MECHANISMS OF ADAPTATION ACTIVITY AFTER COMPETITIVE LOAD IN AEROBIC GYMNASTICS: PHYSIOLOGICAL AND BIOCHEMICAL ASPECTS

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ABSTRACT

Rapid physiological recovery after intense exercise is a hallmark of elite athletic performance. The aim of this study was to evaluate the recovery dynamics of multiple physiological, biochemical, and neuroregulatory parameters in elite athletes in sport aerobics. Twelve athletes of the Ukrainian national team were tested before, immediately after, 5 minutes, and 30 minutes of recovery after a high-intensity exercise cycle. Measurements included cardiovascular function, external respiration, oxygen capacity, blood lactate and glucose, microcirculation, venous return, and heart rate variability. Results demonstrated significant acute changes in all systems, with most parameters recovering near baseline within 30 minutes. The results support the use of integrative monitoring to optimize training and recovery in female athletes after an intense cycle of sport aerobics.

KEYWORDS: Recovery, physiological response, heart rate variability, lactate, microcirculation

INTRODUCTION

Sports aerobics is a unique sport characterized by a combination of high-intensity anaerobic and aerobic exercises that create special benefits for vital processes in the athlete's body. This sport relies on good physical and functional training.

Competitive compositions in sports aerobics are performed at a high pace with a large amplitude of movements. Athletes demonstrate complex acrobatic elements, strength elements and choreographic combinations that require maximum mobilization of all functional systems of the body.

The modern stage of development of sports aerobics is characterized by an increase in the intensity of the training process and an increase in the benefits for the functional readiness of athletes. Physiological recovery after training is a critical factor not only for the beginning of training, but also for maintaining the health of athletes and preventing overexertion.

Athletes in sports aerobics perform high-intensity and precise movements that require optimal cardiorespiratory and metabolic efficiency. Understanding the dynamics of recovery, you can optimize the training process and control the performance of injury-prone elements. The ability to maintain performance during intense training and recover quickly is a key indicator of adaptation in high-level athletes. Monitoring the recovery dynamics of various physiological systems allows for a comprehensive assessment of training effectiveness and athlete's functional readiness. Previous studies have examined recovery processes in endurance and team sports, but there is a limited number of studies on aerobic gymnastics, a sport that combines anaerobic bursts, complex coordination, and sustained effort. In this context, it is important to assess not only cardiorespiratory and biochemical markers, but also microcirculation and autonomic nervous system function, such as heart rate variability (HRV). The present study helps to examine the temporal dynamics of multiple physiological and biochemical parameters in athletes engaged in aerobic gymnastics. Our objective was to assess the speed and completeness of recovery within 30 minutes after intense physical activity using an integrative approach at the systems level.

MATERIALS AND MAETHODS

Participants.

The study involved 12 highly qualified athletes, members of the Ukrainian national team in sports aerobics, aged 18 to 28 years. Athletes' qualifications: 8 - MMSMK, 4 - MMS of Ukraine. The athletes were healthy and free of injuries and illnesses at the time of testing. All athletes signed consent forms to participate in the experiment.

All parameters were measured before the competition, immediately after the competition, after 5 minutes, and after 30 minutes of recovery.

Procedures.

The analysis of the research results was carried out using the methods of mathematical statistics. The following methods were used in the experiments: timing, monitoring of daily respiratory parameters (lung ventilation - MV (using a spirometer), respiratory rate - RR (increase in the number of two-day cycles per 1 min.), respiratory volume - RV), gas analysis of visible air (with an additional gas analyzer), pulse ometry (with an additional fitness tracker and smart watch). Biochemical studies are carried out in the laboratory of the clinic of Zaporizhzhya Medical University. Blood was taken from the finger of all athletes participating in the experiment. The amount of glucose in the blood was determined by the Dole method, the amount of lactic acid - by the enzymatic method. It was also proposed to measure the heart rate, blood pressure, room temperature, microcirculation (laser Doppler flowmetry) and venous outflow (rheography) before training, after training, 5 and 30 minutes after the end of training. This approach allows us to track dynamic recovery processes and evaluate the effectiveness of the adaptation mechanisms of athletes' bodies.

Statistical Analysis

Data were analyzed using SPSS (version 26.0; IBM Corp., Armonk, NY, USA). Statistics are presented as mean ± standard deviation. One-way repeated-measures analysis of variance with Bonferroni post hoc correction was used to assess differences between time points. Statistical significance was set at $p < 05$.

RESULTS

The presented results of our research indicate that the effectiveness in sports aerobics depends on the body's ability to adapt to the alternation of aerobic and anaerobic modes of work. Aerobic endurance ensures the performance of movements with maximum load without reducing their quality and technique of execution. Aerobic mechanisms ensure long-term recovery through oxidation processes in the mitochondria of muscle cells. Anaerobic attenuation allows you to perform complex elements with high intensity, which requires instant mobilization of energy, resistance to hypoxia and places increased demands on the cardiovascular and respiratory systems. Anaerobic processes are activated with significant acid deficiency and are characterized by rapid or short-term renewal of energy reserves through glycolysis and creatine phosphate mechanism.

Competitive compositions in sports aerobics involve the development of general and especially special endurance. The duration of the competition composition is 1 minute 20 seconds. + 5 sec. and is performed at a high tempo with a large amplitude of movements, which is due to the anaerobic mechanisms of energy supply. This will lead to the accumulation of lactic acid and other metabolic products that will require effective elimination at the time of renewal. The relationship between aerobic and anaerobic mechanisms in the renewal process depends on the nature of the training requirement. In sports aerobics, which is characterized by high intensity and sudden changes in work modes, the effectiveness of switching between these energy systems is especially important (Figure 1).

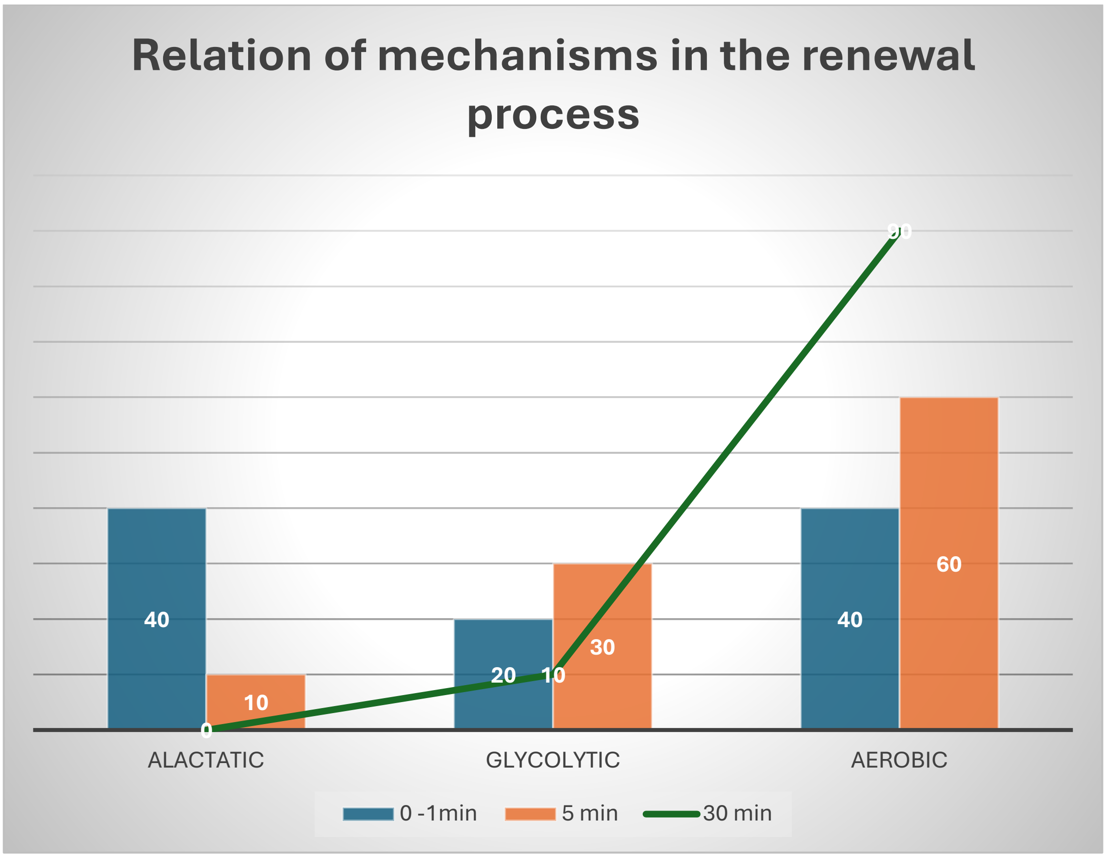

Figure 1

To objectively assess the effectiveness of recovery in athletes specializing in sports aerobics after completing a competitive routine, a comprehensive study of physiological parameters was conducted. During the experiment, respiratory parameters (pulmonary ventilation, RV, RV), exhaled air gas analysis (oxygen consumption), and subsequent calculation of respiratory efficiency and economy indices (RES, O2RC, O2SS) and saturation (SpO2) were determined (Table 1).

Table 1. Dynamics of physiological parameters in elite aerobic gymnastics athletes (n=12)

Indicators	Before training	Immediately after load	After 5 minutes	After 30 minutes
TV (BTPS), ml · min–1	55330,69±792,5	96253,71±374,2	680079,05±475,14	58883,81±388,9
RR, resp.· min–1	19,8±2,4	31,7±2,5	22,2±2,6	19,1±1,8
RV (BTPS), мl	1216,68±109,47	1386,67±82,39	1362,78±125,43	1261,96±98,39
VO2 (STPD), ml · min–1	3039,35±39,0	6268,24 *±73,2	4872,68±68,1	3581,58*±57,9
VE, relates to unit	24,3 ± 1,2	33,6 ± 2,4	28,7 ± 2,1	25,0 ±1,5
O2 RC, ml./l	37,2 ± 2,1	30,4 ± 2,5	33,8 ± 2,3	36,5 ± 2,0
O2 CC, ml	22,67*± 0,92	17,58*± 1,23	18,12± 0,76	19,49± 1,29
HR, beats per minute	65,1 ± 4,8	164,5 ± 7,9	92,4 ± 5,1	68,7 ± 2,44
SpO2, %	98,2 ± 0,4	95,6 ± 0,6	96,1 ± 0,5	97,5 ± 4,5

Note: *Statistically significant changes ($p < 0.05$).

Respiratory volume (RV) values before performing a competitive exercise are consistent with those of trained athletes. After the exercise, a sharp increase in RV is observed, which is associated with a compensatory response to oxygen debt. Values decrease 5 minutes after the exercise but remain elevated, indicating the active recovery phase continues. After 30 minutes, values almost reach baseline, indicating the completion of the primary recovery phase.

During intense physical exercise, oxygen demand exceeds the maximum possible supply. This causes the body to accumulate underoxidized glycolysis products, primarily lactic acid. The oxygen debt accumulated during intense physical exercise is "repaid" after the exercise, resulting in increased oxygen consumption compared to rest. This increased oxygen consumption is accompanied by increased pulmonary ventilation.

For a more in-depth analysis of the functional capabilities of the body of female athletes, a number of biochemical studies were conducted. Blood glucose and lactate levels are important biochemical markers used to assess energy metabolism and the physiological state of athletes during and after exercise, particularly in aerobic sports. This sport combines high-intensity exercise with coordination, endurance, and precision, which causes a pronounced metabolic response in the body (table 2).

Table 2. Biochemical blood parameters dynamics in aerobic gymnastics athletes (n=12)

Biochemical parameter	Before training	Immediately after load	After 5 minutes	After 30 minutes
Glucose, mmol/	l4,62 ± 0,17	6,06 ± 0,15	5,59 ± 0,08	4,96 ± 0,17
Lactate, mmol/l	1,39*±0,46	9,58*±0,25	5,80 ±0,31	2,13 ±0,40

Note: *Statistically significant indicator ($p<0.01$).

During intense exercise, the glucose level increases significantly due to the activation of the sympatho-adrenal system and the mobilization of glycogen. After 30 minutes of rest, the level returns to the initial level in trained athletes. Lactate increases significantly after exercise due to the activation of anaerobic glucose. The maximum value of this indicator is at the same time after training. After 5 minutes, the indicators begin to decrease due to the redistribution and metabolism of lactate (liver, heart, muscles), and after 30 minutes the indicators approach normal.

The rate of decrease in the concentration of lactate in the blood is an indicator of the effectiveness of recovery processes. Athletes can remove lactate faster, which provides more effective recovery after intense exercise.

One of the key aspects is the recovery of the cardiovascular system, which is expressed in the normalization of heart rate (HR), blood pressure and peripheral circulation. (Table.3)

Table 3. Dynamics of physiological indicators during recovery after intensive training in sports aerobics (n=12)

Parameter	Before training	Immediately after load	After 5 minutes	After 30 minutes
Heart rate (bpm)	69,1 ± 4,8	199,5 ± 2,23	149,4 ± 5,1	78,7 ± 4,5
SBP (mmHg)	116 ± 6,4	165,6 ± 3,16*	138 ± 7,2	118 ± 6,6

DBP (mmHG)	74 ± 4,4	89 ± 5,6	77 ± 4,2	75 ± 3,2
Heart rate variability (HRV) RMSSD (ms)	38,7 ± 5,4	64,1 ± 7,2	42,3 ± 2,6	37,8 ± 4,3
SDNN (ms)	24,6 ± 4,1	48,5 ± 6,0	35,2 ± 5,0*	28,6 ± 6,4
Skin temperature (^{0}C)	35,9	37,33 (due to hyperemia)	36,9	36,1
Microcirculation Index (arbitrary units)	3,4 ± 0,6*	5,8 ± 0,9	4,1 ± 0,7	3,6 ± 0,5
Venous outflow (impedance plethysmography)	0,19 ± 0,03	0,15 ± 0,02	0,17 ± 0,02	0,19 ± 0,03

Note: *Statistically significant indicator ($p<0.01$).

Assessment of the dynamics of physiological recovery after intensive aerobic exercise training demonstrated pronounced changes in the indicators of the cardiovascular system and peripheral circulation. Data were collected in four periods: before training, immediately after its completion, after 5 minutes and after 30 minutes of rest. The results are shown in Table 3. The dynamics of the heart rate are particularly indicative, which increases to 169.5 + 2.23 beats / min after training and gradually decreases to almost the initial values after 30 minutes - 70.2 + 2.44 beats / min. Such dynamics indicate a high level of fitness and effective functioning of the autonomic regulation of cardiac activity. Systolic blood pressure (SBP) increased significantly after exercise (up to 182.0 + 3.16 mm Hg), and then rapidly decreased during the recovery period, which in some cases was accompanied by short-term post-exercise hypotension. Diastolic blood pressure (DBP) remained relatively stable throughout the observation period.

Heart rate variability (HRV) — (the changes in the intervals between heartbeats) is an important indicator of the state of the autonomic nervous system and general health. HRV is used to assess the body's response to stress, physical activity and the overall level of adaptation. High HRV indicates flexibility and resilience of the nervous system, while low HRV may indicate chronic stress or imbalance. HRV values have pronounced individual characteristics, so what is important is not the absolute value, but the dynamics of changes in each individual athlete compared to her own initial indicators. Heart rate variability (HRV) decreased as expected immediately after exercise due to the dominance of sympathetic activity, gradually recovering in the following minutes, reflecting the restoration of parasympathetic tone.

Skin temperature and microcirculatory activity also demonstrated dynamics characteristic of recovery processes. Skin hyperemia caused an increase in its temperature (up to 360 C), which normalized within 20-30 minutes. This process is a physiological reaction of the body to remove excess heat from working muscles. The speed of normalization of skin temperature is one of the indicators of the level of functional fitness of athletes. According to laser Doppler flowmetry (which was performed by medical specialists), the level of microcirculation increased to 5-6 points after training, with a subsequent gradual return to the initial values.

Rheographic examination of venous outflow in the lower extremities revealed a temporary decrease in vascular tone after physical exertion. Rheographic indicators were recorded using a computer rheograph. Complete restoration of venous circulation occurred within the next 30 minutes, which indicates the effectiveness of adaptive mechanisms and the absence of stagnant phenomena.

It is important to note that muscle recovery includes normalization of muscle tone, restoration of muscle fiber elasticity, and elimination of microdamages that occur during intensive training. Effective microcirculation ensures adequate supply of oxygen and nutrients to the muscles, and also promotes the removal of metabolic products accumulated during physical activity. In sports aerobics, the muscles of the limbs and abdominal muscles that perform work during jumps and power elements are particularly stressed. Monitoring microcirculation indicators allowed us to assess the effectiveness of recovery processes and timely identify possible violations that could lead to reduced performance or injuries.

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DISCUSSION

The results of this study contribute to the growing body of research on adaptive physiological and biochemical responses in high-performance athletes, especially in aerobic sports. The observed dynamics of cardiovascular, microcirculatory, and metabolic parameters support the hypothesis that elite athletes demonstrate a complex, multilevel adaptation system that is formed under conditions of repeated cycles of high-intensity training and recovery.

Platonov V. (2019) emphasized the systemic nature of adaptation in high-performance sports, noting that stable adaptive responses arise as a result of long-term, individually optimized training processes. This is consistent with our findings, where stable biochemical parameters (e.g., lactate and glucose levels) were observed only after prolonged exposure to structured aerobic training loads.

Levitsky (2004) and Kokarev (2023) emphasized the role of neurohumoral regulation in the adaptation of athletes to anaerobic loads. In our experiment, changes in activity corresponded to changes in the tone of the microcirculatory bed, which indicates the active participation of neuroregulatory mechanisms in the adaptation to intensive aerobic loads.

Lörinczi, F. (2024) emphasized the need to monitor individual indicators to optimize the adaptation process. Accordingly, our results indicate that regular screening can improve the personalization of training in sports aerobics.

The effectiveness of microcirculation restoration suggests that local vascular adaptations, particularly in the skin and muscle, play a vital role in overall performance stability and fatigue resistance in aerobic gymnastics. Interestingly, individual differences in the timing and magnitude of physiological normalization have been noted. This may be explained by differences in training experience, hormonal profile, genetic predisposition, and recovery strategies used by athletes (Kellmann et al., 2018; Saw et al., 2016). These observations highlight the importance of individualized recovery monitoring and planning in elite sport.

The rapid decrease in heart rate and blood pressure, as well as the restoration of capillary perfusion parameters, support the idea of accelerated recovery of the autonomic and peripheral nervous systems in well-trained athletes, which is consistent with previous data obtained in high-intensity sports (Borresen & Lambert, 2008; Buchheit, 2014). The results of our study demonstrate the high sensitivity of the cardiovascular and microcirculatory systems in elite aerobic gymnasts during the recovery period following competitive exercise.

Our results also highlight the need to integrate objective physiological measures with subjective self-assessment tools to capture the full spectrum of recovery. Although heart rate and capillary blood flow returned to baseline levels relatively quickly, subjective reports of fatigue and perceived exertion remained elevated in some athletes, reflecting a possible dissociation between the physical and psychological aspects of recovery (Meeusen et al., 2013; Halson, 2014).

Overall, this study contributes to the growing body of evidence supporting multidimensional diagnostics of recovery in elite sport. In the context of aerobic exercise, where training places increased demands on both the neuromuscular and cardiorespiratory systems, timely and complete recovery is essential not only for optimal performance but also for injury prevention and the long-term health of athletes.

CONCLUSIONS

This study demonstrates that elite female aerobic athletes exhibit a highly adaptive physiological response to high-intensity competitive workloads. The cardiovascular and respiratory systems respond immediately to physical activity with significant increases in heart rate, respiratory rate, pulmonary ventilation, and oxygen transport capacity. Despite the high intensity, functional parameters return to baseline levels within 30 minutes after completing the competitive routine, indicating a well-developed recovery mechanism.

Biochemical markers such as lactate and glucose show a transient increase after the competitive workout, consistent with anaerobic metabolism and mobilization of energy substrates. These markers also normalize within 30 minutes, confirming the athletes' metabolic efficiency and their readiness for repeated exercise.

Microcirculation and venous outflow parameters reflect a rapid increase in peripheral blood flow and venous return during the early stages of recovery. Heart rate variability (HRV) dynamics demonstrate autonomic modulation with a temporary decrease in parasympathetic activity and its gradual recovery, reflecting a balance between sympathetic activation and recovery mechanisms.

Overall, these results confirm that elite aerobic gymnasts have well-coordinated physiological and neurohumoral systems capable of withstanding intense physical exertion and quickly initiating effective recovery, highlighting the importance of monitoring multisystem dynamics in high-performance work and recovery planning. Our results support the need for comprehensive monitoring protocols that incorporate both central and peripheral recovery indicators. This approach allows coaches and sports scientists to evaluate not only training loads but also the effectiveness of recovery strategies and athletes' overall competition readiness.

Further research should focus on individual athlete capabilities, recovery, and the integration of biochemical and neurophysiological indicators to create a more complete picture of adaptation processes in aerobic gymnastics, facilitating the development of personalized training and recovery plans.

REFERENCES

1. Aleksandravičienė R., Stasiulis A. Physiological responses during competitive sports aerobics exercise. Lithuanian Academy of Physical Education. 2005

2. Atamanyuk, S. I., & Kirichenko, O. V. Current system of sports selection in sports aerobics. Sci. J. Natl. Pedagog. Univ. M. P. Drahomanov. Ser. Sci.-Pedagog. Probl. Phys. Cult. 2023. (3K (162) 23), 216–221.

3. Bahenský, P., Marko, D., Grosicki, G. J., & Malátová, R. Warm up breathing exercises accelerate VO_2 kinetics and reduce subjective strain during incremental cycling exercise in adolescents. J. Phys. Educ. Sport, 2020. 20(6), 3361–3367.

4. Borresen, J., & Lambert, M. I. Autonomic control of heart rate during and after exercise: Measurements and implications for monitoring training status. Sports Med., 2008. 38(8), 633–646. https://doi.org/10.2165/00007256-200838080-00002

5. Bucheit, M. Monitoring training status with HR measures: Do all roads lead to Rome? Front. Physiol., 2014. 5, 73. https://doi.org/10.3389/fphys.2014.00073

6. Chayun, D., Kletsov, K., & Manzheley, I. Acrobatics as a new trend in aerobic gymnastics. J. Phys. Educ. Sport, 2020. 20(2), 759–767. https://doi.org/10.7752/jpes.2020.02109

7. Halson, S. L. Monitoring training load to understand fatigue in athletes. Sports Med., 2014. 44(Suppl 2), 139–147. https://doi.org/10.1007/s40279-014-0253-z

8. Harbour, E., Stöggl, T., Schwameder, H., & Finkenzeller, T. Breath tools: A synthesis of evidence based breathing strategies to enhance human running. Front. Physiol., 2022. 13, 813243. https://doi.org/10.3389/fphys.2022.813243

9. Kellmann, M., et al. Recovery and performance in sport: Consensus statement. Int. J. Sports Physiol. Perform., 2018. 13(2), 240–245. https://doi.org/10.1123/ijspp.2017-0759 ncbi.nlm.nih.gov

10. Kokarev, B., Kokareva, S., Atamaniuk, S., Terehina, O., & Putrov, S. Effectiveness of innovative methods in improving the special physical fitness of qualified athletes in aerobic gymnastics. J. Phys. Educ. Sport, 2023. 23(3), 622–630. https://doi.org/10.7752/jpes.2023.03077

11. Kyselovičová O., Zemková E. The effects of aerobic gymnastics training on performance-related variables in an elite athlete: a 2-year follow-up study.//Journal Frontiers in Physiology. 2024. 15, 138.

12. Levitsky, V. Current sports and health technologies in physical training. Theory Methodol. Phys. Train. Sports, 2004. (1), 27–31.

13. Lörinczi, F., Lörincziová, D., & Augustovičová, D. Immediate impact of various breathing modes on short term local muscular endurance performance and physiological responses. J. Phys. Educ. Sport, 2024. 24(1), 141–148. https://doi.org/10.7752/jpes.2024.01148 portal.issn.org

14. Meeusen, R., et al. Prevention, diagnosis, and treatment of the overtraining syndrome. Eur. J. Sport Sci., 2013. 13(1), 1–24. https://doi.org/10.1080/17461391.2012.730061

15. Mujika, I., & Padilla, S. Cardiorespiratory and metabolic characteristics of detraining in humans. Medicine & Science in Sports & Exercise, 2001. 33(3), 413–421.

16. Platonov, V. N. Motor qualities and physical preparation of an athlete [Dvigatel'nye kachestva i fizicheskaya podgotovka sportsmen] 2019. (656 pp.). Moscow: Sport.

17. Saw, A. E., et al. Monitoring the athlete training response: Subjective self reported measures trump commonly used objective measures. Br. J. Sports Med., 2016. 50(5), 281–291. https://doi.org/10.1136/bjsports-2015-094758