Bio-mechanical aspects of elite cyclists' motor system adaptation in process of competition activity

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Abstract

Purpose: to study the laws of motor structure adaptation of elite cyclists, specializing in 4 km individual pursuit racing on track.

Material: in the research 18 elite athletes participated. We studied special aspects of athletes' coordination structure in experiment, which simulated competition activity.

Results: at start segment of distance high speed depends on effectiveness of right leg's pulling; on pressing and pushing of left leg. At initial stage of distance high efficiency of pedaling is ensured by pressing and pulling of right and left legs. At middle segment high workability depends on movement of right leg; pressing, pulling and pushing of left leg. On finish speed depends by effectiveness of pressing, pulling and moving of right leg; pressing and pulling of left leg.

Conclusions: the presented material creates real pre-conditions for development of bio-mechanical models of cyclists' pedaling technique. The received data can be used for special searching of optimal movement, considering competition tactic. The received results can be used for choosing of means and methods of athletes' movements' pedagogic re-constructions.

Keywords: fatigue, bicycle sport, electromyography, bio-mechanics, model.

Introduction

Competition activity of elite athletes is regarded as important factor of pedagogic and physical influence. Competition is characterized by extreme conditions for manifestation of special fitness's different sides. Competition is an effective mean of maximal realization of athletes' functional potentials [8].

Most specialists mark out conventionally start, distance and finish segments [19, 27]. Such division is a result of pedagogic observations. Recent years more detail division of competition distance has been offered [8, 26].

Optimization of competition activity's structure implies searching of the most effective variants of qualitative and quantitative interconnections of athletes' special fitness different sides [28]. For example in cyclists' 4 km pursuit racing on track it can be reduced to solution of the following tasks: rational fulfillment of start acceleration; transition to distance speed; finish acceleration [18]. Effectiveness of the mentioned elements can influence on final sport result [9]. Especially it is noticeable in competitions of athletes of approximately the same level [5]. However, in elite athletes' training, work with the mentioned elements takes rather modest place.

In other works it was found: Influence of pedal's speed and crank length on pedaling mechanic in period of sub-maximal load. The authors found that distribution of joint torques and powers is mainly sustained in different conditions of pedaling [2]; For assessment of joint and segment movements working load of from 65 to 95% from maximal output power of separate cyclists can be used [3]; Dependences of power pedal's output and electromyography (EMG) of lower limb in different cyclic position. Besides, in this work the authors determined indicators of bilateral asymmetry of pedaling force and EMG. These results show that cyclists can "re-switch" between sitting and standing positions during competitions, for increasing race efficiency in different situations [6]; Professional cyclists increase pulling force in the phase of recreation for sustaining the same output power [12]; Effectiveness of cycling is influenced by profiles of foot angle. This factor is one of the most important and directly correlates with effective force, applied to bicycle [32].

Solution of the following problems is very important in athletes' training: Control of physical loads [17]; Optimization of physical loads [1, 15]; Consideration of athletes' individual characteristics [10, 11]; Determination of successfulness factor in sports [16, 22, 23]; Athlete's ability to distribute load being on distance. Such ability is required for prevention from too early fatigue [25].

In numerous studies there were found quantitative and qualitative changes of cyclists' motor actions' structure under influence of complex of factors. These factors determine external and internal conditions of realization of athletes' motor potential in the process of competition activity [13, 27]. Winners of elite competitions in kinds of sports for endurance do not reduce speed at the end of distance but increase it in state of rising fatigue [29]. With it, technique of main sport movement changes [4, 18]. However it is still not cleared up: what factors influence on sustaining of high distance speed in the state of fatigue [7]. Besides, working out of bio-mechanical pre-conditions for optimization of competition activity's structure is of great practical importance [21]. This problem touches wide circle of questions. These questions are connected with searching of laws of individual adaptive reactions in motor system [24]. Differentiated character of their manifestation depends on specificities of different physical qualities' development [30, 31].

The purpose is to study the laws of motor structure adaptation of elite cyclists, specializing in 4 km individual pursuit racing on track.

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Material and methods

Participants: in the research 18 elite athletes participated. (12 international masters of sports and 6 honored masters of sports).

Organization of the research: we applied complex method to bio-mechanical researches. The athletes were tested in laboratory and natural conditions (4 km individual pursuit racing). We studied dynamic of kinematic and dynamic characteristics of horizontal and vertical components of forces, applied by cyclist. Besides, we studied bio-electrical activity of the following muscles: quadriceps and biceps of thigh; shin and frontal tibialis of right leg. We registered amplitude and frequency of bio-potentials; rhythm structure of electric activity; integrated bio-electrical activity of muscles. Besides, we calculated indicators of effectiveness and efficiency of motor functioning and determined variability of the studied motor characteristics [20].

Statistical analysis: in statistical processing we found mean values of indicators and their errors (X±m), difference between mean values and confidence of differences (t, p), correlation between the studied indicators (r); and the value of dispersion (variant around mean value (σ, CV)).

In our complex pedagogic, bio-mechanical and biological athletes' examinations we observed legislation of Ukraine about health protection; Helsinki declaration 2000 and directive №86/609 of European community about human participation in medical-biological researches.

Results

In the course of our researches we determined dynamic of interconnections of pedaling technique and cyclist's speed in individual pursuit racing. We found the indicators, which influence on cyclist's speed to the largest extent. They are: coefficient of force efficiency (r=0.726-0.836), the spent forces (r=0.694-0.883), useful efforts (r=0.713-0.911), total impulse of force (r=0.723-0.892), indicators of symmetry in legs' functioning (r=0.566-0.829), relative impulses of efforts in pedaling zones (r=0.551-0.891), maximal (r=0.512-0.893) and average (r=0.542-0.913) efforts; space time (r=0.500-0.931) characteristics of cyclists' efforts.

Integral indicators of pedaling technique (effectiveness, efficiency and symmetry of cyclist's legs' work) are highly stable (see fig. 1).

Realization moments of forces maximums are in constant definite zones of pedaling cycle (see table 1). It is interpreted as specific characteristic of elite cyclists. The constancy is achieved owing to many years' process of special training. The moments of beginning and end of vertical forces are highly stable. Space characteristics of horizontal forces gradually increase from the beginning to the end of distance.

Characteristic feature of distance's finish segment is significant increase of zone of application of both legs' forces' horizontal components. It should be regarded as a method of sustaining high speed on finish segment in conditions of rising fatigue.

Time indicators of vertical forces are also highly stable (see table 2). Time characteristics of pushing increase with approaching finish. Increase of pushing forces duration (by left and right legs) is connected with increase of duration of force's reduction phase. Duration of forces' increase up to maximal value is constant on all distance segments. Time indicators of right leg's moving reduce by 32% by the middle of the distance. In the second half of the distance time indicators of right and left legs' moving also increase. On finish segment time indicators of right and left legs' moving exceed average level on distance by 40%. Duration of left leg's moving has opposite direction.

Maximal forces of both legs' pressing and left leg's pulling up are highly stable (see table 3). Maximal forces of right leg are pulling up increase by 41% by the end of distance. Forces of both legs' pushing and moving reduce by 15% by the end of distance.

The character of pedaling technique's adaptive reconstructions changes, depending on athletes' individual characteristics (see Fig. 1).

Reconstructions in pedaling technique depend on the following:

- share participation of many factors in pedaling technique's structure;
- Compensation of insufficient level of one movement's characteristics by hypertrophied level of other;
- Variability of motor system's adaptive reconstructions, which appear under influence of fatigue.

Speed at different segments of distance is conditioned by the structure and quantitative characteristic of interconnection with pedaling technique. Multiple correlation analysis determined the influence of more than 120 indicators of cyclists' pedaling technique on competition distance. On some distance segments one-side influence of certain indicators' groups is observed. It permits to unite separate segments of distance. They are:

- Start segment (up to 19% from total distance or 285.77-400.00 m, depending on the structure of bicycle track;
- Main portion, which consists of three segments: initial (11-30 % or from 285.77-400.00 m to 1143-1333.32 m), middle (31-50 % or from 1143-1333.32 m to 1999.98-2000.39 m) and final (51-80 % or from 1999.98-2000.39 m to 3429.24 m); finish segment (81-100 % or from 3429.24 m to 4000.00 m).

Conventionally we marked out the groups of indicators, which condition pedaling speed on different distance segments. High speed on start segment depends on effectiveness of right leg's pulling up and pressing/moving of left leg. On initial part of distance segment high efficiency and effectiveness of pedaling technique is ensured by legs' pressing and pulling up. On middle part effectiveness of left leg's pushing is important. With rising of fatigue, importance of horizontal components of forces increases. On final part of distance segment high workability depends on the following: right leg's moving; left leg's pressing, pulling up and pushing. Finish segment requires great mobilization of athlete's

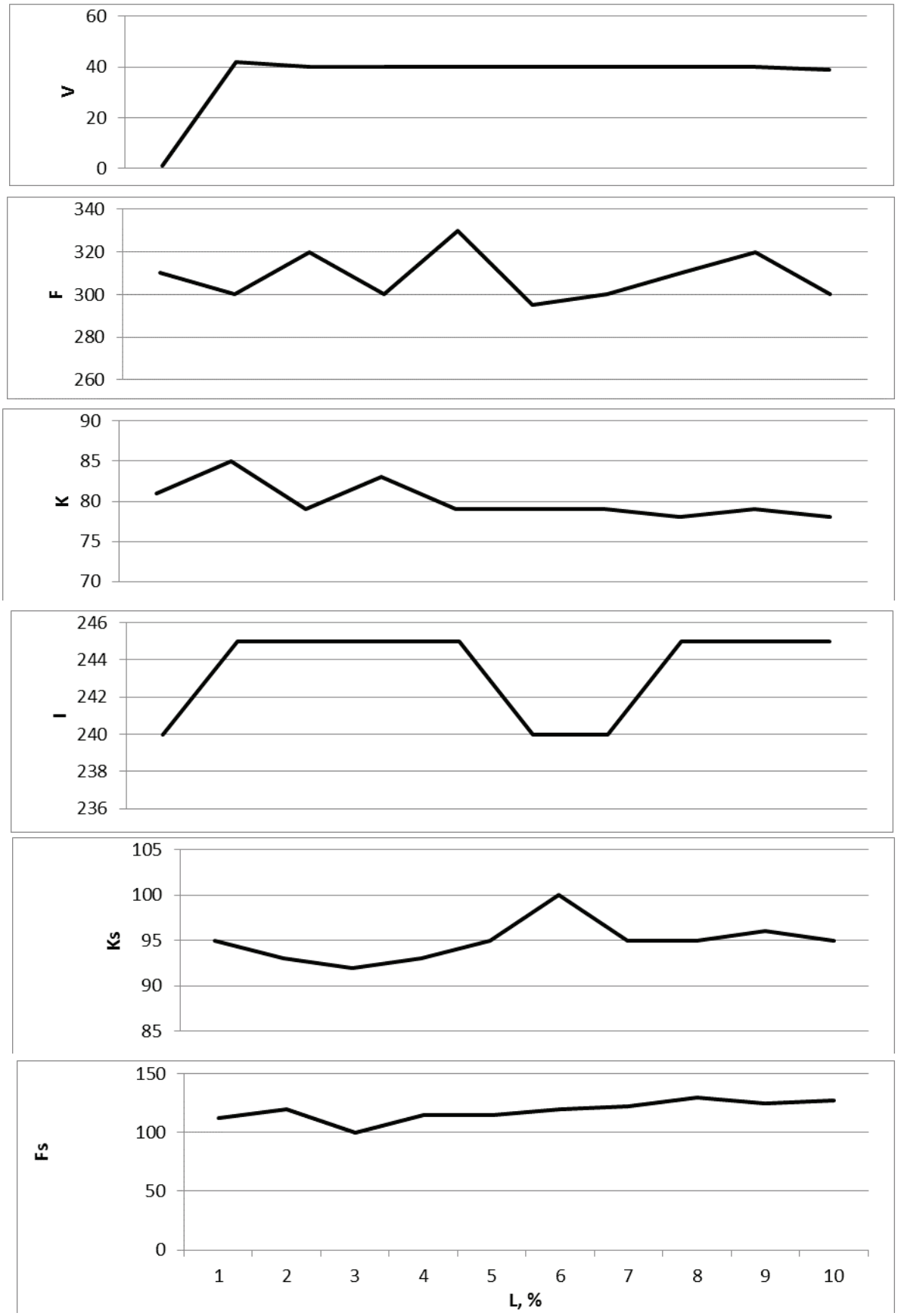

Fig. 1. Dynamic of integral indicators of elite cyclists' pedaling technique on model distance of pursuit racing: V – speed, km/hr; F – spent forces, N; K – coefficient of force efficiency, %; I – total impulse of force, N•s; Ks – symmetry indicator by coefficient of force efficiency, %; Fs - symmetry indicator by spent forces, %; L – length of distance, %.

Table 1. Dynamic of space characteristics (moments of maximal forces) in pedaling cycle of elite cyclists on model pursuit racing, degrees

Legs	Pedaling cycle	Length of distance, %									
		10	20	30	40	50	60	70	80	90	100
Right leg	Pressing	106	105	106	108	105	104	105	103	107	105
	Pulling up	300	305	302	299	302	303	300	300	304	300
	Moving	181	185	187	185	186	185	187	184	188	185
	Pushing	38	40	35	35	35	36	38	36	37	35
Left leg	Pressing	98	96	99	95	96	98	96	94	97	99
	Pulling up	305	310	308	310	309	306	305	305	308	310
	Moving	190	192	195	190	187	190	192	190	190	189
	Pushing	40	42	40	40	42	40	42	40	40	39

Table 2. Dynamic of time characteristics (moments of maximal forces) in pedaling cycle of elite cyclists on model pursuit racing, sec.

Legs	Pedaling cycle	Length of distance, %									
		10	20	30	40	50	60	70	80	90	100
Right leg	Pressing	0,28	0,26	0,28	0,27	0,26	0,27	0,28	0,26	0,26	0,26
	Pulling up	0,34	0,35	0,33	0,34	0,30	0,34	0,30	0,33	0,34	0,33
	Moving	0,20	0,15	0,16	0,17	0,18	0,22	0,20	0,21	0,22	0,23
	Pushing	0,35	0,34	0,32	0,29	0,25	0,30	0,32	0,31	0,32	0,32
Left leg	Pressing	0,25	0,27	0,25	0,23	0,27	0,21	0,25	0,26	0,27	0,25
	Pulling up	0,32	0,35	0,34	0,34	0,33	0,36	0,35	0,33	0,34	0,33
	Moving	0,20	0,30	0,23	0,30	0,23	0,25	0,27	0,28	0,29	0,28
	Pushing	0,35	0,35	0,37	0,38	0,40	0,39	0,25	0,29	0,28	0,27

Table 3. Dynamic of maximal forces in pedaling cycle of elite cyclists on model pursuit racing, H

Legs	Pedaling cycle	Length of distance, %									
Right leg	Pressing	270	250	240	240	260	240	230	240	260	250
	Pulling up	145	180	145	180	160	170	160	190	160	190
	Moving	110	120	110	110	130	140	130	120	130	120
	Pushing	150	160	170	170	175	170	150	140	160	145
Left leg	Pressing	240	230	240	210	240	220	230	230	240	230
	Pulling up	180	170	160	160	180	180	170	170	160	170
	Moving	120	115	110	90	110	90	110	110	100	90
	Pushing	100	100	100	100	95	100	90	70	100	90

functions for sustaining high speed. Passing this segment is characterized by fatigue's rising. Significant reconstructions in motor structure take place on finish segment. Speed on this segment is determined by right leg's pressing, pulling up and moving; as well as by left leg's pressing and pulling up.

Discussion

Changes of pedaling technique's time characteristics shall be regarded as adaptive reconstructions of cyclists' motor structures. It witnesses about gradual transition of cyclists' technique to qualitatively new coordination level by the end of distance [5]. With fatigue's emersion correction of external motor characteristics occurs. With fatigue, significance of horizontal elements of pedaling technique increases. At finish effectiveness of cyclists resulting forces increases [27]. Our results concord well with other data and are confirmed by them [2, 3, 6].

Increase of pedaling power is conditioned by change of applied forces. Choice of biomechanically the most reasonable zone of maximal force application in pedaling cycle is a decisive condition, determining pedaling technique's effectiveness [31]. Horizontal components of forces are of special significance. Duration of horizontal components of forces is less than in vertical components. It is confirmed by other researches [2, 32].

Sustaining of pedaling high speed on distance is determined by possibilities and purposefulness of motor system's adaptive reconstructions. The mentioned reconstructions are pre-conditioned by changes of motor activity's regime. It is connected with involvement of additional muscular motor units in work. On finish

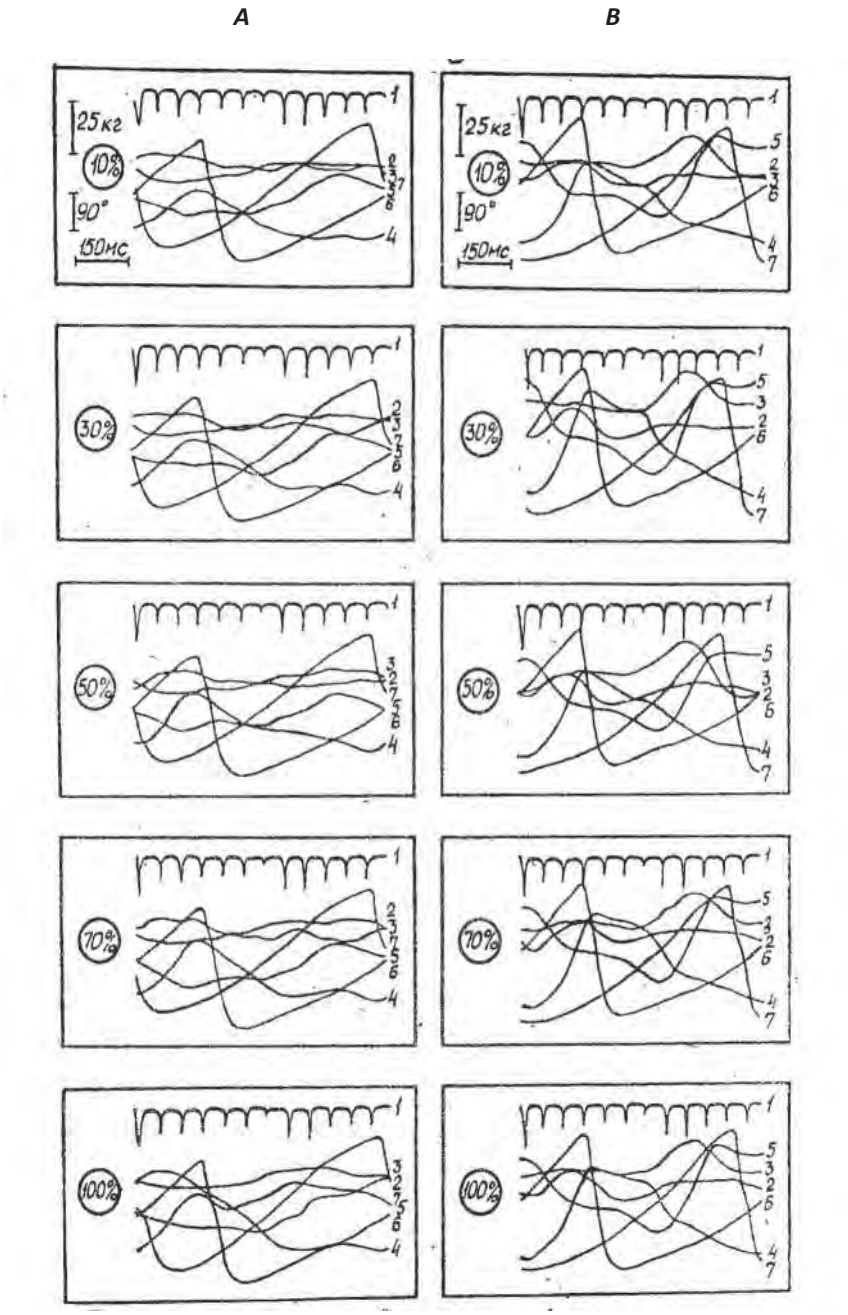

Fig. 2. Tenso-dynamic graphs of elite cyclists' forces in model racing: A – honored master of sports V. K-ts, B – international master of sports D. L-sh. 1 – marker of rod position; 2 – horizontal forces of right leg; 3 – horizontal forces of left leg; 4 –vertical forces of right leg; 5 –vertical forces of left leg; 6 – goniogram of angle between pedal and rod (right leg); 7 – goniogram of angle between pedal and rod (left leg);

reconstruction of separate muscles' innervations happens as well as re-distribution of their activity.

The material, presented in this article, creates real pre-conditions for working out of elite cyclists' pedaling technique's models. The received data can be used for special searching of optimal movements' variant, considering competition tactic. The received results can be used for choosing of means and methods of pedagogic reconstructions of elite athletes' movements.

Conclusions

High speed on start segment depends on effectiveness of right leg's pulling up; pressing and left leg's pushing. On initial part of distance segment high efficiency and effectiveness of pedaling technique is ensured by pressing and pulling up. On middle part of distance segment left leg's pushing is effective. High workability on final part of distance segment depends on right leg's moving and left leg's pulling up and pushing. Speed on finish of distance is determined by effectiveness of right leg's pressing, pulling up and moving as well as pressing and pulling up of left leg.

Conflict of interests

The authors declare that there is no conflict of interests.

References

1. Arziutov G, Iermakov S, Bartik P, Nosko M, Cynarski WJ. The use of didactic laws in the teaching of the physical elements involved in judo techniques. *Ido Movement for Culture*, 2016;16(4):21-30. doi:10.14589/ido.16.4.4
2. Barratt PR, Martin JC, Elmer SJ, Korff T. Effects of Pedal Speed and Crank Length on Pedaling Mechanics during Submaximal Cycling. Medicine and Science in Sports and Exercise. 2016;48(4):705-13.
3. Bini RR, Dagnese F, Rocha E, Silveira MC, Carpes FP, Mota CB. Three-dimensional kinematics of competitive and recreational cyclists across different workloads during cycling. European Journal of Sport Science. 2016;16(5):553-9.
4. Bini RR, Rossato M. Kinetics and Pedaling Technique. *Biomechanics of Cycling*. Springer International Publishing Switzerland; 2014.
5. Castronovo AM, De Marchis C, Bibbo D, Conforto S, Schmid M, D'Alessio T. Neuromuscular adaptations during submaximal prolonged cycling. Conf. Proc. *IEEE Medicine Engineering and Biology Society,* 2012; P. 3612-3615.
6. Chen CH, Wu YK, Chan MS, Shih Y, Shiang TY. The force output of handle and pedal in different bicycle-riding postures. Research in Sports Medicine. 2016;24(1):54-66.
7. Crouch TN, Burton D, Thompson M, Martin DT, Brown NAT, Sheridan J. A phase-averaged analysis of the pedalling cyclist wake. *19 th Australian Fluid Mechanics Conference*, Melbourne: Australia; 2014. P. 100-115.
8. Dahmen T. Optimization of pacing strategies for cycling time trials using a smooth 6-parameter endurance model. *Pre-Olympic Congress on Sports Science and Computer Science in Sport* (IACSS2012). Liverpool: UK; 2012.
9. Dorel S, Drouet JM, Couturier A, Champoux Y. Changes of pedaling technique and muscle coordination during an exhaustive exercise. *Medicine and Science in Sports and Exercise*, 2009;41(6):1277-1286.
10. Druz VA, Iermakov SS, Artemyeva GP, Puhach YI, Muszkieta R. Individualization factors of students' physical education at modern stage of its realization. *Physical education of students*, 2017; 21(1): 10-16. doi:10.15561/20755279.2017.0102
11. Druz VA, Iermakov SS, Nosko MO, Shesterova LYe, Novitskaya NA. The problems of students' physical training individualization. *Pedagogics, psychology, medical-biological problems of physical training and sports*, 2017; 21(2): 4-12. doi:10.15561/18189172.2017.0201
12. Garcia-Lopez J, Diez-Leal S, Ogueta-Alday A, Larrazabal J, Rodriguez-Marroyo JA. Differences in pedalling technique between road cyclists of different competitive levels. J Sport Sci. 2016;34(17):1619-26.
13. Hanaki S, Robert S, Richard R. *The effects of seat post angle in cycling performance*. University of Kentucky: UKnowledge; 2012.
14. Hug F, Turpin NA, Guevel A, Dorel S. Is interindividual variability of EMG patterns in trained cyclists related to different muscle synergies? *Journal of Applied Physiology*, 2010;108:1727-1736.
15. Iermakov SS, Arziutov GN, Jagiello W. Quick training of students to judo techniques. *Archives of Budo*. 2016;12:15-24.
16. Iermakov SS, Podrigalo LV, Jagiello W. Hand-grip strength as an indicator for predicting the success in martial arts athletes. *Archives of Budo*. 2016;12:179-86.
17. Khudolii OM, Ivashchenko OV, Iermakov SS, Rumba OG. Computer simulation of Junior gymnasts' training process. *Science of Gymnastics Journal*, 2016;8(3):215-228.
18. Lépine J, Champoux Y, Drouet J-M. Technique to Measure the Dynamic Behavior of Road Bike Wheels. *Topics in Modal Analysis*, 2012;2(6):465-470.
19. Lukes R, Carre M, Haake S. Track Cycling: An Analytical Model. *The Engineering of Sport*, 2006;1:115-120.
20. Monogarov VD, Bratkovsky VK. *Coordination motions of sportsmen in the period of the compensated fatigue during muscular work of cyclic character.* Kiev, 1979
21. Mornieux G, Gollhofer A, Staperlfeldt B. Muscle coordination while pulling up during cycling. *International Journal of Sports Medicine*, 2010;31:843-846.
22. O'Connor D, Larkin P, Williams AM. Talent identification and selection in elite youth football: An Australian context. European Journal of Sport Science. 2016;16(7):837-44.
23. Podrigalo LV, Galashko M N, Iermakov SS, Rovnaya OA, Bulashev AY. Prognostication of successfulness in arm-wrestling on the base of morphological functional indicators' analysis. *Physical education of students*, 2017; 21(1): 46-51. doi:10.15561/20755279.2017.0108
24. Sigrist R, Dolder V, Riener R, Wolf P. Sonification in cycling – a feasibility study. *10 Symposium der dvs Sportinformatik*, Vienna: Austria; 2014. P.100-116.
25. Skorski S, Abbiss CR. The Manipulation of Pace within Endurance Sport. *Frontiers in Physiology*. 2017;8:102.
26. Sundström D, Carlsson P, Tinnsten M. On Optimization of Pacing Strategy in Road Cycling. *Procedia Engineering*, 2013;60:118-123.
27. Theurel J, Crepin M, Foissac M, Temprado JJ. Effects of different pedalling techniques on muscle fatigue and mechanical efficiency during prolonged cycling. *Scandinavian Journal of Medicine and Science in Sports*, 2011;22:714-721.
28. Thomas K, Lee M, Ian M, James C. Effect of Pedaling Technique on Mechanical Effectiveness and Efficiency in Cyclists, Medicine Science. *Sports Exercise*, 2007;39:991-995.
29. Turpin NA, Guevel A, Durand S, Hug F. Fatigue-related adaptations in muscle coordination during a cyclic exercise in humans. *Journal of Experimental Biology*. 2011;1;214(19):3305–14. doi:10.1242/jeb.057133
30. Umberto E, Tamara H, Jachen D. Influence of racing position on cycling patterns, *Portuguese Journal of Sport Sciences*, 2011;11:211-214.
31. Wangerin M, Schmitt S, Stapelfeldt B, Gollhofer A. Inverse dynamics in cycling performance. *Advances in Medical Engineering*, 2017;114:329-334.
32. Xu JY, Nan XM, Ebken V, Wang Y, Pottie GJ, Kaiser WJ. Integrated Inertial Sensors and Mobile Computing for Real-Time Cycling Performance Guidance via Pedaling Profile Classification. *Ieee Journal of Biomedical and Health Informatics*. 2015;19(2):440-5.

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