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The influence of different intensity treadmill efforts on the sense of rhythm of non-professional runners – pilot study

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Purpose: The purpose of this study was to determine how global effort affects the rhythm of multi-joint coordination in the global task. We wanted to examine how this specific kind of fatigue impacts sense of rhythm. *Methods*: In this study, fourteen non-professsional runners performed two effort trials of different intensity, where speed was set individually according to the speed of running when participants reached lactate threshold. Before and after each effort trial they had to perform the rhythm test. *Results*: Two-way analysis of variance ANOVA did not reveal significant differences among the variables of pre- and post-effort rhythm test. It is suggested that these results are supported by the application of different movement strategies to compensate for fatigue, and possible motor learning effect of simple timing performance. *Conclusions*: In our opinion the training workout routine should include cyclic technical exercises after fatigue. Not only to develop and improve energetics of movement, but also to learn and perfect different movement patterns and develop novel movement strategies.

Key words: *fatigue, rhythm, cyclic movements*

1. Introduction

A sense of rhythm is critical for repetitive movement tasks. Precise timing activates the optimal automatic motor pattern needed for successful motor tasks [20], which is crucial for daily motor activities and sports performance. Many sports disciplines, such as dancing, ballet and gymnastics, depend strongly on one's sense of rhythm [7]. Performance in competitive hurdles, sprints, basketball, tennis and swimming is also affected by this phenomenon [26].

Earlier research concerning the rhythm of movement focused mainly on finger tapping tasks and the amount of muscles and joints engaged in movement [10]. Most of the research dealing with this issue concerns locomotion [18] and jumping performance [23]. The full understanding of the complex multi-joint coordination involved in the sense of rhythm is still in progress. For this study, we have accepted the definition of the sense of rhythm proposed by Fraisse [11], who defined it as an "order of the movement". Fraisse also recognized rhythm perception, which, in his understanding, was the motor skill responsible for producing movements. These movements are usually made according to exact timing and give temporal references in the motor system. It is of extreme importance that during prolonged effort, such as during sports competition, this motor system sustains a high level of timing accuracy. Our study analyzed how fatigue might influence a human's sense of rhythm.

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Although the literature regarding the influence of fatigue on human performance is substantial, only a few studies have described the impact of neuromuscular fatigue on the sense of rhythm. Gutin [15] studied psychomotor performance after physical effort. He suggested that various levels of activity impact mental and psychomotor tasks differently. Low activation after light exercise (HR 90–120 bpm) can positively affect psychomotor and mental performance, while higher activation triggered by over 15 minutes of physical activity followed by a heart rate higher than 160 bpm may cause decreased performance in tasks that demand high-level information processing. These results were not confirmed by Hogervorst et al. [16]. In their research, those who engaged in an extensive physical activity at a heart rate between 160 and 180 bpm did not perform worse on psychomotor and cognitive tasks. Gates & Dingwell [13] studied the effects of neuromuscular fatigue on task performance during repetitive goal-directed movements. They observed no significant differences in test performance before and after fatigue. The authors suggested that subjects altered their biomechanical movement patterns in response to muscle fatigue, and this allowed preservation of the timing features of task performance. Several other reports concerning repetitive upper extremity tasks had similar results [5]. Research by Lorist et al. [19] and van Duninen et al. [8] reported the influence of muscle fatigue on psychomotor performance, which is often estimated by changes in reaction time. One can see that these results are dissimilar. The differential impact of fatigue on the neuromuscular system usually depends on the task and the fatigue protocol.

In our opinion, common neural pathways may be equally influenced by fatigue. Therefore, we postulate that muscle fatigue can disturb the sense of rhythm and motor performance. Although many researchers used exercise models of fatigue (e.g., cycling, running and voluntary contractions of muscles) and different approaches for quantification, the question about the mechanism of fatigue and its influence on proper movement timing remains unanswered [22]. We want to emphasize the importance of timing performance and rhythm in sports exercise, as it influences training process and competition. Rhythm is one of the strongest factors that determines the construction of the training process and competition results. The problem of muscle fatigue, including its physiological and neuromuscular mechanisms, indicators, and effects, has been examined for years by many authors [22]. Depending on the mechanism of fatigue – from accumulation of metabolites in muscles to inadequate motor command from the central nervous system – different definitions of fatigue are used, and it is difficult to characterize this phenomenon by one global mechanism [9]. For the purpose of this study, “fatigue” is defined as a “reversible, exercise-induced reduction in maximal power output (e.g., during cycle exercise) or speed (e.g., during running exercise), even though the task can be continued” [2]. Fatigue is a combination of both central and peripheral mechanisms [12] and can adversely affect the rhythm of the task performance, which is associated with the type of fatigue (local or global) or its mechanism. Whole body exercises engage many muscle groups and multiple joints, while local exercises usually involve one joint and several synergistic muscle groups, and fatigue in these two cases can be different. Intensive whole body exercises, such as running and cycling, impair the sensory, proprioceptive, and exteroceptive information and decrease muscular system efficiency [22]. It has been shown that this type of exercise (and the fatigue induced by it) alters proprioceptive, visual, vestibular and plantar cutaneous inputs [22].

The purpose of this study was to determine how a global, effort-based trial with various intensities affects the rhythm of multi-joint coordination in the global task. We consider this to be a novel approach to this problem, as it is similar to both everyday activities and sports activities. We hypothesize that higher intensity exercises, which induce high fatigue changes, significantly deteriorate the ability of whole body timing performance, while lower intensity exercises will not affect the sense of rhythm and will instead be facilitating factors to timing performance.

2. Methods

Subjects

Fourteen male physical education students (age 25.4 ± 7.5 yr., body mass 73.7 ± 7.7 kg, height 178.5 ± 5.61 cm) took part in the experiment. All of them were recreational runners. The participants were healthy and reported no neural or musculoskeletal disorders. Informed consent was provided by all participants who voluntarily took part in the study. The study was approved by the Institutional Review Board (5/2012).

Procedures

Before the measurements, the participants were instructed regarding how to perform the coordination and treadmill tests. All tests were conducted in one laboratory under similar conditions of temperature (21,7 °C) and humidity (64,0%). The rest period between the fatigue sessions was 7 days. The lactate threshold and maximal oxygen uptake of each participant was estimated according to the procedure described below, one week before the first effort test. The tests were carried out on a treadmill (HP Cosmos) using a progressive load protocol. The starting load was 6 km/h, and it was increased every 3 minutes by 2 km/h until exhaustion and volitional refusal to continue the run. The following physiological variables were measured during the treadmill run: heart rate (HR), minute ventilation (VE), oxygen uptake (VO_2) and expired carbon dioxide (CO_2) (MetaLyzer 3B-2R, Cortex). Capillary blood samples were taken to determine lactate concentration at the beginning of the test and at each time the load was changed. To estimate VO_{2max}, we used software calculations and the RER = 1.10 method. For estimating the lactate threshold, the D-Max method was used.

The next phase of the experiment comprised two different effort trials and coordination tests before and after fatigue. The intensity of each effort trial was adjusted to the individually estimated speed of running when participants reached the lactate threshold and were 10% under the lactate threshold speed (uLT speed) and 10% over the lactate threshold speed (oLT speed). For example, if the estimated speed of running when participants reached the lactate threshold was 14 km/h, the effort trials' speeds were 12,6 km/h (uLT speed) and 15,4 km/h (oLT speed). After a 6-min warm-up at a speed of 4 km/h lower than that used during the test, each participant was asked to run 2 km at the chosen speed depending on the experimental phase. Capillary blood samples were taken at the beginning of the test, after warm-up and after the effort trial to estimate blood gas parameters ($PaCO_2$, PaO_2, HCO_3, pH) and lactate concentration (LA). Only values of LA are presented in this research.

The rhythm test was performed twice during each effort trial session: before the treadmill test and then just after the fatigue procedure. The familiarization with the procedure took place 5–7 days before first effort. Participants were asked to stand in the selected area between the bars of the Optojump Next, measurement system (Microgate, Italy) with their arms behind their backs. Participants were instructed to jump at the rhythm given by a metronome. The metronome signal was set at 1 Hz. The rhythm test comprised 45 continuous jumps. The first 5 jumps at the beginning of the test familiarized participants with the task and were not included in the analysis. The next 40 jumps were divided into two phases, 20 jumps each. During the first phase, the subjects were able to hear the metronome signal – the "assisted phase" (AP). The next phase of 20 jumps were done without the metronome signal – the "unassisted phase" (UP). Participants were asked to remember the pace of the metronome during the first 25 jumps and continue jumping at that pace without stopping. The reliability of the rhythm test used herein has been established in previous research [27]. The following data were analyzed: mean frequency of jumps for the assisted and unassisted phase (Xf AP and Xf UP), standard deviation of jump frequency for the assisted and unassisted phase (SDf AP and SDf UP), mean absolute error for the assisted and unassisted phases of the test (XER AP and XER UP, respectively), which was calculated as 1 minus the observed frequency, and standard deviation of the absolute error for the assisted and unassisted phases of the test (SDER AP and SDER UP, respectively).

Statistical analyses

The data were further processed using standard methods of descriptive statistics (Table 1). A two-way analysis of variance (ANOVA) including the factors effort intensity (two levels: lower and higher level of intensity) and time (two levels: pre and post effort) was used. In the case of LA level analysis, an ANOVA for repeated measures was used with 3 levels of intersession factors and 2 levels of effort factors. For the post-hoc comparisons, a Tukey's HSD post hoc test was used. All statistical calculations were performed using Statistical 12 software (StatSoft, USA).

3. Results

There was a statistically significant main effect of effort for the blood lactate (LA) values as determined by ANOVA F (1.26) = 89.4, $p < 0.001$, and there was a significant effect of intersession for both efforts F (2.52) = 162.3, $p < 0.001$. Post-hoc comparisons using the Tukey's HSD test indicated that the mean values of LA after both effort trials were significantly different from the tests before effort trials. Additionally, the mean values of LA after the different effort trials were significantly different from each other (Fig. 1).

Statistical analyses of these indices confirm that the intensity of each effort trial was different from the other, and its impact on subjects from the physiological point of view was also different. The intensity of each trial expressed as the percentage of values of $\mathrm{VO}_{2\max}$ and HR measured during the first diagnostic test was: 74% $\mathrm{VO}_{2\max}$ and 81% $HR_{\max}$ for the uLT trial and 87.7% $\mathrm{VO}_{2\max}$ and 86.7% $HR_{\max}$ for the oLT trial.

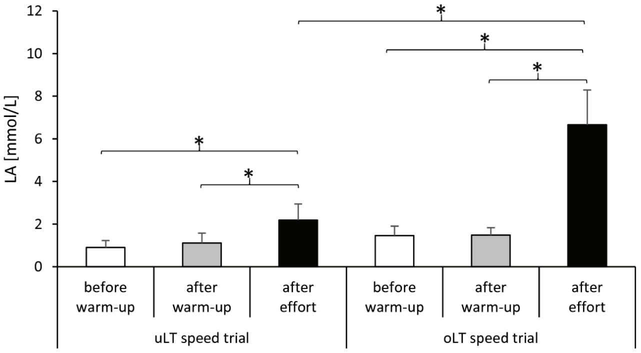

Fig. 1. Comparison of LA between different speed endurance trials

A two-way ANOVA was conducted to determine the influence of the two independent variables (effort, time) on the selected rhythm test variables. Effort included two levels (10% under the lactate threshold, 10% over the lactate threshold) and time (before effort, after effort). We did not observe any influence of different endurance protocols on rhythm test indices. All effects were not statistically significant (Tables 1 and 2).

4. Discussion

We examined how aerobic fatigue due to different intensities during a treadmill exercise influences whole body timing performance. The values of physiological fatigue markers showed that the fatigue protocol induced significant changes in the system

Table 1. Results of descriptive statistics for both effort trials

	–10% uLT speed				+10% oLT speed			
	Before fatigue		After fatigue		Before fatigue		After fatigue	
	M	SD	M	SD	M	SD	M	SD
X f AP [Hz]	0.999	0.032	1.004	0.013	1.008	0.020	0.998	0.015
X f UP [Hz]	0.987	0.029	0.992	0.023	0.986	0.026	0.987	0.022
SD f AP [Hz]	0.049	0.059	0.031	0.014	0.050	0.059	0.033	0.015
SD f UP [Hz]	0.030	0.011	0.041	0.031	0.035	0.027	0.035	0.026
XER AP [Hz]	0.036	0.027	0.024	0.010	0.031	0.022	0.027	0.016
XER UP [Hz]	0.033	0.016	0.032	0.016	0.035	0.027	0.032	0.011
SD ER AP [Hz]	0.038	0.059	0.021	0.013	0.038	0.058	0.020	0.013
SD ER UP [Hz]	0.023	0.009	0.028	0.025	0.032	0.015	0.028	0.027

Legend: X f AP – mean frequency of jumps for the assisted phase, X f UP – mean frequency of jumps for the unassisted phase, SD f AP – standard deviation of jumps frequency for the assisted phase, SD f UP – standard deviation of jumps frequency for the unassisted phase, XER AP – mean absolute error for the assisted phase, XER UP – mean absolute error for the unassisted phase, SD ER AP – standard deviation of absolute error for the assisted phase, SD ER UP – standard deviation of absolute error for the unassisted phase.

Table 2. Results of two-way analysis of variance

	df	*F*			*p*		
		effort	time	interaction	effort	time	interaction
X f AP [Hz]	1.52	0.05	0.23	1.53	0.832	0.633	0.222
X f UP [Hz]		0.17	0.18	0.03	0.682	0.669	0.854
SD f AP [Hz]		0.01	2.35	0.004	0.918	0.131	0.953
SD f UP [Hz]		0.03	0.68	0.70	0.873	0.414	0.407
XER AP[Hz]		0.02	2.14	0.47	0.889	0.149	0.497
XER UP [Hz]		0.04	0.00	0.04	0.846	0.946	0.837
SD ER AP [Hz]		0.0001	2.39	0.0004	0.990	0.128	0.985
SD ER UP [Hz]		0.10	0.13	0.20	0.753	0.719	0.659

and was consistent with the previously published methodology [14].

The results did not support our hypothesis, wherein we assumed that the higher running intensity, with a speed 10% over the estimated lactate threshold speed, would affect the sense of rhythm. Analysis of the results showed that after the highest intensity run, the absolute error and frequency during the unassisted phase of the rhythm test did not change significantly. After the run at the oLT speed, the runners were exhausted, and they finished the 2-kilometer distance test with difficulty. Other experiments [14], [24], wherein high level endurance sportsman underwent training workouts that caused LA values of approximately 6 mmol, led us to think that the same stimuli in amateurs would be enough to cause extensive fatigue effects. Nonetheless, after the short rest needed to prepare for the rhythm test the subjects could perform the test as during the pre-fatigue session. Although the intensity of anaerobic work during this experiment (expressed by the blood lactate concentration) might be demanding, even for professional runners, it was too low to disturb muscle homeostasis or the CNS, as demonstrated by the rhythm test. Still, the mean values of LA after the oLT trial were approximately 6.34 mmol/L, which was not high, compared to the values induced by difficult interval workouts [21] or during incremental tests. The results of pre- and post-fatigue rhythm tests might have been significantly different after fatigue induced by interval training where the LA level was above 15 mmol/L.

In a study by Waśkiewicz [25] wherein subjects performed three 30-second Wingate tests and had to perform a tapping rhythm test after each Wingate test, statistically significant differences were reported after the last anaerobic fatigue trial, when the blood lactate concentration was above 15 mmol/L. This level of fatigue probably causes changes in the motor apparatus such that most global movements might be disturbed, including rhythm abilities. Similar results were also reported by Isaacks and Pohlman [17], who observed that heavy load (cycling at 100% of the VO_{2max}) had a negative impact on skilled timing performance. This led us to conclude that even after fatigue, as long as muscle functions are not disturbed by critical homeostatic dysfunction, subjects can perform rhythmic global movements. Different biomechanical strategies provide compensatory mechanisms as a counterbalance to the loss of the muscle force caused by fatigue [2], [4]. Well-motivated and concentrating subjects can do the test using different movement strategies that lead to the same effects. Observations made in experiments on selected muscle groups in non-global movements [1], [6] may be well-applied in our experiment. Gates and Dingwel [13] observed different biomechanical movement patterns in response to fatigue during their experiment regarding repetitive goal-directed movements. In our opinion, the global task used in our study offered more possibilities for different biomechanical compensations in order to achieve the desired goal. Different strategies to compensate for accumulated fatigue and sustaining power output during hopping tasks were also reported by Bonnard et al. [3]. In their study, the compensatory mechanism involved reorganization of muscle activation due to fatigue. One strategy consisted of tradeoffs between the muscles at the ankle level, while the other strategy consisted of tradeoffs between muscles working at the level of different joints. A compensatory mechanism at various levels of the neuromuscular system may act to delay the effects of fatigue and to sustain the accuracy of the motor activity [9].

Although we used standard and reliable procedures of rhythm testing, the reason we did not achieve significant changes after fatigue may be due to the construction of the rhythm test, which might have been too easy. Experiments where the rhythm test was based on different rhythmic patterns have shown that regular rhythm patterns are easier to reproduce than synoptic patterns. The intention behind our rhythm test design was to construct a test that was easy to understand and execute. Interpreting the results was straightforward, and the test was suitable for many different populations. Additionally, most of the cyclic sports, e.g., running, cycling or swimming, are organized by a homogenous, repeatable rhythm of movement known as a pace, as are most of the testing procedures for this ability. Depending on the conditions (e.g., distance, mastery level, experience), the pace may be faster or slower. The pace can also change during the performance, but it is always homogeneous. This was an important factor for the construction of the rhythm test.

The last issue that may play an important role in this study is motor learning. Construction of the test included an assisted phase, which lasted 20 seconds and gave the subjects time to "learn the rhythm" and rest a little after fatigue. Even randomization of trials gives the subjects enough time to learn and prepare in a way to do the desired task rhythmically and accurately. Similar observations were made by other authors [13], and their conclusions about the influence of this factor on the results of their study were similar to our conclusions. Importantly, we know that this process is not significantly influenced by fatigue.

5. Conclusions

The most important conclusions, based on the results and on research by different authors, include conclusions about motor learning and how to apply different movement scheme strategies. Task-oriented and motivated runners could repeat the rhythm test after fatigue. This may be important under training conditions, especially in disciplines where regular rhythm may determine success. The cyclic movements seen in running, cycling, swimming or rowing are rhythm-dependent. Based on the results of our experiment, we believe that a training workout should take into account post-fatigue 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 overlapping fatigue, athletes probably engage different muscle groups or different sequences of muscle stimulations.

The present study has some limitations that should be taken into account. First, the small number of participants reduces the application of some statistical analyses and the power of the conducted analysis. Second, the rhythm test may have been too easy and not sufficiently sensitive. Additionally, the "ceiling effect" connected with the intensity of the effort should be taken into account.

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