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EFFECTS OF TWO HIGH-INTENSITY INTERVAL TRAINING CONCEPTS ON PHYSIOLOGICAL AND PERFORMANCE PARAMETERS OF RECREATIONAL RUNNERS

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Introduction

Over the last years, there has been a growing interest focused on training protocols to improve physiological parameters and performance in recreational runners (Harris DJ, 2015, Brick NE 2016, Burgomaster KA 2008). Typical recreational runner's training program consists of different combinations among continuous high-volume, low-intensity training and high-intensity interval training (HIIT) sessions. Concerning the continuous training, it involves activity without rest intervals, whereas HIIT involves repeated short (about tens of seconds) to long (few minutes) bouts of high intensity exercise, interspersed with brief periods of low-intensity work or inactivity. The purpose of HIIT is to repeatedly stress the physiological parameters involved during a specific endurance-type exercise (Billat et al. 2000) largely than those actually required during the activity. HIIT has been shown to be effective in improving VO_2max, cardiovascular and peripheral adaptations, and running economy in both untrained and endurance-trained participants (Laursen et al. 2002), Several variables should be taken into account when designing a training program, including work interval intensity and duration, as well as between-series recovery duration and intensity.

The aim of the present thesis was to compare in recreational runners two types of high intensity interval training (HIIT) can produce higher improvements in running performance in recreational runners, the physiological, performance and perceptual responses induced by 10-20-30 training program with those induced by 30-30 training, in order to provide general recommendations for the more effective HIIT program in these runners.

The present dissertation is articulated in two Sections and 11 chapters. In Section I, (chapters 1-6) I will describe the historical bases and evolution of HIIT; the scientific basis of HIIT; a summary of how to prescribe HIIT for athletes; the acute responses to variation of HIIT and the effects of HIIT on neuromuscular and musculoskeletal systems, and, finally, the perspectives of HIIT adoption in health promotion and cardiac rehabilitation. Section II (chapters 7-11) is dedicated to the experimental study and discussion of the results obtained during the research period.

SECTION I

1 Origins and evolution

Interval training consists in the repetition of bouts of rather high intensity exercises – equal or superior to maximal lactate steady state velocity – and recovery intervals consisting of light exercise or rest. Reindell and Roskamm first described this particular training practice in 1959 (Reindell H, 1959) and in the 1950s the Olympic champion Emil Zatopek contributed its popularization. Concomitantly athletes used it to train at levels of intensity similar to competition speed. Although interval training has always been used by cross-country athletes for their own training activities, it was not published in scientific journal and thus we don't have any information regarding the scientific about this training.

Measuring VO_2 during exercise was already possible in 1910, but athletes weren't tested for training improvement although medium distance running athletes already used interval training for their training programs. In fact, the Finnish 10000 m Olympic championship runner Hannes Kolehmainnen had already used interval training at the specific pace of 10 km in 1912. Short interval training at an intensity superior to a specific velocity was introduced during the 1920s and 1930s, in the same period when Hill invented the concept of VO2max and oxygen deficit in order to explain the shape of velocity-time relationship, precursor of Fartlek run after a short time by the Swedish coach Gösta Holmer.

After world war II, interval training became largely diffused among European runners. Emil Zatopek was the most popular athlete to use interval training: he adopted short interval training at low amplitudes and running at critical velocity. In the 1960s the first scientific studies on interval training were conducted. The pioneer Swedish physiologist Per Oløf Astrand in 1960 developed long interval training at a range of velocity between the critical velocity and vVO_2max, which corresponds to 90-95% of vVO_2max. As a result, these 3 minutes run at about 90-92% of vVO_2max generated VO_2max in the last repetitions, in spite of the complete rest in between.

As all cardiorespiratory parameters were at their maximum, Astrand et all. believed that this was among the best forms of interval training (Astrand Ii 1960).

The first study describing the metabolic response during interval training with specially short periods ranging from 5 to 30 seconds was published in 1960. Considering that, at the time, automatic methods for VO_2 measure were not available, this study was very notable. In particular, the Authors reported that a runner (the individual BS, with a VO2 max equal to 5.6 L/min, 56 ml/min/kg) sustained a 30 minutes training consisting in very short intermittent runs of 15 seconds, alternating brief heavy intensity repetitions at 100% VO_2max with 15 seconds of complete rest, with low levels of blood lactate, equal to 2.3 mmol/L. Furthermore, this runner, at the end of the exercise, reached VO_2max.

The first studies examining both the immediate and log term effects on metabolism were published in the 1960s by the Astrand and Christensens group.

In the first study, the Authors compared the same work at the same power output, consisting in 360 W and and 98% of power output, or pVO_2max, but differing in terms of work durations (30 seconds, 1, 2, and 3 minutes). For this hard exercise, the Authors set a continuous time limit of 9 minutes. They found that splitting the cycling exercise in short periods of work and rest resulted in a sub-maximal load on both circulation and respiration: indeed they observed 63% of VO_2max and a lactate level of 2 mmol/L. As a consequence, the training was well tolerated during 1 hour (Astrand 1960).

In another research article published in the same volume, the group proposed the hypothesis that myoglobin would represent an oxygen store to be used during the first phase of work, before the actual oxygen demand could be met by the values reached by circulation and respiration (Astrand I 1960). This oxygen reserve was calculated to correspond to 0.43 L, which constitutes nearly the 10% of the maximal cumulative oxygen deficit gained in 2 minutes-all-out exercise (Medbo JI 1990).

This group also studied the oxygen kinetics during all-out exercise at pVO_2max, with a time limit of 9 minutes. They pointed the dependency of oxygen increase time course on both the work output and the subject's fitness; moreover the time course of oxygen increase was found to be unusually resistant to the mental state of the training subject. They found that for this specific athlete at this work rate, the VO_2max was reached in 4 minutes.

In the USA, at the end of the 1960s, the group of Fox and co-workers studied interval training in the military context comparing metabolic energy sources during same rates of continuous and interval training. In addition, they made a comparison between the physiological response for a recovery run, corresponding to 60% of VO_2 Max, and passive complete rest. As a result, they found that coaches were successful in enhancing the performance of highly trained athletes using the method of interval training: this result was explained by the slower accumulation of lactate and the consequent delayed onset of fatigue. (Fox EL, 1967).

The Swedish physiologists Bengt Saltin and Per Oløf Astrand in 1967 reported data on VO_2max for different athletes including Kip Keino, holder of the world record for 3000 m, which was 7 minutes and 39 seconds (Saltin B 1967). The Authors reported the highest value ever registered for a runner: it corresponded to 82 ml/min/kg and it was similar to the one reported by Robinson et al in 1937 for Donald Lash, the holder of the 2 miles word record, whose VO_2 max was 81 ml/min/Kg (Robinson S, 1937).

During the 1970s it began a common practice to constantly measure VO_2max in athletes, and later on, in the 1980s also lactate threshold was measured. Extraordinary runners such as Sebastian Coe (800 to 1500 m) were active during the 1980s. Coe's trainer was his father, a men very inspired by scientific methods. Sebastian Coe adopted both aerobic and anaerobic interval training as well as circuit training for the improvement of strength and power.

Interval training sessions with different velocities were used by North African runners such as the great middle-distance runner Said Aouita, who held the world record for both the 1500 m and the 5000 m. He used to run, in the same interval training session, at velocities ranging from the maximal lactic acid steady-state velocity to v5000: 94% of vVO_2max and then to 1500m, with distance varying from 3000 to 200 m.

The development of strength and power is another key factor in athletes training. Its importance becomes more and more prominent for the performance improvement over long distances, by reducing the cost of the activity. This aspect was highlighted by trainers such as Percy Cerutty. He trained two Australian distance runners, Herb Elliott and Hohn Landy, who were on top of international competitions in the late 1950s and early 1960s. Cerutty made these runners train in interval runs up sand-hills and perform extended weight training sessions. He advised all distance runners to spend at least one third of their training time in non-running activities, especially weight training, which can be organized in circuit training as an interval training.

Recently, the necessity of adopting weight training has been confirmed. They described the positive correlation between velocity over 5 km and maximal velocity, contact time and stride rates over 20 m (i.e. the running start). They reported a correlation between both velocity over 5 and 10 km and the average contact time of the constant velocity laps during 5 and 10 km.

The ability of fast force production during maximal as well as sub-maximal running was linked to both 5 and 10 km performance (Paavolainen et al. 1999).

Therefore, every type of interval training should be adopted in particular by middle distance runners up to 10000 m and, probably in the next future, by marathon runners.

In the 1950s interval training was successfully applied to the Swedish cross-country skiers; it included measurements of parameters such as heart rate, oxygen uptake (VO_2) and blood levels of lactic acid and scientific reports of physiological data were released only 20 years later.

2 Scientific basis

HIIT is today considered one of the most effective forms of exercise for improving physical performance in athletes (Billat et al. 2001, Laursen 2012), as it enhances both cardiorespiratory and metabolic functions. "HIIT involves repeated short-to-long bouts of rather high-intensity exercise interspersed with recovery periods". When programming HIIT different physiological variables have to be taken into account, starting from the maximal oxygen uptake (VO_2max). Considering that, both maximal cardiovascular and peripheral adaptations could be reached when athletes spend several minutes per session in the so-called "red zone" reaching at least 90 % of their VO_2max, it is suggested that HIIT protocols elicit VO_2max, or at least a very high percentage of VO_2max for the longest time possible (T@VO_2max). This kind of exercise allows:

- Maximally stressing the oxygen transport and utilization systems (Laursen et al. 2002, Midgley et al. 2006);
- Recruiting type II muscle fibers (Altenburg et al. 2007, Gollnick ei al. 1974);

- Achieving near-to-maximal cardiac output resulting in oxidative muscle fiber adaptation and myocardium enlargement

Then, considering that any exercise training session challenges, at different levels relative to the training content, both the metabolic and neuromuscular/ musculoskeletal systems, other physiological variables have to be considered for designing a HIIT session. As a matter of facts, acute physiological response to HIIT could be characterized in terms of contribution to metabolic processes (splitting of the stored phosphagens ATP and PCr, anaerobic glycolytic energy production by means of anaerobic breakdown of carbohydrate and combustion of carbohydrates and fats in the presence of oxygen) neuromuscular load and musculoskeletal strain.

In light of this, as suggested by Buchheit et al., (2013), physiological variables that have to be considered when programming HIIT session are summarized in the following table.

Primary variables	**Secondary variables**
Cardiorespiratory (i.e. Oxygen uptake; VO_2) data Cardiovascular work Stored energy Cardiac autonomic stress responses	Anaerobic glycolytic energy contribution Neuromuscular load/musculoskeletal strain

Table 1: Primary and secondary variables when programming HIIT

Thus, when a coach administers a HIIT program, he/she must evaluate the acute physiological responses it produces according to:

- Athlete's profile;
- Long-term adaptations;
- Performance and physiological model of the sport-specific;

- Training Periodization.

The schematization of athletes specific variables and the desired acute physiological responses to HIIT (in terms of metabolic and/or neuromuscular load) is shown in the following figure.

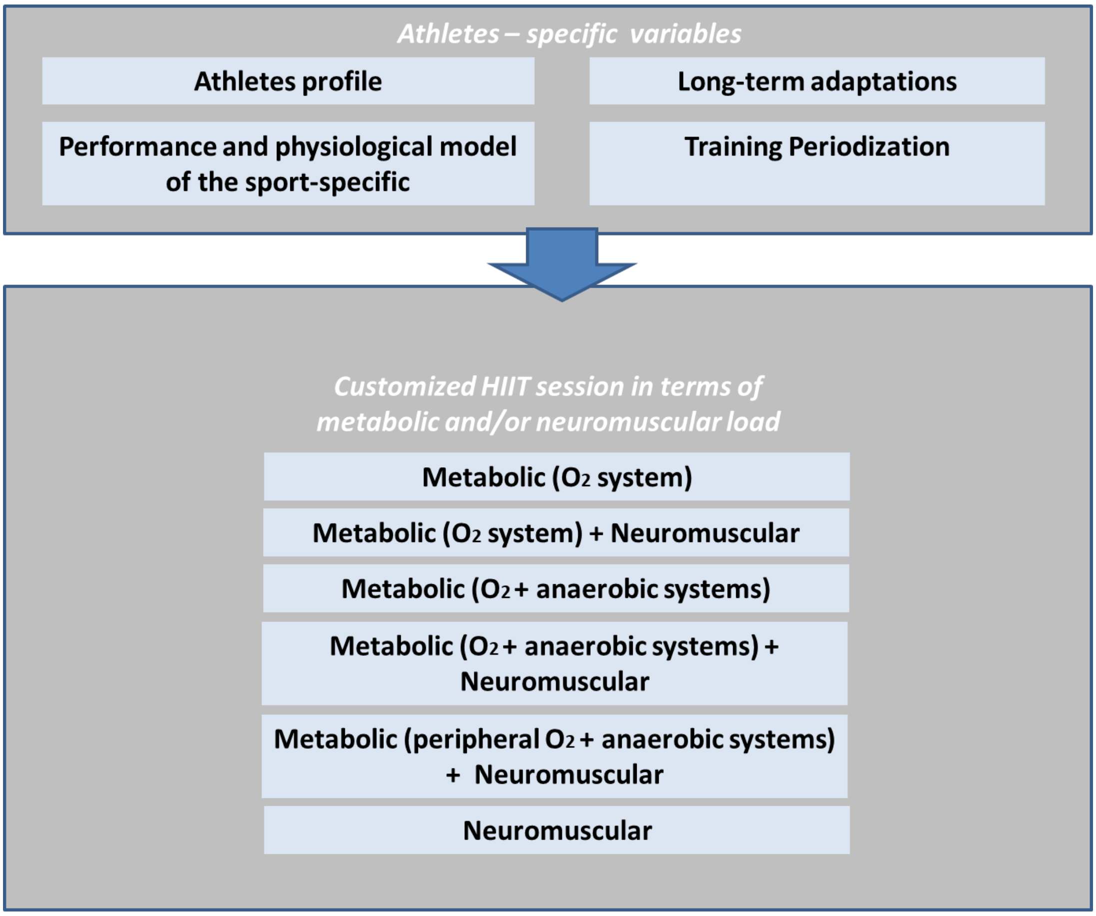

Figure 1: Athletes-specific variables and the desired acute physiological responses to HIIT

To obtain the aforementioned desired physiological responses coaches could manipulate at least nine variables (Fig. 2), as listed hereinafter:

- Duration of the work phase;
- Intensity of the work phase;
- Work modality/Operating mode;
- Duration of the recovery (relief) phase;

- Intensity of the recovery (relief) phase;
- Number of series;
- Series duration;
- Time between series;
- Between series recovery intensity.

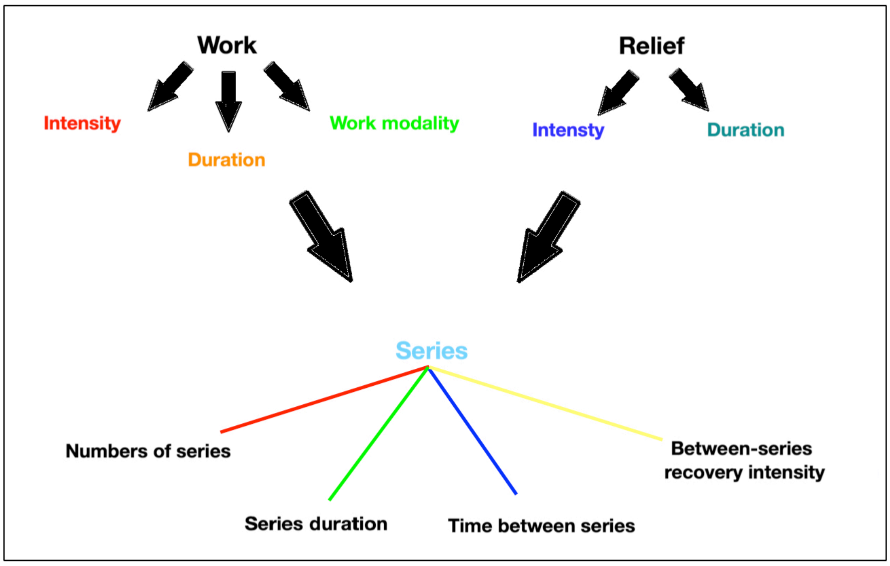

Figure 2: Illustration of the nine training variables defining a HIIT session

Managing each variable in isolation, where possible, produces a direct impact on metabolic, cardiopulmonary and neuromuscular responses; while the joint manipulation of different variables generates a less predictable training response, due to the close interrelation between the variables (Buchheit et al., 2013).

2.1 HIIT and recovery interval

As previously seen, one of the variables that influences performance is represented by the recovery interval between series. The recovery interval can be implemented with:

- Different times (short and long)
- Modes (active vs. passive)
- Types of exercises (running, cycling, and swimming)
- Intensities when active recovery is performed

A different organizations of recovery intervals may influence:

- Energy demand
- Muscle fatigue etiology
- Time to voluntary exhaustion (Tlim)
- O2 volume consumed
- Time to $\dot{V}O2max$
- Time spent at high percentages of $\dot{V}O2max$

Recovery interval can be of two different types:

- Active: this type of recovery allows remaining at a high percentage of VO_2max and maximal heart rate (HRmax), and a shorter time to return to these maximum parameters (Smilios I et al., 2018). The benefit of active recovery has often associated with changes in blood lactate concentration, which has little to do with muscle lactate concentration. Additionally, neither blood nor muscle lactate has a direct (nor linear) relationship with performance capacity. The current understanding is that active recovery can lower muscle oxygenation, impair PCr resynthesis (O2 competition) and trigger anaerobic system engagement during the following effort.

- Passive: it induces greater restoration of the intramuscular pH and, therefore, allow longer exercise time, and, consequently, a higher volume of O2 consumed (Spencer M et al., 2006). Also this type of recovery shows a greater resynthesis of PCr, and, consequently, maintenance or improvement of performance.

The choice of one type of recovery interval over another is not always easy, since several variables must be taken into account, such us:

- Type of sport practiced
- Level of fitness
- Duration of the recovery interval itself

A recent study carried out by Germano (Moisés D. Germano et al., 2019) on runners investigated how recovery interval’s type (passive and active) and duration (short and long) brings better results on performance. Within the study, each session was performed with a type and duration of the recovery:

- Short Passive Recovery (SPR - 2 minutes)
- Long Passive Recovery (LPR - 8 minutes)
- Short Active Recovery (SAR - 2 minutes)
- Long Active Recovery (LAR - 8 minutes)

The results obtained show:

- Blood lactate concentration: there were no significant differences between recoveries during the exercise period, but the LAR presented a significantly lower blood lactate value during the post-exercise period compared with LPR

- All the recoveries permitted reaching and time spent at high percentages of V̇O2max.
- All the recoveries may be efficient to generate disturbances in the cardiorespiratory system.

Another study of Kostoulas (Kostoulas ID et al., 2017) applied a protocol (similar to Germano's protocol) in 12 swimming athletes, with the use of passive and active recoveries that were short (2 minutes) and long (4 minutes). The athletes were submitted to 6x50 m sprints, and the intensity of the active recovery was performed at the lactate threshold of each subject. The 2 minute intervals showed no difference for lactate concentration and performance. However, the lactate concentration for the active recovery of 4 minutes was lower, in comparison to the passive recovery of 4 minutes. However, passive 4 minutes recovery resulted in better performance than the active 4 minutes protocol. It is important to note that although swimming is a different modality from that used in the study of Germano, the metabolic behavior seems to be similar for both modalities, as the lactate concentration was found to lower when active recovery was applied, and this was irrelevant to the performance.

3 HIIT for athletes in the field

The present section describes how to prescribe HIIT for athletes in the field with a particular focus on endurance runners. To program HIIT for endurance runners, coaches have traditionally used specific running speeds based on set times for distances ranging from 800 m to 5000 m, but without using physiological markers such as the speeds associated with VO_2max, lactate or ventilatory thresholds. The attraction of this method is that the entire locomotor profile (i.e. both maximal sprinting and aerobic speeds) of the athlete can be used to 'shape' the HIIT session, so that each run can be performed in accordance with the athlete's (maximal) potential. While for short intervals (i.e. 10-60 s) the reference running time will be a percentage of the time measured over a maximal 100 - 400 m sprint, the speed maintained over 800 - 1500 m to 2000-3000 m can be used to calibrate longer intervals (e.g. 2-4 to 6–8 min).

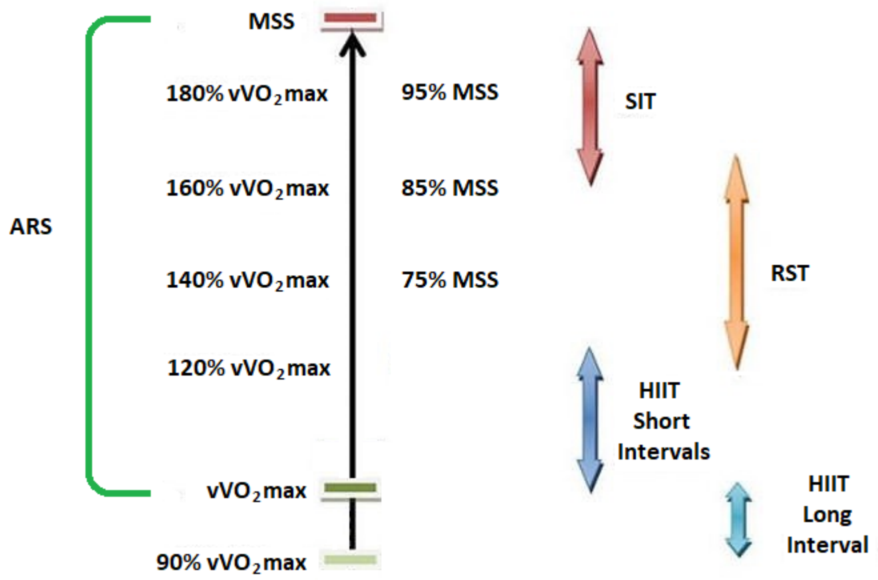

Figure 3: Intensity range used for the various run-based High-Intensity Interval Training (HIIT) formats. ASR, aerobic speed reserve; MSS, maximal sprinting speed; RST, repetitive sprint training; SIT, sprint interval training; VO_2max, maximal oxygen uptake; vVO_2max, minimal running speed required to elicit VO_2max.

There are three different methods, used by running coaches, to set and organize the HIIT training sessions and micro/meso/macrocycles: heart rate, Rate of Perceived Exertion (RPE) and Velocity/Power Associated with Maximal Oxygen Uptake (VO_2max).

Heart rate

Pros: direct and fairly precise evaluation of the internal load; (there are commercially available watches capable of detecting HR directly from the wrist without the aid of heart rate monitors).

Defects: for medium - long (1-2 min) and above all very short (<30 sec) exercises, it does not adequately estimate the exercise intensity for the temporal dissociation between HR, VO_2, blood lactate and work output during the sessions by HIIT (Buchheit et al., 2013). It has been seen that different types of HIIT sessions can determine a similar average cardiac response but with a higher blood lactate level in generic exercises and different running speeds in small sided games and therefore a different load.

Rate of Perceived Exertion (RPE)

Pros: it is a simple and versatile method, which allows athletes (after familiarization with the scale) to self-regulate the intensity of the exercise and coaches to prescribe the training by communicating to the athlete to maintain a certain value of the scale (intended as perception of effort) during the work and / or recovery phase (usually the work phase takes place at a value greater than or equal to 6 with the Borg CR10 scale).

Defects: in some cases it may not allow precise manipulation of the target variables for specific adaptations. Furthermore, some studies suggest that the ability to regulate or evaluate intensity through RPE may be dependent on the fitness status, age, intensity of exercise and athlete's satisfaction

Velocity/Power Associated with Maximal Oxygen Uptake (v/pVO_2max)

Following early works in the 1970s and 1980s (Volkov et al., 1975 Daniels et al., 1984), the physiologists Billat and Hill popularized the speed (or power) associated with VO2max (so-called v/pVO2max or maximal aerobic speed/power (MAS/MAP) (Billat et al., 1996, Hill et al., 1996) as a useful reference intensity to programme HIIT. The attractiveness of the v/pVO_2max method is that it represents an integrated measure of both VO_2max and the energetic cost of running/cycling into a single factor; hence, being directly representative of an athletes' locomotor ability, pVO_2max can be determined, or estimated, in a number of different ways. Methods include using the following:

- The linear relationship between VO2 and running speed established at sub-maximal speeds (Daniels et al., 1984);
- The individual cost of running to calculate a theoretical running speed for a given VO2max, either with (Di Prampero et al., 1986) or without (Lacour et al.,1990) resting VO2 values;
- Direct measurement (i.e. pulmonary gas exchange (Billat et al., 1994) during ramp-like incremental running/cycling tests to exhaustion, either on the track, on a treadmill or using an ergometer;
- A 5-min exhaustive run (Berthon et al.,1997), since the average time to exhaustion at VO2max has been reported to range from 4 to 8 min.

4 Acute Responses to Variations of Interval Training

In the review of Buchheit et al. (2013), a comprehensive analysis of the VO_2 responses to variations of Interval Trainings is presented, according to the following categories: Long intervals, Sprint Interval Training, Short Intervals and Repeated-Sprint Sequences sessions. A brief summary of these four typology and main characteristics is schematically presented in the following pictures, whereas more detailed information are described in the following subchapters.

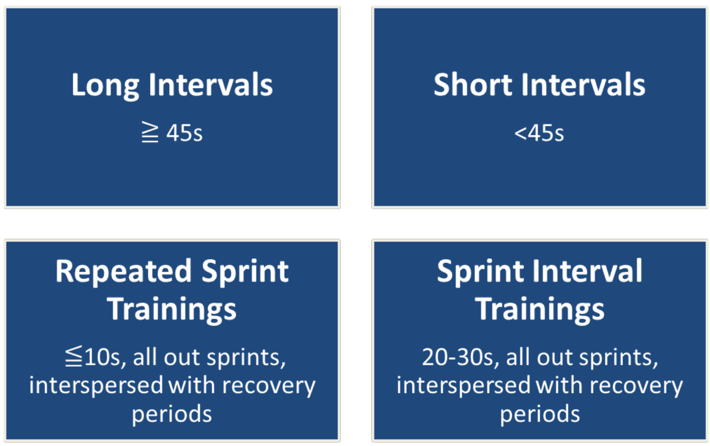

Figure 4: HIIT format

Long intervals

During a single constant-speed or power exercise, work intensity close to v/pVO_2max is required to elicit maximal VO_2 responses.

Repetition intensity

In the practice, athletes do not exercise to exhaustion, but use intervals or series. Slightly lower intensities (90% v/pVO_2max) can also be used when considering repeated exercise bouts (as during HIIT sessions), since interval VO_2 is likely to increase with repetitions with the development of a VO_2 slow component. As suggested in the 1960s, (Astrand et al., 1960) exercise intensity does not need to be maximal during an HIIT session to elicit VO_2max.

Interval Duration

During typical HIIT sessions (work interval duration/time needed to reach VO_2max), VO_2max is usually not reached on the first interval. VO_2max values can, however, be reached during consecutive intervals, through the priming effect of an adequate warm-up and/or the first intervals (that accelerates VO_2 kinetics (Gerbino A. 1996, Dorado C. 2004)) and the development of a VO_2 slow component. For this reason it is recommended using fixed intervals durations of 2–3 minutes.

Relief Interval

When programming HIIT, both the duration and intensity of the relief interval are important (Muller, 1953). In the context of long interval HIIT, passive recovery is therefore recommended when the relief interval is less than 2–3 min in duration. If an active recovery is chosen, relief intervals should last at least 3–4 min at a submaximal intensity to allow the maintenance of high-exercise intensity during the following interval. In practice, active recovery is psychologically difficult to apply for the majority of athletes, especially for non-endurance athletes.

Short intervals

For short interval HIIT runs to exhaustion, T@VO_2max is largely correlated with total exercise time (i.e. time to exhaustion) In practice, however, coaches do not prescribe HIIT sessions to exhaustion; they prescribe a series or set of HIIT (Millet GP 2003). In this context, it is important to consider the strategies needed to maximize T@VO_2max within a given time period, or to define 'time-efficient' HIIT formats with respect to the T@VO_2max /exercise time ratio (i.e. T@VO_2max in relation to the total duration of the HIIT session, warm-up excluded).

Repetition intensity

Billat et al. (2001) were the first to show the effect of exercise intensity on T@VO_2max during HIIT with short intervals (15 s/15 s) in a group of senior (mean age: 52 years) distance runners (vVO_2max = 15.9 ± 1.8 km/h). While the concurrent manipulation of the relief interval intensity (60–80 % of v VO_2max, to maintain an average HIIT intensity of 85 %) might partially have influenced the VO_2 responses, the Authors suggested that increasing work interval intensity from 90 % to 100 % of vVO_2max was associated with a 'small' improvement in the T@VO_2max/ exercise time ratio (81 % vs. 68 %, ES =0.5). However, the T@VO_2max/exercise time ratio (85 %) was not substantially greater using a work interval fixed at 110 compared with 100 % of v VO_2max (ES = 0.2). Using a fixed relief interval intensity, increasing work intensity from 100% to 110% of vVO_2max during a 30s/30s format in trained young runners (vVO_2max=17.7 ± 0.9 km/h) induced a 'moderate'increase in the T@VO_2max/exercise time ratio (ES= 0.6), despite 'very large' and 'moderate' reductions in time to exhaustion (ES = -4.4) and T@V O2max (ES = -0.7). A slight increase in work intensity from 100% to 105% of vVO_2max during a 30s/30s HIIT format in well trained triathletes (vVO_2max = 19.8±0.93 km/h) was associated with a 'large' improvement in the T@VO_2max/exercise time ratio. To conclude, it appears that during HIIT that involves short work intervals, selection of a work bout intensity that ranges between 100% and 120% of vVO_2max may be optimal.

Interval Duration

Increasing the duration of intervals and keeping constant recovery time $T@VO_2max$ increases (Millet et al., 2003). For instance, increasing the duration from 30s to 60s in a group of triathlon athletes (vVO_2max = 19.9 ± 0.9 km / h) has induced "significant increases of the $T@VO_2max$ (9 vs 1.5 min, ES = 2.4), despite a shorter total session time (28 versus 34 min). Considering the importance of VO_2 kinetics for extending $T@VO_2max$ (Millet, 2003), these data suggest that longer work intervals (e.g. 30 s/30 s vs. 15 s/15 s) are preferred for individuals with slow VO_2 kinetics (i.e. older/ less trained (Hill DW, 2003), or for exercising on a bike.

Relief interval

Generally, it is recommend programming passive recovery <15–20s for non-endurance sport athletes not familiar with performing active recovery, and/or performing active recovery during longer-relief interval durations (>20 s). In general, the characteristic of the relief interval intensity can be adjusted in alignment with the work intensity, with higher-relief interval intensities used for lower-work interval intensities (Billat, 2001), and lower-relief exercise intensities used for higher-work interval intensities and durations.

Sprint interval training

Few studies have been carried out in this framework. Nevertheless among those few available, very different individual VO_2 responses are recorded and partly correlated to variation in cardiorespiratory fitness and VO_2 kinetics at exercise termination. During these kind of sessions, despite pulmonary VO_2 is relatively low, muscle O_2 demand is high and tends to increase during sprint repetitions as the dependence on oxidative metabolism becomes greater.

Duration of repetition: between 20 and 30 seconds;

Repetition intensity: all-out, i.e. maximum possible speed in each interval;

Recovery mode: passive, to keep sprint performance fairly constant;

Duration of recovery: greater than or equal to three times the duration of the sprint (always manage it on the basis of the acute and chronic physiological response wanted).

Repeated sprint training

As for sprint interval training, also for reaped sprint training only few studies and results are available showing the related effects on VO_2. Nevertheless, it is shown that VO_2max is often reached and sustained for 10–40% of the entire RSS duration. If RSS are repeated two to three times per session, as is often done in practice, the majority of athletes may spend up to 2–3 min at VO_2max during the repeated sprints. To increase T@VO_2max during an RSS, it appears that sprints/efforts should last at least 4s, and that the recovery should be active and less than 20s. Nevertheless, with very short passive recovery periods (i.e. 17s), some athletes can reach VO_2max by repeating 3s sprints only (15 m). Future studies will have to focus on the optimal training modality. It can be useful to include changes of direction in repeated sprints, bearing in mind that this increases the neuromuscular contribution.

Duration of repetition: 3-10 seconds;

Repetition intensity: all-out;

Recovery mode: active or passive based on the physiological response wanted and the training objectives (in the same way as that described for the other types);

Recovery time: between repetitions between 20 seconds and 60 seconds, bearing in mind that less recovery determines more time spent at VO_2max.

5 Neuromuscular load and musculoskeletal strain

Quantifying the neuromuscular load of a HIIT session is important, since it influences the performance of a HIIT session, the T@VO_2max and could influence the subsequent training session. Modulating long-term neuromuscular adaptations can influence the risk of injury during training, leading athletes to incur traumatic injuries, and post-training, chronic excessive load injuries. Fatigue induced by HIIT from very short (<20 sec) to short (1 min) and/or non-maximal efforts (≤ ~ 120% vVO_2max) tends to be predominantly peripheral (changes in muscle excitability and excitation-contraction coupling. In this type of effort induced fatigue tends to become central if the number of repetitions is increased (> 10 rep) leaving passive recovery unchanged. Increasing the duration of the efforts (> 1 min) and the intensity of the efforts determines an increase in the induced fatigue both at the peripheral and central level, to prevent this from happening it is necessary to manipulate the HIIT variables in order to maximize the training stimulus and minimize the risk of injury and / or muscle injury. There seems to be no correlation between intermittent training and the decrease in strength in the lower limbs investigated by means of a CMJ Test (Counter Movement Jump); the subjects, marathon runners and medium distances, after running sessions (3x20 sec v@VO_2max with 40 sec of passive recovery) were tested on the CMJ and there was no drop in the height of the jumps performed .Acute neuro-muscular responses in performing 5x300 m reps (77% of MSS and 120-130% vVO_2max) interspersed with 1 min of recovery (100 m of trotting walk) were examined in long distance runners. Despite the non-significant variations during a maximum extension of the MVC knee (-5%, with ES ~ -1.2) the HIIT session caused peripheral fatigue, as evidenced by a loss of efficiency in the excitation-contraction coupling efficiency (e.g. -28% for contraction ES-5). The contractile function of the muscle is recovered and also improved within 10 minutes from the end of the session while the maximum extension of the MVC knees remained decreased for at least 120 min (-5-6%, ES-1.2). The high intensity anaerobic commitments seem to induce a modification on the muscular elements such as to drastically reduce the athletic performance. During a workout based on an RSS protocol, the reduction in running speed between sprint repetitions is due to the progressive increase of stress on the locomotor system. The rate of decrease in speed (%dec) is the most commonly used index for assessing acute fatigue during SSR. The %dec correlated positively with the work/relief ratio (r = 0.48; 90% the confidence limits 0.21, 0.68). A higher work/relief ratio is generally associated with a reduced PCr resynthesis and an accumulation of lactate and metabolites in the muscle, which may partly explain the greater impairment of the ability to repeat sprints. If you use extremely short recovery periods (10 sec), the rate of decrease in speed increases considerably. This can lead to a significant load on the musculoskeletal system, therefore the neuromuscular aspect must be considered in order to avoid training overloads. In planning and periodization of training, the neuromuscular contribution in HIIT must be kept in mind, which increases mainly in the following cases:

- Tall grass, sand and heavy soil;
- Changes in direction;
- Introduction of jumps in the work interval;
- Imperfect running technique.

It is also essential to consider lactacid accumulation and therefore the contribution of this mechanism. In principle and as appropriate, the lactacid contribution increases (Buchheit et al., 2013):

- Increasing the intensity (mainly for short intervals);
- Decreasing the recovery time at a fixed work interval;
- Using passive recovery, especially in all-out intensities.

6 HIIT and Health Promotion

As previously mentioned HIIT is an increasingly popular training method, not only because it is able to bring benefits by reducing training times, but also because it can be applied in different contexts: from individual to team sports, in different training conditions (from amateur sportsmen to professionals), in different age groups, and above all in the framework of health promotion.

6.1 HIIT in cardiac rehabilitation

For the secondary prevention of cardiovascular disease, comprehensive cardiac rehabilitation is required. This involves optimal medical therapy, education on nutrition and exercise therapy, and smoking cessation. Of these, efficient exercise therapy is a key factor. A highly effective training protocol is therefore warranted, which requires a high rate of compliance. Although moderate-intensity continuous training has been the main training regimen recommended in cardiac rehabilitation guidelines, HIIT has been reported to be more effective in the clinical and experimental setting from the standpoint of peak oxygen uptake and central and peripheral adaptations.

However, the rationale for HIIT adoption is not fully substantiated in the scientific literature. Established guidelines for exercise testing and training, when carefully adhered to, reduce the likelihood of triggering a cardiac event or inducing musculoskeletal injury. Clinicians should likewise consider patient risk stratification and introduce HIIT as an alternative to MICT only after patients exhibit stable and asymptomatic responses to vigorous exercise training. Although HIIT adherence appears comparable with MICT during outpatient rehabilitation, compliance drops dramatically for unsupervised exercise. Despite the enthusiasm surrounding HIIT, its main advantage over MICT appears to be short-term exercise performance outcomes and indices of vascular function. Regarding benefits to cardiovascular disease risk factor modification, management of vital signs, and measures of cardiac performance, current evidence indicates that HIIT does not outperform MICT. Long-term outcomes to HIIT are currently uncertain and logistical constraints to HIIT incorporation need additional clarification. Based on these limited findings, derived from facilities and clinicians at the forefront of cardiac rehabilitation, the routine adoption of HIIT should be viewed cautiously. In conclusion, specific research directives are needed before the safety and effectiveness of HIIT can be confirmed and widely adopted in patients with known or suspected coronary artery disease, especially in unsupervised, nonmedical settings.

6.2 HIIT and Metabolic Pathologies

In the framework of metabolic pathologies, the use of interval training allows subjects suffering from metabolic syndrome, to increase aerobic capacity, improve endothelial functions, decrease diastolic and systolic blood pressure, improve insulin sensitivity and increase the use of fatty acids.

Interval training is also effective for improving other health indices including those indicative of blood sugar control. A recent systematic review and meta-analysis concluded that HIIT induces cardiometabolic adaptations similar to those of MICT in prediabetes and type 2 diabetes (Fealy CE et al., 2018). The effect of resistance compared with aerobic interval training is less well-studied, but a recent report described the effects of a CrossFit program that involved calisthenics, gymnastics, and weightlifting in addition to other exercises such as rowing (De Nardi AT et al., 2018). The sessions ranged from 8 to 20 minutes in duration including a warm-up and cool-down, and the main high-intensity phase elicited a heart rate of >85% of maximum. Six weeks of training, three times per week, improved insulin sensitivity and other indices of metabolic syndrome in overweight and obese adults with type 2 diabetes.

6.3 HIIT and the Brain

The impact of interval exercise on the functions of the brain through mechanisms is still under study nowadays. The main mechanisms identified are:

- Increased blood flow to the brain: it occurs at moderate training intensity (about 60% of VO2max), and therefore HIIT has no greater advantages than continuous moderate training.
- Upregulation of growth factors, such as Brain-Derived Neurotrophic Factor (BDNF): compared with MICT, HIIT produces more BDNF, suggesting that it may be an advantageous mode of exercise for promoting brain function via this mechanism; BDNF is critical for the growth, functioning, and survival of brain cells targeting key brain regions including the hippocampus, frontal and motor cortices, and the striatum. In these areas, BDNF enhances cell-to-cell communication. BDNF also promotes growth of new brain cells in the hippocampus. Although this cannot be directly measured in the human brain, magnetic resonance imaging can be used to characterize changes

in the structure of the hippocampus (Duzel E, 2016). Indeed, aerobic exercise has been shown to increase the size of the hippocampus in both young adults and older adults. It also may counteract the typical loss of hippocampal size that occurs with aging and Alzheimer's disease.

Brain processes improved via HIIT are:

- Motor learning: Individuals can learn new movements or re-learn movements after a neurological disease. Motor learning plays an essential role in rehabilitation and motor rehabilitation. HIIT improves the ability to learn a new motor skill, especially if this new task is performed shortly thereafter. In addition, the improvements in motor learning are more evident when interval training is performed at high intensity, suggesting that high intensity exercise also produces greater benefits in this area. (Thomas R, et al., 2016)
- Cognition: the two key brain regions affected by the interval exercise are the hippocampus and the frontal cortex. The hippocampus is essential for learning and memory. HIIT improves the memory function supported by the hippocampus, including high interference memory (i.e., the ability to distinguish very similar events and, for example, to find a known face in the crowd). The frontal cortex governs the functions exercises linked to self-regulation and attention. Interval exercise improves executive functions and selective attention in children and young adults. (Heisz JJ, et al., 2017).

The application of HIIT in the cognitive field could lead to following benefits:

- Improvements in some neurological diseases: HIIT reduces the risk of developing Alzheimer's disease or may still help slow the progression of the disease. In addition, HIIT has also been shown to be very useful for people with Parkinson's disease. After 16 consecutive weeks of interval training, in individuals with moderate Parkinson's, symptoms improved and there were benefits to the muscles (e.g. less fatiguing myofibers). In addition, 16 weeks of HIIT in these subjects increased brain activity, reporting an improvement in quality of life (Kelly NA, et al., 2017)
- Improvements also on the cognitive performance of healthy subjects: cerebral benefits were also confirmed in a 2017 study examining the effect of HIIT on cognitive performance in a group of 318 children. The authors show that HIIT is beneficial for cognitive control and working memory capacity compared to "a mixture of board games, computer games and quizzes" and that this effect is mediated by the Brain-Derived Neurotrophic Factor (BDNF).

SECTION II

7 Experimental study

As previously stated, the purpose of a High-Intensity Interval Training is to repeatedly stress the physiological parameters involved during a specific endurance-type exercise (Billat et al., 1996) largely than those actually required during the activity. This training has been shown to be effective in improving VO_2max, cardiovascular and peripheral adaptations, and running economy in both untrained and endurance-trained participants (Barnes et al., 2015; Buchheit et al., 2009). Several variables should be taken into account when designing a training program. These variables include work interval intensity and duration, as well as between-series recovery duration and intensity. As concerns exercise intensity, it has been demonstrated in both well-trained and moderate trained runners that the greater improvement in performance and VO_2max is obtained spending greater time per session in exercise bouts at an intensity close to or above at the VO_2max (i.e., “red zone”) (Buchheit et al., 2013 part1). Longitudinal studies demonstrated in endurance sports that the HIIT consisting of 30 s near maximal work interspersed with 30 s rest (30-30 training) improved performance (Billat et al., 2000; Thevenet et al., 2007) and oxygen uptake (Gorostiaga et al., 1991; Overend et al., 1992). Recently, it was proposed a new HIIT protocol for recreational runners, the 10-20-30 training concept, which consists of 1 min intervals of 30, 20 and 10 s at an intensity corresponding to ≈30%, ≈60% and ≈90% - 100% of maximal aerobic speed (MAS), respectively (Gunnarson and Bangsbo, 2012). This training, in which 10 s sprint intervals are combined with 30 s of low and 20 s of moderate intensity running, integrates anaerobic near maximal sprint work with periods of aerobic work. A following study demonstrated that this training protocol was able to induce higher performance improvements compared to continuous training, when applied to moderately trained runners (Billat et al., 2000).

At present, the scientific literature focused on the comparison between 10-20-30 training protocol and continuous training. However, it would be interesting to evaluate its efficacy in recreationally active runners with respect to others HIITs.

Furthermore, affective variables and psychophysiological stress are important predictors of individual compliance to training programs and future participation in recreational sport activities. Nevertheless, to the best of our knowledge, no study has compared physiological and performance effects as well as internal training loads between different HIIT regimes in recreational runners.

Thus, the aim of this thesis was to compare, in recreational runners, the physiological, performance and perceptual responses induced by 10-20-30 training program with those induced by 30-30 training, in order to provide general recommendations for the more effective HIIT program in these runners. The psychophysiological stress experienced by the participants during the two different HIIT regimes was evaluated by measuring the whole-body rating of perceived exertion (RPE).

Methods

Participants

Twenty-two recreational male runners, with at least 3 years of experience in running and a weekly training volume of about 15 km, were enrolled for the study and randomly divided into 2 groups with a block randomization design. They were assigned to one of the 2 training programs: the 10-20-30 group (n=11) and the 30-30 group (n=11). The participant characteristics of the 2 groups at baseline are reported in Table 2.

Before entering the study, participants were fully informed about the study aims and procedures, and they provided written informed consent before the testing procedure. All participants were instructed not to change their diet and physical activity practices throughout the intervention period. The experimental protocol was conformed to the code of Ethics of the World Medical Association (Declaration of Helsinki) and it was approved by the Ethics Committee of the University of Genoa.

	10-20-30 group	**30-30 group**	**p-value**
Age (years)	32.54 ± 3.05	38.18 ± 3.57	n.s.
Weight (kg)	69.83 ± 2.76	68.11 ± 2.68	n.s.
Height (cm)	174.09 ± 1.84	169.27 ± 2.84	n.s.
VO_2max (ml/kg/min)	43.01 ± 2.90	40.77 ± 2.78	n.s.

Table 2. Participant characteristics at baseline. Data are means ± SE. p values refer to the result of t-tests comparing data of the 2 groups.

Sample size

Estimation of sample size for this investigation was performed using VO_2max as a physiological response to exercise as one of our primary outcome measures. Sample size was estimated combining the normative data and the genuine change in VO_2max determined in previous works (Barnes and Kilding, 2015; Gormley et al., 2008). These assumptions generated a desired sample size of at least 18 participants. However, we recruited 22 subjects, 11 in the 10-20-30 group and 11 in the 30-30 group, to allow for drop-out during the intervention period.

Experimental design

Before and after the intervention period, participants underwent a) body composition assessment; b) cardiopulmonary exercise test (CPET), to determine both the VO_2max (ml/kg/min and L/min) and the maximal aerobic speed (MAS) (km/h), and c) 1 km run test (min). Immediately after the end of the last session of the first (T1) and of the eighth-wk (T8) training, internal workload was assessed through RPE. Intervention period lasted 8 wk. During the intervention, the10-20-30 group performed two 10-20-30 training sessions/wk, interspersed with one continuous training (CT) session/wk, the 30-30 group performed two 30-30 training sessions/wk, interspersed with one CT session/wk (Fig. 5). Participants were instructed to arrive in a rested and fully hydrated state and at least 3 h after a standardized meal and to avoid strenuous exercise in the 24 h preceding each test session. In addition, they were asked to refrain from caffeine and alcohol 24 h before the test. All tests were performed at 11 a.m. (± 1 h) of the day to avoid influence of circadian rhythms. All participants completed the testing and training sessions without complication. The procedure was generally well tolerated, and participants did not report dizziness, lightheadiness of nausea, symptoms that occasionally occur during this type of test. They were wearing a global position system (GPS) watch (FORERUNNER 15, Garmin, Olathe, KS, USA), to monitor the training intensity. All training sessions were performed outdoor on a 400 m synthetic track in dry and windless conditions.

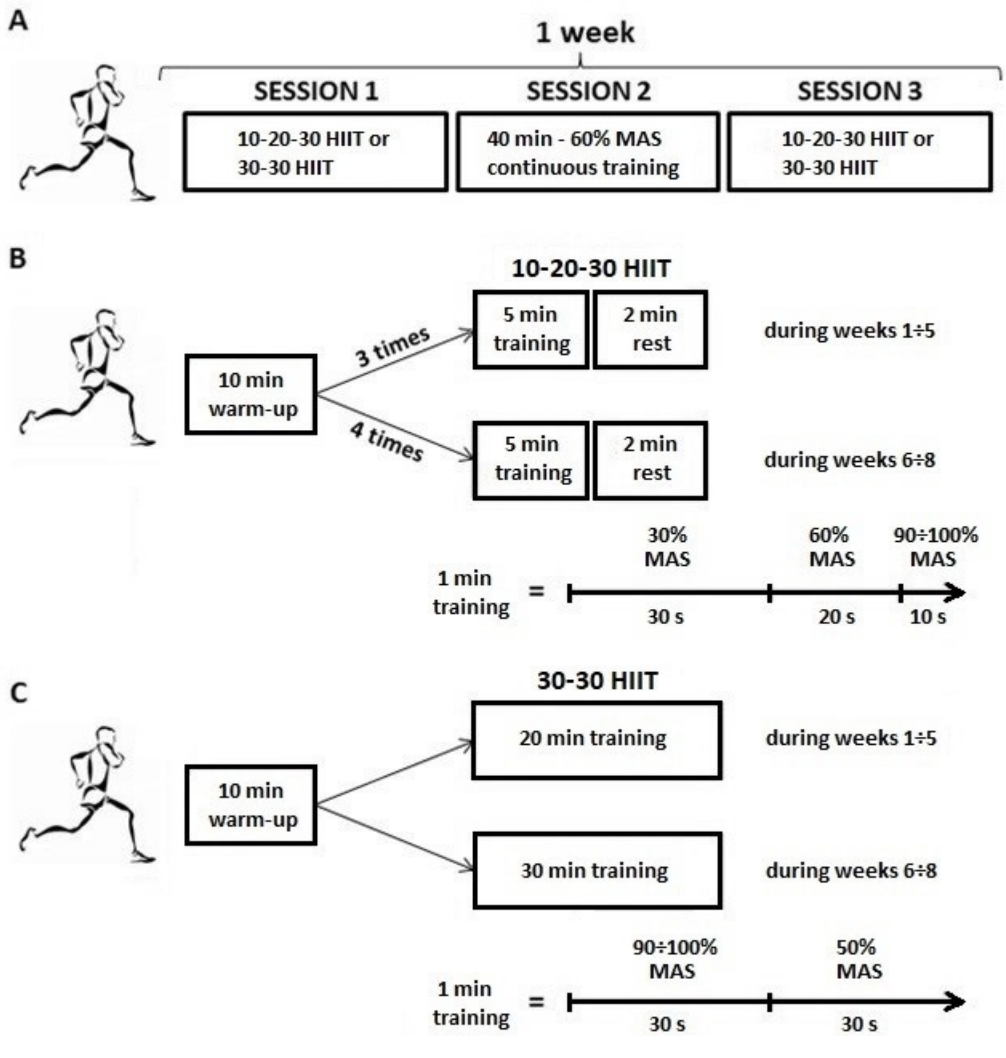

Figure 5: Experimental design. a: weekly training program; b: 10-20-30 HIIT program; c: 30-30 HIIT program; HIIT, High Intensity Interval Training; MAS, Maximal Aerobic Speed.

10-20-30 training sessions

The 10-20-30 training session consisted of a standardized 10 min warm-up at a low intensity, followed by 5 min running period, interspersed by 2 min of rest. Each 5 min running period consisted of five consecutive 1 min intervals, divided into 30,20, and 10 s, at an intensity corresponding to 30, 60 and 90-100 % of MAS, respectively (Gunnarson and Bangsbo, 2012). The training in the first 5-wk and in the remaining 3-wk consisted of 3 series x 5 min intervals and, 4 series x 5 min intervals per training session, respectively.

30-30 training sessions

The 30-30 training session consisted of a standardized 10 min warm-up at a low intensity, followed by the 30-30 interval training, that consisted of 30 s at 90-100% MAS interspersed with 30s of active recovery (50% MAS) (Gorostiaga et al., 1991). The 30-30 training lasted from 20 min (1-5 wk), to 30 min (6-8 wk)

Continuous training session

All subjects performed one CT session/wk, at an intensity corresponding to 60% MAS. Each session lasted 40 min, including 10 min warm-up.

Body composition

Body composition was evaluated using bioelectrical impedance analysis (BIA; Tanita, BC-420 MA). The parameters used to measure the body composition were weight (kg), body mass index (BMI, kg/m^2), lean mass (kg) and fat mass (%).

Cardiopulmonary exercise test

Participants were asked to run on a treadmill for 5 min at 7 km/h speed at 1 % grade as warm-up, then strenuous exercise was performed, running with an increasing speed from 7 km/h with steps of 1 km/h at each minute until exhaustion. All subjects experimented maximal effort at the step of the exercise phase. The athletes performed the CPET with an ergospirometer (Sensormedics, Viasys, CA, USA) to obtain cardio-respiratory parameters all long the bouts, from warm-up to the end of the exercise. Before the measurement, the ergospirometer was calibrated following the recommendation of the manufacturer. Analysis of expired gas was sampled breath-by-breath. Heart rate(HR), maximal oxygen uptake (VO_2max), maximal aerobic speed (MAS) and respiratory exchange ratio (RER) were monitored to assess the intensity of the exercise. According to Thevenet et al. (2007), VO_2max was considered to be reached when at least 3 of the 4 following criteria were fulfilled: i) a steady state of VO_2 despite increasing running velocity (change in VO_2 at $VO_2max \leq 150$ ml/min), ii) final respiratory-exchange ratio (RER) exceeded 1.1. iii) visible exhaustion or iv) a HR at the end of exercise (HRmax) equal to the predicted maximum (210— (0.65 x age)).

1 km run test

The 1 km run test consisted of 2.5 laps in the first lane on a 400 m synthetic track. To avoid altering their self-regulatory cognition (Brick et al., 2016), athletes were asked not to wear the GPS during the test. The time to complete the 1 km was used as the test result.

Training volume

The weekly training volumes of the two groups (including warm-up 1.2 km) were measured during the 8-wk of the intervention period.

Rating of perceived exertion (RPE)

RPE was measured by the Borg's 6-20 scale (Borg, 1982). A verbal-anchored scale was shown to the participants, after each training session. Each subject was previously familiarized on the use of this scale, including anchoring procedures.

8 Statistical analysis

We checked that variables were normally distributed (Shapiro-Wilk test) and that sphericity was respected (Mauchly's test). Training volume, fat mass, lean mass, weight, BMI, VO_2max, 1 km run time, and MAS were normally distributed, whilst RPE not. The training volumes of the two groups were compared by means of a t-test. Changes in body composition (fat mass, lean mass, weight andB MI), metabolic parameters (VO_2max ml/kg/min, VO_2max l/min), and running performance (1 km time and MAS) were evaluated by means of two-ways ANOVAs, with GROUP, as between subjects' factor (2 levels, 30-30 and 10-20-30), and TIME, as within subjects' factor (2 levels, PRE and POST). Since RPE values were not-normally distributed, non-parametric analyses were used to evaluate its modifications from T1 to T8 (Wilcoxon test) and between groups (Mann-Whitney test). A significance level of $p<0.05$ was chosen. Data are presented as means ± standard error.

9 Results

Training volume

The results of the t-test showed that the measured training volume of the two groups were significantly different. In particular, the weekly training volume (including warm-up 1.2 km) of the 10-20-30 group (11.63 ± 0.55 km) was significantly lower than that of the 30-30 group (15.14 ± 0.79 km) ($t= 3.65$, $p = 0.002$).

Physiological parameters

The analyses on the aerobic fitness, evaluated by means of the VO_2max expressed as ml/kg/min and L/min, showed a significant effect of the factor TIME (ml/kg/min: F (1,20) = 44.52, p = 0.000002, L/min: F (1,20) = 67.23, p = 0.000001), showing an increase of the aerobic fitness after the training in both groups (Fig. 6).

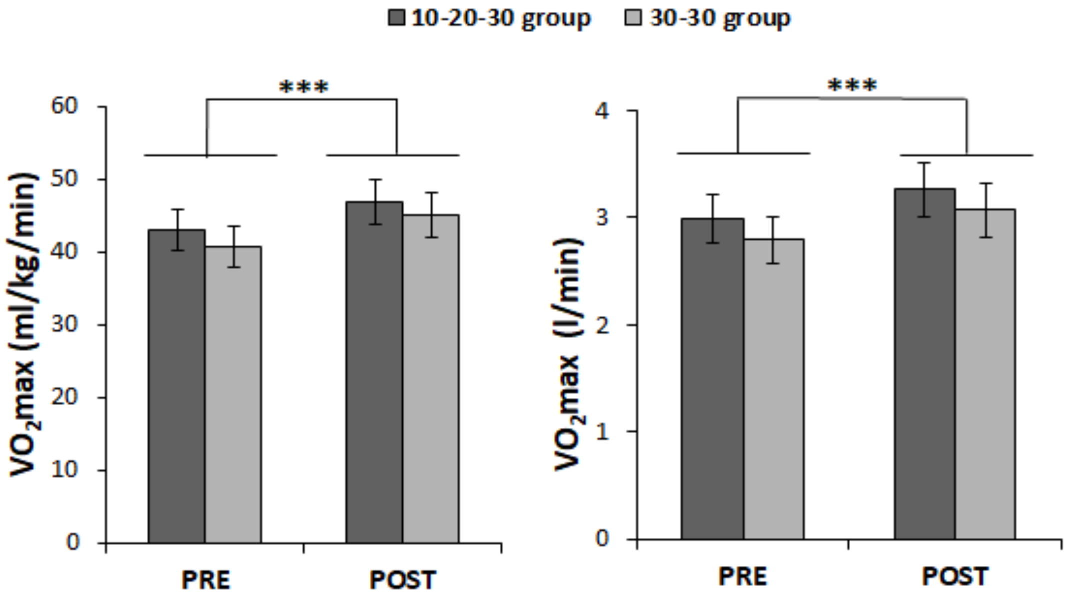

Figure 6: Maximal oxygen uptake (VO_2max) values of 10-20-30 (dark grey) and 30-30 (light grey) groups, before (PRE) and after (POST) the intervention period. * * * p <0.001

Running performance

The running performance parameters improved in both groups. The result of the statistical analyses showed a significant effect of the factor TIME. In particular, on the 1 km run time ANOVA showed a significant decrease of this value in both groups (TIME: F (1,20) = 4.51, p = 0.04) (Fig. 7). Coherently, the analysis on MAS values revealed a significant increase in both groups after the training period (TIME: F (1,20) =77.60, p= 0.000001).

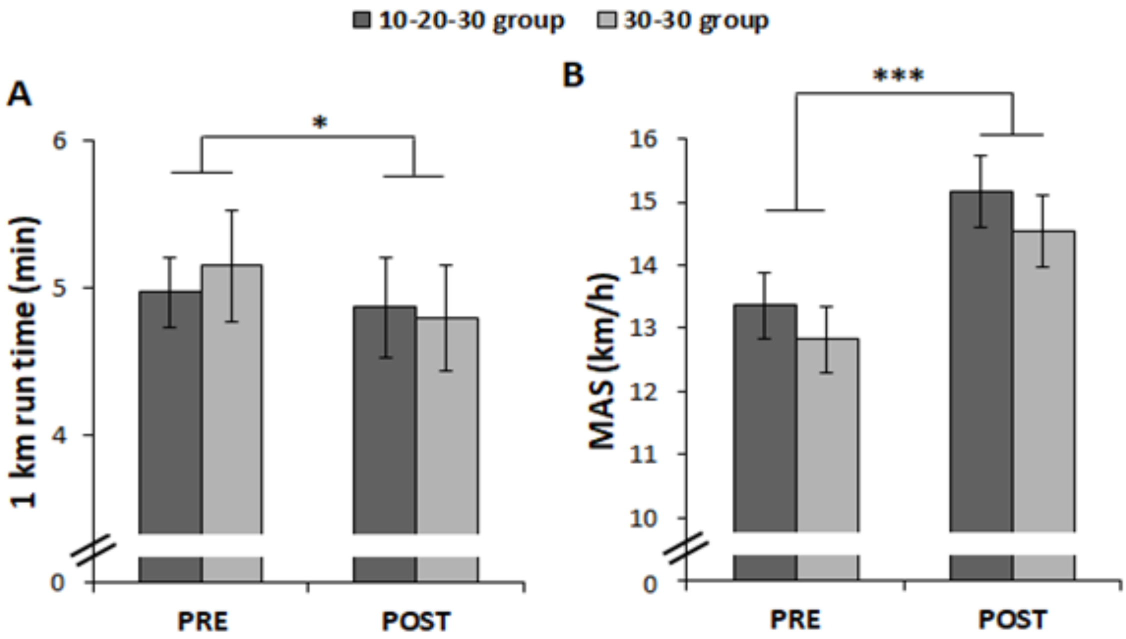

Figure 7: 1 km run time (panel a) and maximal aerobic speed (MAS; panel b) data, of 10-20-30 group (dark grey) and 30-30 groups (light grey) before (PRE) and after (POST) the intervention period. * $p<0.05$; * * * $p<0.001$.

Body composition

The results of the statistical analysis showed that, after the intervention period, the lean mass significantly increased (TIME: $F(1,20) = 22.83$, $p = 0.0001$), whereas the percentage of fat mass significantly decreased (TIME: $F(1,20) = 26.54$, $p = 0.00005$) in both training groups (Table 3). In the end, BMI and body weight did not significantly change after the training period in both groups.

	10-20-30 group		p-value	30-30 group		p-value
	PRE	POST		PRE	POST	
BMI (kg/m^2)	23.17 ± 0.89	22.95 ± 0.90	n.s.	23.66 ± 0.66	23.48 ± 0.64	n.s.
Lean mass (kg)	55.3 ± 2.51	58.01 ± 2.27	0.001	54.62 ± 3.31	56.4 ± 3.14	0.001
Fat mass (%)	17.7 ± 2.89	13.43 ± 2.55	0.001	16.48 ± 2.75	13.30 ± 2.30	0.001

Table 3: Body composition of the two groups, before (PRE) and after (POST) the intervention. Data are means ± SE.

Rating of perceived exertion (RPE)

The comparison between the 2 groups after the first week of training showed a significantly higher RPE in the 30-30 group than in the 10-20-30 group (Z= -2.59, p= 0.009). At the end of the intervention period RPE values of both groups decreased significantly (10-20-30 group: Z =2.67, p=0.008; 30-30 group: Z=2.37, p = 0.02) and the mean RPE value of the 10-20-30 group was significantly lower than the 30-30 group (Z= -3.68, p=0.0002) (Fig. 8).

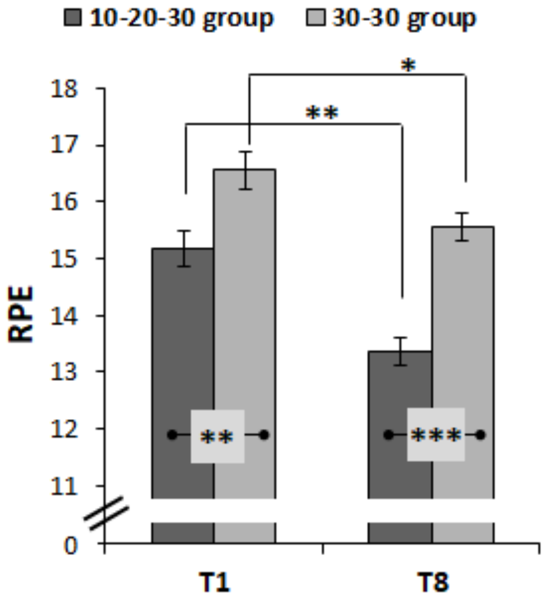

Figure 8: Rating of perceived exertion (RPE) of 10-20-30 (dark grey) and 30-30 (light grey) groups, measured at the end of the last session of the first (T1) and the eighth (T8) week. *p<0.05; **p<0.01; ***p<0.001.

10 Discussion

The present study analysed, for the first time, in recreational runners, two different HIIT regimes, *10-20-30 and 30-30 training concepts,* characterized by significantly different training volume and intensity, and by different between-series recovery durations and intensities. This study was designed to provide general recommendations for the most feasible and effective HIIT program for recreational runners, from the perspective of both physiological and performance enhancements as well as internal training loads, measured through RPE. The major findings were that 8-wk of 10-20-30 training significantly improved VO_2max, 1 km time, maximal aerobic speed (MAS), and body composition and these physiological and performance enhancements were similar to those induced by 8-wk of 30-30 training, the last one being characterized by significantly higher training volume and time spent at or near the “red zone”.

Effects on physiological parameters and running performance

The duration and intensity of the training and recovery modalities are the most important variables to consider in order to prescribe different HIIT protocols. Indeed, a number of studies reported that in well-trained subjects the increase in VO_2max is dependent on intensity and duration of the exercise (Perry et al., 2008; Burgomaster et al., 2008; Warburton et a., 2005). Indeed, it is believed that the optimal stimulus to improve cardiorespiratory and metabolic function and, in turn, physical performances of elite or well-trained athletes, is the one where they maintain long periods of time above 90% of their maximal oxygen uptake, i.e. in their “red zone” (Thevenet et al., 2007).

Our results suggest that in recreational runners not only the 30-s near-maximal sprint intervals are efficient in improving aerobic fitness and performance, but also training with

10-s sprint intervals have an equally significant impact on maximal oxygen uptake and performance. These findings are in line with previous studies in moderately trained runners, showing that 10-20-30 training concept improves performance and VO_2max, and lowers resting blood pressure, suggesting a beneficial effect also on the health profile of these runners (Gliemann et al. 2015; Gunnarson et al. 2012).

Effects on body composition

The present findings showed that both HIIT protocols induced significant improvements in body composition. In particular, after 8-wk of training, the percentage of fat mass significantly decreased and the lean mass significantly increased in both groups, whilst no changes in BMI and body weight were found. A limitation of this study is that energy intake was not quantified over the intervention period. However, participants were instructed to continue their normal dietary and physical activity practices throughout the experiment.

Effects on psychophysiological stress

The measure of internal load, derived from rating of perceived exertion, showed significant lower values in the 10-20-30 group compared to 30-30 group. RPE response may reflect "a conscious sensation on how hard, heavy and strenuous exercise is" (Buchheit and Laursen, 2013 part 1), thus combining physiological and psychological stress-fatigue imposed on the body during exercise. Although this finding could be expected, considering the significant differences in training volumes between the two HIIT protocols, this information may be relevant to provide a further criterion to privilege the choice of 10-20-30 training in recreational runners, as this type of HIIT resulted to be more tolerable and easily applied. This conclusion can be reinforced by the awareness that ratings of perceived exertion and effort are considered extremely important in the regulation of intensity of training during self-paced physical activity (Abbiss and Laursen, 2008), particularly concerning recreational sport activity.

11 Conclusion

The evaluation of a hypothetical dose-response relationship, between training loads and improvements in physiological parameters and performance, leads to recommend to recreational runners a weekly training program characterized by two sessions of 10-20-30 training concept, combined with an additional continuous training session. Indeed, the 10-20-30 training program has been demonstrated to be equally effective in promoting aerobic fitness, health and performance, with a lower subjective perception of exertion and effort, when compared to a 30-30 HIIT training program, characterized by a significantly higher training volume and intensity.

In conclusion, 10-20-30 HIIT concept has been shown to be a feasible and effective training concept, resulting to be more pleasant and enjoyable, thus enhancing individual compliance and adherence to the prescribed training program.

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