addressed while explaining changes in postural control induced by cycling exercises is neck musculature fatigue [25,40]. The cycling position, which require extreme trunk horizontal flattening [41], predisposes one to fatigue in the neck muscles [42]. It has been reported that nociceptive sensorial inputs induced by fatigue of the neck muscles deteriorate the ability to correctly perceive verticality and, moreover, the fatigue degrades spatial body orientation, influencing postural balance [25,43,44]. Postural control disturbances may also be the effect of a large acid–base imbalance [45]. The applied effort induced large increases in BL concentration among the studied athletes (the median BL concentration was 12.9 and 11.9 mmol $\times$ L^{-1} during the third and sixth minutes, respectively, following the effort).

Interestingly, in our study, MV did not significantly change after the effort, while MF decreased substantially. Other authors using anaerobic exercise to induce fatigue obtained different results, i.e., increased MV [17–20], and no changes in MF [17,20]. We have suggested that divergent results may be caused by the different time intervals between the end of the effort and body sway measurements. In our research, posturography was performed between the third and sixth minutes following the fatiguing protocol, while all the cited authors, excluding Jastrzębska [18], carried out measurements immediately after the effort. The protocol used in our study reduced the aggravation of body sway arising from post-exercise tachycardia, hyperventilation, as well as body liquid movement. Another aspect to be considered in trying to explain divergent results is that the anaerobic fatigue in our study was induced via sport-specific exercise, while other authors used non-specific exercise. The observed postural control reaction may, therefore, be characteristic only of road cyclists in whom permanent large exposure to fatigue of various etiologies, in combination with destabilising factors, potentially causing an adaptation in postural control corrective responses. The significant MF decrease noted in our study could also suggest that road cycling training modifies the implemented corrective strategy. Our suggestion is supported by the work of Harkins et al. [39] who observed that in young subjects, balance strategies may change—from the ankle to the hip strategy—when the fatigue is localised at the ankle musculature level. Due to the fact that MF is part of the ankle corrective strategy, it would be probable that a high level of calf muscle fatigue caused by cycling exercise may result in a shift to the hip corrective strategy as that is superior in postural control regulation.

This study showed that short-term, high intensity effort (such as acceleration during a road race) inducing anaerobic fatigue deteriorates postural control in adolescent cyclists, and therefore may increase the risk of falls during competition or training. Decock et al. [46] have reported that 10–13% of all competing Flemish youth riders experience falls during a race and each such incident results in some injuries. Moreover, De Bernardo et al. [47] have suggested that falls cause almost half of the injuries among professional road cyclists. We think that the situations in which anaerobic fatigue is combined with technically difficult and unsafe sectors of the competition/training may be especially dangerous for athletes' health, e.g., a downhill ride from a pass with high speed after a mountain premium sprint. Due to this, we recommend implementing sport-specific balance exercises carried out in anaerobic fatigue conditions in the training programmes of cyclists. Meta-analysis performed by Brachman et al. showed that such exercises have a positive effect on balance performance; therefore, their implementation may reduce the risk of falls and the traumatic injuries induced by them.

The limitations of this study included: (i) the lack of additional measurements regarding body sway immediately after the effort; (ii) the lack of cardiopulmonary parameter registration during the restitution period, showing fatigue status; (iii) potential visual or auditory interference due to not wearing ear muffs and eye masks during postural control assessment with eyes closed; (iv) the lack of a control group, e.g., amateur athletes or those representing different sports disciplines; (v) performing research on a homogeneous (in terms of sex and age) population; thus, the results cannot be generalised to a broader population.

5. Conclusions

In our study, it has been indicated that anaerobic fatigue induced by sport-specific exercise deteriorates postural control in adolescent road cyclists. Moreover, based on the results of our research, we suggest that cycling training, due to its specificity, may affect the quality of postural corrective reactions occurring in response to anaerobic fatigue, which may differ from those occurring in athletes performing other disciplines or in non-training people. Therefore, we recommend implementing balance exercises carried out in anaerobic fatigue conditions in the training programmes of cyclists, because they may result in positive effects in terms of fall prevention. Future studies should consider evaluating the effects of fatigue induced by protocols combining long-duration, low-intensity efforts, and short-duration, high-intensity efforts on postural control. In addition, in the future, a greater number of measurements should be taken into account (with regard to body sway) after the applied fatiguing protocol in order to determine changes of postural control during the restitution period.

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Informed Consent Statement: Written informed consent was collected from participants and their legal guardians.

Data Availability Statement: All data are available from the corresponding author on request.

Conflicts of Interest: The authors declare no conflict of interest.

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