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The Influence of Intensive Anaerobic Effort on the Rhythm of Movement

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Purpose: To estimate the influence of global anaerobic fatigue on rhythm performance. ***Methods:*** Fifteen young males participated in the experiment. Anaerobic fatigue was induced with 2 consecutive running-based anaerobic sprint tests (RAST). The level of lactate was controlled before the first RAST and 3 minutes after each RAST. The rhythm performance was assessed by using Optojump Next (Microgate, Bolzano, Italy). The rhythm test was conducted 3 times, before fatigue and immediately after each RAST. Eight variables of the rhythm test were analyzed: the mean frequency of jumps for the assisted and unassisted phase (Xf_{AP} and Xf_{UAP}), SD of jump frequency for the assisted and unassisted phase (SDf_{AP} and SDf_{UAP}), and mean absolute error for the assisted and unassisted phases of the test (XER_{AP} and XER_{UAP}, respectively). ***Results:*** One-way repeated-measures analysis of variance showed a significant main effect of anaerobic effort on rhythm variables only in the unassisted phase of the test. Statistically significant differences were observed in Xf_{UAP} between the first and third rhythm measurements ($F_{2,28} = 4.98$, $P < .014$, $\eta_p^2 = 26.23\%$), SD of jump frequency for the unassisted phase (SDf_{UAP}; $F_{2,28} = 3.48$, $P = .05$, $\eta_p^2 = 19.9\%$), and mean absolute error for the unassisted phase (XER_{UAP}; $F_{2,28} = 3.36$, $P = .006$, $\eta_p^2 = 19.43\%$). ***Conclusions:*** The results show that rhythm of movement may be negatively influenced after intensive anaerobic fatigue. The exact mechanism of this phenomenon is not precisely defined, but both central and peripheral fatigue are suspected to be involved.

Keywords: physical performance, exercise performance, motor control

The sense of rhythm is critical to repetitive movement tasks. Precise timing activates an optimal automatic motor pattern needed for successful motor task realization,[1,2] which is crucial for daily motor activities, as well as in sport performance. But, in fact, we do not know how fatigue influences rhythm and, consequently, how it can disturb multijoint activities based on rhythmic, cyclic movement. This knowledge may be useful in sport science to obtain a maximal training effect, especially in a sport where rhythm of movement may be a factor determining final success. Many sports disciplines like dancing, ballet, and gymnastics are strongly dependent on one's sense of rhythm,[3] which may be classified more as a rhythm perception according to an external rhythm pattern. There is no doubt that performance in competitive hurdles, sprints, cycling, rowing, basketball, tennis, and swimming is also conditioned by this phenomenon,[4–6] in a way, where the sportsman acts according to an internal rhythm pattern, which may be regulated by external conditions (eg, hurdles running). Many of the above-mentioned sport disciplines are based on high-intensity anaerobic effort.[7–11]

For the purpose of this study, we accept the definition of the sense of rhythm proposed by Fraisse,[12] who defined it as an "order of the movement." The author also recognized rhythm perception, which in his understanding, is that the motor skill is responsible for producing the movements. These movements are usually made according to the exact timing and give a temporal reference in the motor system.

Earlier research concerning rhythm of movement focused mainly on the local examples of this coordination phenomenon, engaging only a small number of muscles in the movement, for example, the finger-tapping task.[13,14] It is difficult to apply these results in daily activities and sports competition, where, usually, global multijoint movements are performed. Due to the complexity of these movements and many systems involved, it is quite difficult to study the problem of global coordination. Most of the research dealing with this issue concerns locomotion[15] and jumping performance.[16,17] The full understanding of complex multijoint coordination with respect to a sense of rhythm is still in progress.

Although the literature on the influence of fatigue on human performance is substantial, only a few studies describe the impact of neuromuscular fatigue on the sense of rhythm. Gutin[18] studied psychomotor performance after physical effort. He suggested that various levels of activation impact mental and psychomotor tasks differently. Low activation after light exercise (heart rate = 90–120 bpm) can positively affect psychomotor and mental performance, whereas higher activation triggered by over 15 minutes of physical activity followed by a heart rate > 160 bpm should lead to a deterioration in performance on tasks with a high information-processing demand. These results were not confirmed by Hogervorst et al.[19] In their research, the results of psychomotor and cognitive tasks after long effort at a heart rate of 160 to 180 bpm did not worsen. The differential impact of fatigue on the neuromuscular system usually depends on the realized task and the fatigue protocol.[20]

In this study, the authors emphasize the importance of timing performance and rhythm in sport, as it strongly influences the training process and competition. Usually, it is one of the strongest factors that determines the construction of the training process and, in effect, competition results. The problem of muscle fatigue and its physiological and neuromuscular mechanism, indicators, and effects were deliberated for years by many authors.[21,22] A different definition of fatigue is used depending on the fatigue mechanism—from the accumulation of metabolites in muscles to inadequate motor command from the central nervous system—and it is

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difficult to characterize this phenomenon by one global mechanism.[23] For the purpose of this study, "fatigue" is defined as a "reversible, exercise-induced reduction in maximal power output (eg, during cycle exercise) or speed (eg, during running exercise), even though the task can be continued."[24] Fatigue is a combination of both central and peripheral mechanisms,[25] it can adversely affect the performance timing, which is associated with the type of fatigue (local or global) or its mechanism.

In this study, the aim was to estimate the influence of global fatigue inducted by anaerobic efforts on rhythm performance and to examine how this specific kind of fatigue impacts rhythm and timing of movement. The purpose of this study was to determine how global anaerobic effort affects the rhythm in the global task; we consider this to be a novel approach to this problem, as it is closer to everyday and sports activities. We hypothesize that high-intensity anaerobic exercise, which induces the highest fatigue changes, significantly deteriorates the ability of whole-body timing performance.

Material and Methods

Subjects

We conducted a sample-size estimate. Based on the Cohen guidelines (Cohen 1988), with an alpha level of .05 and power of 0.8, sample sizes 6 to 12 appeared to be necessary to detect the differences between consecutive tests. We conservatively recruited 15 male students (age 20.1 ± 0.7 y, body mass 72.7 ± 6.8 kg, and height 176.3 ± 6.11 cm) from a physical education course for the experiment. All of them had sport experience in the past on a basic level in different sport disciplines. The participants were healthy and did not report any neuronal or musculoskeletal disorders. They voluntarily participated in the study, and an informed consent was provided by all participants. The basic body composition values of the participants were estimated as the height and body mass. Before any measurements were collected, the study participants were informed about the testing procedures. The participants were not familiarized with the rhythm test before the experiment. The same day the experiment was conducted, they did 1 rhythm test to understand the procedure; then, the experiment started. The running-based anaerobic sprint test (RAST) was performed by them during their athletics lessons 3 weeks before the experiment. The study was approved by the Academy's Institutional Review Board.

Procedures

The experiment was conducted at approximately 12:00 PM. The subjects had no special instructions about nutrition; they were only told to minimize their physical activity 48 hours before the experiment. To obtain anaerobic fatigue, the RAST was chosen. The RAST consists of 6 maximal efforts of 35 m, separated by a passive recovery period of 10 seconds.[26] The time of each run was measured by Microgate Kit Racetime (Microgate, Bolzano, Italy) at the beginning and end of the 35 m. All tests were performed on a synthetic surface, a track-and-field track. The subjects performed RAST twice, with a 5-minute break before the next attempt. We decided to use a stimulus that would trigger progressive changes in homeostasis (measured by the lactate [LA] level) over the 15 mmol/L. A blood sample was taken to estimate the level of LA before the procedure, after the warm-up, and 3 minutes after each RAST test. The level of LA was estimated by the enzymatic amperometric detection method via Lactate Scout Plus (SensLab GmbH, Leipzig, Germany) and used dedicated precalibrated sensors.[27]

To assess rhythm performance, the specially designed test was performed with the use of the Optojump Next measurement system (Microgate). The participants were asked to stand in the testing area, between the Optojump bars, with their arms behind their backs. The participants were instructed to jump at the rhythm given by the metronome at 1 Hz. The rhythm test consisted of 45 continuous jumps. The first 5 jumps of the test familiarized the participants with the task and were not included in the analysis. The next 40 jumps were divided into 2 phases of 20 jumps each. During the first phase, the subjects were able to hear the metronome—the "assisted phase." The next phase of 20 jumps was done without the metronome feedback—the "unassisted phase." The participants were asked to remember the pace of the metronome during the first 25 jumps and continue jumping at that pace without stopping during the remaining 20 jumps. The rhythm test was done 3 times: first, before fatigue and, second and third, immediately after each RAST test. The following variables of the collected data were analyzed: mean frequency of jumps for the assisted and unassisted phase (Xf_{AP} and Xf_{UAP}), SD of jump frequency for the assisted and unassisted phase (SDf_{AP} and SDf_{UAP}), mean absolute error for the assisted and unassisted phases of the test (XER_{AP} and XER_{UAP}, respectively), which was calculated as 1 minus observed frequency, and SD of absolute error for the assisted and unassisted phases of the test ($SDER_{AP}$ and $SDER_{UAP}$, respectively). The reliability analysis conducted for the studied variables revealed that they were reliable, with an intraclass correlation coefficient (2,1) ranging from .85 to .89 for the number of jumps employed in the rhythm test (SEM = 0.02, coefficient of variance = 5.03).

Statistical Analyses

All collected data were further processed using standard methods of descriptive statistics. The Kolmogorov–Smirnov normality test revealed the data of the analyzed variables to be normally distributed. The data were tested for sphericity, and the 1-way repeated-measures analysis of variance and Fisher LSD post hoc tests were used when needed to estimate the differences between the rhythm test variables after successive anaerobic fatigue trials. Partial eta squared (η^2_p) in percentage were used as measures of effect size. A paired samples *t* test was conducted to compare the scores of the RAST test. All statistical calculations were performed using Statistica 12 software (TIBCO Software Inc, Palo Alto, CA).

Results

The results of the RAST test and the statistical significant differences between its variables are presented in Table 1.

The one-way repeated-measures analysis of variance showed a significant main effect of anaerobic effort on rhythm variables only in the unassisted phase of the test. Statistically significant differences were observed in Xf_{UAP} between the first and third rhythm measurement ($F_{2,28} = 4.98$, $P < .014$, $\eta^2_p = 26.23\%$; Figure 1), SD of jump frequency for the unassisted phase (SDf_{UAP}; $F_{2,28} = 3.48$, $P = .05$, $\eta^2_p = 19.9\%$; Figure 2), and mean absolute error for the unassisted phase (XER_{UAP}; $F_{2,28} = 3.36$, $P = .006$, $\eta^2_p = 19.43\%$; Figure 3).

Discussion

We examined how anaerobic fatigue of different intensities influences whole-body rhythm performance. The values of physiological fatigue markers showed that the used fatigue protocol induced

Table 1 Results of the RAST and LA Values

	RAST 1		RAST 2	
	Mean	SD	Mean	SD
Maximum power, W	793	150	757	177
Minimum power, W	445	115	410*	116.7*
Average power, W	533.3	106.6	542	136
Fatigue index	10.7	3.04	10.5	3.68
LA 2, mmol/L	14.3*	3.72		
LA 3, mmol/L			18.7*	3.41

Abbreviations: LA, lactate; RAST, running-based anaerobic sprint test.
*Statistically significant differences for $P \leq .05$.

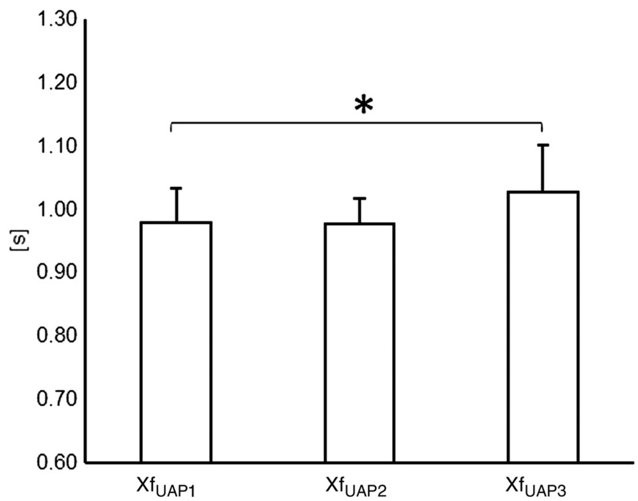

Figure 1 — Difference between values of Xf_{UAP} during 3 running-based anaerobic sprint tests. Xf_{UAP} indicates mean frequency of jumps for the unassisted phase.

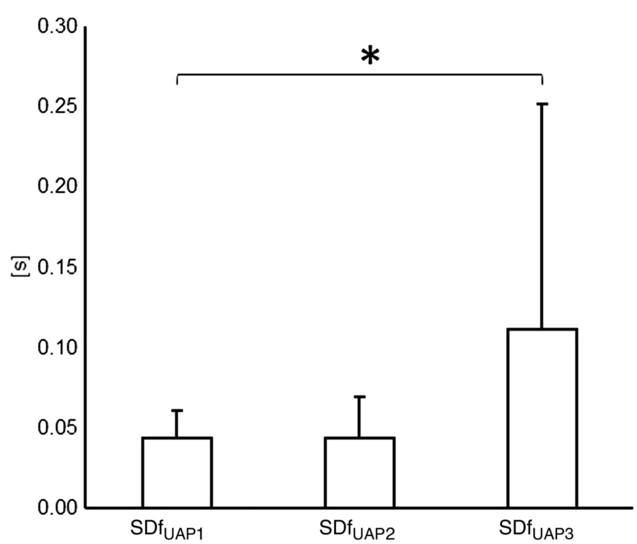

Figure 2 — Difference between values of SDf_{UAP} during 3 running-based anaerobic sprint tests. SDf_{UAP} indicates SD of jump frequency for the unassisted phase.

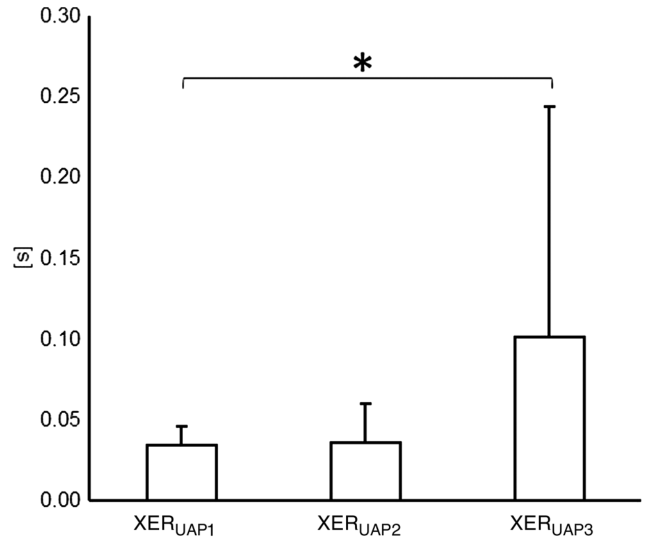

Figure 3 — Difference between values of XER_{UAP} during 3 running-based anaerobic sprint tests. XER_{UAP} indicates mean absolute error for the unassisted phase.

significant changes in the system and was consistent with the previously published methodology.[28]

The results supported our hypothesis whereby we assumed that the increasing anaerobic fatigue induced by the repeated RAST would affect the sense of rhythm. An analysis of the results showed that, after the second RAST, the values of all rhythm test variables changed significantly. In particular, the values of the mean absolute error and its SD of the unassisted phase of the test were higher, and the SD of the absolute error was almost 3 times higher than the values of the mean absolute error. We observed that only the results of the last rhythm test performed under acidosis over 15 mmol differed significantly from the baseline. After the first RAST trial, in which the level of lactic acid was under 15 mmol, the subjects were able to maintain the rhythmic performance. In our previous experiment, where we examined how aerobic efforts of lower intensity impact the sense of rhythm, the highest observed level of lactic acid was about 8 mmol/L; we also did not observe significant differences among the rhythm test indices before and after fatigue.[29] Therefore, the intensity of physical exertion and, consequently, the accumulation of metabolites may decide the rhythm performance. Similar results were also reported by Isaacs and Pohlman,[30] where heavy load (cycling at 100% of the VO_2max) had a negative impact on skilled timing performance.

The role of lactic acid in muscle fatigue is not so obvious. Many different views exist regarding the physiological effect of LA and its role in muscle physiology.[22] Westerblad et al[31] support the claim that lactic acid is the cause of acidosis; however, they oppose the belief that acidosis is the main cause of muscle fatigue. LA is an aerobic metabolite when glucose or glycogen is the fuel source and adequate oxygen is available. Muscle is now considered a consumer of LA. The rate at which LA is used is dependent on the rate of metabolism, blood flow, LA concentration, hydrogen ion concentration fiber type, and exercise training.[32] The breakdown of creatine phosphate, which releases inorganic phosphate, appears to be the main cause of skeletal muscle fatigue. LA production associated with muscular fatigue has little impact on limitation in athletic performance. Rather, its role is connected with athletes' sense of discomfort, and it also impairs ATP production from glycogen.[33] It has also been suggested by some authors that the ionic disturbances affecting the role of the Na+/K+ pump may negatively impact muscle excitability.[20] Some findings also suggest that H^+ accumulation in blood and muscles after intermittent sprint exercise may affect performance.[20,34] These findings support the peripheral fatigue theory,[23] that the accumulation of metabolites such as LA, or substrate depletion, induces catastrophic failure of homeostasis in the exercising muscles, leading directly to exercise termination.

In our opinion, the theory of "peripheral fatigue" does not explain our observations. Recent ideas called the "central governor model" explain the fatigue mechanism in different ways. According to this concept, the neural control system in the brain and spinal cord control establish the number of motor units that are activated in the muscles to maintain the performance in acceptable homeostasis disorder without critical system failure.[35] The information gained by the central nervous system about level of fatigue and readiness to maintain performance comes from the muscle receptors. Sensory information from the periphery is integrated by the brain to determine the proper exercise intensity that ensures body homeostasis. LA is an important oxidative energy substrate in the cerebrum. The brain is able to take up LA from the blood during exercise, as well as during the initial stage of recovery.[36] During intensive performance when LA is used as a source of energy in the brain, the way it controls the performance changes. However, it is not equally distributed, but is localized in the regions of the brain related to locomotion, the maintenance of equilibrium, cardiorespiratory control, and vision.[37] Recent research concerning rhythm, its nature, and the way it is controlled by the central nervous system from the neuroscientist point of view specifies the neural structures responsible for rhythm control.[38] We have no information about whether the neural structures responsible for the rhythm control belong to this primary region. Therefore, there is a possibility that both the peripheral and central fatigue mechanisms are responsible for rhythm perception failure. In our previous experiment,[29] where the subjects, after fatigue under 8 mmol/L, performed the same test and no differences between the baseline and post fatigue rhythm test indices were observed, we assumed that the compensatory mechanism observed by other authors[16] probably reduced the fatigue consequences. Other studies involving running, sprinting,[24,28] and continuous hopping exercises[17] provide evidence that some compensatory mechanisms are used to counterbalance the loss of the muscle force-generating properties because of fatigue. Our study,[29] where fatigue had an anaerobic character, did not reveal any compensatory mechanism effects. After high-intensity performance, the level of metabolites rises in the periphery and the central fatigue mechanisms start to regulate the rate of intensity of performance to prevent exhaustion and, consequently, deregulate the sense of rhythm. Because maximal sprint exercise demands high levels of neural drive, failure to fully activate the contracting musculature should decrease force production and reduce intermittent-sprint performance. This suggests that, under conditions of considerable fatigue, failure to fully activate the contracting musculature may only make a small contribution to fatigue during the intermittent-sprint exercise.[24] A rhythm test performed by the subjects after fatigue does not demand that the subjects generate high muscle force, while the jumps, according to a 1-Hz rhythm, are about 1 cm high. It is suggested that the observed decline in performance after fatigue is due to the central nervous system deficiency rather than the muscle peripheral fatigue.

While our experiment concentrated only on the effect of fatigue on the rhythm of movement, not on its mechanism, we cannot clearly describe this phenomenon. Both of the previously mentioned mechanisms are involved in this process, but we do not exactly know which of them is responsible for the observed effect. The results of our experiment show that a disturbance of homeostasis expressed by the level of LA over 15 mmol affects the rhythm of movement in global multijoint tasks.

Conclusions

The results of our experiment show that the rhythm of movement may be negatively influenced by intensive anaerobic fatigue. It is difficult to transfer our findings straight into training or competition conditions, but training methods involving exercises inducing acidosis discomfort have been applied for many years. One of the aims of these methods is to prepare sportsmen to deal with this state of fatigue without losing pace or technique. We suppose that, in a sport discipline based on high-intensive anaerobic effort, where regular rhythm of movement is crucial for success, this kind of workout may positively impact the ability of sportsmen to adapt to different fatigue mechanisms and finally improve their results. In sport disciplines, where anaerobic fatigue during training and competitions is a common factor, our findings may be useful for the training and planning process.

Practical Applications

In our opinion, the most important conclusions based on the results, but also on the research of different authors, are 2 factors: motor learning and applying different movement scheme strategies. Task-oriented and motivated runners were able to repeat the rhythm test after fatigue. In training conditions, this may be important information, especially in sport disciplines where regular rhythm may determine success. Cyclic movements like running, cycling, swimming, or rowing are rhythm dependent. Among them there are events where success is connected with high-intensive anaerobic performance, usually short "all-out" efforts. Based on the results of our experiment, we believe that a training workout in these groups of sport events should consider postfatigue cyclic technical exercises not only to develop and improve the energetics of movement, but also to learn and perfect different movement patterns. The pattern is still consistent with technical demands, but because of growing and overlapping fatigue, it probably engages different muscle groups or different sequences of muscle stimulations.

Study Limitations

The simple field test and uncomplicated LA measurement equipment were used with purpose. Our aim was to stay close to the training practice and tools used by coaches, but this method may be less accurate compared with a laboratory test. The loss of accuracy due to a chosen methodology and, consequently, the limited ability to precisely describe the fatigue mechanism affecting the rhythm of movement in our experiment are the main limitations. Also, the methods used in this study did not let us gain enough data about movement coordination; thus, our findings are based on the previous research of different authors. The application of our conclusions concerns sport events determined by high-intensive anaerobic efforts, where the levels of LA after fatigue are approximately 15 mmol/L. Last but not least, we are aware that the results of our experiment are based on young, untrained subjects, whose physiological reactions to applied fatigue may be different from those of experienced subjects and may apply to a limited number of sport disciplines. In our opinion, this problem needs further research that would address an advanced sportsmen group and different equipment.

Future Studies

The limitations listed above clearly indicate the direction of future studies. In our opinion, the rhythm test we used in this experiment needs to be improved upon or replaced by a method that will enable researchers to examine the rhythm of movement in a more diverse way. We also suggest that methods providing information about the fatigue mechanism should be used to get as much information as possible.

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