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PHYSIOLOGICAL RESPONSE TO NON-TRADITIONAL HIGH-INTENSITY INTERVAL TRAINING

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Summary: High intensity interval training (HIIT) is an exercise program not only for professional athletes, but also for the general population. Usually, one-dimensional modalities such as running or a cycling simulator are used. There also exist protocols that use the HIIT principles but apply full-body exercises (HWT). The purpose of the study was to verify the response to unconventional loads based on HIIT and HWT protocols using the near infrared spectroscopy (NIRS) and spiroergometry: wall ball (WB); SKI ergometer, toes to bar (TTB) and assault air bike (AB) in a selected proband. Working interval was 60 s resp. 30 s, the rest between sites was progressively reduced from 60 s to 30 s. The proband completed a total of 3 laps. The results showed that the load applied had been similar to that of HWT or HIIT, where the effect on cardiorespiratory and metabolic functions was confirmed. Acute changes in the observed parameters of SmO2 in *m. vastus lateralis* indicate a possible effect on the development of strength capabilities. It has also been confirmed that the application of variable types of load can be applied simultaneously with the adjustment of rest time and thus using conditions that can reflect current options (material, environment, time) and specific goals. The measured values of muscle tissue oxidation, carbon dioxide output, heart rate confirm that a similar type of load can be a suitable means of affecting cardiovascular and metabolic functions.

Key words: high intensity interval training; whole-body training; near infrared spectroscopy; spiroergometry

Introduction

High intensity interval training (HIIT) is a training program that is characterized by a relatively low workload and high intensity (Batacan et al. 2016). It is an intermittent method where a large short load alternates with passive rest or a very light load (20 – 40 % VO2 max) (Norton & Sadgrove 2010). The intensity is determined by various parameters such as RPE, V02max, heart rate. The common denominator is the movement of the athlete in submaximal to maximum values (ACSM 2009).

HIIT differs from classic interval training by load and rest length. The working interval is in the range of 6 s – 4 min, the rest period is 10 s – 5 min and the total time is 4 - 30 min (Sloth et al. 2013). Among the practitioners, the popular protocol is the so-called Tabata training, where 20 s work and 10 s rest alternate (Tabata 2019). The means for HIIT are usually one-dimensional modalities such as running, cycling, rowing. They are not combined with each other nor are they varied (Batacan et al. 2016). HIIT has proven to be a suitable and safe means of developing cardio-metabolic health in patients as well as in diabetic patients (Cassidy et al. 2017). Compared to continuous medium intensity training, HIIT appears to be a more appropriate means of weight reduction and has a positive effect on fat reduction (Keating et al. 2017). HIIT seems to be a very good and effective exercise tool that has the potential to comprehensively influence physiological, anatomical, and performance parameters at optimal settings.

In practice, in addition to the above mentioned HIIT, similar forms are used, which need to be terminologically defined. For example, Circular Training (CT). Exercise usually includes 6 – 12 low resistance exercises (40 – 60 % 1 RM) with higher repeats (12 – 20). Rest between series is often set at 1: 1 to load time, i.e. 30 – 60 s (Muños-Martínéz et al. 2017). Machado et al. (2017) uses the High-intensity interval training using whole body exercise (HWT). The concept is very similar to the classic HIIT, but the means are complex exercises (burpee, Jumping jack, or jump squat), which are performed at maximum effort for 30 s with equally long rest and a total duration of 20 – 30 minutes (Machado et al. 2018). However, there may be a different timing (Ho et al., 2012). The development of aerobic and strength skills by HWT is also demonstrated by Myers et al. (2015), where it was compared with CT. The HWT application has the advantage over HIIT in the complex connection of the upper body and the application of power exercises. This benefit is demonstrated by the development of strength endurance with simultaneous action on cardiovascular fitness or maintenance of training levels (Gist et al. 2015; McRae et al. 2012; Schaun et al. 2018). These studies involved the use of exercises with their own body that were not combined with other endurance or power modalities (exercises with external load or exercise on machines). For similar combinations, Feito et al. (2018) uses the term High-intensity functional training (HIFT). It should be an umbrella term for different combinations of exercises, load/ rest size and total exercise time. He places here all CrossFit exercises; this is not an intermittent load, but a variable continuous high-intensity training (Murawska-Cialowicz et al. 2015).

Near infrared spectroscopy (NIRS) is a non-invasive imaging technique that monitors the oxidation and hemodynamics in the muscle using infrared radiation. It has been used for sports sciences since the 1990. Since then, it has been applied to groups of runners, cyclists, rugby players, or swimmers, as well as various muscle groups. NIRS was used at different loads including HIIT. Brocherie et al. (2015) followed the oxygen saturation of the lower limb in the 6 x 35 m sprint with 10 s active rest. The load caused a rapid decrease in the level of oxidation, especially in *m. vastus lateralis*. During this period, the ability to re-oxidize, influence on repeated performance and saturation index progression has also been shown. The interval protocol (10 s work, 20 s rest) on the Ski Erg (SKI) double poling ergometer was applied by Frais et al. (2015) to cross-country skiers. Testing was performed under simulated hypoxic conditions in the experimental group and showed differences in total hemoglobin (THb). Short interval load similar to HIIT is also used as a test criterion in combination with NIRS (Jones et al. 2015). We are not aware of any study that would monitor NIRS in combined load endurance activities, exercises with one’s own body, or external-load exercises.

The research used Moxy oxygen monitor, which measures, among other things, local oxygen saturation (Sm02) and total hemoglobin (THb), whose value corresponds to the current blood flow through the muscle. Proven to be a valid and reliable tool (Crum 2017). Spiroergometry (SP) is used for the qualitative and quantitative assessment of acute cardiovascular, pulmonary, and metabolic load responses. It brings important information from the point of view of diagnostics and forecasting for various scientific fields. Significant monitored variables are carbon dioxide production, minute ventilation, oxygen consumption and heart rate. The most important parameter in SP is the maximum oxygen demand (VO2max). It defines the capacity of the cardiopulmonary system and provides an objective estimate of physical fitness. Minute ventilation (VE) consists of respiratory rate and tidal volume (Vt). In addition, the ventilation threshold and the "respiratory compensation point" can be determined as submaximal fitness parameters. The principle of SP examination is to analyze the composition of inhaled and exhaled air and serves to determine the functional response of the organism to the load. The quality and optimal respiratory rate that may represent performance limitations is also important for diagnosis (Jernej 2013). SP is used to detect an acute response to exercise and is also a very good control tool for monitoring the body's adaptation to recurrent workload (Guio de Prada et al. 2019).

Research has not been focused on combining cyclic endurance activities yet, exercises with one’s own body, and external workloads within HIIT or HWT (Gibala & Jones 2013). The question is what kind of physiological response this kind of burden has and how it can help in the development of health or selected motoric skills.

Methods

Participant

The present study is in the form of a case study: the proband was a 35-year-old athlete, 179 cm, 85 kg with experience in HIIT, HWT and given exercises. He was an athlete with very good level of fitness (CrossFit competitor). Two tested Moxy sensors (*m. vastus lateralis and m. deltoideus*), a heart rate sensor (HR) and a Cortex MetaMax 3BR2 portable spiroergometry system were placed on the body. The Borg scale (1 – 20) was used to determine subjectively perceived intensity. The following parameters were monitored:

1. Breathing - MV (minute ventilation - L/min)
2. Cardiovascular system - HR, VO2 / HR (pulse oxygen)
3. Metabolism - guideline value of aerobic/anerobic metabolism rate by Respiratory Equivalent Ratio (RER = VCO2 / VO2); carbon dioxide dispensing (VCO2)
4. Muscle tissue - SmO2, THb.

In connection with the description of the development of quantities, it should be noted that the monitored person knew in advance the protocol and counted on the total time and nature of the load. Therefore, the measurement is influenced by a certain tactic whereby the proband tried to complete the whole protocol at high / maximum intensity, but did not try to "all out" (instantaneous maximum performance regardless of later progress) from the beginning. The purpose was to approach the conditions during the real training process.

Procedure

The load protocol contained 4 sites, the working interval was 30 s – 90 s, the rest between the sites progressively reduced from 60 s to 30 s. He completed a total of 3 rounds, including a 60 s pause (Fig. 1). Four exercises were selected:

1. wall ball (WB) (squat with medicine ball 9kg and throw on the wall)
2. SKI (double poling ergometer)

3. toes to bar (TTB)
4. assault air bike (AB).

The aim of the test was to select exercises that affect the upper and lower half of the body under uneven conditions with changing rest periods; two exercises represent endurance cycling movements, one exercise with one's own body, one complex exercise for the whole body with a light load. The medicine ball throw is a slight 1 RM load. Therefore, it does not meet the requirements for a typical CT and can be used in a similar way as the HSW exercises. Exercises and their order were chosen so that they burden the organism differently, even from the point of view of the involved muscle groups. For the WB and TTB exercises the requirement was not to interrupt the movement during the full interval, for SKI and AB to maintain a high speed that would not decrease significantly.

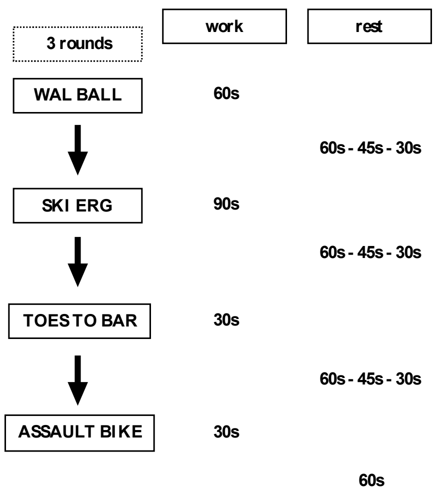


Figure 1

Test flow chart with time intervals of work and rest

Data processing

Moxy monitor (Moxy, Fortiori Design, LCC, Minnesota, USA) uses 630 – 850 nm wavelength, records the amount of returned scattered light at two detectors positioned 12,5 and 25 mm form the light source. The NIRS data transfer was computerized via Bluetooth. Subsequently, all data was evaluated using Moxy5 software. Spiroergometry was performed using the Cortex MetaMax-3B telemetry system, which is used for field testing and also exports selected parameters to graphs

Results

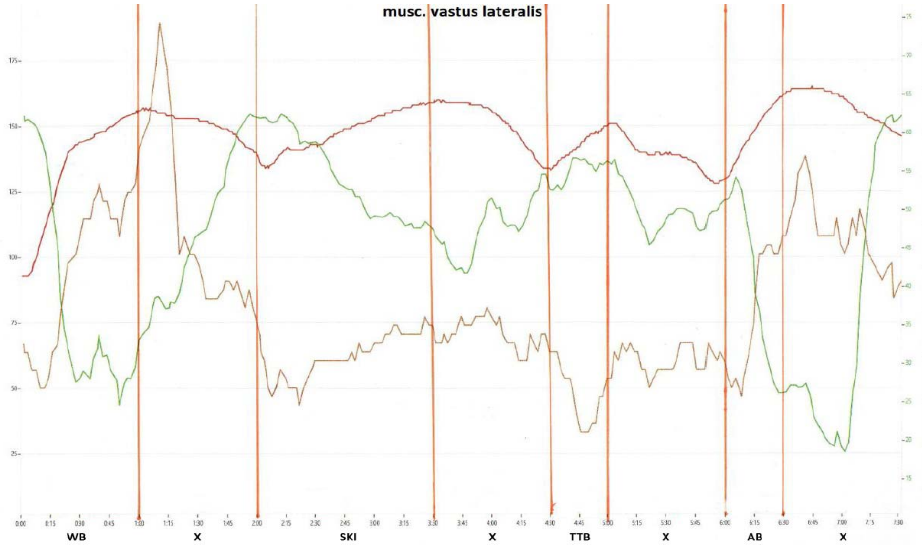
Fig. 2 and Fig. 3 show a record of two Moxy sensors, which monitored the physiological response to the load in the form of muscle oxygenation. Due to similar values, the record of the first round was chosen for the explanation.

In *m. deltoideus*, it is apparent that the first exercise (WB) was subject to large THb fluctuations. This was due to the nature of the exercise that disrupted the reading of the given values in all rounds. In other exercises, the response was no problem despite the swings in the TTB or SKI. Even so, thanks to SmO2 and the subsequent development of the THb curve, the active (power) wiring of the m. deltoideus can be observed.

It is evident that the flow rate in the monitored muscles decreases at working intervals. With *m. deltoideus*, we find more fluctuations, but also faster resaturation. WB dropped to 25 %, returning above 70 % during the rest. For instance, at TTB, when the muscle is isometrically working, shows a very low percentage of SmO2 (10 %), but in subsequent rest, it returns rapidly to its original values.

Moxy record values clearly show different effects of individual exercises on both Sm02 and THb. Both TTB and SKI involve mainly the upper half of the body, which has been demonstrated in the course of *m. vastus lateralis* curves. Since the proband was an athlete with good fitness abilities, there is a rapid return to baseline. Despite this, there was a high breath and RPE increase, which was subjectively perceived at 18 – 19 (20 was maximum). The aforementioned return was also not identical for all exercises. A marked difference was observed after riding an AB, especially after the end of the interval due to the delayed response of the organism.

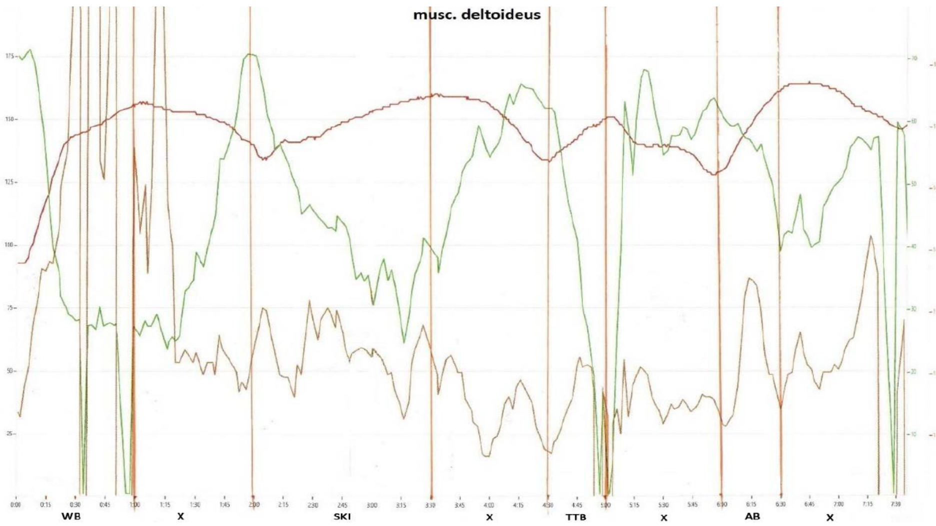
The highest NIRS load was for WB and AB, which are dominant in the involvement of lower limb muscles and at the same time require considerable work on arm and torso muscles. For these exercises, there is a noticeable power load related to the Sm02 fluctuation, including subsequent development after the end of the interval. The dynamics of muscle resaturation changed over time and showed a logically worse trend. Due to the fact that the athlete was working at a high intensity from the beginning, he exhausted the gradually related compensation mechanisms (respiratory, muscular, circulatory), which affected work in the next rounds and increased the perceived RPE. This is also confirmed by the heart rate, which was higher than the first interval.



Notes: red - heart rate [beats/min], green - smO2 [%], brown THb[g/dl], WB- wall ball, X – rest, SKI- Ski Erg, TTB – toes to bar, AB – assault bike

Figure 2

Moxy record of load progress (m. vastus lateralis)



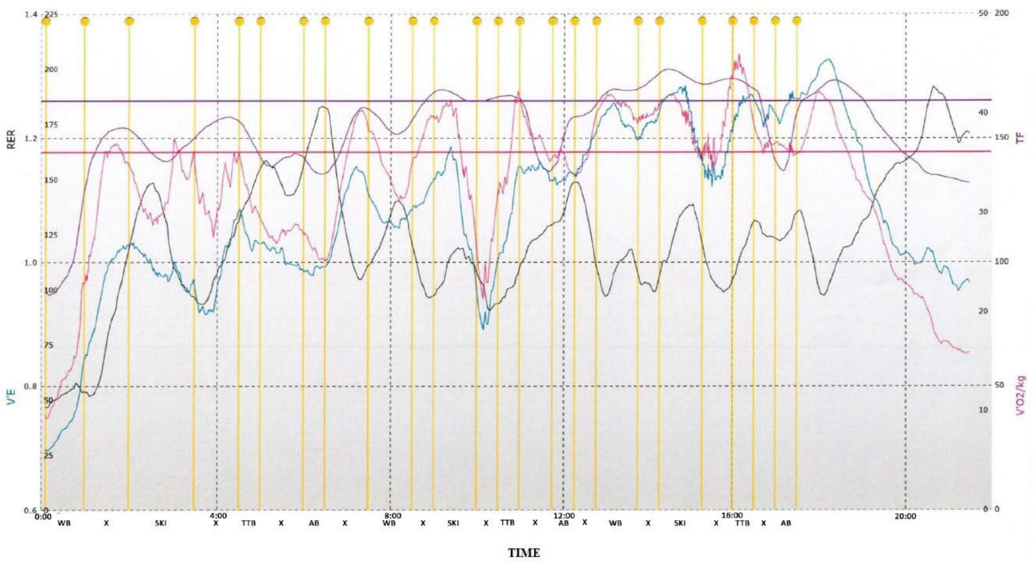
Notes: red - heart rate [beats/min], green - smO2 [%], brown THb[g/dl], WB- wall ball, X – rest, SKI- Ski Erg, TTB – toes to bar, AB – assault bike

Figure 3

Moxy record of load progress (m. deltoideus)

The following Fig. 4 shows the course of the individual respiratory parameters and HR. Again, different responses to specific exercises can be seen. When comparing SKI and AB as representatives of cyclic endurance activities, it is evident that there is a significantly different response of the organism. V'E value decreased during and after SKI (by 30 – 50 L/min), on the contrary it increased after AB (by 10 – 30 L/min). The SKI in this case was a exercise that did not increase the overall load intensity. Even though SKI was the simplest exercise in terms of load, it did not affect the overall intensity (influence on the course of the heart rate curve, V'E).

The reaction with the TTB exercise, during which V'E decreased, is interesting. TTB is not a typical static exercise (athlete performs kipping, at the same time raises his legs up, which is by nature closer to the isotonic load). This is probably due to the nature of the exercise, where the breath pattern changes when hanging and simultaneously compressing the torso, which affects the depth and quality of breathing. AB showed the potential to be very heavily loaded during the interval training. Especially after the last interval when the participant was motivated for high performance. Here, the highest values of V'E and RER were achieved. Due to the expected delay in the recording of respiratory parameters, monitoring was continued for several minutes after the end of the protocol.



Notes: V'O2 - oxygen consumption [L/min.kg], RER - Respiratory Equivalent Ratio, V'E - minute ventilation [L/min], TF - heart rate [beats/min]

Figure 4
Recording of respiratory parameters

Discussion

During the testing, there was a different load, which was reflected in the Sm02 or VCO2 values. The deflections of these variables correspond to HIIT and indicate intense muscular work associated with high effort (Brocherie et al. 2015). Muscle oxidation (mainly *m. vastus lateralis*) was then directly related to the respiratory functions, which reflected the work of large muscle groups. Large changes in oxygen saturation were evident mainly after the wall ball and assault bike sites. As these were not all-out intervals and as it was also a short overall load time, such reactions as in Jones et al. (2015) cannot be stated. Different fluctuations as well as the rate of return to resting values in the monitored muscles were more evident in *m. deltoideus* due to the muscle size and intermittent (in WB) and lighter isometric (at TTB) loads.

On the basis of the records, it can be concluded that the total intensity (in the form of RPE, HR) was dependent on the involvement of the lower limbs. Although all exercises were compound, but for example, exercise on bar was connected with the strength endurance of the center of the body, which does not require oxygen saturation. Thus, the monitoring of *m. vastus lateralis* seems to be a suitable means of monitoring the overall intensity (Grassi & Quaresima 2016). Faiss et al. (2015) has shown that even with SKI, high metabolic values can be achieved. Similar conclusions have been reached in our case study (e.g. V'O2 value), although such a high load was not achieved. Cross-country skiing (double poling) is a comprehensive exercise that dominates the upper half of the body. The monitoring of *m. deltoideus* has not proven to be ideal for monitoring this type of load. In Faiss et al. (2015), a sensor was placed on the *m. triceps brachialis*, which better reflects this movement. To record the effects of various compound exercises, *m. deltoideus* seems to be a more appropriate means because it is a larger muscle group that is more involved in the whole body exercises. Monitoring of large muscle groups seems to be more suitable for overall load analysis (Re et al. 2018). In WB, deltoids are strongly involved in muscle work, similarly in AB, a pressure movement is performed. The measured values do not correlate with difficulty in terms of respiratory parameters (eg V'O2, V'E). Monitoring of lower limb load appears to be decisive.

In a set of the selected exercises, SKI was the least difficult exercise in the records, but this does not mean that it was not a suitable means for this type of load. In cycling simulators, the intensity measure can always be easily influenced, but in this measurement we did not intentionally do that. The aim was to maintain a high non-decreasing speed at all intervals. Both HIIT and HWT change spiroergometric parameters by varying the load and rest intervals. For exercises, the proband sets a certain respiratory rate, which changes based on the protocol. In this test, the depth of inhalation/exhalation and frequency varied based on the nature of the exercises. Each exercise naturally forces a certain pattern of breath, which is related to the power load, body position or frequency of movement (Jernej 2013).

Significant differences can be found, for example, in TTB, where there was a lower frequency of movements and at the same time light compression of the body, which also affects the quality of breathing. Even this fact contributes to the higher demands of the chosen protocol. HIIT is characterized by the rapid rise of HR and its subsequent ripple (Keating et al. 2017), which was confirmed in this case as well. Although the HR is not a fully reliable indicator (does not accurately reflect the level of the aerobic and anaerobic systems, does not take into account the lactate metabolism, etc.), it helps to evaluate the intensity and partly training effect. In addition to HRmax, an average HR of 151 is important factor of aerobic system development effect. The total protocol time was 18 min, which is shorter than in Machado et al. (2018), but, for example, Tabata (2019) or Engel et al. (2018) confirm the effectiveness of much shorter loads for improving endurance and anaerobic performance. Unlike other studies (Cassidy et al. 2017; Machado et al. 2017; McRae et al. 2012), the pause between the rounds has been progressively reduced to increase the demands of the protocol (due to procedure). This was confirmed, although it was not so distinctive in the upper body exercises (see Fig 4). The pause between the intervals/exercises and its nature is an important factor for the overall training effect and involvement of individual energy systems (Gibala & Jones 2013). Shortened rest was far from sufficient regeneration and an increase in RER was reported, suggesting an increased involvement of anaerobic metabolism.

Although the various parts of the body and the way of their load were involved, this led to the maintenance of the required intensity, resp. to increase in sense of HR, RPE etc. (RPE value was 18-19 at the end). As in the studies by Machado et al. (2018) and Schaun et al. (2018), variable interval training seems to be an effective means for significant physiological responses to the body (cardiorespiratory adaptation, lactate metabolism etc.). Given the originality and nature of testing, it is not clear whether it would be more effective in comparison with HWT or HIIT (Machado et al. 2017; Sabag et al. 2018), but the potential in developing endurance and aerobic fitness of such a protocol has been shown.

Conclusion

The acute physiological response to non-traditional HIIT was verified from the point of view of oxidation of the selected muscles and spiroergometric parameters. The results show that there is a similar load to HWT or HIIT, which affects cardiorespiratory and metabolic functions. Acute changes in the observed parameters (SmO_2 in *m. vastus lateralis*) also indicate a possible impact on the development of strength endurance. Furthermore, it has been confirmed that variable load types can be applied at the same time as rest time adjustments, thus using conditions that can reflect current options (material, environment, time) and specific goals in the form of fitness development. It is necessary to take into account the limitations of the field testing where there is a risk of worsening or distortion of records due to non-standard measurements. Based on the results, similar protocols can be recommended to develop fitness or as a part of specific sport training. This was a case study and therefore it is necessary to confirm the results on a larger sample and especially from the point of view of long-term adaptation, resp. influence on the development of selected performance parameters.

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