EFFECTS OF A 10-DAY HIGH-INTENSITY INTERVAL TRAINING MESOCYCLE ON PHYSICAL PERFORMANCE IN MALE JUDO ATHLETES

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ABSTRACT

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Introduction. Judo is an Olympic combat sport where the competition emphasizes several consecutive 20-30 seconds high-intensity efforts interspersed by short recovery periods. High-intensity block training has been found to be an efficient way to develop physical performance, wherein shorter training periods are focused on developing one or two chosen physical abilities. The purpose of this study was to investigate the effects of a 10-day high-intensity interval training period on the performance in male judo athletes.

Methods. The study included pre and post-tests as well as a 10-day training intervention. The subjects were 19-28 years old men who had competed at least at the Nordic level during the last year (n = 7). The training period included simulated judo matches (4x4 min or intermittent 20–120 s work periods, 85–90%/HR_{max}) as interval training. In addition, there were technique and tactical training sessions at lighter intensity (50–60% of maximum). Moreover, in strength exercises, maximum strength was maintained sustainably with 2–4 repetitions (90–95% 1 RM). The study included measurements of the neuromuscular system for countermovement jump (CMJ), squat jump (SJ) and power in bench press (BP) and squat, maximum isometric strength (BP and leg press), as well as measurements of maximal anaerobic and aerobic performance (30 s Wingate and incremental VO_2max running test). Furthermore, the control measurements were taken during the first and last HIIT session of the training period. The variables measured were the CMJ and the power output in the bench press.

Results. There were no statistically significant changes in the neuromuscular system. However, muscle power improved slightly in SJ (2.4%), squat (2.5%) and BP (3.1%) from pre to post. Maximum isometric strength levels remained almost the same. The change in leg press was -2.3% and in BP 1.0%. A significant correlation was found between relative maximum BP and its relative change (r = 0.761, p = 0.047). The relative mean power change in the anaerobic Wingate was -1.2%. Blood lactate 4 min after the Wingate decreased significantly (-11.8%, p = 0.03). Significant correlations were found between the relative and absolute VO_2max pre and their pre-post changes (r = -0.831, p = 0.02 and r = -0.775, p = 0.04). Acute responses showed no significant changes for CMJ (from -1.5% to 2.3%) nor for BP (from -4.4% to -0.9%) within a single HIIT session.

Conclusions. The 10-day short-term HIIT mesocycle implemented as simulated judo matches might not improve the physical performance characteristics in male judo athletes. At least more time for the recovery and tapering should be needed after the HIIT block before the competition.

Key words: block periodization, high-intensity interval training, HIIT, judo

TIIVISTELMÄ

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Johdanto. Judo on olympiakamppailulaji, jossa kilpailutilanteessa korostuu useat peräkkäiset korkeatehoiset 20–30 sekunnin työjaksot lyhyillä palautuksilla. Korkeaintensiteettinen blokkiharjoittelu on havaittu tehokkaaksi keinoksi parantaa fyysistä suorituskykyä. Ylikuormitusperiaatteella tapahtuvassa blokkiharjoittelussa keskitytään muutamien valittujen fyysisten ominaisuuksien parantamiseen. Tämän tutkimuksen tarkoituksena oli selvittää 10 päivän korkeatehoisen intervalliharjoittelujakson vaikutuksia miesjudokoiden suorituskykyyn.

Menetelmät. Tutkimus sisälsi alku- ja loppumittaukset sekä 10 vuorokauden harjoittelujakson. Tutkittavat olivat 19-28-vuotiaita miesjudokoita, jotka olivat kilpailleet viimeisen vuoden aikana vähintään pohjoismaisella tasolla (n=7). Harjoittelujakso sisälsi intervalliharjoituksia harjoitusotteluina (4x4 min tai pätkittyinä 20–120 s työjaksoina, tavoiteteho 85–90 % maksimista). Lisäksi suoritettiin erikseen tekniikka- ja taktiikkaharjoittelua kevyemmillä tehoilla (50–60 % oletetusta maksimista). Voimaharjoituksissa tehtiin ylläpitävästi maksimivoimaa 2–4 toistoilla (90–95 % 1 RM). Tutkimus sisälsi hermolihasjärjestelmän (kevennys- ja staattinen hyppy, penkkipunnerrus sekä jalkakyykky) ja maksimaalisen voimantuoton mittaukset (penkki- ja jalkaprässi) sekä nopeuskestävyyden ja kestävyyden mittaukset (30 s Wingate alavartalolle ja suora hapenottokyvyn testi juoksumatolla). Lisäksi kontrollimittaukset tehtiin harjoitusjakson ensimmäisessä ja viimeisessä intervalliharjoituksessa. Mitattavina muuttujina olivat kevennyshyppy ja penkkipunnerruksen voimantuottoteho.

Tulokset. Hermolihasjärjestelmän suorituskykymittauksissa ei havaittu tilastollisesti merkitseviä muutoksia. Voimantuottoteho parani hieman staattisessa hypyssä (2.4 %), kyykyssä (2.5 %) ja penkkipunnerruksessa (3.1 %). Isometrinen maksimivoimataso pysyi samana. Jalkaprässin muutoksen ollessa -2.3 % ja penkkiprässin 1.0 %. Suhteellisen isometrisen penkkiprässin ja sen suhteellisen muutoksen välillä havaittiin tilastollisesti merkitsevä korrelaatio ($r = 0.761$, $p = 0.047$). Anaerobisen Wingate-testin suhteellisen keskitehon muutos oli -1.2 %. Laktaattinäyte 4 minuuttia Wingaten jälkeen laski merkitsevästi (-11.8 %, $p = 0.03$). Tilastollisesti merkitsevät korrelaatiot havaittiin suhteellisen ja absoluuttisen VO_2max lähtötestin ja intervention aiheuttaman muutosprosentin välillä ($r = -0.831$, $p = 0.02$ and $r = -0.775$, $p = 0.04$). Yksittäisten HIIT-harjoituksien akuutit vasteet eivät olleet tilastollisesti merkitseviä kevennyshypyssä (muutokset -1.5 % ja 2.3 %) eikä penkkipunnerruksessa. (-4.4 % ja -0.9 %).

Johtopäätökset. 10 päivän korkeatehoinen intervalliharjoittelujakso toteutettuna tässä tutkimuksessa suoritetulla tavalla ei paranna miesjudokoiden fyysistä suorituskykyä. Näyttäisi siltä, että suorituskyvyn palautumiselle ja herkistelyllä on annettava riittävästi aikaa ennen kilpailemista.

Avainsanat: blokkiharjoittelu, HIIT, korkeatehoinen intervalliharjoittelu, judo

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ABBREVIATIONS

BP	Bench press
CMJ	Countermovement jump
HIIT	High-intensity interval training
HR	Heart rate
La	Blood lactate
SJ	Squat jump
VO_2max	Maximal oxygen uptake
1 RM	One repetition maximum

CONTENTS

1. INTRODUCTION

Judo is an Olympic combat sport which involves high-intensity efforts interspersed by short recovery periods. A full match consists from 10 to 15 blocks of these 20-30 s high-intensity bouts. It is common that an athlete has several matches in the same day. The physiological demands of a competitive judo match involve both anaerobic and aerobic metabolism (Franchini et al. 2011; Franchini et al. 2016).

The international Judo Federation established a world ranking list (WRL) in 2009. It categorizes athletes according to their results in a series of competitions. The spot on the WRL determines the qualification into the Olympics and the draw. Athletes focusing on the elite level normally participate in 5-10 competitions per year to earn points to qualify for the Olympics (Franchini & Takato 2014). To prepare for international competitions athletes must train technically, tactically and physically. Usually athletes train 12 times a week, twice a day. Because of high physiological demands, a lot of training and competitions and weight-loss procedures, it is difficult to optimize training periods between competitions (Franchini et al. 2011).

Previously there were only two main judo competitions in a year, the European Championships in spring and the World Championships in autumn. Nowadays one needs to be in a good shape throughout the year. The new competition system has changed the traditional approach to periodization. High training workloads are not anymore possible and, instead, those are replaced by higher intensity training (Franchini et al. 2016).

Higher intensity training is commonly called as high-intensity interval training (HIIT) which recruits fast twitch motor units for repeated short-to-long high-intensity bouts interspersed with brief passive or active recovery periods (Gibala & McGee 2008). HIIT can be defined as repeated sessions of short to long sets performed at the intensity that is greater than the anaerobic threshold (Laursen & Jenkins 2002).

Results have shown that the use of short mesocycles, blocks, with high loading of the high-intensity intervals leads to performance improvements of already well-trained athletes in different sports, like cycling, kayaking or skiing, (Breil et al. 2010; Garcia-Pallares et al. 2010; Rønnestad et al. 2014a; Rønnestad et al. 2014b; Rønnestad 2016; Wahl et al. 2014). This approach is called as block training which is built on the overload principle (Issurin 2010).

HIIT together with low intensity training has been shown to have positive effects on aerobic endurance (VO_2max) and power output at the lactate threshold (LT), e.g. Vasconcelos and co-authors (2020) did their study with combat sport athletes. Rønnestad et al. (2014a) pointed out that an improved LT in theory indicates that an athlete is able to keep a higher power output during a long-term endurance effort. The size of the improvements depends on the duration, intensity and frequency of training sessions in addition to the training status of the athlete. (Breil et al. 2010; Rønnestad et al. 2014a.) As the competition calendar for judo is tight, the training program and how to organize the central physical abilities to achieve an ideal training effect and performance, stays challenging. In addition, at the same time the performance level of the athlete rises, it seems to be required to increase the intensity of the aerobic training to gain more improvements in LT and maximal oxygen consumption (Rønnestad et al. 2014a).

There is limited data regarding how to add HIIT in daily training in short periods in intermittent sports where complex performance are required such as strength, power and endurance (Fernandez-Fernandez et al. 2015; Manchado et al. 2018; Rønnestad et al. 2019). Solli et al. (2019) showed in the long term of macro, meso and micro-periodization of HIIT blocks, how to grow HIIT volume but the study was carried out with a successful world-class skier.

There are only few studies relating to the block periodization in judo (Marques et al. 2017; Sikorski 2010) but those did not reveal how they accomplished the transmutation phase, and both studies missed a control group. Therefore, the purpose of this study is to analyze the block periodization, the effects and programming of different kinds of high-intensity interval training procedures and how these two elements can be suited to training and periodization in judo.

2. TRAINING PERIODIZATION

The theory of training was established around the 1960s when the knowledge of physical preparation was minor and objective research results were rare. In those days, traditional ‘training periodization’ was proposed and explained. The term was based on knowledge of elite sport in the ex-Soviet Union and physiological studies printed by USSR scientists at those times (Yakovlev 1955).

Earlier Gorinevsky (1927) had written textbooks about the division of the entire preparation process into separate periods of general and more specialized training phases. The general preparation included cardiorespiratory fitness, general coordination, and basic athletic abilities. Specialized preparation had a focus on sport-specific training. Though, the first serious summary was written by Matveyev (1964), who later was known as the creator of the traditional theory of training periodization. Since then, the training periodization seems to be an essential part of training theory.

2.1 Traditional model

The traditional periodization is based on the generalized concept of ‘load-recovery’ interaction in the view of supercompensation concept, general principles of periodized training, the hierarchy of periodized training cycles and proposed variations of the annual cycle (Issurin 2010). Yakovlev (1955) introduced the supercompensation cycle after a single workout. This phenomenon of supercompensation is based on the interaction between the load and recovery. The supercompensation occurs when a single physical load causes fatigue and acute reduction in human’s work capability. After that, the second phase is considered with marked fatigue and an obvious process of recovery. Then the human’s work capability rises and reaches the pre-load levels. The third phase continues to increase work capability surpassing the previous level and achieving the climax (supercompensation phase). Later if physical stress is not reloaded, work capability returns to the pre-load level.

Afterwards Matveyev (1981) presented a common scheme of the numerous load summation. Based on this, several training sessions can be done while the athlete is still tired. The supercompensation impact can be achieved after a particular training cycle but not a single training session.

Periodized training is built on the four principles that Matveyev presented in 1964 (Issurin 2010). Firstly, training should be cyclical. This comes from the daily calendar rhythm, competition schedule and cyclical character of training adaptation. Secondly, there is a unity of general and specialized preparation which is emphasized by the importance of specific workloads depending on the seasonal focuses of training. Thirdly, training workloads should be waving during the week and longer periods (monthly). Lastly, training should be continuous throughout the year.

The traditional periodized system is developed from *multi-year preparation*, where the Olympic quadrennial cycle gives the importance for the whole training system (Matveyev 1964). The multi-year plan is further divided into *macrocycles*, which usually last one year but can be shortened into i.e. 3-6 months. The macrocycles are split into training periods (*mesocycles*) which consist of the preparatory phase where the focus is on general and preliminary work with a high training volume. After follows the competition phase where one concentrates on more sport-specific work and competitions with a reduced volume but a higher intensity. Furthermore, is the shortest period, transition which is dedicated for active recovery and rehabilitation.

Issurin (2008) claims that the traditional periodization has limitations when many targeted abilities are developed simultaneously in one training period. Each ability requires a specific physiological, morphological and psychological adaptation and many of these workloads are not matching which causes a conflict. For lower level athletes versatile training is more enjoyable. But elite level athletes need higher training stimuli to progress (Rønnestad et al. 2016). Traditional periodization with long training phases disturbs multi-peak preparation and successful preparation during the entire annual cycle.

2.2 Alternative models

The modern world needed to change the traditional periodization because the total number of competitions increased, athletes were financially motivated to compete more, and coaches shared more information with each other which raised the level of the training quality and the level of athletic performance (Issurin 2008). This decreased the total volume of training workloads and progressed training methods while training information were easier accessible. The traditional periodization model for team sports was also controversial because they had long competition phases (15-35 weeks) especially in the professional level (Issurin 2010).

Nowadays, it is known that the traditional model leads to reduction in maximal strength (Astorino et al. 2004), maximal anaerobic power (Häkkinen 1993) and even maximal speed (Kraemer et al. 2004). This rising knowledge about training residuals and the time of detraining was important when planning trainings. Today it is more common to use team-sport specific terms like off-season, pre-season, in-season and postseason phases.

2.3 Block periodization

In the beginning of 1980s, the use of *training blocks* became more common among athletes and coaches. Training blocks meant a training phase of highly specialized workloads (Issurin 2008). These cycles included a big volume of exercises targeted at a marginal number of focused abilities. This approach was an option to traditional multi-targeted mixed training. Slowly, positive efforts to implement training blocks resulted into the preparation system called *block periodization.*

The scientific background for block periodization comes from the concepts of *cumulative* and the *residual* training effects (Issurin 2008). The cumulative long-term training settles the athlete’s way to the elite level. Progression is built on the development of both physiological, biochemical variables, and sport-specific abilities leading to better athletic performance in the athlete’s preparedness. The residual training effect can inform how fast the athlete will lose the attained ability level after cessation of training. This approach is important while planning especially short-term training programs, where an athlete develops one ability and loses another one at the same time. Knowing the duration of residual effects is essential when planning a block-periodized training program (table 1). Studies showed that prolonger training causes longer residuals and older and more trained athletes retain their trainedness for longer periods (Issurin 2008).

TABLE 1. Length of residual training effects for different motor abilities after cessation of training (Issurin 2008).

Motor ability	Residual Duration days	Physiological background
Aerobic endurance	30 +/-5	Increased amount pf aerobic enzymes. Number of mitochondria. Muscle capillaries. Hemoglobin capacity. Glycogen storage and higher rate of fat metabolism.
Maximal strength	30 +/-5	Improvement of neural mechanism and muscle hypertrophy due mainly to muscle fiber enlargement.
Anaerobic glycolytic endurance	18 +/-4	Increased number of anaerobic enzymes. Buffering capacity and glycogen storage and higher possibility of lactate accumulation.
Strength endurance	15 +/-5	Muscle hypertrophy mainly in slow-twitch fibres, improved aerobic-anaerobic enzymes. Better local blood circulation and lactic acid tolerance.
Maximal speed (alactic)	5 +/-3	Improved neuromuscular interactions and phosphocreatine storage.

Issurin (2016) wrote that the block periodization has developed into two versions: the concentrated unidirectional training model and the multi-targeted block periodization approach. He stated that concentrated unidirectional training was developed from speed-strength training, like jumping, where a high concentration of training workloads is focused on improving one important targeted ability. The concentrated unidirectional training system was proceeded from power/strength progress (2-3 months) to more specialized sport-specific development (2 months) and event-specific technique phase with a competition practice (3-5 weeks). According to Issurin (2016), this was called the three-block sequence. The concentrated unidirectional training model had the potential to improve one main fitness ability, but its limitations occurred when sport required many targeted abilities.

In the multitargeted block periodization approach, the solution of periodization is based on consecutive development of targeted abilities by properly sequencing specialized training blocks (Issurin 2010). The multi-targeted block periodization consists of 3-4 short periods (2-4 weeks) with focus on improving minimal number of specific abilities while other abilities are maintained and without unnecessary fatigue accumulation (Issurin 2010). The first of the four main principles of the block periodization are to have high concentration of training workloads within given block, states Issurin (2008). He continues that the number of target abilities should be minimized within a single block. In most sports all essential sport-specific abilities cannot be trained at the same time in one block, there by those abilities should be programmed in consecutive blocks, and lastly, the implementation of an appropriate taxonomy of mesocycle blocks.

The block periodization includes three mesocycles: accumulation, transmutation, realization and ends with participation in a competition. It is important to concentrate the training workloads on a minimum number of abilities during one training session to produce sufficient stimulus (Sikorski 2011). The positive effects of training last after its cessation, depend on its physiological background.

Accumulation phase. This can be divided further into the aerobic and strength phases. It concentrates on basic abilities such as muscular strength, basic aerobic endurance and general coordination. These abilities yield the longest training residuals which last for 30 days (+/- 5) after working out (table 1). That is why this phase or mesocycle is categorized by a relatively high volume and reduced (medium) intensity of workloads. Usually the accumulation phase lasts from 2 to 6 weeks (Issurin 2010).

Transmutation phase. The second mesocycle focuses on sport-specific abilities like special (aerobic-anaerobic or glycolytic) endurance, strength endurance and individual technical and tactical skills during competition-like training sessions (Issurin 2010). This is the most exhausting and stressful phase where the intensity is increased but volume decreased. In judo, it is usually called the lactic period. Generally, transmutation phase takes about 2-4 weeks.

Realization phase. The last stage is for tapering to gradually reduce training volume aiming to facilitate the recovery processes and maximize performance for competition (Garcia-Pallares et al. 2010). Normally it contains drills for modelling the competitive performance but with full recovery inside the one and between several training sessions. Recovery time between training sessions depends on the type of training that has been done. Extreme endurance loads need 48-72 hours to recover. Lighter, medium and substantial loads take approximately 12 to 24 hours time to recover (Sikorski 2011). This phase ranges typically from 8 to 15 days (Issurin 2008).

The methodological factor that contributes the three stages of block periodization is the biological differentiation between the extensive volume (accumulation phase) and those intensive stress (transmutation phase). The biological background comes from the fundamental theories of human adaptation, especially homeostatic regulation, which shelters stability of the biological factors and stress adaptation. In the accumulation phase, homeostatic mechanisms subordinate the development of basic abilities. While in the transmutation phase, where emphasis is on the implementation of highly intensive glycolytic program, the demand and trigger are on stress reactions. (Issurin 2016.)

These three mesocycles formulate one training stage (figure 1). The number of training stages in a year depends on the particularities of sport and its competition calendar. Usually there are 5-7 periods in a year, where the last one is the main competition of the entire year. (Issurin 2010.)

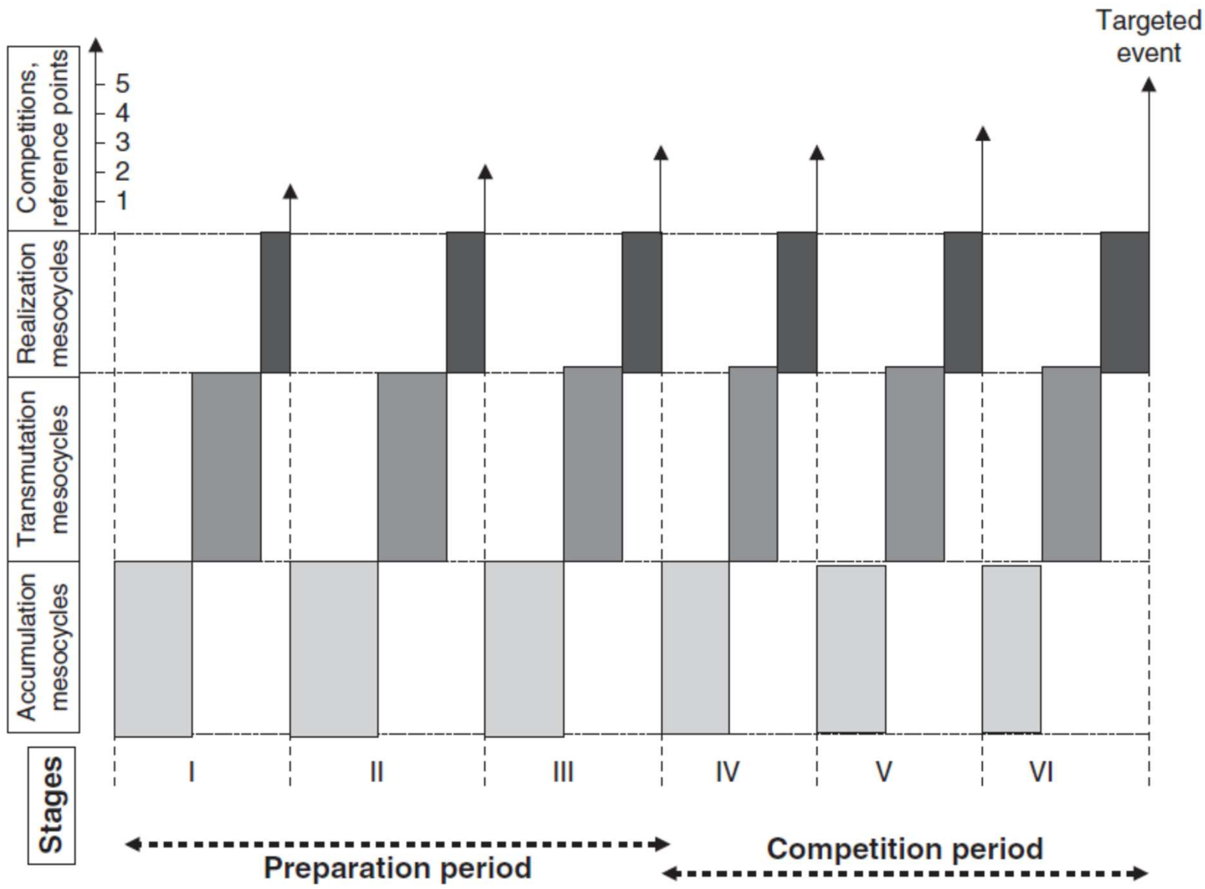

FIGURE 1. Schematic chart of a block-periodized cycle (Issurin 2010).

The multi-targeted block periodization programs have been examined in several studies by evaluating the training effects mostly on endurance performance. For example, Clark et al. (2014) examined the effects of two seven-day high-intensity overload training phases on the performance levels of competitive cyclists. Training sessions were based on either short or longer sprints with the work to rest ratio 1:5. The short training group performed 25 times of 5, 10 and 20 s lasting bouts in sequence for a total work period of 14.6 minutes. In the long training group, they did 10 sets of 15-, 30- and 45-seconds maximal intensity bouts with a total work of 15 minutes. Both the short and long efforts improved significantly the 20-km time trial performance ($p<0.05$).

Garcia-Pallares and co-authors (2010) compared the performance effects between traditional training and block periodization in elite kayakers during two separate seasons. The findings suggested that five-week training phases resulting from block periodization using greater workload with half of the overall training volume leads to a more effective training stimulus and performance level. The authors proposed also that the block periodization might be more useful than the traditional model to avoid the loss of residual training effects. Rønnestad et al. (2019) had similar findings while they investigated the effects of block periodization compared to a traditional mixed organization of strength/power and endurance in well-trained ice hockey players. Two groups did identical volumes and intensities during the 6-week training intervention. The block periodization group made significant improvements in maximal oxygen uptake (VO_2max) (5.1%, $p=0.05$). According to Issurin (2018), the purpose of highly loaded HIIT blocks are to cause valuable metabolic effect and suitable hormonal responses to optimize the later adaptations.

Breil and co-authors (2010) tested the effect of high-intensity training according to block periodization on the aerobic capacity in alpine skiers with a short-term training phase. Junior athletes did in an 11-day shock microcycle with 15 HIIT sessions (4x4 min at 90-95% of HR_{max} separated with 3 min rest periods) during off-season. After 7 days of complete recovery and supercompensation, VO_2max significantly improved by 6.0% ($p<0,01$). The study highlighted that this study-like shock microcycle can be fitted to a busy training schedule, where other training tasks like sport specific technical-tactical training take priority.

Similar results were found by Rønnestad et al. (2014a) in trained cyclists. Their intervention indicated that arranging endurance training five times a week performed HIIT block followed by 3 weeks of concentration on low-intensity training resulted in a 4.5% increase in VO_2max. According to Seiler (2012), low intensity training usually refers to work producing a steady blood lactate (La) concentration of <~2 mmol/L and HIIT refers to training above the maximum blood La steady intensity (La ≥4 mmol/L). In the study by Rønnestad et al. (2014a), the 4-week block model had the same training volume as the 4-week traditional model, while the number of HIIT sessions (8) was identical in the block periodization and in the traditional group.

There are only a few studies concerning block periodization in high-level judo athletes. Marques et al. (2017) compared different competitive level judo athletes relating to maximal strength, muscle power, and judo-specific performances, as well as the hormonal responses during a 13-week block periodization. They presented that block periodization increased specific judo test performance, especially among national level athletes comparing to higher level athletes. But no significant changes were found for cortisol and testosterone concentrations which could mean that athletes cope appropriately with the demands of block periodization. However, a control group was missing which makes the analysis challenging. Still the authors proposed that block periodization may be an alternative periodization method for elite athletes.

Stojanovic et al. (2009) studied physiological adaptations of the 8-week precompetitive training period in female judokas. They divided an 8-week training program into two 4-week periods where the first focus was on the general physical fitness (weight training and running) while judo training sessions contained of technical skills. The second phase aimed to improve sport specific performance (combat) where judo training sessions consisted of exercises varied in intensity and technical-tactical demands. The results showed superior increases in anaerobic performance.

2.4 Long-term effects of block periodization

The long-term effects of block periodization in practice remain unknown and more studies are needed especially in intermittent sports. Afonso et al. (2017) even claimed that long-term researches seem to be missing in the field of whole periodization. The highly loaded mesocycles are short but physiologically demanding and need high motivation from the athletes.

However, long-term studies are found in endurance sports. Rønnestad and Hansen (2018) did a single-case study with an elite cyclist. The 58-week block periodization increased relative and absolute VO_2max 18.5% and 12.3%, respectively. Solli et al. (2019) showed how an elite level endurance athlete had successfully used two different periodization models throughout her career, HIIT blocks and a traditional method with a similar endurance training load. In HIIT, block varied from 7-11 days, each including 8-13 HIIT sessions. Researchers emphasized the significance of balanced micro-periodization during HIIT blocks by making most of variable exercises modes and carefully looking after intensity, training load and amount. Hence, the chosen periodization model is affected by athlete’s training status and response to over-reach as well as his or her stress on the immunological system. However, the limitation of this study was that the comparison between block periodization and the traditional method had a difference of 10 years, so the effects of training history was not the same between the compared two periodization methods. For now, it is unclear how elite level athletes respond to several years of continuing block periodization.

3. HIGH-INTENSITY INTERVAL TRAINING

High-intensity interval training is a time-efficient training system for developing cardiorespiratory and metabolic function and physical performance in athletes. HIIT involves repeated short (15-45 s) to long (2-4 min) bouts of high-intensity exercise interspersed with recovery periods. (Buchheit & Laursen 2013a; 2013b.) The meaning of HIIT is to constantly stress the physiological systems which are used through a certain exercise to greater extent than which is needed during the movement (Laursen & Jenkins 2002). With HIIT the total accumulated time of vigorous exercise is higher than could be achieved during a single bout of continuous exercise at the same intensity until exhaustion (Tschakert & Hofmann 2013). A lot of improvements in both aerobic and anaerobic system have been found after HIIT (e.g. increased resting glycogen content, muscle oxidative capacity and muscle buffering capacity) (Gibala et al. 2006).

Lately repeated "all -out" sprints have also occurred (Iaia & Bansbo 2010). These extra intense forms of HIIT consist of repeated-sprint training (RST) which includes several supramaximal sprints lasting 3-10 s interspersed less than 60 s recovery periods, or sprint interval training (SIT) which includes 30-45 s "all-out" efforts interspersed with 2–4 min inactive recovery periods (Buchheit & Laursen 2013a; 2013b). SIT is also referred as speed endurance training (Iaia & Bangsbo 2010).

One of the most used SIT protocols has been developed by Tabata et al. (1996). The Tabata SIT protocol contains 7-8 sets of 20 s intervals (usually cycling at 170% of VO_2max velocity) with a 10 s passive recovery. According to the study results, this protocol seems to be effective to increase anaerobic and aerobic capacity related to moderate-intensity continuous training in moderately active young men while blood pH tolerance and the size of muscle mitochondria have shown to increase (Gibala & McGee 2008; Tabata et al. 1997). Noteworthy is that this 20 s work and 10 s rest is the same effort:pause ratio that has been found in the time-motion analysis of judo matches (Miarka et al. 2012).

Ravier et al. (2009) also studied aerobic and anaerobic adaptations by adding SIT session twice a week during a 7-week karate training period. The SIT contained 7-9 sets of 20 s running at about 140% of VO_2max velocity with a 15-s recovery periods. The addition of SIT induced beneficial physiological adaptations allowing improvements in the duration of intense physical exercise before a state of fatigue was reached. The SIT training period significantly improved the VO_2max and the maximal oxygen deficit which describes anaerobic capacity (4.6% and 10.3%, $p<0.05$). (Ravier et al. 2009.)

SIT has also been studied with the short-term training protocol by Koral et al. (2018). The 2-week training period consisted of 4-7 bounds of 30 s running at the maximal intensity with 4 min rest between bouts, 3 times a week. Trained runners improved their maximal aerobic speed in the maximal aerobic speed test (2.8%, $p=0.01$) and 3,000-m time trial shortened (6%, $p<0.001$) but VO_2max was not measured in this study (Koral et al. 2018).

3.1 Desired training intensity

Laursen (2010) has examined high-intensity training and according to his findings, since the main goal of HIIT is to improve the determinants of VO_2max, HIIT sessions should be done above the second ventilatory threshold or maximal lactate steady state or even with "all-out" supramaximal intensity. He continues that usually HIIT work intensities tend to be at 90-100% velocities at the level of VO_2max, heart rate (HR) values ~90% relative of maximum (HR_{max}) and training sessions recruit especially fast twitch motor units. Since SIT is performed "all-out", they can be prescribed without pre-testing the athlete (Buchheit & Laursen 2013a; 2013b).

To have an optimal stimulus to induce both maximal cardiovascular and peripheral adaptations, athletes need to spend at least several minutes per training above 90% of their VO_2max (Buchheit & Laursen 2013a) or HR_{max} (Fernandez-Fernandez et al. 2015). Seiler (2012) demonstrated 5-zone intensity scales used in endurance training prescribed by Norwegian Olympic Federation (table 2). It describes that HIIT refers to the training above 4 mmol/L La. Typical effective work time within the two hardest zones, 4 and 5, can vary from 15 to 60 min. The training protocol 4-6 sets of 4 min work at 90-95% HR_{max} separated with 2-3 min of active rest is commonly used to improve VO_2max (Breil et al 2010; Seiler 2012). In this case, the effective work time would be 16-24 min depending on the number of repetitions.

TABLE 2. A 5-zone intensity scale to prescribe and monitor training of endurance athletes (modified from Laursen & Buchheit 2019; Seiler 2012).

Intensity zone	Heart rate (% max)	Lactate (mmol/L)	rate of perceived exertion (RPE)	Typical effective work time within zone
1	60-72	0.8 – 1.5	1-2	1-6 h
2	72-82	1.5 – 2.5	2-3	1-3 h
3	82-87	2.5 – 4.0	3-4	50-90 min
4	88-93	4.0 – 6.0	4-6	30-60 min
5	94-100	6.0 – 10.0	7≥8	15-30 min

Buchheit and Laursen (2013a) stated that continuous interval training with high intensities should improve VO_2max by increasing the stroke volume and maximal cardiac output due to extended time periods where the cardiovascular system is working at VO_2max. It seems that improved performance is because of a better ability of the engaged skeletal muscle to produce ATP aerobically (Laursen 2010). Furthermore, other physiological variables that also need to be considered while programming HIIT contains aerobic and anaerobic metabolisms, acute neuromuscular load and musculoskeletal strain. Seiler (2012) wrote that training minutes at 90% of VO_2max seems to have same or even better effect and are slightly less stressful than training briefer sessions at 95-100% VO_2max.

Various elements define the preferred acute physiological response to a HIIT session (figure 2). The HIIT workouts should be particular to the physical adaptations preferred and not automatically obligatory to the sport itself (Buchheit & Laursen 2013a). Most models of HIIT are successful stressing the aerobic energy system both centrally and peripherally and part of them are connected to a big anaerobic glycolytic energy contribution. The athlete's sport (training specificity) and his profile are important factors while programming, and above all the entire training periodization has the greatest impact on the HIIT programming. As the athlete's performance level improves, it appears necessary to also develop the intensity of the aerobic endurance training to achieve more increases in LT and VO_2max (Edge et al. 2006; Rønnestad et al. 2014b). Hence the coach must be aware of the isolated acute responses to different HIIT formats.

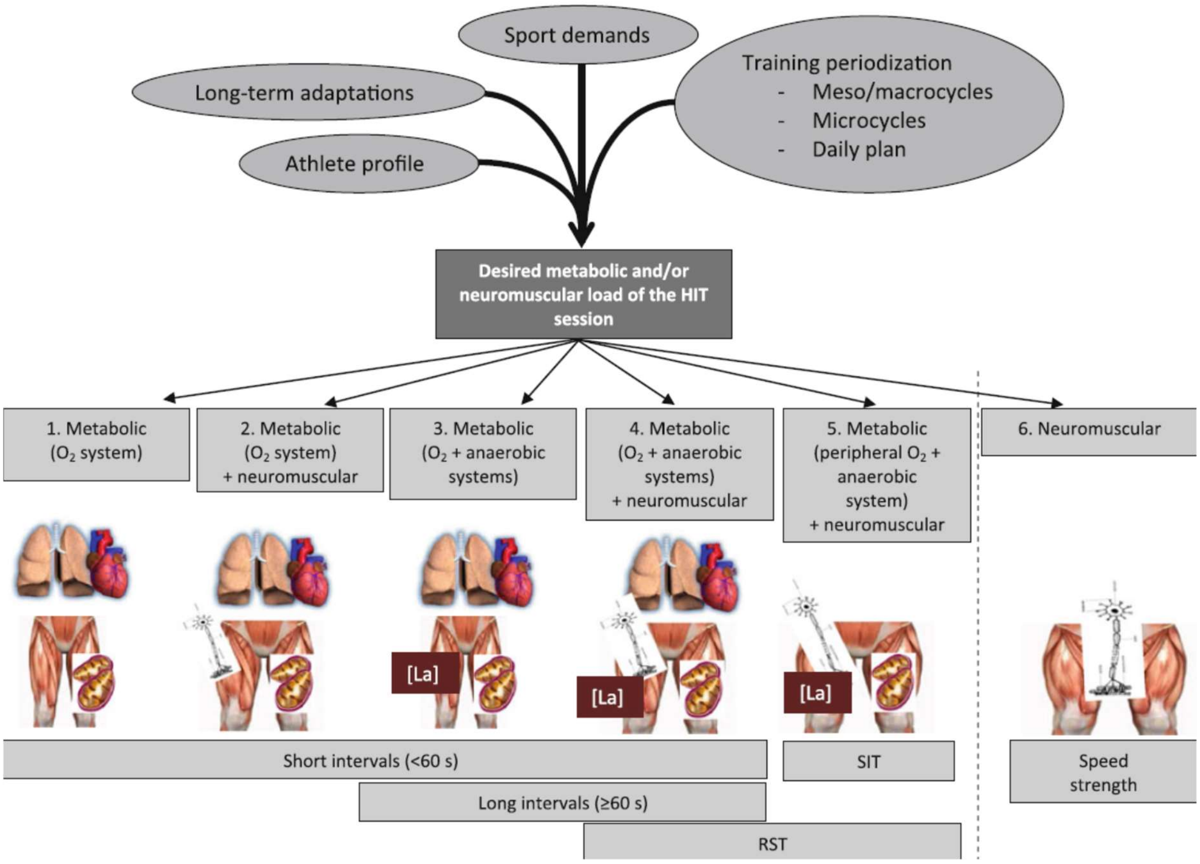

FIGURE 2. The process to select a HIIT form based on the wanted acute physiological response/strain (Buchheit & Laursen 2013a).

There are nine variables that can be manipulated to create different HIIT sessions (Buchheit & Laursen 2013a). The intensity, duration of work and relief intervals are the most important factors. The number of intervals, series and between-series recovery durations and the intensities determine finally the total workload. Laursen (2010) summed up in his review that the manipulation of each variable in isolation has a direct impact on metabolic pathways within the muscle cells and oxygen delivery to muscle, improvement of cardiovascular dynamics, neural recruitment patterns, muscle bioenergetics and enhanced morphological, metabolic substrate and skeletal muscle acid base status. Iaia and Bansbo (2010) also underlined that the differences in the relative exercise intensity and length of the relief intervals should be taken into consideration while comparing scientific studies using high-intensity interval training.

Buchheit and Laursen (2013a) argued that with elite athletes, long intervals and/or short intervals with a work/relief ratio >1 should allow a longer time at the VO_2max /exercise time ratio during HIIT sessions. Billat (2001) wrote also that the recovery duration between short intervals is the determinant for the utilization of anaerobic and aerobic pathways.

3.2 Metabolic and neuromuscular responses to HIIT

The measurement of the accumulated O_2 deficit and muscle blood La concentration are the most used methods to evaluate the anaerobic glycolytic energy contribution in high-intensity exercise although both methods have some limitations. O_2 deficit is laborious to measure and lactate have large individual responses, timing of the sampling post exercise, possible variations between different analyzers and sampling sizes (finger vs. ear lobe) and its poor association with muscle lactate (Buchheit & Laursen 2013b).

Buchheit and Laursen (2013b) discussed in their review about the solutions of programming HIIT and its periodization, that the manipulation of HIIT variables with short intervals may allow coaches to vary the level of anaerobic glycolytic energy contribution to a given session. They presented that if the aim is to produce a high amount of lactate, rest periods should be long enough (>1,5-2 min) to allow for the aerobic system to return to resting levels, to enable an O_2 deficit to occur at the onset of the following exercise. While high intramuscular H^+ concentrations with the decrease of pH_i might inhibit glycolysis and phosphocreatine (PCr) recovery, lengthening the rest period may also allow for the coming bout to be achieved with a recovered acid status and greater PCr stores which in turn allows greater mechanical power output and anaerobic glycolytic energy contribution. (Buchheit & Laursen 2013b; Edge et al. 2006.) Laursen and Jenkins (2002) presented also that an increase in the skeletal muscle buffering capacity may be one mechanism which enables a better performance level in elite level athletes. They pointed out that the capacity of working muscle to buffer H^+ ions is related to sprint performance.

In addition, Edge et al. (2006) also studied the changes in muscle buffer capacity, VO_2peak and the LT after 5 weeks of HIIT above LT. The training took place three times a week including 6-10 x 2 min at 120-140% LT with 1 min rest. A control group performed continuous training below LT with the same training volume. They found out that the changes in muscle buffer capacity seemed to depend on the metabolic needs set on muscles during training. They stated that athletes involved in sports with higher anaerobic demands have a higher muscle buffer capacity. (Edge et al. 2006.)

According to Iaia and Bangsbo (2010), anaerobic training has been shown to decrease the proportion of slow twitch fibers as the relative number of fast twitch fibers has increased or remained unaltered in trained athletes. The study by Monks et al. (2017) determined the effects of 4-week high-intensity repeated sprints (5-60 s) on the aerobic and anaerobic capacity and physical fitness in taekwondo athletes in the pre-competition season. The results showed the efficiency of eleven sessions of HIIT which significantly improved the anaerobic capacity ($p<0.05$). The authors presented that the increase of anaerobic capacity may be described with the growth of intermediate and fast twitch muscle fibers due to greater force used in the muscles during the sprints comparing to continuous endurance running. (Monks et al. 2017.)

One possible factor that may induce improvements in aerobic and anaerobic performance after HIIT in already well-trained athletes is the lower energy expenditure during exercise and changes in the Na^+ K^+ pump which via the reduced contraction-induced net loss of K^+ from the working muscles may contribute to preserve cell excitability and force production (Iaia & Bansbo 2010). In addition to that, Laursen and Jenkins (2002) wrote that in already trained athletes, the altered expression of Na^+-K^+-ATPase and sarcoplasmic reticulum Ca^{2+}-ATPase may explain the increased endurance performance following HIIT. These two enzymes regulate the activity of the pumps involved in cation transport, which in turn maintains muscle membrane potential. However, more studies are needed to analyze the probability that HIIT training induces a changed appearance of cation pumps in already well-trained athletes (Laursen & Jenkins 2002.)

Buchheit and Laursen (2013b) wrote in their review that extending the interval duration of the HIIT session without changing the rest periods, the anaerobic glycolytic energy contribution increases when more work is done in a given time. Therefore, only work intervals longer than one minute tend to lead to high blood La levels. However, anaerobic glycolytic energy contribution is probably already increased when a single exercise is longer than 30 s. When the exercise is repeated multiple times, the rate of glycolysis decreases progressively while the aerobic system increases (Iaia & Bangsbo 2010).

The load of neuromuscular responses of the HIIT session is important to measure, while it affects the HIIT performance and might have potential carry-over effects for following training sessions and it even may influence injury risk during and following the HIIT session. It is important to understand how to manipulate HIIT variables to modulate neuromuscular load to maximize a given training stimulus and minimize musculoskeletal pain and/or injury risk. Still only few studies have investigated neuromuscular responses to the HIIT sessions in laboratory. More common are field-based measurements, like countermovement jump (CMJ) height and sprint speed (Buchheit & Laursen 2013b).

Kinnunen et al. (2019) found out that a short-term HIIT can enhance athletes' ability to perform maximal and explosive forces, probably as a result of improved voluntary activation of their muscles and decreased antagonist coactivation. They studied HIIT-related neuromuscular adaptions, changes in force production, and sport-specific performance in female ice-hockey players during a preseason with the 2½-week HIIT period. Training in their study consisted of two times a week by performing six 30-seconds all-out sprints on a hill (4-minute rest). The results showed that on-ice performance did not significantly improve which pointed out that the training period should have been longer, e.g. at least 4 weeks to lead to better on-ice performance.

The neuromuscular load seems to be greater with short intervals because the work intensity is higher with shorter intervals (Buchheit & Laursen 2013b). Most of muscle fibers might already be recruited during long intervals because the firing rate and relative force development per fiber is greater during short intervals. Short intervals require also frequent accelerations, decelerations, and re-accelerations. More acceleration phases require also greater absolute speed.

3.3 Programming HIIT

It is important to program the HIIT variables appropriately to maximize daily and weekly periodization. High training volumes at high intensity can produce large strain on the neuromuscular/musculoskeletal system, so the time needed to recover from the HIIT session need to be taken care (Buchheit & Laursen 2013b). Judo athletes normally train two times a day and have several anaerobic energy and neuromuscular systems loading training sessions within a week. This should be considered in the light of the other physical and technical/tactical sessions to avoid overload and to optimize adaptation. The coach must also understand the physiological responses to technical/tactical sessions because it is an important aspect of the successful training process.

Thibault (2003) presented an interval training model which can be used to program HIIT sessions (figure 3). The model defines the correct amount of repetitions and series that reach parallel ratings of perceived exertion. The number of repetitions used is normally 3 to 30 and work intervals lasting from a few seconds to several minutes. The interval training model shows that there are in total 35 various possible exercises at intensities of 85, 90, 95, 100, 105 and 110% of maximal aerobic power. Endurance athletes are able to accumulate, depending on the HIIT format, from 10 min >90% to 4-10 min >95% at VO_2max per session. A lower volume which means shorter series or less sets, may be used for other sports, like team sports, when 5-7 min is expected to be enough (Buchheit & Laursen 2013a).

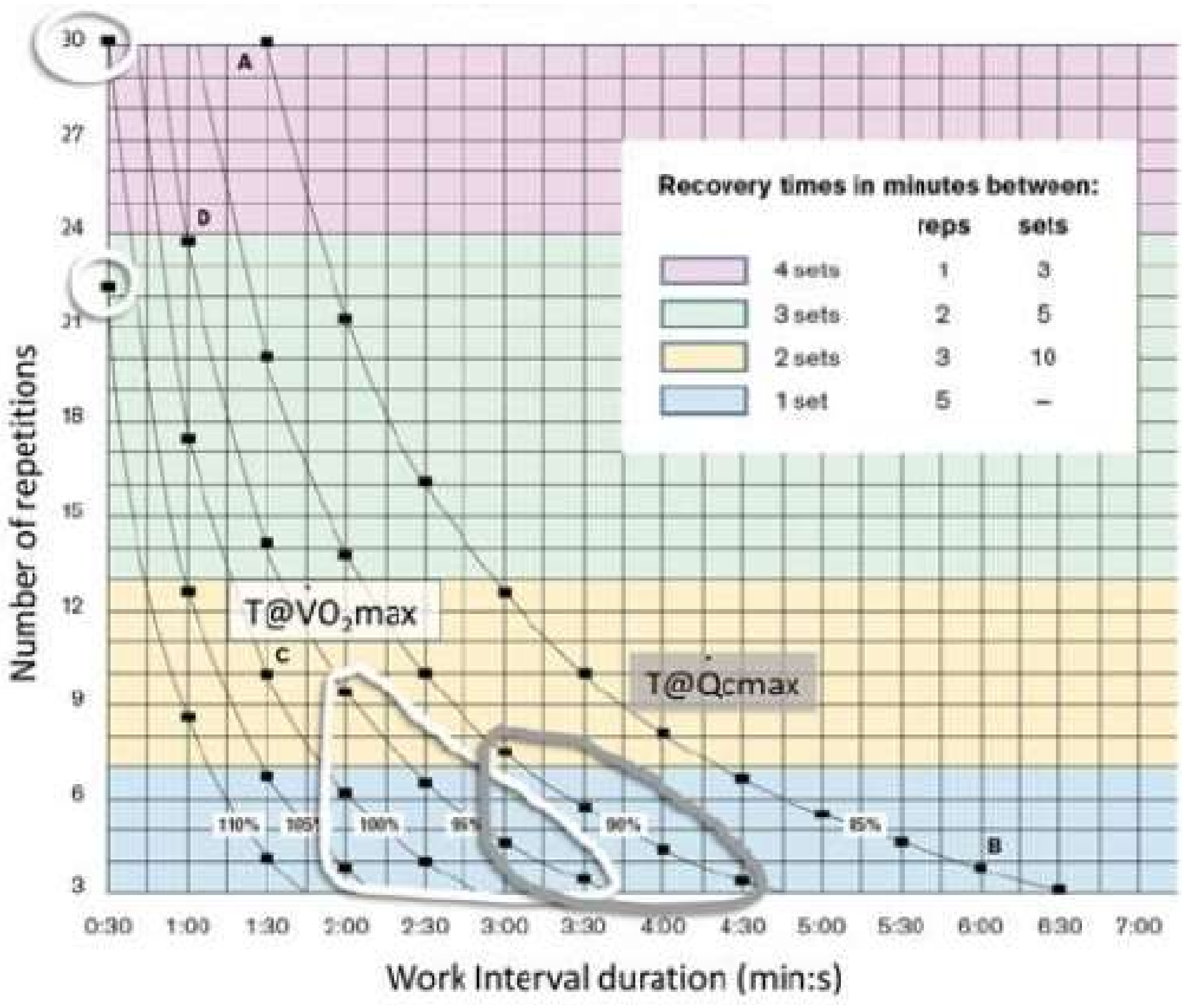

FIGURE 3. The Thibault's model of interval training (Buchheit & Laursen 2013b).

The long-interval HIIT sessions are typically used during the preseason for their benefits for the cardiopulmonary system despite their lack of specificity. When the rest period between the long (3-4 min) intervals is > 4-5 min, active recovery at submaximal intensity (60-70% HR_{max}) can be used to speed up blood La clearance compared to passive rest. Recovery can be passive when recovery period is 2 min or less. (Buchheit & Laursen 2013a, b.)

Shorter intervals (5-90 s) are used to improve the anaerobic power and capacity so that athlete tolerates better with lactate production and H^+ buffering capacity. The work-to-rest ratios are usually from 1:1 to 1:4 so that rest periods are performed either with low-intensity exercise or complete rest (Laursen 2010; Laursen & Jenkins 2002). These varying-length efforts combine to create training sessions that last 5-40 min including recovery intervals. Iaia and Bangsbo

(2010) proposed that for SIT, the exercise rest ratio of 1:1-3 seem to be appropriate to increase the ability to maintain exercise at high-intensity. This is referred as 'maintenance training'. (Iaia & Bangsbo 2010.)

Kim et al. (2011) examined the effects of 8 weeks SIT in elite judo athletes during normal off-season training phase. The athletes performed 4 times a week 6-10 sets of 30 s maximal running at 80-90% velocity of VO_2max with 4 min rest between the sprint bouts. Their aerobic and anaerobic abilities were tested after 4 and 8 weeks. VO_2max did not change significantly but anaerobic peak power and mean power was significantly increased (16% and 17% at 4 weeks; 17% and 22% at 8 weeks, respectively) ($p<0.05$). The authors suggested that this type of SIT program combined with judo training volume seem to be effective to improve anaerobic power in a short period in the off-season phase. (Kim et al. 2011.)

In the study by Franchini et al. (2017), 4 weeks of the SIT program had twice a week 2 blocks of 10 sets of 20 s of all-out effort sport-specific work with 10 s interval between sets and 5 min between blocks. Their study results showed that short-term, low-volume SIT added to regular judo training improved the performance in judo-specific performance test (e.g. blood La values increased).

Farzad and others (2011) also investigated the effects of 4 weeks SIT in wrestlers during a preseason. The SIT protocol performed twice a week consisted of 3-6 sets of 6 x 35 m sprints at the maximum effort with 10 s rest between each sprint and 3 min rest between the sets. The training program produced significant improvements in VO_2max (+5.4%) and increased peak and mean power output in 4 successive 30 s Wingate tests with a 4 min rest between each test ($p<0.05$).

Buchheit and Laursen (2013b) highlighted in their study that when planning HIIT sessions to a weekly plan, coaches should prefer morning HIIT sessions that are most effective for depleting glycogen stores. The researchers continued that the acute neuromuscular load/musculoskeletal strain should also be taken into account with the long-term development while HIIT sessions may interference with other training sessions, as well as acute and chronic injury risk. If neuromuscular fatigue keeps up for several hours or even days after a HIIT session, it can have a direct effect on the quality of upcoming training sessions. According to their review, neuromuscular fatigue after HIIT might decrease force production capacity and rate of force use during the following speed or strength sessions. (Buchheit & Laursen 2013b.) Understanding the physiological reactions to technical and tactical training is also an essential part of successful training in judo, so that the optimal HIIT sessions can be planned as an extra training session.

There is limited information about the time needed to post-HIIT muscle metabolite clearance, glycogen store repletion and neuromuscular recovery (Buchheit & Laursen 2013b). Along with each athlete's individual responses to training and person's training background makes the challenge of programming more difficult. It is quite common that HIIT sessions are separated by 48 to 72 h from each other and are generally followed by an easy session the following day, like rest or a light aerobic session, which accelerates post-HIIT metabolic and neuromuscular recovery (Buchheit & Laursen 2013b). Therefore, the HIIT sessions are typically performed 2-3 times per week to strike a good balance between positive effects and stress load (Seiler 2012). However, it is normal, especially during the preseason, that HIIT sessions are performed at least 48 h before strength or speed-oriented training sessions, to ensure optimal recovery of athletes in these sessions.

Several studies (see, e.g. Esteve-Lanao et al. 2007; Laursen 2010, Seiler 2012) have summarized that it is important to combine periods of both low (below the first ventilatory threshold) and high-intensity training into the training programs in elite athletes. This training distribution is called a polarized model, where approximately ~75% of training sessions are done below the first ventilatory threshold and the rest ~25% either above the second ventilatory threshold or between the two ventilatory thresholds.

Too much of weekly HIIT training performed too many weeks in a row, may lead to signs of overtraining with increased subjective ratings of fatigue, muscle soreness and poor sleep quality (Buchheit & Laursen 2013b). The daily responses to training load should be systematically monitored either objectively (e.g. heart rate) or with subjective markers of well-being to reduce the risks of overtraining. Athletes are familiarized to use the training volume (e.g. kilometers or minutes per week) as an index of training but this method ignores the intensity of training. Foster et al. (2001) evaluated the session rating of perceived exertion (sRPE) to monitor training. The session-RPE pays attention to the intensity and duration of a training session. In the method, 30 min after exercise, the athlete is asked “How was your workout?” to rate the exercise using the modified CR-10 scale (Borg 1962). Then the training load is calculated by the multiplication of given sRPE and the length of training (minutes). The researchers found out that the sRPE method is a valid method of quantitating training. (Foster et al. 2001.) RPE is found to be an appropriate model to evaluate training load also in judo (Agostinho et al. 2015; Canestri et al. 2019).

An appropriate recovery and tapering are needed before the competition phase when a lot of high-intensity training is done. Mujika (2010) wrote that the management of training intensity is important while appropriate tapering can improve one’s performance level (e.g. running economy, repeated sprint ability, muscle strength and power). Bosquet et al. (2007) described that 2 weeks of tapering with a total decrement in the training volume of 41-60% without changing the training intensity or regularity appear to be the most effective strategy to maximize performance improvements. The duration of taper may range from 8 to 14 days. The length of successful tapering depends on the sport and individual’s fatigue status before tapering. Furthermore, the athletes’ diet may affect the tapering while a carbohydrate diet seems to be essential. (Bosquet et al. 2007.) While a judo athlete usually loses weight before the competition, a rich carbohydrate diet is quite impossible to carry out, and this should be remembered when planning the tapering.

The tapering should be done by shortening the length of the training sessions (Mujika 2010). Rønnestad et al. (2014b) referred also to maintenance of training intensity during an optimal taper and programmed at least one HIIT session per week during the recovery phase. Therefore, after the overload phase of some HIIT sessions it may be crucial to gain benefits of block training of HIIT. But Mujika (2010) stated also that more evidence is needed for the taper in the context of multiple peaking. Now most of the studies about tapering from intense training are too short in duration and there is no evidence how often one can gain the performance benefits of an effective taper (Mujika 2010).

4. SPORT ANALYSIS OF JUDO

The judo combat is characterized by multilateral technical and tactical motor skills of short time with high-intensity that are performed periodic and need energy to be provided by both aerobic and anaerobic metabolisms (Braudry & Roux 2008, Franchini et al. 2005; Franchini et al. 2011; Torres-Luque et al. 2016). To be successful in judo, the techniques should be performed with accuracy, within a good 'window of opportunity', with strength, velocity and power (Franchini et al. 2011).

4.1 Physiological profile

It has been studied that the length of fighting and recovery periods during a high-level judo match varies from 20 to 30 s of activity and 5-10 s of pause meaning the 2:1 effort:pause ratio. Match time is approximately 3 to 4 min, but it can be less or even up to 10 min with overtime. (Franchini et al. 2011.) During judo competitions blood La levels have shown to be 9.9-12.3 mmol/L (Degoutte et al. 2003; Sbriccoli et al. 2007) or even 25.1 mmol/L (Laskowski et al. 2012). Also, the mean HR have demonstrated to be in male judo athletes of 85-90% of HR_{max}. HR has been also used to measure training intensity during judo training (Torres-Luque et al. 2016). These high demands highlight the importance of anaerobic metabolism at the starting and aerobic metabolism towards the last minutes of the match. That is why one aim of the training periodization in judo is to develop the capacity of both aerobic and anaerobic metabolisms so that athletes can keep ideal performance for the whole length of the judo match.

As judo is a sport including seven weight categories for both male (<60 kg, 66 kg, 73 kg, 81 kg, 90 kg, 100 kg and >100 kg) and female judo competitors (<48 kg, 52 kg, 57 kg, 63 kg, 70 kg, 78 kg and >78 kg), it is common that high-level judo athlete's body fat is usually small except for the heavyweights (Franchini et al. 2011). Each weight category points out marked changes in technical and tactical aspects along with physiology, performance, and body composition in separate weight classes. Hence, it directly impacts some of the important parts of athletes' training, including the management of bodyweight and body composition.

Although judo is highly technical, it is commonly known that when all other physical abilities are equal, the stronger will win. This highlights the strength as an important component of judo. Maximal strength levels are often analyzed relatively to bodyweight (relative strength), since it is useful in bodyweight classified sports like judo (Fagerlund & Häkkinen 1991). Maximal (dynamic) strength is mostly evaluated with one-repetition maximum (1 RM) usually in the bench press, seated row and back squat. Isometric strength is needed especially while gripping the opponent's gi (i.e. jacket). Upper body strength is emphasized with muscle endurance (pushing and pulling the opponent) to successful control and throw the opponent. For the lower body, the need is for muscle power while performing a powerful action during throwing. (Franchini et al. 2011.)

The anaerobic profile of judo athletes has been evaluated mostly with the Wingate test. The typical Wingate test evaluates peak power, mean power and fatigue index for the upper and lower body actions. The upper body Wingate has been the most common one, because in judo upper body actions are important. Elite judo athletes typically have higher upper body anaerobic power and capacity than recreational players. For the lower body anaerobic capacity values are not prominently higher than in non-elite level. (Franchini et al. 2011.)

The high-intensity bouts rely mainly on anaerobic metabolism, but the aerobic system is also important in judo, as it is faster to recover during the short recovery periods between efforts and between the matches during the competition day. Franchini et al. (2011) published a physiological profile of elite judo athletes and stated that the aerobic power and capacity have been evaluated through VO_2max in judo. They wrote that these two variables are relevant to the judo performance because they allow one to maintain higher intensity during the fight, postpone the accumulation of metabolites related with fatigue processes and improve the recovery between two competition fights or training sessions. Their study data showed that most male judo athletes have VO_2max -values around 50-60 mL/kg/min and in females around 40-50 mL/kg/min.

4.2 Training and periodization in judo

High levels of strength, anaerobic power and capacity and aerobic power are needed for successful judo performance (Franchini et al. 2015). The time structure of the sport should guide coaches to repeat the temporal structure in training sessions (Frachini et al. 2017). The main aim of training periodization in judo is to develop those qualities, particularly an improvement in upper-body anaerobic power and capacity, lower body muscle power, upper-body aerobic power, and strength endurance, while maintaining body composition (Franchini et al. 2015). Thus, it is important to try to maintain the training-induced aerobic and anaerobic systems with high-intensity training also in the off-season (Kim et al. 2011).

The organization of the judo training process is a complex task which is normally based on the traditional periodization approaches (Issurin 2010; 2016). Franchini et al. (2015) monitored the physiological changes in different variables during judo training periodization (figure 4). Their study's design consisted of a basic judo training periodization model which is commonly used in the judo field. Nowadays a multidirectional block periodization has also claimed to be an alternative option in judo athletes now that the number of competitions has increased a lot (Sikorski 2010).

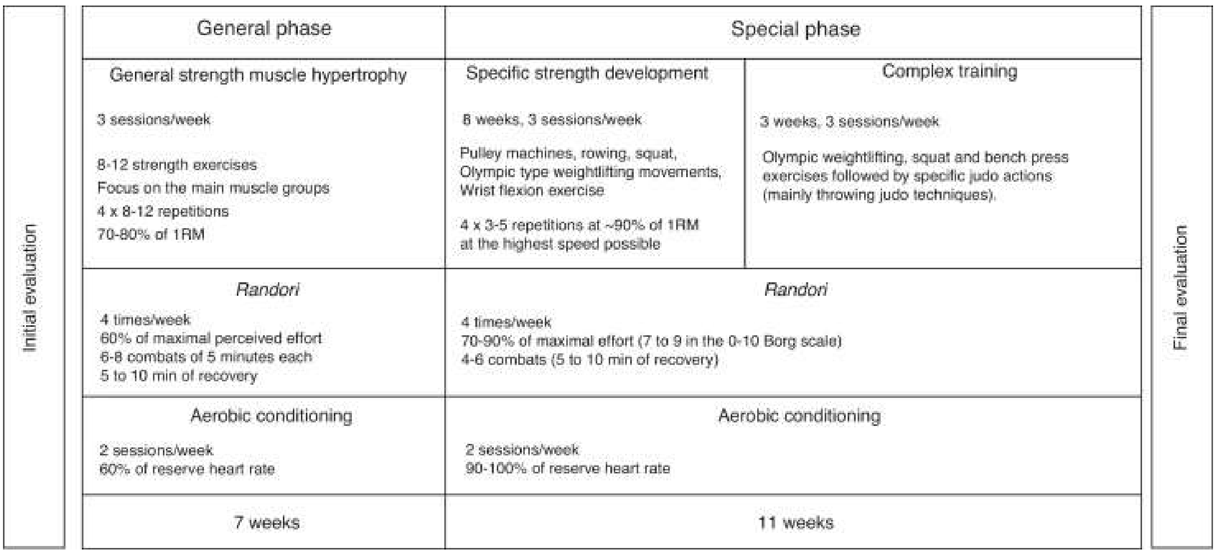

FIGURE 4. A model of the training phases and periods (Franchini et al. 2015).

The general phase. The focus was on general and preliminary work with high training volume. Generally, the aim was to improve general strength and promote muscle hypertrophy (2-3 times a week), develop technical skills through *randori* (match simulation performed 40-60 min almost continuously having 6-8 fights approximately 3-4 times per week at 60% of maximal perceived effort) and improve aerobic conditioning (1-2 times 40-60 min running sessions/week at 60% of reserve heart rate). (Franchini et al. 2015.)

The special phase. After this followed the second phase with more sport-specific work and competitions with reduced volume but higher intensity. The goal was to improve judo specific maximum strength performed at high intensity (~90% of 1 RM at the highest speed possible). Match simulation intensity was increased to 70-90% of maximal effort with 4-6 combats per session with longer rest periods (5-10 min) between them, using the same number of sessions per week. Aerobic training also increased its intensity (90-100% of RHR, twice a week), performed intermittently (1:1 work:rest ratio) and in a lower volume (30 min per session). (Franchini et al. 2015.)

5. RESEARCH QUESTIONS AND HYPOTHESES

The purpose of this study was to examine the effect of high-intensity interval training according to block periodization on physical performance levels in male judo athletes. In addition, this study investigated, how other judo performance levels can be maintained during a mesocycle.

Research question 1: Will the 10-day long high-intensity interval training block added to the normal training content improve performance levels in male judo athletes during the preseason training phase?

Hypothesis: A short-term high-intensity interval training block added to normal training can improve aerobic and anaerobic performance levels in already well-trained athletes (Breil et al. 2010; Garcia-Pallares et al. 2010; Rønnestad et al. 2014a & b; Rønnestad 2016; Wahl et al. 2014). According to Laursen (2010), 6-8 HIIT sessions performed in 2-4 weeks can increase performance of 2-4% in well-trained athletes.

Research question 2. How does the HIIT training block effects on muscle power in male judo athletes?

Hypothesis: Although high-intensity interval training recruits fast twitch motor units for repeated high-intensity bouts, it is suggested that a short-term HIIT block does not significantly improve muscle power (Breil et al. 2010; Wahl et al. 2014).

Research question 3. Can maximum strength levels be maintained during the HIIT training block?

Hypothesis: Yes, there are very few studies that have examined the effects of a short-term HIIT block on maximum strength levels. According to Astorino et al. (2012) a HIIT has little or no effect on maximum muscle force.

6. METHODS

7.1 Subjects

Nine healthy male judo athletes (mean ±SD: 21.6 ±4.5 years; height 1.77 ±0.05 m and body mass 77.6 ±9.6 kg), who compete at least at the Nordic level participated voluntary to this study. All athletes had over 5 years of judo training experience and they were familiar with high-intensity interval training protocols.

All participants had been in judo competitions during the previous year, they had trained at least six times in a week and competed in weight categories between -60 kg and -90 kg. They were not participating in any weight-loss programs or any supplementation or medical treatment. They were informed of the study procedure and the risks involved with the measurements. All judo athletes signed an informed consent form prior to participation. Two of the judo athletes did not complete the study because of injury or own will during the intervention period, and their data were excluded leaving a total of seven judo athletes. The University of Jyväskylä Ethical Committee approved the study in January 2020.

7.2 Experimental design

The study was performed during the preseason training phase. The study was a training intervention (table 3). Fitness tests were performed before (pre-test) and 3-4 days after the intervention (post-test). The group performed a high-intensity interval training (HIIT) phase for 10 days with seven HIIT sessions. In addition, the control tests were made during the first and last HIIT session. After the training phase, the group had 3-4 days of tapering after which they performed the post-tests.

TABLE 3. Training program for 10 days HIIT cycle.

microcycle		day -2	day -1	day 1	day 2	day 3	day 4	day 5
1st w	AM	*pre-test strength	*pre-test endurance	judo speed	strength	judo technic	speed/ strength	HIIT
	PM			HIIT 1)	HIIT	rest	HIIT	rest
2nd w		day 6	day 7	day 8	day 9	day 10	day 0	day +1
	AM	active rest	judo speed	strength	active rest	judo/ strength	rest	rest
	PM		HIIT	HIIT		HIIT 2)		
3rd w		day +2	day +3					
	AM	#post-test strength	#post-test endurance					

AM morning, PM evening. 1) Start of training program. 2) End of training program. *Pre-tests were 1-2 days before training program started. #Post-tests were done two days after training program had ended.

The examined HIIT cycle was based on the fact that it is common to rely on an integrated approach on conditioning and skill-based technical work which results in sport-specific, on-mat exercises that include both technical and tactical assignments as part of sport-specific conditioning. A judo match lasts usually 3 min, with 5-10 s pause (*mate*) between short, 20-30 s bouts of high-intensity work (Miarka et al. 2012). The HIIT training sessions in this study were judo matches as in competition and circuit training exercises that consisted of judo-specific circuit training exercises, like throwing the training partner as fast as possible as many times as possible or fighting for a dominant grip. Braudry and Roux (2009) proved that judo-specific circuit training affects aerobic and anaerobic metabolisms with relative contributions depending on the rest duration. They did 6 x 40 s work periods of technical judo exercises with the work/rest ratios (in seconds) of 40/40, 40/120 and 40/200.

The study took place in Spring so that athletes did not have any main competitions coming up after the training period. This study was done in co-operation with the Finnish Judo Association. The study was founded by Urheiluopistosäätiö and the Finnish Judo Association. The funding covered athlete’s accommodation and test expenses in Varala Sport Center, Tampere.

7.3 Training program

The 10 days intervention consisted of seven HIIT sessions, each with a similar training volume but a different work-to-rest-ratio (table 4). Physiological focus was on anaerobic capacity. Training sessions consisted of simulated judo matches (4 min per round without opponent changes) with 85-90% of maximal effort. Also, shorter intervals (20 s – 2 min) were done. Examples of the measured heart rates from the same subject during different training sessions can be seen in Figure 5. The aim of training was to improve tolerance to fatigue and do all the circuit movements as fast as possible with maximal effort.

TABLE 4. HIIT training protocols. High-intensity training volume altogether 90 min.

HIIT session	Week 1	HIIT session	Week 2
1	4 sets of fight work 4 min/rest 6 min	5	3 sets (8 x work 30 s/rest 30 s)/rest 8 min
2	4 sets (2x work 2 min/rest 4 min)/rest 8 min	6	3 sets (8 x work 20 s/rest 30 s)/rest 8 min
3	4 sets of fight work 4 min/rest 6 min	7	4 sets of fight work 4 min/rest 6 min
4	7+7 sets (work 1 min/rest 1 min)/rest 10 min		-

4x(2x2 min/5 min/)10 min: one bout of circuit training for 2 min followed by a rest of 5 min. Then again work 2 min, then rest 10 min. Altogether 4 sets of 2 x 2 min.

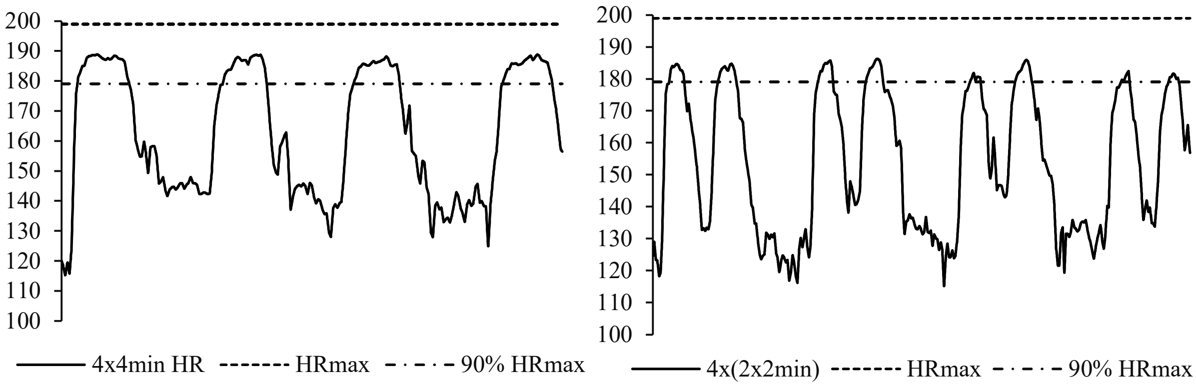

FIGURE 5. Examples of measured heart rates from the same subject during 4x4 min and 4x(2x2 min) training sessions.

During the intervention, the group continued their judo training which consisted of technical/tactical drills in sport-specific situations (60-90 min each, 50-60% maximal perceived effort). Also, they did maximum strength sessions consisting mainly of free-weights exercises including clean, squat, bench press, bench row and core training. These strength sessions contained 3-4 sets per movement, 2-4 repetitions at 90-95% 1 RM with the highest speed possible to maintain their strength levels. Therefore, the present subjects were submitted to an overall training volume of almost 23 h during 10 days.

In the beginning of each training sessions, subjects completed a standardized dynamic warm-up (approximately 15 min) followed by judo-specific activity of 25 min, where the goal was to rise HR shortly to near ~85-90% of HR_{max}. The judo-specific HIIT-drills consisted of uchi-komi and nage-komi in the competition like simulation. Uchi-komi and nake-komi are judo movements used to learn throwing techniques. Uchi-komi is a movement in which one performs the throwing movement without the last throwing phase, whereas nage-komi contains the total throwing movement. (Baudry & Roux 2009.)

HR was monitored during the HIIT sessions (Firstbeat Sport Team System, Jyväskylä, Finland). The HIIT sessions were analyzed, and the training intensity divided into three different heart rate zones (1 < 82% of maximum heart rate, 2 = 82-87% of maximum heart rate and 3 > 87% of maximum heart rate). An overview of the distribution of the HIIT sessions into three HR zones is presented in figure 6.

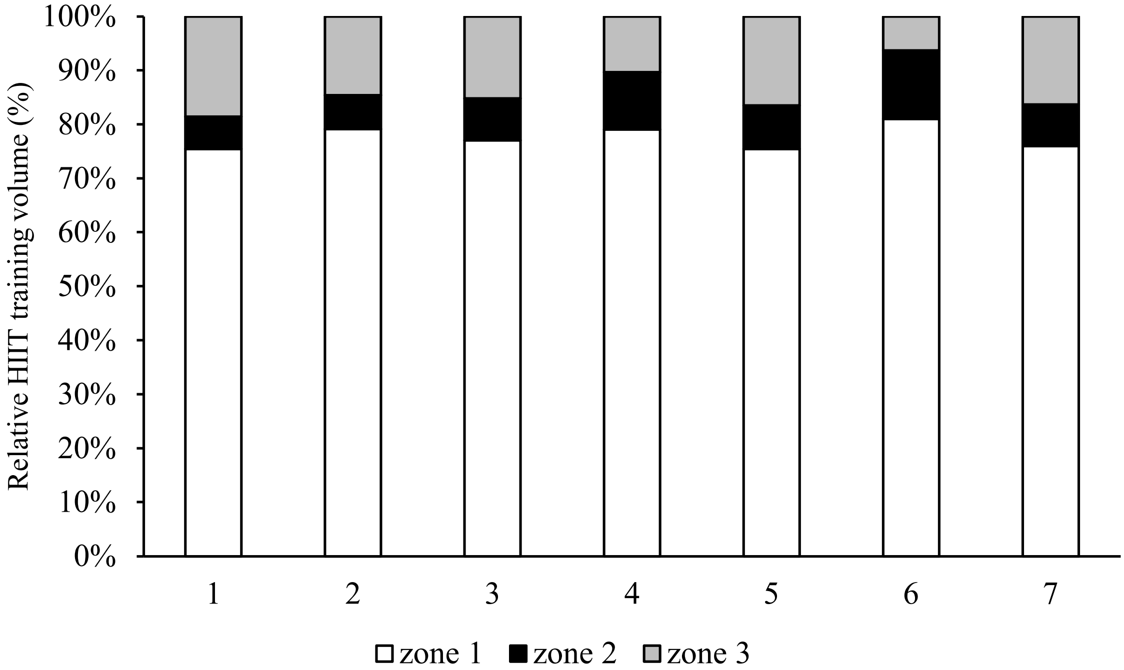

FIGURE 6. The relative distribution of seven HIIT sessions into different intensity zones during the intervention. Training zone 1 < 82%/HR_{max}, 2 = 82-87% HR_{max} and 3 > 87% HR_{max}.

HR has become the most commonly measured physiological marker for controlling exercise intensity in the field although its effectiveness for controlling the intensity of a HIIT session may be imperfect. HR can indirectly indicate the contribution of aerobic metabolism during intermittent efforts, but HR cannot inform the intensity of work above VO_2max, like supramaximal speed, which is common in programming HIIT sessions. Furthermore, HR response for short (<30 s) and medium-long (1-2 min) intervals do not respond as fast as VO_2max values do. (Buchheit & Laursen 2013a.) Tschakert and Hormann (2013) reported that intervals with long durations and its exercise intensity prescribed via $HR\%_{max}$ or % VO_2max

are not proper because the heterogeneity of acute physiological responses increases with the duration of workload phases.

Blood La was controlled in three HIIT sessions: first, third and seventh i.e. the last one. These three training sessions had the similar content (4x4 min of match). The blood samples were sampled at the beginning and right after the first and the last judo match rounds. A blood sample was taken from the fingertip with a capillary-blood-sampling that was afterwards inserted into the lactate analyzer (Biosen C-line, EKF-diagnostic GmbH, Barleben/Magdeburg, Germany). The post-HIIT blood La values focused on the initial rate of blood La accumulation immediately after each exercise period of the match. Post-HIIT blood La values were categorized according to Buchheit and Laursen (2013b) as low <3 mmol/L, moderate >6 mmol/L, high >10 mmol/L and very high >14 mmol/L.

In order to quantify training load during the intervention, the session rating of perceived exertion (session-RPE) method was used (figure 7). RPE is a simple tool to evaluate the process of quantitating training during a wide-ranging selection of types of workout (Bromley et al. 2018; Foster et al. 2001). Training load was evaluated 30 min after each training session using the adapted Borg 10-point scale (Foster et al. 2001). Session-RPE was evaluated by asking each athlete “How intense was your training?”. Daily training load was calculated by multiplying session-RPE by the session duration (minutes).

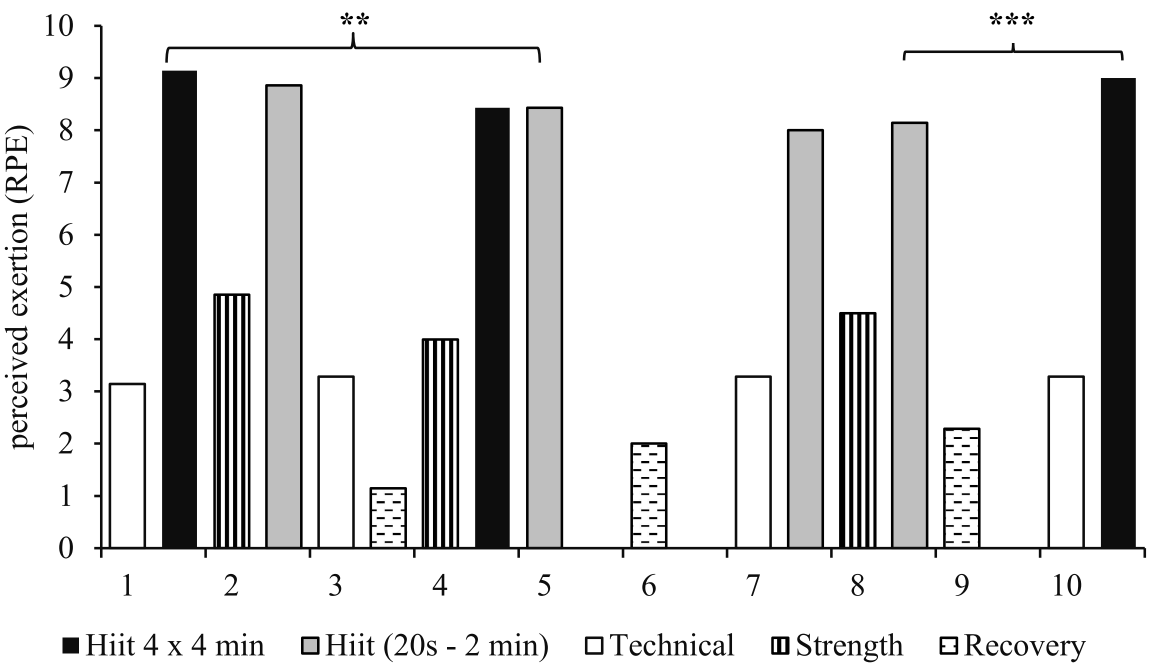

FIGURE 7. Perceived exertion (RPE) during the intervention ($p<0.01$** and $p<0.001$***).

7.4 Measurements

The test subjects were familiar with all test procedures. The test battery consisted of the anthropometry measurements, vertical jumps (countermovement and squat jump), power measurements (squat and bench press), maximal isometric leg press and bench press and aerobic and anaerobic performance tests. Anaerobic performance was evaluated with the 30 s all-out Wingate anaerobic test. Maximum aerobic capacity was evaluated with the incremental exercise test (VO_2max test). The intervention training program took 10 days. The post-tests were hold 3-4 days after the training program.

The speed and strength tests were done on the first day. Participants were divided into three test groups (figure 8). The aerobic test was on the second test day. The same test protocols were done in the post-test period, at the same time of day, to prevent performance and physiological variations concerning the circadian rhythm. The test subjects were asked not to train one day before before the test and to eat their last (caffeine free) meal at least 2 h before the planned test time.

8.00	10.00	11.00	12.00
A	B	C	D

FIGURE 8. Timetable of measurements for the first test group on the first test day.
A Anthropometry (weight, height, body composition, skinfold thicknesses)
B Muscle power measurements (CMJ, SJ, box squat, bench press)
C Maximum isometric force (leg press and bench press)
D Anaerobic performance (30-s Wingate)

The anthropometric measurements were taken before the breakfast at 8 am. It included weight, height, body composition and body fat. Body composition was assessed in two different ways. The body composition analyzer (Tanita MC980, Tokyo, Japan) was used first. After that body fat was calculated from the 4-point skin fold measurement in triplicate using a calibrated skin fold calliper (Durnin & Rahaman 1967). The skinfold thickness was measured from triceps brachii, subscapular, supraspinale and biceps brachii.

The muscle power was measured with vertical jumps and free weight exercises. These methods are commonly used among judo athletes to measure muscle power (Franchini et al. 2011). Vertical jumps, counter movement jump (CMJ: starting from the lengthened leg posture down to the 90° knee flexion followed by a concentric action without the arm swing) and squat jump (SJ: starting from a knee flexion of 90°) were performed on a force platform (HUR, Kokkola, Finland). The device's program (Force Jump Software) calculated jump height by takeoff velocity (cm). Each athlete performed first three maximal CMJs interspered with 30 s of passive recovery and the best height was used for further analysis. The same procedure was used for squat jump. During both tests test subjects were asked to jump "as high as possible".

The free weights measurements (back squat and bench press) were performed with the linear encoder (Muscle Lab, Ergotest A/S, Porsgrunn, Norway) (figure 9). The device was used to examine peak force, velocity, and power in the box back squat and bench press. Test subjects performed squat with three times two repetitions with maximal effort using the load of 60% of 1 RM. One repetition's maximum was calculated from previous strength training experience.

In the bench press the load was less, approximately 50% of 1 RM. (Izquierdo et al. 1999; Thomas et al. 2007.) Equal loads (kg) were used in the pre- and post-tests.

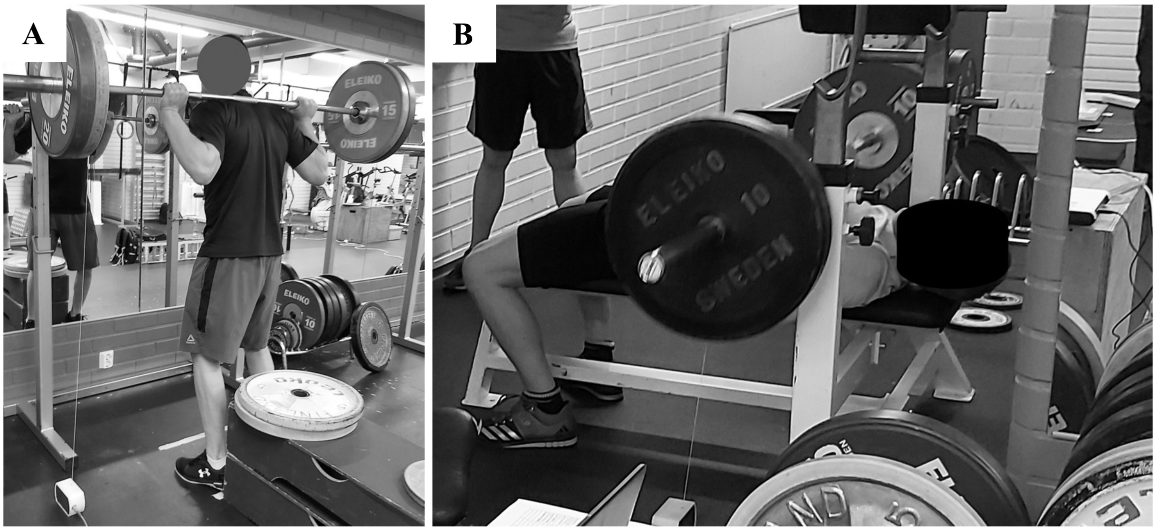

FIGURE 9. Muscle power in the box back squat (A) and the bench press (B).

The maximal isometric strength for leg press was measured using an isometric leg-press (HUR Performance Recorder, Kokkola, Finland) (figure 10). Each test subject made 3-4 maximal attempts with the knee angel 110°. Maximal voluntary isometric contraction was sustained for approximately 3 s with a rest period of 60-120 s between attempts. The same procedure was done with the isometric bench press on the force platform (HUR, Kokkola, Finland). The test subject performed the isometric bench press with the shoulder wide grip feet in the air.

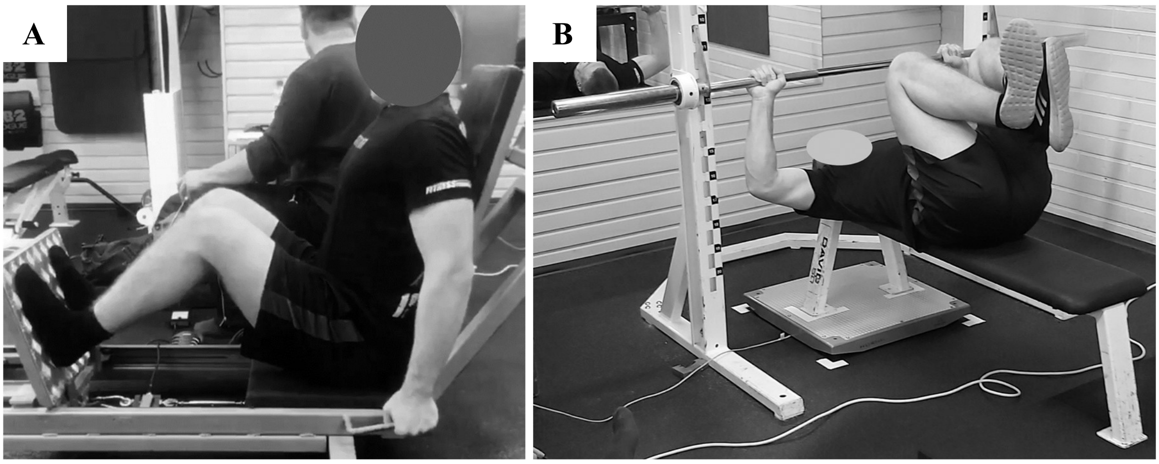

FIGURE 10. The isometrig leg press (A) and the isometric bench press (B).

The anaerobic performance was evaluated with the Wingate 30 s anaerobic power test on a weight ergometer (Monark Ergomedic 894E, Monark Exercise AB, Vansbro, Sweden) (figure 11). During the measurement, test subjects made a short warm up for two minutes which included a brief spurt (6 s) with intended workload. In the measurement, a brake weight was calculated as 7.5% of body weight (Inbar et al. 1996). The test subjects made a quick acceleration (3 s) without load to reach maximal pedaling speed after which the load was released. The entire measurement was recorded to a computer using Monark Anaerobic Test Software. Determined variables throughout the time of the test were peak power (W), mean power (W/kg), fatigue index and maximum post-exercise blood La (immediately, 4, 7 and 10 min) in passive (seated) recovery. During the test, strong verbal support was given to ensure maximal effort.

FIGURE 11. The Wingate 30 s anaerobic power test for lower body.

Maximal aerobic capacity (VO_2max) was determined via running with an incremental exercise test that lasted until exhaustion (figure 12). The start speed was 8.0 km/h with the incline at 0.6°. Before the test, test subject performed 10 min warm-up with the starting speed. Every three minutes the test was stopped in order to take blood samples from a fingertip for the determination of La. Running speed increased every three minutes by 1 km/h up to 15 km/h after which the incline rose every three minutes by 1° until exhaustion.

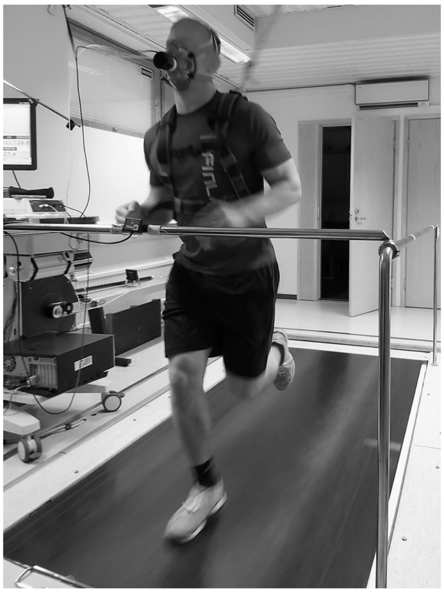

FIGURE 12. The incremental exercise test.

During the test, breath by breath gas exchange data was collected by the spiroergometry system (MetaLyzer 3B, CORTEX Biophysik GmbH, Leipzig, Saksa) and heart rate was recorded. Calibration measurements were carried out according to the manufacturer's instructions. Variables determined were VO_2max, the aerobic and anaerobic thresholds, maximal blood La level and time to exhaustion. VO_2max was determined from the average of the two highest 30-s measurements. A strong verbal support was given to all subjects during all tests until exhaustion to ensure maximal effort.

To measure acute responses of HIIT sessions during the intervention, the control measurements were done during the first and the last HIIT sessions. The measurable variables were CMJ and power output of the bench press (figure 13). The measurements were done after the warm-up and straight after the last interval. Each test subject made two CMJs with short brake and two maximum bench press movements with the same weights as in the pre- and post-tests.

FIGURE 13. The control measurements (CMJ and power bench press) during HIIT sessions on day 1 and day 10.

7.5 Statistical analyses

Descriptive statistics of the data are presented as means ± standard deviation (± SD). The normality of data was tested using the Shapiro-Wilkin test which is suitable for small sample sizes. To test if the training intervention improves performance in male judo athletes, differences between pre- and post-tests were compared using paired Students *t*-test, and two-way ANOVA with different HIIT protocols. In addition, physiological ($\%HR_{max}$) and perceptual (RPE, session-RPE) variables were used. Once significant difference was noticed for either main effect, Bonferroni post-hoc analysis was done in the measurements among different training sessions. The level of significance was set at $p \leq 0.05$. Other *p* values were $p<0.01$** and $p<0.001$***. The associations between HR zone 3 and other measured variables were tested for linearity with Pearson's product-moment correlation coefficients.

Cohen's effect size (ES) was also calculated for comparison of the variables analyzed. Cohen's d statistics represented effect sizes with thresholds of 0.20-0.50, > 0.50-0.80, and > 0.80, interpreted as small, moderate and large effects, respectively (Cohen 1990). Data was processed and graphed using Microsoft Excel for Office 365 (Microsoft Corporation, Redmond, Washington, US) and statistical analysis was done using IBM SPSS Statistics version 26 (IBM Corporation, Armonk, New York, US).

7. RESULTS

8.1 Body Composition

There were no statistically significant changes in body weight (77.6 ± 9.6 kg vs. 78.8 ± 10.1 kg, p=0.03, ES -1.06) nor body composition during the intervention. Body fat increased significantly based on the body composition analyzer but stayed the same according to the 4-point skin fold measurement (10.6 ± 3.4% vs. 12.6 ± 3.6% and 12.3 ± 2.5% vs. 12.6 ± 2.8%, respectively).

8.2 Neuromuscular system

There were no statistically significant changes in the performance variables of the neuromuscular system. The strength performance responses obtained in the seven HIIT protocols used in this are presented in table 5.

TABLE 5. Strength performance values obtained at the pre- and post-test. Values are mean (±SD).

Measurements	before training	3 days after training	*P*	ES	% of change	n
Muscle power						
CMJ (cm)	42.2 ± 4.6	41.5 ± 7.9	.63	0.2	-2.8 ± 11.3	6
Squat jump (cm)	42.5 ± 5.9	43.6 ± 7.4	.34	-0.4	2.4 ± 6.4	6
Squat (W)	802 ± 208	823 ± 199	.33	-0.4	2.5 ± 5.9	7
Bench press (W)	553 ± 99	570 ± 122	.27	-0.5	3.1 ± 6.9	7
Maximum isometric strength						
Leg press (kg)	343 ± 86	339 ± 91	.68	0.2	-1.2 ± 8.2	7
RLP (kg/kg)	4.5 ± 1.1	4.4 ± 1.1	.41	0.3	-2.3 ± 8.6	7
Bench press (kg)	169 ± 16	171 ± 13	.66	-0.2	1.0 ± 5.2	7
RBP (kg/kg)	2.2	7.0	.92	0.0	-0.2 ± 4.8	7

back squat (60% 1 RM) [W]; bench press (50% 1 RM); RLP = relative leg press; RBP = relative bench press

Muscle power improved but the differences between pre- and post-test were not significant ($p>0.05$). There were no significant changes in vertical jumps although the results improved slightly. CMJ increased more than SJ (2.4 ± 6.4% vs. -2.8 ± 11.3%, respectively). Individual changes in CMJ and SJ are plotted in figure 14.

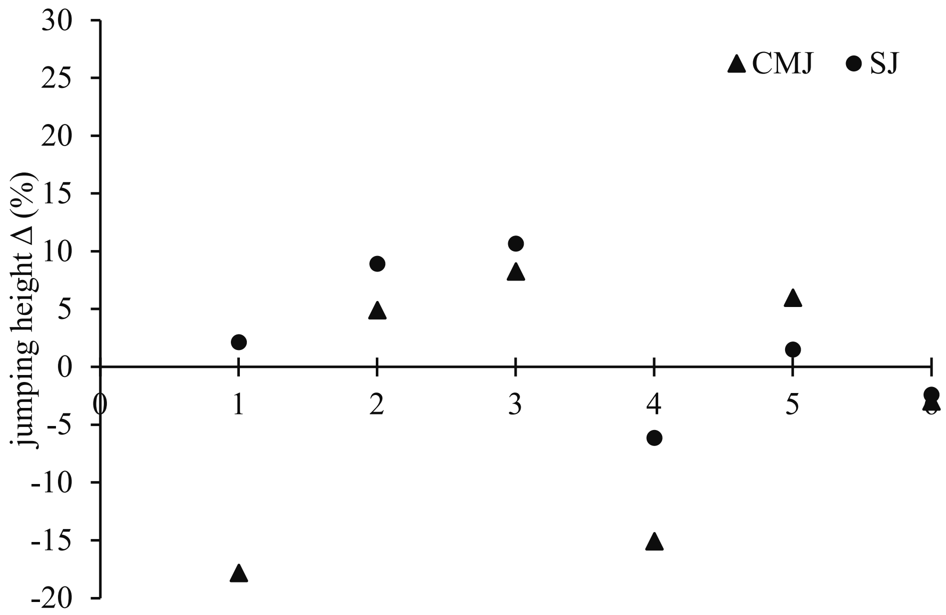

FIGURE 14. Individual changes (%) for counter movement jump (CMJ) and squat jump (SJ) after the training intervention.

Muscle power in back squat had showed a small increase (2.5 ± 5.9%) but this change was not significant ($p=0.33$). Correspondingly, in bench press the increase was 3.1 ± 6.9% ($p=0.27$). Individual changes can be seen in figure 15.

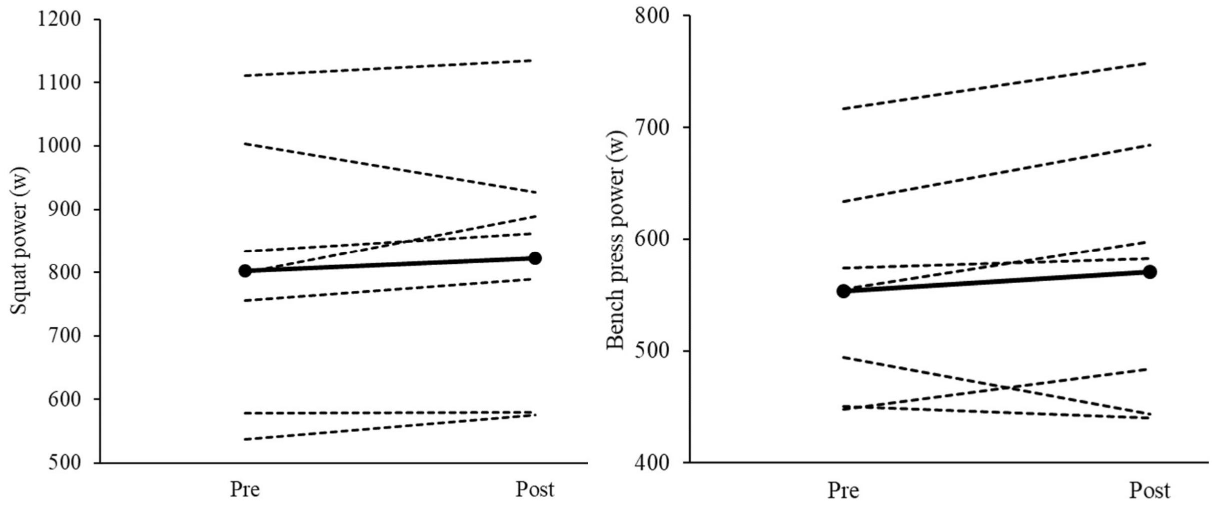

FIGURE 15. Individual muscle power values (W) in back squat and bench press at pre and post.

Maximum isometric strength levels (kg) remained almost the same between pre- and post-tests. Isometric leg press had showed a small decrease (343 ± 86 kg vs. 339 ± 91 kg, p=0.68). Isometric bench press remained about the same (169 ± 16 kg vs. 171 ± 13 kg, p=0.66). Relative maximum bench press correlated significantly between the pretest and its relative change (Δ%) during the intervention (r=0.761, p=0.047). Other measurements showed minor correlations between pretest and Δ% but they were not significant. Individual values for maximum strength can be seen in figure 16.

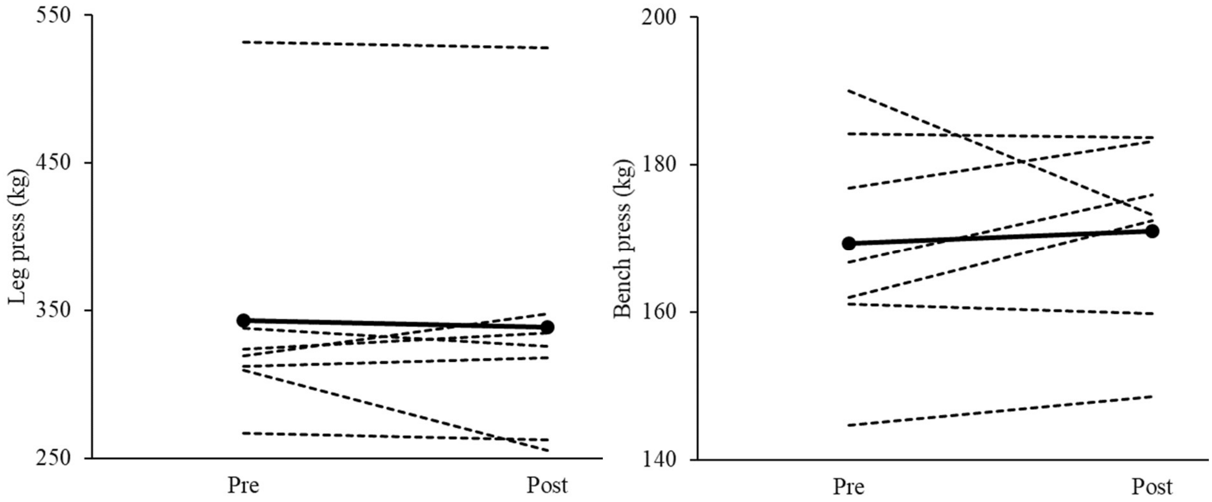

FIGURE 16. Individual maximum isometric strength values (kg) in leg press and bench press at pre and post.

8.3 Anaerobic profile

The 30 s Wingate test results decreased during the intervention but not statistically significantly (table 6). Peak power decreased from 803 ± 108 W to 761 ± 111 W, while the relative mean power (anaerobic capacity) remained the same. Individual changes in absolute peak power and mean power can be seen in figure 17. No significant correlations between pre-tests and Δ% were found.

TABLE 6. Anaerobic profile values at pre and post (n=6). Values are presented as means (±SD).

Measurements	before training	3 days after training	*P*	ES	% of change
Peak power (w)	803 ± 108	761 ± 111	.09	0.8	-5.2 ± 6.2
RMP (W/kg)	7.9 ± 0.2	7.8 ± 0.4	.59	0.3	-1.2 ± 4.3
Fatigue index (%)	41 ± 3	37 ± 5	.06	1.0	-9.3 ± 8.6
La 4 min (mmol/l)	13.1 ± 1.4	11.6 ± 1.4	.028*	1.3	-11.8 ± 9.6
Peak La (mmol/l / min)	13.4 ± 1.1 (5.0 ± 1.5)	12.2 ± 1.8 (8.0 ± 2.4)	.023*	1.3	-9.1 ± 7.3

ES = effect sizes; RMP = relative mean power. La 4 min = blood lactate 4 min after test. Peak La = peak blood lactate value right, 4, 7, 10 min after test. *Significant differences compared to pre-tests (p≤0.05).

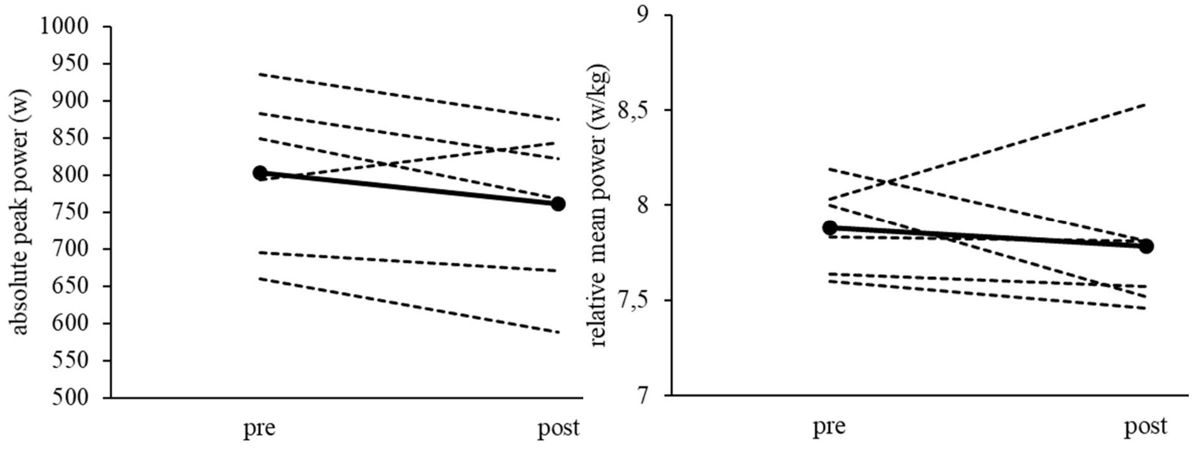

FIGURE 17. Individual values in absolute peak power and mean power at pre and post.

The blood La at 4 min after the Wingate test decreased significantly (-11.8 ± 9.6%) with a large effect size (ES = 1.3) (p=0.03). The mean of the pre-test value was 13.1 ± 1.4 mmol/L and post-test 11.6 ± 1.4 mmol/L (figure 18).

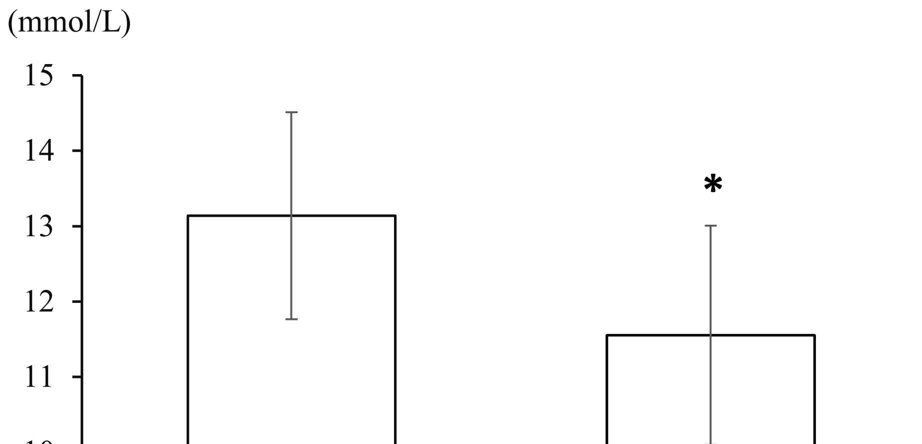

FIGURE 18. Blood La values 4 min after the Wingate test at pre and post (mean ± SD).
*p ≤ 0.05 indicates significant difference between pre- and post-test.

8.4 Aerobic profile

There were no significant differences between pre- and post in the incremental aerobic exercise test results. Neither relative VO_2max (ml/kg/min) (-2.8 ± 4.4%, p=0.13) nor absolute VO_2max (l/min) (-2.1 ± 4.3%, p=0.19) changed significantly (figure 19). Both relative and absolute VO_2max correlated significantly with Δ% changes during the intervention (r=-0.831, p=0.02 and r=-0.775, p=0.04, respectively) (figure 20). Mean ES of the relative decrease in VO_2max (ml/kg/min) and the decrease in absolute VO_2max (l/min) showed moderate effect size after the training intervention (ES = 0.7 and ES = 0.5, respectively).

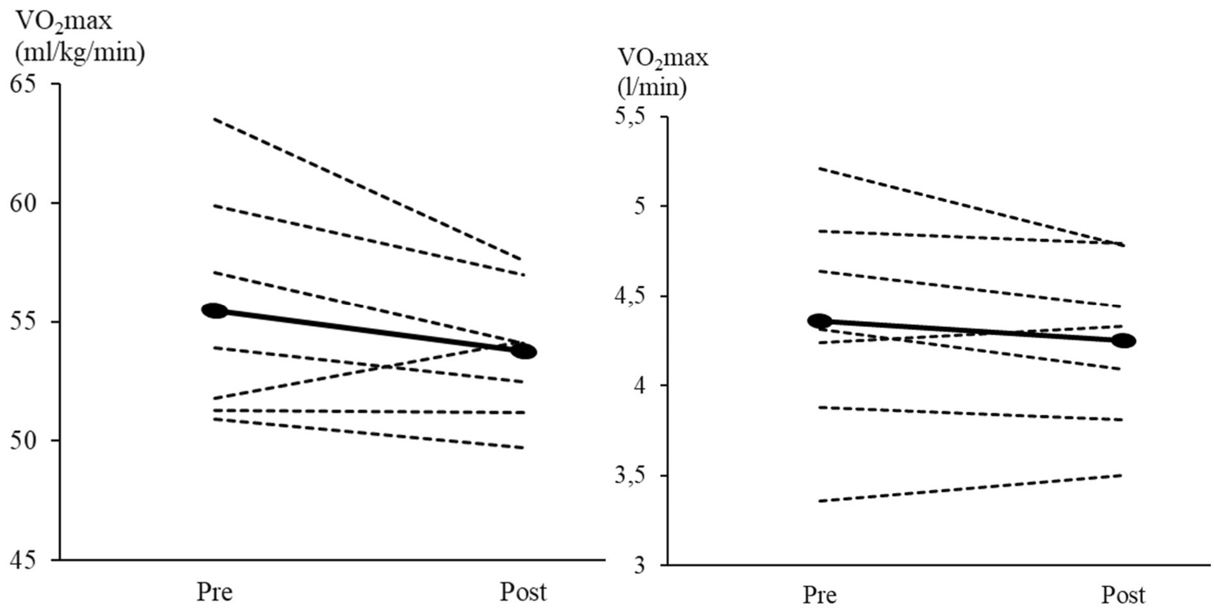

FIGURE 19. Individual data points for relative VO_2max (ml/kg/min) and absolute VO_2max (l/min) values at pre and post.

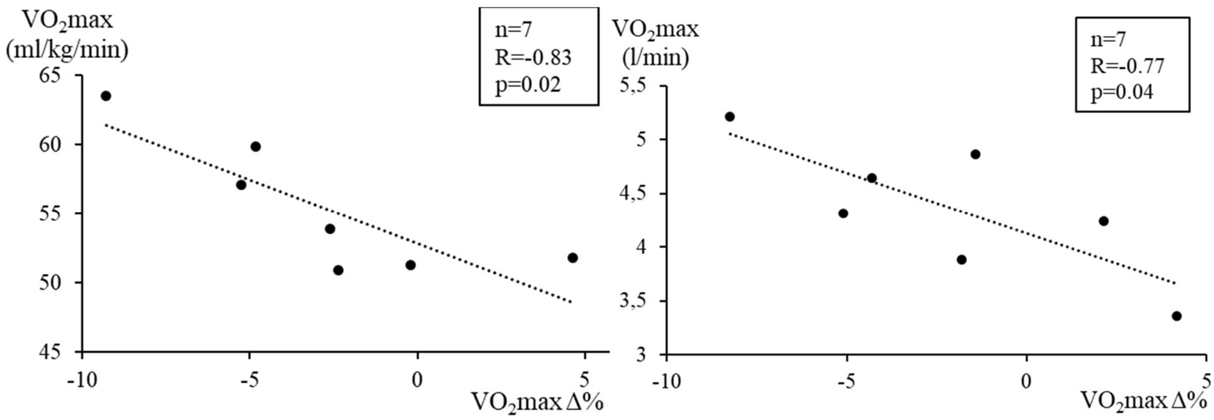

FIGURE 20. Correlations between relative and absolute VO_2max pre and pre-post changes.

During the incremental aerobic test, maximum HR was significantly lower (-1.5 ± 1.3%) at post-test compared to pre-test (p=0.02). Maximum blood La achieved during the test decreased significantly from pre to post-test (-15.4 ± 12.8%, p=0.05). Pre-test max blood La values correlated negatively with Δ% (r=-0.94, p=0.005). Mean ES of both drops were large (ES = 1.2 and ES = 1.1, respectively). The incremental exercise test results are presented in table 7.

TABLE 7. Aerobic power (n=6) at pre and post (means ±SD).

Measurements	before training	3 days after training	*P*	ES	% of change
VO_2max (ml/kg)	55.5 ± 4.8	53.8 ± 2.9	.13	0.7	-2.8 ± 4.4
VO_2max (l/min)	4.4 ± 0.6	4.2 ± 0.5	.19	0.5	-2.1 ± 4.3
LT_1 (bpm)	153 ± 10	154 ± 16	.79	-0.1	0.7 ± 7.2
LT_2 (bpm)	177 ± 10	177 ± 8	.82	0.1	-0.2 ± 2.8
HR_{max} (bpm)	195 ± 6	192 ± 5	.02*	1.2	-1.5 ± 1.3
MaxLa	13.0 ± 1.9	11.0 ± 0.7	.05*	1.1	-15.4 ± 12.8
Duration (min)	28.40 ± 2.48	27.24 ± 2.40	.08	0.9	-4.3 ± 4.7

LT_1 lactate threshold 1, LT_2 lactate threshold 2. MaxLa maximal blood lactate. * Statistically significant difference compared to pre-test ($p \leq 0.05$).

8.5 Acute responses

CMJ. There were no significant acute changes in the CMJ within the intervention's day 1 and day 10 HIIT session including 4x4 min intervals performed with the simulated judo matches (-1.5 ± 7.7% and 2.3 ± 6.9%, respectively). In addition, the difference between the CMJ changes in the HIIT sessions of day 1 and the day 10 HIIT were not statistically significant (p=0.255).

Bench press. Acute changes between the training-specific rest and post value in bench press power were not significant during the intervention's first (day 1) nor the seventh, the last HIIT session (day 10) (figure 21). When comparing the pre-test (rest) values to the intervention's post-test values, a significant difference was found between the last HIIT session's pre and the whole intervention's post value (505 ± 108 vs. 570 ± 122 W).

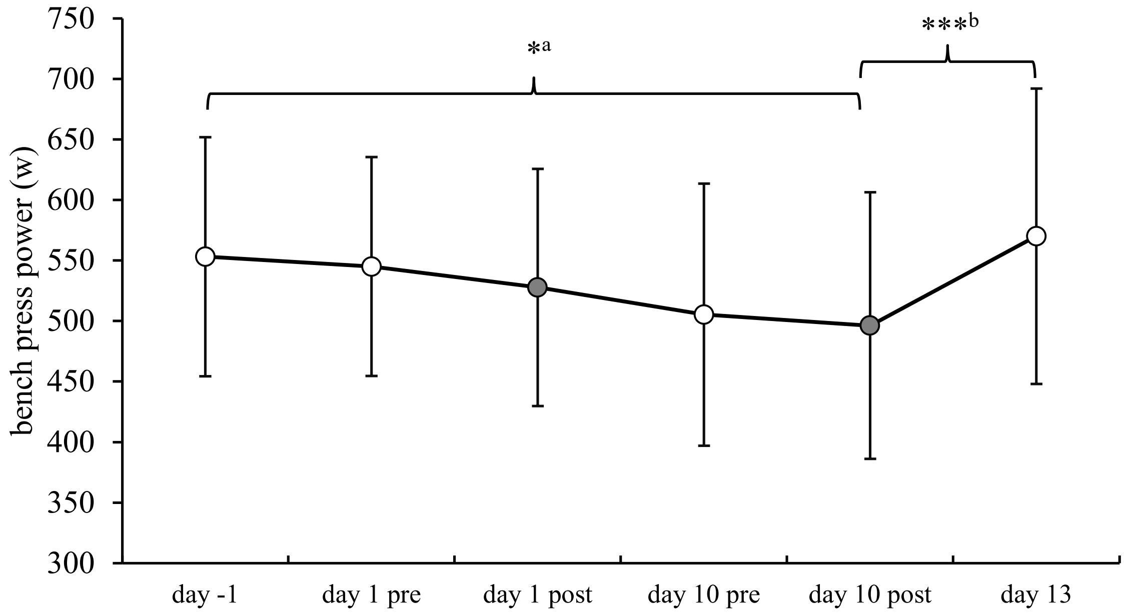

FIGURE 21. Acute changes in bench press power (mean ± SD). White circles are pre values and grey post values after training. * p≤0.05, *** p<0.001. a = Difference between the intervention's pre and last HIIT's post-test. b = difference between the last HIIT's post-test and the intervention's post-test.

Acute blood lactate changes. Blood lactate right after the first 4 min interval round decreased significantly from the first to the last HIIT session although the training contents were the same (-24.2 ± 13.6%, p=0.01). Also, blood La levels right after the third 4 min interval round decreased significantly from the training intervention's day 1 to day 4 HIIT session (26.3 ± 9.3%, p=0.0005). ES for both changes were large (ES = 1.38 and ES = 2.58, respectively) (figure 22).

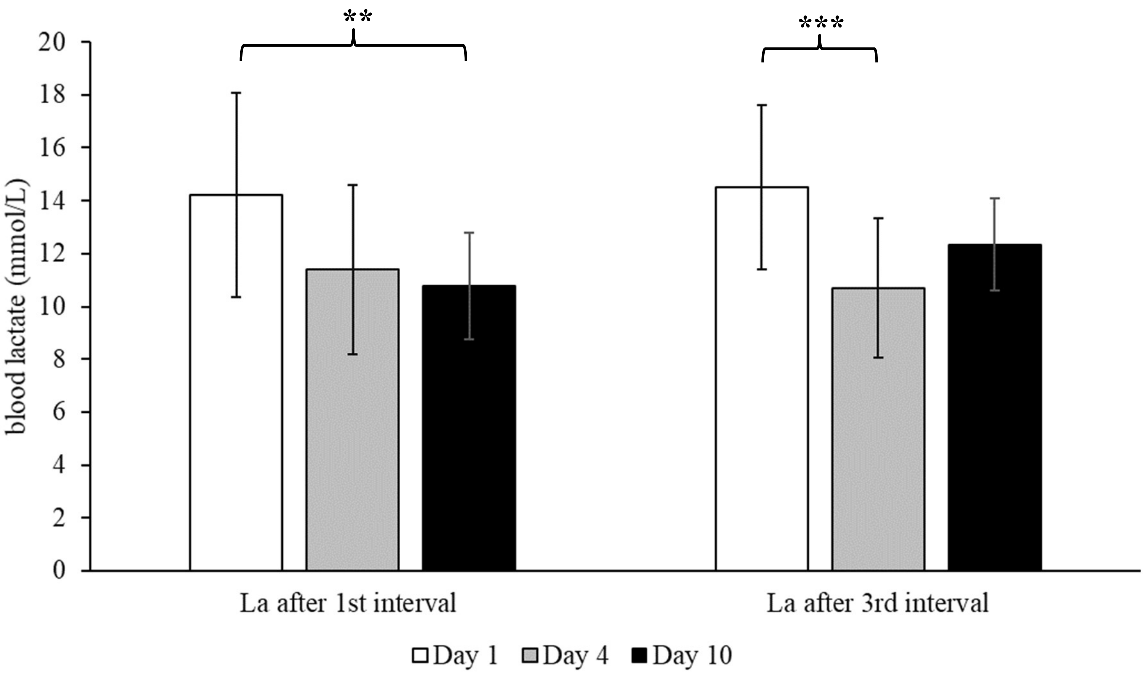

FIGURE 22. Acute blood lactate changes during the HIIT sessions (mean ± SD). La sample after the first 4 min interval. La sample after the third 4 min interval. **Significant difference compared to previous session ($p<0.01$) and *** $p<0.001$.

Training loading. When comparing HIIT session-specific loading, the first HIIT on day 1 seemed to be the most loading, while training $\%HR_{max}$ was 96 and the test group trained in average of 19 min in zone 3. The lightest loading was in the sixth HIIT session on day 8, where $\%HR_{max}$ was 91 and average of 6 min per athlete was spent in zone 3. When comparing the active work minutes at zone 3 during the similar 4x4 min intervals (1st, 3rd and 7th training session), there were no difference between zone 3-minutes (13.4 ± 2.8; 13.7 ± 1.3 and 14.1 ±

0.9 min, respectively). Moreover, there was no statistically significant correlation between VO_2max (ml/kg/min) pre-post change and total training minutes in zone 3 during the intervention (R=0.286, p=0.217). Acute physiological responses obtained in the seven HIIT sessions can be seen in table 8.

TABLE 8. Mean of acute physiological and perceptual responses obtained during the seven different HIIT sessions (means ±SD).

Measurements	Day 1	Day 2	Day 4	Day 5	Day 7	Day 8	Day 10
$\%HR_{av}$	77 ± 3	72 ± 2†	70 ± 3$^{\#}$	70 ± 2	71 ± 2	67 ± 3$^{\#}$	70 ± 3†
$\%HR_{max}$	96 ± 2	94 ± 2$^{\#}$	94 ± 1	93 ± 2	93 ± 1	91 ± 1*	94 ± 1†
zone 3	19 ± 2	16 ± 2$^{\#}$	16 ± 3	10 ± 2†	14 ± 2$^{\#}$	6 ± 4$^{\#}$	17 ± 2†
zone 2	6 ± 1	7 ± 2	8 ± 3	10 ± 2	7 ± 1	12 ± 3	8 ± 2
zone 1	47 ± 3	84 ± 3	81 ± 4	76 ± 4	63 ± 2	75 ± 5	79 ± 3
training (min)	73	107	105	97	83	93	104
La3 (mmol/L)	14.5 ± 3.1		10.7 ± 2.6†				12.3 ± 1.7
RPE	9.1 ± 0.4	8.9 ± 0.4	8.4 ± 0.5	8.4 ± 0.5	8.0 ± 0.6	8.1 ± 0.7	9.0 ± 0.6

$\%HR_{av}$ = percentage of average HR; $\%HR_{max}$ = percentage of maximum HR; RPE = rate of perceived exertion (1-10). * Statistically significant difference compared to previous session ($p \leq 0.05$). Other *p* values $p<0.01^{\#}$ and $p<0.001^{†}$.

8. DISCUSSION

The aim of this study was to investigate the effects of high-intensity interval training according to the short-term 10-day block periodization on physical performance characteristics during preseason training in male judo athletes. The main findings of the present study were that the short-term 10-day intervention including seven HIIT sessions did not significantly improve the physical performance level in male judo athletes. There was a small but not significant increase in muscle power (+2.4 - 3.1%). However, the aerobic and anaerobic performance showed tendency to decrease but large interindividual variation in changes could be observed (-2.1% and -5.2%, respectively).

The neuromuscular system. Judo throwing techniques require high speed and explosive muscle actions because they are performed against a great resistance from the opponent (Fagerlund & Häkkinen 1991). There were no significant changes in the measured performance variables in the neuromuscular system during the present intervention. A small but not significant increase was found in muscle power in SJ, bench press and box back squat. Maximum isometric strength levels remained almost the same. The isometric maximal leg press force decreased but, in contrast, the bench press force increased a little. A significant correlation was found in the relative maximum bench press between the pretest and the relative change during the intervention (r=0.761, p=0.047). Although the size of *n* was small, the result was logical and indicates that with the weaker physical level the development potential was higher. Wahl et al. (2014) found a similar small increase in the CMJ (p=0.06) in the 13-day HIIT intervention carried out in soccer players. Their subjects performed twelve times a HIIT session with 4 x 4 min (90-95 %HRmax) with 3 min active recovery (HIIT total 192 min) added into a regular soccer training program.

In addition to the study by Wahl et al. (2014), the results of the present study are consistent with that of Kinnunen and co-authors (2019). They found out that a short-term 2½-week HIIT period improved maximal and explosive forces in female ice-hockey players during a preseason. Their training consisted of two times a week performed six 30-second all-out sprints on a hill (4-minute rest) added in a regular training program. The results showed that sport-specific performance did not significantly improve which pointed out that the training period should have been longer, e.g. at least 4 weeks to make better on-ice performance. Thus, it can be argued that short HIIT block (e.g. 3 weeks) does not significantly affect on maximal performance of the neuromuscular system.

Anaerobic performance. As stated in the Sport Analysis of Judo, a typical time structure of the judo match is the 2:1 effort:pause ratio with 20 to 30 s of activity and 5-10 s of pause (Franchini et al. 2011). This means anaerobic metabolism that induces lactic acid to blood. No improvements were observed in anaerobic performance in the 30 s Wingate test in the present study. The peak power decreased by 5.2% and the relative mean power decreased by 1.2%. When compared to the pre-test, the test subjects did not achieve the similar blood lactate levels measured 4 min after the Wingate in the post-test since the blood La values decreased significantly (-11.8%, $p \leq 0.05$). The findings are contradictory with previous results. Astorino and co-authors (2012) completed 6 HIIT sessions of repeated 30 s Wingate tests (4-6 times in a session) with 48 hr rest over a 2- to 3-week period. Their study showed that the HIIT block significantly improved peak, mean and minimum power output in active men and women. In another study, Koral et al. (2018) showed that sprint interval training performed three times a week for two weeks improved the power performance in trained athletes. SIT consisted of 4-7 bouts of 30 s interspersed by 4 min of rest performed in the field. The peak and mean power increased by 2.4% and 2.8% ($p=0.009$ and $p=0.002$, respectively). Both Astorino et al. (2012) and Koral et al. (2018) performed repeated short-maximal 30 s sprints with running or cycling while in the present study bouts varied from 20 s to 4 min, most of them being 2 min or longer, and they were performed with judo. Hence, due to differences in the exercise loading characteristics, the results reported by Astorino et al. (2012) and Koral et al. (2018) are not completely comparable.

Aerobic performance. The aerobic power and capacity are believed to be relevant for a judo competition (Franchini et al. 2011). Higher VO_2max values should help judo athletes to keep a higher intensity during the match and adjust the recuperation between matches. In the present study the incremental aerobic exercise test did not show any improvements for aerobic performance. During the present intervention, the test subjects with good values in VO_2max in the pretest, weakened their VO_2max. The maximum heart rate was also lower in the post-test.

Therefore, in the present study the training period seemed to be indirectly too loading which led to a short-term overreaching. A weak correlation was observed between the development of the VO_2max (ml/kg/min) of the incremental aerobic exercise test and the total training minutes in zone 3 (HR > 87 %HRmax) ($r=0.761$, $p=0.047$). Were the reasons for the findings of the present study due to the present protocol because the subjects did not recover during 3-4 days from the training intervention and they were overloaded in the post-test? There is no true answer for this because no measurements were performed after post-test in the present study. However, in a similar short-term study Wahl et al. (2014) observed improved RSA and YoYo Intermittent Recovery Test Level 2 (YYIR2) in 13 days in male soccer players (both $p<0.001$). Similarly, Breil et al. (2010) measured the similar interval effects. The post-test showed significant improvements in absolute and relative VO_2max compared to body mass (+5.1% and +6%, $p<0.01$, respectively) and power output at the second ventilatory threshold (+9.6%, $p<0.01$).

Acute changes. The power level in lower body seems to separate the elite athletes from national judo players (Fagerlund & Häkkinen 1991). In the present study, the 4x4 min simulated judo matches induced no significant acute changes in CMJ. In addition, Carballeira (2008) reported no changes in CMJ immediately after the five 5-minute simulated judo match with 15 minutes of passive rest. However, previous results show some contradictory findings. Thus, Detanico et al. (2015) reported that CMJ declined after the second and third judo match (by 3.2 and 3.6%, respectively). In another study, Del Vecchio et al. (2018) reported a 4% performance loss in the CMJ right after the match.

Judo matches require power, endurance and strength characteristics performed also by the upper body (Franchini et al. 2011). Research have evaluated power from the metabolic point of view using the Wingate test, like Sbriccoli et al. (2007). However, only few studies have examined acute changes in the upper body power after the simulated judo matches. Bonitch-Góngora (2007) found out that there was an increase in the maximum arm power in bench press after judo matches which was based on the significant increase in the movement velocity for upper body. Nevertheless, the present study did not result in an improvement in acute power in bench press. The variable had a small decrease during both training sessions because several judo matches induced fatigue in the upper body.

Blood lactate is shown to be a very reliably variable related with the judo performance (Franchini et al. 2011; Sbriccoli et al. 2007). The HIIT sessions of the present study were controlled by blood lactate and heart rate. The La levels were high during the simulated judo matches (means between 10.7 ± 2.6 and 14.5 ± 3.1 mmol/L), thereby emphasizing the high intensity of the matches. These La findings were similar to previous studies, so the training intensity targeted in the study was achieved. Previous studies have shown also that La levels decrease during a training session (Bonitch-Domínguez et al. 2010; Bonitch-Góngora et al. 2011). This is opposite compared to the competition where La levels have shown to increase as competition progresses (Laskowski et al. 2012). This indicates that athletes must be able to perform with an increasing acidification (Franchini et al. 2011; Sbriccoli et al. 2007).

In the present study the analysis of the acute La changes during the simulated judo matches showed that the test subjects were not able to perform as high La levels as on day 1 compared to day 4 and 10 (figure 22), while the high-intensity interval training had been very loading and acid. Nevertheless, it is noteworthy that for the last acute La measurement on day 10, almost the same La levels were measured as on the first day. This may be because of psychological effect and exercise motivation. The test subjects knew that it will be the last work interval and gave it all for the last La measurement. Unfortunately to best of my knowledge, no studies have analyzed yet how lactate levels behave during the HIIT block in judo.

The purpose of monitoring training load is to control meaningful overload and unnecessary load in order to make training as productive as possible. The present study reported session-RPE values between 8.0 and 9.1 during the HIIT sessions. The values reported were about the same or higher compared to previous studies analysing RPEs with the simulated judo match, e.g. session-RPE 9.0 (Coswig et al. 2018). As planning and implementing the HIIT blocks, coaches should take into notice the training load to prevent overreaching symptoms when recovery and stress is not in the proper balance. To avoid this, a decrease in training load after a HIIT block is needed (Solli et al. 2019).

Limitations of the present study. The main limitations of the present study were an insufficient or too short a training period to create significant physiological improvements, the post-test was too close after the training period and/or that the additional measurements could not be performed also 2-3 days after the post-test. Furthermore, the present study did not use a control group and the sample size remained rather small. The original *n* was 11, two subjects could not start. Unfortunately, the subject number was reduced down to seven, while one subject was later left out for a personal reason and one for the injury. However, the study was performed using a typical real training programme. To obtain a better idea of its workability, a comparison of different training programmes between low intensity vs. HIIT would have been needed. Now the present subjects seem to have been overstressed right after the intervention in the post-test because most of the physical performance levels were weakened. In particular, the decrease of the maximum isometric leg press indicates that the present subjects did not recover after leg loading training period. For example, Fernandez-Fernandez et al. (2015) performed the 17-day HIIT period having the post-test 5 days after the last HIIT session. In addition, Wahl and co-authors (2014) had the 13-day intervention post-test on the sixth and 25th day after the training period. Breil et al. (2010) had 7 days rest before the post-test in a 11-day HIIT study. An important point to be considered in the present study is that the 3-4 rest days after the 10-day training period may not have been enough for the recovery and the tapering before the post-test. Although there are findings that 4 days of training cessation can maintain or even improve strength performance (Pritchard et al. 2018; Weiss et al. 2004). But in the present study, a short-term overreaching might have needed a longer period of training cessation before post-test. However, practical conditions did not give us opportunity to do changes in the design. Due to lack of financial resources and the covid-19, the post-test was performed too close after the training ended and this might have affected on the results. In a real-life content, the present HIIT block would have ended two weeks before a judo competition. This 2-week period would have included few high-intensity training sessions, like Breil et al. (2010) and Wahl et al. (2014) recommended. Besides, Bosquet et al. (2007) described that 2 weeks of tapering with a total decrease seems to be the most effective way to maximize performance improvements.

One disadvantage in the present study was that there might not have been enough training minutes at zone 3 (total 97.5 HIIT minutes) to improve aerobic and anaerobic performance levels. In similar short-term studies HIIT minutes have been around 200 and the intended intensity has been at the level of 90-95% HR_{max}. Wahl et al. (2014) performed 12 HIIT sessions with the total 192 HIIT minutes in 13 days. Correspondingly, Breil et al. (2010) completed 15

HIIT sessions in 11 days in alpine skiers (total 240 HIIT minutes). Moreover, HIIT has shown to be more effective with individualised and controlled intensity using a reference workload, such as the running velocity associated with $\dot{V}O_2max$ or the speed reached at the end of the 30–15 IFT (Buchheit et al. 2009).

Conclusions. The present study showed that a 10-day short-term interval training mesocycle (i.e., 7 HIIT sessions, intervals ranging from 20 to 240 s, intensity >87%HRmax) performed as simulated judo matches did not improve physical performance in the present male judo athletes. These findings are in opposite to the previous studies that have showed a positive effect of a short-term HIIT on physical performance and e.g. an improvement of aerobic capacity without the negative effects of power and strength. However, these training programs have varied from 4 to 12 weeks and HIIT sessions performed from 2 to 5 times per week with running or cycling (Franchini et al. 2019). In addition, their post-test was not so close to HIIT sessions as in the present study. Nonetheless, it is noteworthy that this short-term training block did not weaken the physical performance of the subjects either. More studies are needed in judo to verify if these short high-intensity interval training blocks are useful to judo performance.

Practical applications. Nowadays elite judo athletes have to participate in a large number of competitions throughout the year so that it reduces preparation time. As maintaining technical skills is important to a successful judo performance, simulated judo matches is an important way for improving an athlete's aerobic and anaerobic performance while still maintaining other important judo components. Through using this type of training, training time with sport-specific training will be maximised and training motivation should remain high. However, only the simulated judo matches do not present an appropriate exercise stimulus for individual athletes because of their backgrounds (i.e., ceiling effect for the fittest athletes and overload for those with poor aerobic capacities). Further research analyzing judo specific HIIT blocks are needed to be able to optimize their utilization in periodization of judo.

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