CHAPTER II

REVIEW OF LITERATURE

2.1. INTRODUCTION

According to **Cooper (1988),** a literature review uses as its database reports of primary or original scholarship, and does not report new primary scholarship itself. The primary reports used in the literature may be verbal, but in the vast majority of cases reports are written documents. The types of scholarship may be empirical, theoretical, critical/analytic, or methodological in nature. Second a literature review seeks to describe, summarise, evaluate, clarify and/or integrate the content of primary reports.

This chapter describes the source of review of related literature. The researcher finds out some of the review of literature which could be very supportive and strengthen this study. After going through the available literature, the investigator presented some of the observations and findings of the experts in this area. For any research project to occupy a place in the development of a discipline, the researcher must be thoroughly familiar with both previous theory and research. The literature related to any problem helps the scholar discover already known, which would enable the investigator to have a deep insight, clear prospective and a better understanding of a chosen problem and various factors connected to the study. So a number of books, journals and websites were referred. In the following pages, an attempt has been made to present briefly a few of the important researches, as they have significant bearing on the present study.

The main purpose of related reviews is furnished for better understanding of the problem investigated and to construe the results are presented in this chapter. The reviews are classified under the following headings.

1. Studies related to High intensity interval training(HIIT)with 1:1 work to rest ratio.
2. Studies related to High intensity interval training(HIIT)with 1:0.5 work to rest ratio.
3. Studies related to High intensity interval training(HIIT)
4. Studies related to Physiological variables.
5. Studies related to Athletic performance variables.
6. Summary of literature.

2.2. STUDIES RELATED TO HIGH INTENSITY INTERVAL TRAINING (HIIT) WITH 1:1 WORK TO REST RATIO

Iacono, Eliakim and Mecke (2015) conducted a study on "Improving Fitness of Elite Handball Players: Small-Sided Games vs. High-Intensity Intermittent Training" to compare the effects of high-intensity intermittent training (HIIT) and small-sided games (SSGs) training on fitness variables of elite handball players. Eighteen highly trained players (mean age ± SD: 25.6 ± 0.5 years) were assigned to either HIIT or SSGs group training protocols twice per week for 8 weeks. The HIIT consisted of 12–24 × 15 seconds of high-intensity runs interspersed by 15 seconds of recovery. The SSGs training consisted of 3 against 3 small-sided handball games. Due to the influence of training that there was a significant greater improvement in 10- and 20-m sprint, HAST, 1RM, CMJ, and CMJarm following the SSGs training compared with the HIIT ($p \leq 0.05$ for all). These results indicated that both HIIT and SSGs are effective training methods for fitness development among elite adult handball players. However, SSGs training may be considered as the preferred training regimen for improving handball-specific fitness variables during the in-season period.

Osawa, et al., (2014), in their study, “Effects of 16-week high-intensity interval training using upper and lower body ergometers on aerobic fitness and morphological changes in healthy men: a preliminary study” compared the effects of HIIT using leg-cycling (LC) and arm-cranking (AC) ergometers with an HIIT program using only LC. Effects on aerobic capacity and skeletal muscle were analyzed. Twelve healthy male subjects were assigned into two groups. One performed LC-HIIT (n=7) and the other LC- and AC-HIIT (n=5) twice weekly for 16 weeks. The training programs consisted of eight to 12 sets of >90% VO_2 (the oxygen uptake that can be utilized in one minute) peak for 60 seconds with a 60-second active rest period. VO_2 peak, watt peak, and heart rate were measured during an LC incremental exercise test. The cross-sectional area (CSA) of trunk and thigh muscles as well as bone-free lean body mass were measured using magnetic resonance imaging and dual-energy X-ray absorptiometry. These results suggest that a combined LC- and AC-HIIT program improves aerobic capacity and muscle hypertrophy in both leg and trunk muscles.

Buchheit and Laursen (2013) conducted a study on “High-intensity interval training, solutions to the programming puzzle. Part II: anaerobic energy, neuromuscular load and practical applications”. High-intensity interval training (HIT) is a well-known, time-efficient training method for improving cardiorespiratory and metabolic function and, in turn, physical performance in athletes. HIT involves repeated short (<45 s) to long (2-4 min) bouts of rather high-intensity exercise interspersed with recovery periods (refer to the previously published first part of this review). While athletes have used 'classical' HIT formats for nearly a century (e.g. repetitions of 30 s of exercise interspersed with 30 s of rest, or 2-4-min interval repetitions ran at high but still submaximal intensities), there is today a surge of research interest focused on examining the effects of short sprints and all-out efforts, both in the field and in the laboratory. Prescription of HIT consists of the manipulation of at least nine variables (e.g. work interval intensity and duration, relief interval intensity and duration, exercise modality, number of repetitions, number of series, between-series recovery duration and intensity); any of which has a likely effect on the acute physiological response. Manipulating HIT appropriately is important, not only with respect to the expected middle- to long-term physiological and performance adaptations, but also to maximize daily and/or weekly training periodization. Cardiopulmonary responses are typically the first variables to consider when programming HIT (refer to Part I). However, anaerobic glycolytic energy contribution and neuromuscular load should also be considered to maximize the training outcome. Contrasting HIT formats that elicit similar (and maximal) cardiorespiratory responses have been associated with distinctly different anaerobic energy contributions. The high locomotor speed/power requirements of HIT (i.e. ≥95 % of the minimal velocity/power that elicits maximal oxygen uptake [v/p(•)VO(2max)] to 100 % of maximal sprinting speed or power) and the accumulation of high-training volumes at high-exercise intensity (runners can cover up to 6-8 km at v(•)VO(2max) per session) can cause significant strain on the neuromuscular/musculoskeletal system. For athletes training twice a day, and/or in team sport players training a number of metabolic and neuromuscular systems within a weekly microcycle, this added physiological strain should be considered in light of the other physical and technical/tactical sessions, so as to avoid overload and optimize adaptation (i.e. maximize a given training stimulus and minimize musculoskeletal pain and/or injury risk). In this part of the review, the different aspects of HIT programming are discussed, from work/relief interval manipulation to HIT periodization, using different examples of training cycles from different sports, with continued reference to the cardiorespiratory adaptations outlined in Part I, as well as to anaerobic glycolytic contribution and neuromuscular/musculoskeletal load.

Esfarjani and Laursen (2007), in their study, the greatest improvement came from high intensity intervals with a longer duration compared to max intervals with a shorter duration. Group one completed five to eight intervals at velocity of VO_2max (V. VO_2max) for at least 60% of Tmax with a 1:1 work: rest period. Tmax was the time a subject could sustain V. VO_2max. Group two performed seven to twelve, 30 second bouts at 130% of V. VO_2max with a 4.5 minute recovery period. Testing results showed both groups significantly improved in time trial performance, VO_2max, V. VO_2max, and Tmax but only Group one had a significant improvement in lactate threshold. Group one had greater but not statistically significant improvement over Group 2 in all dependent variables. The greater improvement by Group one was attributed to longer duration, a shorter rest period, and a slightly higher training volume. Certain intensities appear strong enough to provide aerobic and performance enhancement but extremely high intensities may plateau sooner.

Helgerud, **et al., (2007)** made a research work on “Aerobic high intensity intervals improve VO_2max more than moderate training”, The research on high intensity intervals has been categorized into two major outcomes. One theme is when intervals were prescribed as a percentage of VO_2max, VT, or heart rate max the investigators were testing for improvements in cardio respiratory indices. Helgerud (2007) stated high intensity training was an effective method for improving VO_2max, especially when compared to low intensity training. Helgerud’s study tested four different intensities performing equivalent work. Group 1 performed long duration training at 70% of heart rate max. Group 2 completed long duration training at lactate threshold. Group 3 performed 15 x 15 second intervals at to 95% of heart rate max, and Group 4 performed 4 x 4minute intervals at 90 to 95% of heart rate max. The low intensity groups (1 and 2) increased 1 to 3%, while the interval groups (Group 3 and 4) increased 5 to 9 percent in VO_2max suggesting interval training were more effective.

Helgerud, et al., (2006) made a research work on “Differential response to aerobic endurance training at different intensities”. Male students (N = 40) were randomly assigned to one of four groups performing similar workload: 1) long slow distance (70% maximal heart rate; HRmax), 2) lactate threshold (85% HRmax), 3) 15 x 15 seconds interval running (15 seconds running at 90-95% HRmax followed by 15 seconds active resting), and 4) 4 x 4 minutes interval running (4 minutes running at 90- 95% HRmax followed by 3 minutes active resting at 70% HRmax). All groups trained three days per week for eight weeks. The training protocols were matched for total oxygen expenditure. High intensity interval training of 15 x 15 seconds and 4 x 4 minutes, respectively, resulted in significantly larger increases in maximal oxygen uptake compared to long slow distance and lactate threshold training intensities. The percentage increases for the interval training groups were 6.1% and 8.1%, respectively. The stroke volume of the heart changed significantly for the two interval groups. Changes in VO_2max corresponded with changes in stroke volume of the heart, indicating a close link between the two. No significant changes or differences among groups were observed in lactate threshold when expressed as a percentage of VO_2max. Running economy improved in all training groups with no differences between groups. High aerobic intensity interval endurance training is significantly more effective than the same total work of low intensity training in improving VO_2max.

Billat, et al., (2001), in their study, "Very short (15s-15s) interval-training around the critical velocity allows middle-aged runners to maintain VO_2max for 14 minutes" compared the effectiveness of three very short interval training sessions (15-15 s of hard and easier runs) run at an average velocity equal to the critical velocity to elicit VO_2 max for more than 10 minutes. They performed three interval-training (IT) sessions on a synthetic track (400 m) whilst breathing through the COSMED K4b2 portable metabolic analyser. These three IT sessions were: A) 90-80% v VO_2 max (for hard bouts and active recovery periods, respectively), the amplitude= (90-80/85) 100=11%, B) 100-70% v VO_2 max amplitude=35%, and C) 60 x 110% v VO_2 max amplitude = 59%. Interval training A and B allowed the athlete to spend twice the time at VO_2 max (14 min vs. 7 min) compared to interval training C. Moreover, at the end of interval training A and B the runners had a lower blood lactate than after the procedure C (9 vs. 11 mmol x l(-1Author concludes that, short interval-training of 15s-15s at 90-80 and 100-70% of v VO_2 max proved to be the most efficient in stimulating the oxygen consumption to its highest level in healthy middle-aged long-distance runners used to doing only long slow distance-training.

Burgomaster, et al., (2005) conducted a 12-week pilot study to examine the effect of a 12-minute per week SIT protocol (using The X-iser® Machine) upon cardiovascular work economy and body composition. Twenty-seven healthy subjects (aged 52.8 ± 2.2 years; range 34 - 77) completed the program. In response to a modified Harvard Step Test (step height was adjusted as ability allowed but was consistent for pre and post measures), the subjects were tested pre and post training for their rate of perceived exertion (RPE) and heart rate (HR). The RPE used a simple scale of one to 10, with 10 being the hardest and one being the easiest. Subjects were also measured for girth measurements (13 sites) and body weight. The 12-week SIT protocol consisted of the subjects completing four sets of three, 20-second sprints with 20-second recoveries, separated by 4-minute intervals, three days per week (Monday, Wednesday, and Friday). This, then, amounted to just 12-minutes per week of actual sprint time – the protocol being based upon the initial work at Colorado State University and subsequent research that had confirmed the findings. After the 12-week study, the subjects had reduced their body weight by 3.8 ± 0.8 lb. ($p < 0.001$) and the sum of their girth measurements by 13.1 ± 1.6 in. ($p < 0.001$). The relatively small decrease in weight accompanied with the large decrease in the sum of the girth measurements is a clear indication that the subjects lost fat and gained lean muscle mass. This also matched with the study exit interviews when the subjects discussed their impressions of the study; all subjects reported a decrease in dress or waist size. The subjects also reported a marked improvement in strength and endurance while going about their day-to-day activities. So, this pilot study demonstrated that using The X-iser® Machine, just 12 minutes per week for 12 weeks, can have a significant effect on health and performance.

2.3. STUDIES RELATED TO HIGH INTENSITY INTERVAL TRAINING (HIIT) WITH 1:0.5 WORK TO REST RATIO

Harbin, (2014), in his study, "Acute physiological responses during high intensity interval training and continuous exercise training" investigated the correlation between improvements in aerobic and anaerobic power with various acute physiological responses, including blood lactate accumulation (HLa), percent heart rate reserve (%HRR), Rating of Perceived Exertion (RPE), session RPE (sRPE), and the training impulse (TRIMP) during high intensity interval training (HIIT) compared to moderate intensity interval training and continuous training. Fifty-five subjects aged 18 to 29 completed a pre and post VO_2max and Wingate test on the cycle ergometer. Subjects completed 24 sessions of either a steady-state exercise control at 90% of the power output (PO) at the ventilatory threshold (VT), a Meyer interval protocol with 30:60 seconds exercise-to-rest ratio at 100% of peak power output (PPO), or a Tabata interval protocol with 20:10 seconds exercise-to-rest ratio at 170% of VO_2max. During the 8-week training period, HLa, sPRE, %HRR, and TRIMP all followed the study's initial design and the overall relative intensity remained stable. Despite the fact that the Tabata HIIT had the highest average power (403.7 ± 108.60 W), average RPE (7.5 ± 0.83), average sRPE (6.85 ± 1.04), average %HRR (83.1 ± 8.02 %), average HLa accumulation (11.5 ± 2.80 mmol/L), and highest percentage of training time spent in Zone 3 (67.7 ± 16.18 %), it was not associated with significantly greater increases in aerobic or anaerobic capacity when compared to the steady-state control and the Meyer HIIT. These data support the fact that Tabata interval training, despite being associated with higher HLa, %HRR and RPE, elicits similar improvements in anaerobic and aerobic capaicty when compared to steady-state exercise and Meyer HIIT that averaged approximately 90% of the intensity at VT.

Harrison, et al., (2015), in their study, “Aerobic Fitness for Young Athletes: Combining Game-based and High-intensity Interval Training” compared the effect of game-based training (GT) vs. a mix of game-based training and high-intensity interval training (MT) on physical performance characteristics. 26 young athletes (13.9±0.3 years) were assigned to either GT (n=13) or MT (n=13) for 6 weeks. Game-based training consisted of 2×8-11 min 3 vs. 3 'bucketball' SSGs separated by 3 min of passive rest twice per week, while MT consisted of one SSGs session and one high-intensity session of 15 s runs at 90-95% of the speed reached at the end of the 30-15 intermittent fitness test (VIFT) interspersed with 15 s passive recovery. Peak oxygen uptake (V˙O2peak), VIFT, jump height, and speed were assessed pre- and post-training. Following training, V˙O2peak (5.5±3.3%; ES=large) improved after MT, whereas VIFT improved after MT (6.6±3.2%; ES, large) and GT (4.2±5.5%, ES=small). 5-m sprint improved after GT (ES=small), while 20 m sprint and jump height were unchanged. While MT and GT were both effective at increasing performance parameters, greater effects were seen following MT. Therefore, MT should be considered as the preferred training method for improving aerobic power in young athletes.

Talisa Emberts, et al., (2013) made a research work on “Exercise Intensity and Energy Expenditure of a Tabata Workout”. High-intensity interval training (HIIT) programs have become increasingly popular in recent years. “Tabata training," a term that is often used synonymously with HIIT, was first described by the Japanese scientist Izumi Tabata in 1996. Tabata and his colleagues (1996) conducted a study that compared moderate-intensity continuous training at 70% of maximal oxygen consumption (VO_2max) for 60 minutes, with HIIT conducted at 170% of VO_2max. HIIT consisted of eight, 20-second all-out exercise bouts followed by 10 seconds of rest for a total of 4 minutes of exercise. The study found that HIIT improved aerobic capacity to a similar degree as moderate-intensity continuous training, but also resulted in a 28% increase in anaerobic capacity. Sixteen trained volunteers (8♂: 35.3 ± 8.1 years, 1.81 ± 0.06 m, 93.7 ± 8.70 kg, 53.2 ± 0.6 ml•kg•min-1; 8♀: 28.4 ± 9.3 years, 1.71 0.09 m, 71.9 ± 12.0 kg, 42.9 ± 11.3 ml•kg•min-1) served as subjects. After practicing until proficient at all of the exercises, each subject completed two identical workouts. Each workout consisted of four, 4-minute "segments." Each segment consisted of performing the exercises listed in Table 1 twice in succession. Subjects completed as many repetitions of each exercise as possible in 20 seconds followed by 10 seconds of rest. There was 1 minute of rest between each segment. The authors chose to do the four segments of Tabata in succession, since one of the criticisms of Tabata training has been that individuals cannot burn a sufficient number of calories in 4 minutes to favourably impact energy balance.

Rozenek, et al., (2007), in their study, "Physiological responses to interval training sessions at velocities associated with VO_2max" characterized selected physiological responses to short-duration (< or = 60 seconds) interval work performed at velocities corresponding to 100% of v VO_2max. Twelve men participated in 3 randomized trials consisting of treadmill running using work

(W)/recovery (R) intervals of 15 seconds W/15 seconds R (15/15); 30 seconds W/15 seconds R (30/15); and 60 seconds W/15 seconds R (60/15). Work intervals were performed at 100% of v VO_2max, whereas R intervals were performed at 50% of v VO_2max. A fourth trial consisting of continuous work (C) at 100% of v VO_2max was also performed. All subjects completed the 15/15 and 30/15 trials; however, only 5 of the 12 completed the 60/15 trial. The percentage of VO_2max (mean +/- SD) during 15/15 (71.6 +/- 4.2%) was significantly lower (p < or = 0.05) than the percentages during 30/15 (84.6 +/- 4.0%), 60/15 (89.2 +/- 4.2%), or C (87.9 +/- 5.0%). Similar results were found for heart rate and perceived exertion. Blood lactate concentrations following exercise were significantly lower (p < or = 0.05) in 15/15 (7.3 +/- 2.4 mmol x L(-1)) than in the other trials. No significant differences (p > 0.05) existed among 30/15 (11.5 +/- 1.8 mmol x L(-1)), 60/15 (12.5 +/- 1.8 mmol x L(-1)) or C (12.1 +/- 1.8 mmol x L(-1)). High intensity, short-duration 2:1 W/R intervals appear to produce responses that may benefit both aerobic and anaerobic energy system development. A 4:1 W/R ratio may be an upper limit for individuals in the initial phases of interval training.

Millet, et al., (2003) conducted a research work in which the objective of the study were (1) to determine the time sustained above 90% of VO_2max in different intermittent running sessions having the same overall time run at the velocity (v VO_2max) associated with VO_2max, and (2) to test whether the use of a fixed-fraction (50%) of the time to exhaustion at v VO_2max (Tlim) leads to longer time spent at a high percentage of VO_2max. Subjects were 8 triathletes who, after determination of their track v VO_2max and Tlim, performed three intermittent running sessions alternating the velocity between 100% and 50% of v VO_2max, termed 30 s-30 s, 60 s-30 s, and 1/2 Tlim, where the overall time at v VO_2max was similar (= 3 x Tlim). VO_2max achieved in the incremental test was 71.1 +/- 3.9 ml.min-1.kg-1 and Tlim was 236 +/- 49 s. VO_2peak and peak heart rate were lower in 30 s-30 s than in the other intermittent runs. The time spent above 90% of VO_2max was significantly ($p < 0.001$) longer either in 60 s-30 s (531 +/- 187 s) or in 1/2 Tlim-1/2 Tlim (487 +/- 176 s) than in 30 s-30 s (149 +/- 33 s). Tlim was negatively correlated with the time (in % of Tlim) spent above 90% of VO_2max in 30 s-30 s ($r = -0.75$, $p < 0.05$). Tlim was also correlated with the difference of time spent over 90% of VO_2max between 60 s-30 s and 30 s-30 s ($r = 0.77$, $p < 0.05$), or between 1/2 Tlim-1/2 Tlim and 30 s-30 s ($r = 0.97$, $p < 0.001$). The results confirm that vVO_2max and Tlim are useful for setting interval-training sessions. However, the use of an individualized fixed-fraction of Tlim did not lead to longer time spent at a high percentage of VO_2max compared to when using a fixed work-interval duration.

Tabata, et al., (1996) conducted study to find out the effects of moderate-intensity endurance and high-intensity intermittent training on anaerobic capacity and VO_2max. First, the effect of 6 wk of moderate-intensity endurance training (intensity: 70% of maximal oxygen uptake (VO_2max), 60 min.d-1, 5 d.wk-1) on the anaerobic capacity (the maximal accumulated oxygen deficit) and VO_2max was evaluated. After the training, the anaerobic capacity did not increase significantly ($P > 0.10$), while VO_2max increased from 53 +/- 5 ml.kg-1 min-1 to 58 +/- 3 ml.kg-1.min-1 ($P < 0.01$) (mean +/- SD). Second, to quantify the effect of high-intensity intermittent training on energy release, seven subjects performed an intermittent training exercise 5 d.wk-1 for 6 wk. The exhaustive intermittent training consisted of seven to eight sets of 20-s exercise at an intensity of about 170% of VO_2max with a 10-s rest between each bout. After the training period, VO_2max increased by 7 ml.kg-1.min-1, while the anaerobic capacity increased by 28%. Study showed that moderate-intensity aerobic training that improves the maximal aerobic power does not change anaerobic capacity and that adequate high-intensity intermittent training may improve both anaerobic and aerobic energy supplying systems significantly, probably through imposing intensive stimuli on both systems.

2.4. STUDIES RELATED TO HIGH INTENSITY INTERVAL TRAINING

Bogdanis, et al., (2013) investigated the changes in oxidative stress biomarkers and antioxidant status indices caused by a 3-week high-intensity interval training (HIT) regimen. Eight physically active males performed three HIT sessions/week over 3 weeks. Each session included four to six 30-s bouts of high-intensity cycling separated by 4 min of recovery. Before training, acute exercise elevated protein carbonyls (PC), thiobar- bituric acid reactive substances (TBARS), glutathione peroxidase (GPX) activity, total antioxidant capacity (TAC) and creatine kinase (CK), which peaked 24 h post-exercise (252 ± 30%, 135 ± 17%, 10 ± 2%, 85 ± 14% and 36 ± 13%, above baseline, respectively; $p < 0.01$), while catalase activity (CAT) peaked 30 min post- exercise (56 ± 18% above baseline; $p < 0.01$). Training attenuated the exercise-induced increase in oxida- tive stress markers (PC by 13.3 ± 3.7%; TBARS by 7.2 ± 2.7%, $p < 0.01$) and CK activity, despite the fact that total work done was 10.9 ± 3.6% greater in the post- compared with the pre-training exercise test. Training also induced a marked elevation of antioxidant status indices (TAC by 38.4 ± 7.2%; CAT by 26.2 ± 10.1%; GPX by 3.0 ± 0.6%, $p < 0.01$). Short-term HIT attenuates oxidative stress and up-regulates antioxidant activity after only nine training sessions totaling 22 min of high intensity exercise, further supporting its positive effect not only on physical conditioning but also on health promotion.

Gibala and Jones (2013) conducted a study on "Physiological and performance adaptations to high-intensity interval training", As little as six sessions of 'all-out' HIIT over 14 days, totaling ~15 min of intense cycle exercise within total training time commitment of ~2.5 h, is sufficient to enhance exercise capacity and improve skeletal muscle oxidative capacity. From an athletic standpoint, HIIT is also an effective strategy to improve performance when supplemented into the already high training volumes of well-trained endurance athletes, although the underlying mechanisms are likely different compared to less trained subjects. Most studies in this regard have examined the effect of replacing a portion (typically ~15-25%) of base/normal training with HIIT (usually 2-3 sessions per week for 4-8 weeks). It has been proposed that a polarized approach to training, in which ~75% of total training volume be performed at low intensities, with 10-15% performed at very high intensities may be the optimal training intensity distribution for elite athletes who compete in intense endurance events.

Gosselin, et al., (2012) evaluated the metabolic and cardiovascular response in healthy young individuals performing 4 high-intensity (~90% VO_2max) aerobic interval training (HIT) protocols with similar total work output but different work-to-rest ratio. Eight young physically active subjects participated in 5 different bouts of exercise over a 3-week period. Protocol 1 consisted of 20-minute continuous exercise at approximately 70% of VO_2max, whereas protocols 2-5 were interval based with a work-active rest duration (in seconds) of 30/30, 60/30, 90/30, and 60/60, respectively. Each interval protocol resulted in approximately 10 minutes of exercise at a workload corresponding to approximately 90% VO_2max, but differed in the total rest duration. The 90/30 HIT protocol resulted in the highest VO_2, HR, rating of perceived exertion, and blood lactate, whereas the 30/30 protocol resulted in the lowest of these parameters. The total caloric energy expenditure was lowest in the 90/30 and 60/30 protocols (~150 kcal), whereas the other 3 protocols did not differ (~195 kcal) from one another. The immediate postexercise blood pressure response was similar across all the protocols. These finding indicate that HIT performed at approximately 90% of VO_2max is no more physiologically taxing than is steady-state exercise conducted at 70% VO_2max, but the response during HIT is influenced by the work-to-rest ratio. This interval protocol may be used as an alternative approach to steady-state exercise training but with less time commitment.

Little, et al., (2010) determined the performance, metabolic and molecular adaptations to a more practical model of low-volume HIT. Seven men (21 + or - 0.4 years, V(O2peak) = 46 + or - 2 ml kg(-1) min(-1)) performed six training sessions over 2 weeks. Each session consisted of 8-12 x 60 s intervals at approximately 100% of peak power output elicited during a ramp V(O2) peak test (355 + or - 10 W) separated by 75 s of recovery. Training increased exercise capacity, as assessed by significant improvements on both 50 kJ and 750 kJ cycling time trials ($P < 0.05$ for both). Skeletal muscle (vastus lateralis) biopsy samples obtained before and after training revealed increased maximal activity of citrate synthase (CS) and cytochrome c oxidase (COX) as well as total protein content of CS, COX subunits II and IV, and the mitochondrial transcription factor A (Tfam) ($P < 0.05$ for all). This study demonstrates that a practical model of low volume HIT is a potent stimulus for increasing skeletal muscle mitochondrial capacity and improving exercise performance. The results also suggest that increases in SIRT1, nuclear PGC-1alpha, and Tfam may be involved in coordinating mitochondrial adaptations in response to HIT in human skeletal muscle.

Perry, et al., (2008) investigated skeletal muscle and whole-body metabolic adaptations that occurred following 6 weeks of HIIT (~1 h of 10 x 4 min intervals at ~90% of peak oxygen consumption (VO_2 peak), separated by 2 min rest, 3 d.week-1). A VO_2 peak test, a test to exhaustion (TE) at 90% of pre-training VO_2 peak, and a 1 h cycle at 60% of pre-training VO_2 peak were performed pre- and post-HIIT. Muscle biopsies were sampled during the TE at rest, after 5 min, and at exhaustion. Training power output increased by 21%, and VO_2 peak increased by 9% following HIIT. Muscle adaptations at rest included the following: (i) increased cytochrome c oxidase IV content (18%) and maximal activities of the mitochondrial enzymes citrate synthase (26%), beta-hydroxyacyl-CoA dehydrogenase (29%), aspartate-amino transferase (26%), and pyruvate dehydrogenase (PDH; 21%); (ii) increased FAT/CD36, FABPpm, GLUT 4, and MCT 1 and 4 transport proteins (14%-30%); and (iii) increased glycogen content (59%). Major adaptations during exercise included the following: (i) reduced glycogenolysis, lactate accumulation, and substrate phosphorylation (0-5 min of TE); (ii) unchanged PDH activation (carbohydrate oxidation; 0-5 min of TE); (iii) ~2-fold greater time during the TE; and (iv) increased fat oxidation at 60% of pre-training VO_2 peak. This study demonstrated that 18 h of repeated high-intensity exercise sessions over 6 weeks (3 d.week-1) is a powerful method to increase whole-body and skeletal muscle capacities to oxidize fat and carbohydrate in previously untrained individuals.

Tremblay, et al., (1994) investigated the young adults who were subjected to undergo 20-weeks endurance-training (ET) program (eight men and nine women) or a 15-week high-intensity intermittent-training (HIIT) program (five men and five women). The mean estimated total energy cost of the ET program was 120.4 MJ, whereas the corresponding value for the HIIT program was 57.9 MJ. Despite its lower energy cost, the HIIT program induced a more pronounced reduction in subcutaneous adiposity compared with the ET program. When corrected for the energy cost of training, the decrease in the sum of six subcutaneous skin folds induced by the HIIT program was nine fold greater than by the ET program. Muscle biopsies obtained from the vastus lateralis before and after training showed that both training programs increased similarly the level of the citric acid cycle enzymatic marker. On the other hand, the activity of muscle glycolytic enzymes was increased by the HIIT program, whereas a decrease was observed following the ET program. The enhancing effect of training on muscle 3-hydroxyacyl coenzyme A dehydrogenase (HADH) enzyme activity, a marker of the activity of beta-oxidation, was significantly greater after the HIIT program. These results reinforce the notion that for a 34 given level of energy expenditure, vigorous exercise favors negative energy and lipid balance to a greater extent than exercise of low to moderate intensity. Moreover, the metabolic adaptations taking place in the skeletal muscle in response to the HIIT program appear to favor the process of lipid oxidation.

2.5. STUDIES RELATED TO PHYSIOLOGICAL VARIABLES

Costigan, et al., (2015) conducted a study on “High-intensity interval training for improving health-related fitness in adolescents: a systematic review and meta-analysis” Background High-intensity interval training (HIIT) may be a feasible and efficacious strategy for improving health-related fitness in young people. The objective of this systematic review and meta-analysis was to evaluate the utility of HIIT to improve health-related fitness in adolescents and to identify potential moderators of training effects. Studies were considered eligible if they: (1) examined adolescents (13–18 years); (2) examined health-related fitness outcomes; (3) involved an intervention of ≥4 weeks in duration; (4) included a control or moderate intensity comparison group; and (5) prescribed high-intensity activity for the HIIT condition. Meta-analyses were conducted to determine the effect of HIIT on health-related fitness components using Comprehensive Meta-analysis software and potential moderators were explored (ie, study duration, risk of bias and type of comparison group). The effects of HIIT on cardio respiratory fitness and body composition were large, and medium, respectively. Study duration was a moderator for the effect of HIIT on body fat percentage. Intervention effects for waist circumference and muscular fitness were not statistically significant. HIIT is a feasible and time-efficient approach for improving cardio respiratory fitness and body composition in adolescent populations.

Smith-Ryan, Melvin and Wingfield (2015) evaluated the effects of two types of interval training protocols, varying in intensity and interval duration, on clinical outcomes in overweight/obese men. Twenty-five men [body mass index (BMI) > 25 kg•m(2)] completed baseline body composition measures: fat mass (FM), lean mass (LM) and percent body fat (%BF) and fasting blood glucose, lipids and insulin (IN). A graded exercise cycling test was completed for peak oxygen consumption (VO_2peak) and power output (PO). Participants were randomly assigned to high-intensity short interval (1MIN-HIIT), high-intensity interval

(2MIN-HIIT) or control groups. 1MIN-HIIT and 2MIN-HIIT completed 3 weeks of cycling interval training, 3 days/week, consisting of either 10 × 1 min bouts at 90% PO with 1 min rests (1MIN-HIIT) or 5 × 2 min bouts with 1 min rests at undulating intensities (80%-100%) (2MIN-HIIT).HIIT may be an effective short-term strategy to improve cardiorespiratory fitness and IN sensitivity in overweight males.

Hasan, et al., (2014) determined the effects of 12 weeks of high-intensity interval training (HIIT) on visfatin and insulin resistance (IR) in overweight adult men during a weight-loss program. Eighteen overweight men (age ¼ 31.8 9.2 years; body mass index ¼ 28.6 1.4 kg/m2) were randomly recruited into one of the two groups, namely, HIIT (3 days/week, 20 minutes/day; 85e95% peak oxygen uptake) and diet-induced weight-loss combined (DHIIT; n ¼ 10) and diet-induced weight loss only (DIO; n ¼ 8). The DHIIT and DIO groups undertook a 12-week weight-loss intervention using a moderate isocaloric energy-deficit diet. Adding a low-volume 20-minute HIIT (three times/week) to an energy-deficit diet not only can improve the efficiency of weight-loss program in the reduction of body fat, plasma visfatin levels, and HOMA-IR, but also has a reservation effect on lean body mass.

According to **Hrazdíra, et al., (2014)**, high intensity interval training (HIIT) is effective strategy including short repeated sprints with very high intensity followed by low intensity exercise or active rest phase. In the 30sec Wingate test was done during 2-6 week cycles, 3 times per week with frequency of 4-7x 30sec (Wingate test), 4-4,5min rest phase with 80-100% submax./max. capacity. Authors of researches identically say that after 14 days it is getting to significant increase of VO_2max ±25%. Next observed effects of HIIT are associated with improving endurance abilities and oxidative capacity by 10-35%. In the second type of HIIT training, authors describe 2-24 weeks cycles, 2-4 times per week, 20 min: 6-24sec lasting exercise with 90% VO_2max capacity, the active rest phase takes 12-36sec. Authors say, there are significant changes in reduction of glycogen, increasing oxidative capacity and reduction of subcutaneous and visceral fat already from second week against the control groups.

Salassi, et al., (2014) compared the acute cardiopulmonary and metabolic effects of four high-intensity interval training (HIIT) protocols using varying intensities during the work and recovery periods. Eleven participants (5 males, 6 females) performed four, 20- minute HIIT protocols at a 1:1 "work:recovery" ratio on a cycle ergometer in random order. The work:recovery relative intensities, based upon previously determined maximum work rates, were: 80%:0%, 80%:50%, 100%:0%, and 100%:50%. Oxygen uptake, heart rate, blood lactate, and rating of perceived exertion were measured. Data were analyzed using a two-way, repeated measures ANOV A ($p \leq 0.05$). Oxygen uptake and heart rate were expressed as a percentage of the peak values established during a prior graded exercise test. There were clear differences in physiological response between protocols. The 80:50 and 100:0 may produce the best combination of effects. The 100:50 produced the greatest physiological response, however, it may not be practical for the general population.

Bacon, et al., (2013) conducted a study on “VO_2max Trainability and High Intensity Interval Training in Humans: A Meta-Analysis”. Endurance exercise training studies frequently show modest changes in VO_2max with training and very limited responses in some subjects. By contrast, studies using interval training (IT) or combined IT and continuous training (CT) have reported mean increases in VO_2max of up to ~1.0 L • min−1. This raises questions about the role of exercise intensity and the trainability of VO_2max. To address this topic the authors analyzed IT and IT/CT studies published in English from 1965–2012. Inclusion criteria were: 1)≥3 healthy sedentary/recreationally active humans <45 yrs old, 2) training duration 6–13 weeks, 3) ≥3 days/week, 4) ≥10 minutes of high intensity work, 5) ≥1:1 work/rest ratio, and 6) results reported as mean ± SD or SE, ranges of change, or individual data. Due to heterogeneity (I2 value of 70), statistical synthesis of the data used a random effects model. The summary statistic of interest was the change in VO_2max. A total of 334 subjects (120 women) from 37 studies were identified. Participants were grouped into 40 distinct training groups, so the unit of analysis was 40 rather than 37. An increase in VO_2max of 0.51 L •min−1 (95% CI: 0.43 to 0.60 L • min−1) was observed. A subset of 9 studies, with 72 subjects, that featured longer intervals showed even larger (~0.8–0.9 L • min−1) changes in VO_2max with evidence of a marked response in all subjects. These results suggest that ideas about trainability and VO_2max should be further evaluated with standardized IT or IT/CT training programs.

Faude, et al., (2013) compared the endurance effects of high-intensity interval training (HIIT) with high-volume running training (HVT) during pre-season conditioning in 20 high-level youth football players (15.9 (s 0.8) years). Players either conducted HVT or HIIT during the summer preparation period. During winter preparation they performed the other training programme. Before and after each training period several fitness tests were conducted: multi-stage running test (to assess the individual anaerobic threshold (IAT) and maximal running velocity

(Vmax)), vertical jumping height, and straight sprinting. A significant increase from pre- to post-test was observed in IAT velocity ($P < 0.001$) with a greater increase after HVT (+0.8 km • h-1 vs. +0.5 km • h-1 after HIIT, $P = 0.04$). Maximal velocity during the incremental exercise test also slightly increased with time ($P = 0.09$). Forty per cent (HIIT) and 15% (HVT) of all players did not improve IAT beyond baseline variability. The players who did not respond to HIIT were significantly slower during 30 m sprinting than responders ($P = 0.02$). No further significant differences between responders and non-responders were observed. Jump heights deteriorated significantly after both training periods ($P < 0.003$). Both training programmes seem to be promising means to improve endurance capacity in high-level youth football players during pre-season conditioning.

Mandana Gholami, et al., (2013) investigated the effect of training intensity and volume changes on cardiorespiratory endurance and resting heart rate. Forty-five non-athletic healthy B. Sc male students (with an average age of 25±1/87 years, weight 71±1/95 kg and height 175±2/30 cm) were randomly divided into three groups including: 1G, 2G and 3G groups. In first six weeks, 1G (n=15) run for 15 min with an intensity of 70% maximum reserve heart rate (MRHR), 1day/week; 2G (n=15) (at 15 min, 60% MRHR, 2 days/week); and 3G (n=15) (at 15 min, 50% MRHR, 3days/week) for 8 weeks. At the last two weeks, 1G run at 75% MRHR, 2G at 65% MRHR, and 3G at 55% MRHR. Findings showed that there was a significant difference in VO_2max change in 1G and 3G groups. Also, 3G showed a more significant reduction in resting heart rate than 1G. Based on these findings, it seems that aerobic training with low intensity and long period has more effects on cardiorespiratory fitness and resting heart rate than high intensity and short period training.

Astorino, et al., (2012) examined the effects of short-term high-intensity interval training (HIIT) on cardiovascular function, cardiorespiratory fitness, and muscular force. Active, young (age and body fat = 25.3 ± 4.5 years and 14.3 ± 6.4%) men and women (N = 20) of a similar age, physical activity, and maximal oxygen uptake ($\dot{V}O_2max$) completed 6 sessions of HIIT consisting of repeated Wingate tests over a 2- to 3-week period. Subjects completed 4 Wingate tests on days 1 and 2, 5 on days 3 and 4, and 6 on days 5 and 6. A control group of 9 men and women (age and body fat = 22.8 ± 2.8 years and 15.2 ± 6.9%) completed all testing but did not perform HIIT. Changes in resting blood pressure (BP) and heart rate (HR), $\dot{V}O_2max$, body composition, oxygen (O_2) pulse, peak, mean, and minimum power output, fatigue index, and voluntary force production of the knee flexors and extensors were examined pretraining and posttraining. Results showed significant ($p < 0.05$) improvements in $\dot{V}O_2max$, O_2 pulse, and Wingate-derived power output with HIIT. The magnitude of improvement in $\dot{V}O_2max$ was related to baseline $\dot{V}O_2max$ ($r = -0.44$, $p = 0.05$) and fatigue index ($r = 0.50$, $p < 0.05$). No change ($p > 0.05$) in resting BP, HR, or force production was revealed. Data show that HIIT significantly enhanced $\dot{V}O_2max$ and O_2 pulse and power output in active men and women.

Dunham and Harms (2012) determined whether high-intensity interval training (HIT) would increase respiratory muscle strength and expiratory flow rates more than endurance training (ET), 15 physically active, healthy subjects (untrained) were randomly assigned to an ET group (n = 7) or a HIT group (n = 8). All subjects performed an incremental test to exhaustion (VO_2max) on a cycle ergometer before and after training. Standard pulmonary function tests, maximum inspiratory pressure (PImax), maximum expiratory pressure (PEmax), and maximal flow volume loops were performed pre training and after each week of training. HIT subjects performed a 4-week training program, 3 days a week, on a cycle ergometer at 90% of their VO_2max final workload, while the ET subjects performed exercise at 60-70% VO_2max. The HIT group performed five 1-min bouts with 3-min recovery periods and the ET group cycled for 45 min continuously. A five-mile time trial (TT) was performed prior to, after 2 weeks, and after completion of training. Both groups showed improvements ($P < 0.05$) in VO_2max (~8-10%) and TT (HIT 6.5 ± 1.3%, ET 4.4 ± 1.8%) following training with no difference ($P > 0.05$) between groups. Both groups increased ($P < 0.05$) PImax post training (ET ~ 25%, HIT ~ 43%) with values significantly higher for HIT than ET. There was no change ($P > 0.05$) in expiratory flow rates with training in either group. These data suggest that both whole-body exercise training and HIT are effective in increasing inspiratory muscle strength with HIT offering a time-efficient alternative to ET in improving aerobic capacity and performance.

Natasha Carr (2011) conducted a study on "The Effect of High Intensity Interval Training on VO_2 Peak and Performance in Trained High School Rowers" to analyze the effect of HIIT on VO_2 peak and performance in trained rowers when compared to traditional, endurance training. A total of 20 high school female rowers participated in the study (mean ± SD; age = 16 ± 1). Baseline testing was comprised of a 2000m time-trial test on the Concept IIc Rowing Ergometer and a maximal exercise test, which was also completed on the Concept IIc Ergometer, in order to determine VO_2 peak. Subjects were randomly assigned to a HIIT or endurance group for four weeks of intervention. Three days/week the HIIT group completed a 6 by 30second repeated Wingate protocol on the Concept II Ergometer at or above 100% VO_2 peak, in which each 30s maximal effort was immediately followed by an active recovery of four-minutes. The endurance group completed 30 minutes of sub-maximal rowing at 65% of VO_2 peak three days/week. After four weeks of intervention, post-testing took place, which was identical to baseline testing. Results from this study suggest HIIT was just as effective as endurance training at improving 2k time (mean ± SD; HIIT: 498.7 ± 23.1; Endurance: 497.5 ± 17.6). There were no significant within or between group differences in VO_2 peak post-intervention (mean ± SD; HIIT: 44.8 ± 4.0; Endurance: 45.8 ± 5.6). The current study suggests four-weeks of HIIT training can yield similar adaptations in performance when compared to endurance training.

Upadhyay et al., (2010) compared the effect of VO_2max, a measure of endurance capacity, on school-going males. Twenty-two school-going non-athlete males between 14 and 17 years of age with no history of systemic illness were randomly divided into HIT group (n=12) and slow continuous training (SCT) group (n=10). The HIT group was imparted thrice weekly training of six bouts of 2-min high-intensity run alternated with 2-min rest while SCT group was made to run five times every week for 60 min of slow continuous run (75% of HRmax for age). Both groups were trained for 6 weeks. Pre- and post-training VO_2max were recorded for each group by bleep test. Pre-training mean VO_2max was 40.3 ml/kg/min. Subsequent to training, HIT group showed mean improvement in VO_2max by 4.5 ml/kg/min (11.7%) while SCT group showed mean improvement in VO_2max by 2.2 ml/kg/min (6.0%). High intensity interval training is an effective endurance training tool in non-athletic school going male population and provides better improvement in VO_2max than SCT.

Wakefield and Glaister (2009) examined the effect of work-interval duration (WID) and intensity on the time spent at, or above, 95% VO_2max (T95 VO_2max) during intermittent bouts of supramaximal exercise. Over a 5-week period, 7 physically active men with a mean (+/-SD) age, height, body mass, and VO_2max of 22 +/- 5 years, 181.5 +/- 5.6 cm, 86.4 +/- 11.4 kg, and 51.5 +/- 1.5 ml.kg-1.min-1, respectively, attended 7 testing sessions. After completing a submaximal incremental test on a treadmill to identify individual oxygen uptake/running velocity relationships, subjects completed a maximal incremental test to exhaustion to VO_2max and subsequently (from the aforementioned relationship) the minimum velocity required to elicit VO_2max (vVO_2max). In a random order, subjects then carried out 3 intermittent runs to exhaustion at both 105% and 115% vVO_2max. Each test used a different WID (20 s, 25 s, or 30 s) interspersed with 20-second passive recovery periods. Results revealed no significant difference in T95 vVO_2max for intermittent runs at 105% versus 115% vVO_2max ($p = 0.142$). There was, however, a significant effect ($p < 0.001$) of WID on T95 VO_2max, with WIDs of 30 seconds enabling more time relative to WIDs of 20 seconds ($p = 0.018$) and 25 seconds ($p = 0.009$). Moreover, there was an interaction between intensity and duration such that the effect of WID was magnified at the lower exercise intensity ($p = 0.046$). In conclusion, despite a number of limitations, the results of this investigation suggest that exercise intensities of approximately 105% vVO_2max combined with WIDs greater than 25 seconds provide the best way of optimizing T95 VO_2max when using fixed 20-second stationary rest periods.

Baquet, et al., (2002) compared a High Intensity Experimental Group (HIEG) to a control group. The HIIT group was comprised of 13 boys and 20 girls between the ages of 8-11 years. This experimental group participated in two additional HIIT- specific, physical education (PE) sessions each week. The additional PE sessions were 30 minutes in duration and were comprised of short intermittent exercises in which the students had to run at a velocity ranging between 100-130% of maximal aerobic speed (MAS) on a track for 10 or 20 seconds in one direction. After each student had 10 or 20 seconds of passive recovery, they had to once again run at MAS in the opposite direction, and each set (i.e. five sets of 10 x 10s at 110% MAS) was interspersed with three minutes of passive recovery. The control group was comprised of 10 boys and 10 girls, and they participated in the standard PE program, which did not have the two additional 30 minute PE sessions each week. Data from this study suggests that after seven weeks of HIIT training the experimental group significantly improved absolute peak VO_2 and VO_2 peak relative to body mass and responses were similar in both the boys and girls. The control group's absolute and relative VO_2 peak remained unchanged. However, based on the protocols utilized, the HIEG group did a greater volume of work, so changes in VO_2 could have been a result of the 14 additional 30 minute sessions over the 7 weeks of training.

2.6. STUDIES RELATED TO ATHLETIC PERFORMANCE

Brian, et al., (2015) compared the effectiveness of a novel exercise protocol the investigators developed for kettlebell high-intensity interval training (KB-HIIT) by comparing the cardiorespiratory and metabolic responses to a standard sprint interval cycling (SIC) exercise protocol. Eight men volunteered for the study and completed two preliminary sessions, followed by two 12-minute sessions of KB-HIIT and SIC in a counterbalanced fashion. In the KB-HITT session, three circuits of four exercises were performed using a Tabata regimen. In the SIC session, three 30-second sprints were performed, with 4-minutes of recovery in between the first two sprints and 2.5-minutes of recovery after the last sprint. A within-subjects design over multiple time points was used to compare oxygen consumption (VO_2), respiratory exchange ratio (RER), tidal volume (TV), breathing frequency (f), minute ventilation (VE), caloric expenditure rate (kcal.min-1), and heart rate (HR) between the exercise protocols. Additionally, total caloric expenditure was compared. A significant group effect, time effect, and group x time interaction were found for VO_2, RER, and TV, with VO_2 being higher and TV and RER being lower in the KB-HIIT compared to the SIC. Only a significant time effect and group x time interaction were found for f, VE, kcal.min-1, and HR. Additionally, total caloric expenditure was found to be significantly higher during the KB-HIIT. The results of the present study suggest that KB-HIIT may be more attractive and sustainable than SIC, and can be effective in stimulating cardiorespiratory and metabolic responses that could improve health and aerobic performance.

Giannaki, et al., (2015) examined the effect of a combination of a group--based HIIT and conventional gym training on physical fitness and body composition parameters in healthy adults. Thirty nine healthy adults volunteered to participate in this eight--week intervention study. Twenty three participants performed regular gym training 4 days a week (C group), whereas the remaining 16 participants engaged twice a week in HIIT and twice in regular gym training (HIIT--

C group) as the other group. Total body fat and visceral adiposity levels were calculated using bioelectrical impedance analysis. Physical fitness parameters such as cardiorespiratory fitness, speed, lower limb explosiveness, flexibility and isometric arm strength were assessed through a battery of field tests. Both exercise programs were effective in reducing total body fat and visceral adiposity ($p < 0.05$) and improving handgrip strength, sprint time, jumping ability and flexibility ($p < 0.05$) whilst only the combination of HIIT and conventional training improved cardiorespiratory fitness levels ($p < 0.05$). A between of group changes analysis revealed that HIIT--C resulted in significantly greater reduction in both abdominal girth and visceral adiposity compared with conventional training ($P < 0.05$).

Smith, et al., (2013) compared the effects of two high-intensity, treadmill interval-training programs on 3000-m and 5000-m running performance. Maximal oxygen uptake (.VO($_2$max)), the running speed associated with .VO($_2$max) (v.VO($_2$max)), the time for which v.VO($_2$max) can be maintained (T(max)), running economy (RE), ventilatory threshold (VT) and 3000-m and 5000-m running times were determined in 27 well-trained runners. Subjects were then randomly assigned to three groups; (1) 60% T(max), (2) 70% T(max) and (3) control. Subjects in the control group continued their normal training and subjects in the two T(max) groups undertook a 4-week treadmill interval-training program with the intensity set at v.VO($_2$max) and the interval duration at the assigned T(max). These subjects completed two interval-training sessions per week (60% T(max)=six intervals/session, 70% T(max) group=five intervals/session). Subjects were re-tested on all parameters at the completion of the training program. There was a significant improvement between pre- and post-training values in 3000-m time trial (TT) performance in the 60% T(max) group compared to the 70% T(max) and control groups [mean (SE); 60% T(max)=17.6 (3.5) s, 70% T(max) =6.3 (4.2) s, control=0.5 (7.7) s]. There was no significant effect of the training program on 5000-m TT performance [60% T(max)=25.8 (13.8) s, 70% T(max)=3.7 (11.6) s, control=9.9 (13.1) s]. Although there were no significant improvements in .VO($_2$max), v.VO($_2$max) and RE between groups, changes in .VO($_2$max) and RE were significantly correlated with the improvement in the 3000-m TT. Furthermore, VT and T(max) were significantly higher in the 60% T(max) group post- compared to pre-training. In conclusion, 3000-m running performance can be significantly improved in a group of well-trained runners, using a 4-week treadmill interval training program at v.VO($_2$max) with interval durations of 60% T(max).

Fernandez-Fernandez, et al., (2012) examined the effects of high-intensity interval training (HIIT) and repeated-sprint training (RST) on aerobic fitness, tennis-specific endurance, linear and repeated-sprint ability (RSA), and jumping ability. Thirty-one competitive male tennis players took part in a training intervention of 6 weeks. The players were matched into 3 groups, HIIT ($n = 11$), RST ($n = 12$), or control group (CON, $n = 9$). The results showed significant time × intervention interactions for $\dot{V}O_2$peak, with a significant increase in the $\dot{V}O_2$peak level of 6.0% in HIIT ($p = 0.008$) and 4.9% in RST ($p = 0.010$), whereas no changes occurred in CON. However, the following differences were found between the intervention groups: The HIIT-induced greater improvements in tennis-specific endurance (HIIT 28.9% vs. RST 14.5%; $p < 0.05$) and RST led to a significant improvement in RSA (i.e., reduction in the mean sprint time of 3.8%; $p < 0.05$). Neither training strategy induced any effects on jumping and sprinting abilities. Both training interventions showed similar improvements in general aerobic fitness. Also, the present results suggest that RST represents a time-efficient stimulus for a simultaneous improvement of general and tennis-specific aerobic fitness as well for RSA.

Kohn, et al., (2011) investigated physiological and skeletal muscle adaptations in endurance runners subjected to 6 weeks HIIT. Eighteen well-trained endurance athletes were subjected to 6 weeks HIIT. Maximal and submaximal exercise tests and muscle biopsies were performed before and after training. Results indicated that peak treadmill speed (PTS) increased (21.0 ± 0.8 vs 22.1 ± 1.2 km/h, $P<0.001$) and plasma lactate decreased at 64% and 80% PTS ($P<0.05$) after HIIT. Cross-sectional area of type II fibers tended to have decreased ($P=0.06$). No changes were observed in maximal oxygen consumption, muscle fiber type, capillary supply, citrate synthase and 3-hydroxyacetyl CoA dehydrogenase activities. Lactate dehydrogenase (LDH) activity increased in homogenate ($P<0.05$) and type IIa fiber pools (9.3%, $P<0.05$). The change in the latter correlated with an absolute interval training speed ($r=0.65$; $P<0.05$). In conclusion, HIIT in trained endurance runners causes no adaptations in muscle oxidative capacity but increased LDH activity, especially in type IIa fibers and in relation to absolute HIIT speed.

Ziemann, et al., (2011) investigated the aerobic and anaerobic benefits of high-intensity interval training performed at a work-to-rest ratio of 1:2 because little performance enhancement data exist based on this ratio. Recreationally active male volunteers (21 years, 184 cm, 81.5 kg) were randomly assigned to a training (interval training [IT] n = 10) or control group (n = 11). Baseline assessments were repeated after the last training session. Each participant underwent basic anthropometric assessment and performed a $\dot{V}O_2max$ test on an electronically braked cycle ergometer and a 30-second Wingate test. Venous samples were acquired at the antecubital vein and subsequently processed for lactate (LA); samples were obtained at rest, and 5 and 15-minute post-Wingate test. The interval training used a cycling power output equivalent to 80% of $\dot{V}O_2max$ (80% p$\dot{V}O_2max$) applied for 6 90-second bouts (each followed by 180-second rest) per session, 3 sessions per week, for 6 weeks. The control group maintained their normal routine for the 6-week period. Twenty-seven minutes of cycling at 80% p $\dot{V}O_2max$ applied with a work-to-rest ratio of 1:2 and spread over 3 sessions per week for 6 weeks provided sufficient stimulus to significantly improve markers of anaerobic and aerobic performance in recreationally active college-aged men. This type of training program may rapidly restore or improve a client's or athlete's maximal functional capacity.

Laursen (2010) conducted a study on short-term period (six to eight sessions over 2-4 weeks) of high-intensity interval training (consisting of repeated exercise bouts performed close to or well above the maximal oxygen uptake intensity, interspersed with low-intensity exercise or complete rest) can elicit increases in intense exercise performance of 2-4% in well-trained athletes. The influence of high-volume training is less discussed, but its importance should not be downplayed, as high-volume training also induces important metabolic adaptations. While the metabolic adaptations that occur with high-volume training and high-intensity training show considerable overlap, the molecular events that signal for these adaptations may be different. A polarized approach to training, whereby ~75% of total training volume is performed at low intensities, and 10-15% is performed at very high intensities, has been suggested as an optimal training intensity distribution for elite athletes who perform intense exercise events.

Wong, et al., (2010) examined the effect of concurrent muscular strength and high-intensity running interval training on professional soccer players' explosive performances and aerobic endurance. Thirty-nine players participated in the study, where both the experimental group (EG, n = 20) and control group (CG, n = 19) participated in 8 weeks of regular soccer training, with the EG receiving additional muscular strength and high-intensity interval training twice per week throughout. Muscular strength training consisted of 4 sets of 6RM (repetition maximum) of high-pull, jump squat, bench press, back half squat, and chin-up exercises. The high-intensity interval training consisted of 16 intervals each of 15-second sprints at 120% of individual maximal aerobic speed interspersed with 15 seconds of rest. EG significantly increased ($p <$ or $= 0.05$) 1RM back half squat and bench press but showed no changes in body mass. Within-subject improvement was significantly higher ($p <$ or $= 0.01$) in the EG compared with the CG for vertical jump height, 10-m and 30-m sprint times, distances covered in the Yo-Yo Intermittent Recovery Test and maximal aerobic speed test, and maximal aerobic speed. High-intensity interval running can be concurrently performed with high load muscular strength training to enhance soccer players' explosive performances and aerobic endurance.

According to **Burgomaster, et al., (2008)**, low-volume 'sprint' interval training (SIT) stimulates rapid improvements in muscle oxidative capacity that are comparable to levels reached following traditional endurance training (ET) but no study has examined metabolic adaptations during exercise after these different training strategies. The authors hypothesized that SIT and ET would induce similar adaptations in markers of skeletal muscle carbohydrate (CHO) and lipid metabolism and metabolic control during exercise despite large differences in training volume and time commitment. Active but untrained subjects (23 +/- 1 years) performed a constant-load cycling challenge (1 h at 65% of peak oxygen uptake (.VO(2peak)) before and after 6 weeks of either SIT or ET (n = 5 men and 5 women per group). SIT consisted of four to six repeats of a 30 s 'all out' Wingate Test (mean power output approximately 500 W) with 4.5 min recovery between repeats, 3 days per week. ET consisted of 40-60 min of continuous cycling at a workload that elicited approximately 65% (mean power output approximately 150 W) per day, 5 days per week. Weekly time commitment (approximately 1.5 versus approximately 4.5 h) and total training volume (approximately 225 versus approximately 2250 kJ week(-1)) were substantially lower in SIT versus ET. Despite these differences, both protocols induced similar increases (P < 0.05) in mitochondrial markers for skeletal muscle CHO (pyruvate dehydrogenase E1alpha protein content) and lipid oxidation (3-hydroxyacyl CoA dehydrogenase maximal activity) and protein content of peroxisome proliferator-activated receptor-gamma coactivator-1alpha. Glycogen and phosphocreatine utilization during exercise were reduced after training, and calculated rates of whole-body CHO and lipid oxidation were decreased and increased, respectively, with no differences between groups (all main effects, P < 0.05). Given the markedly lower training volume in the SIT group, these data suggest that high-intensity interval training is a time-efficient strategy to increase skeletal muscle oxidative capacity and induce specific metabolic adaptations during exercise that are comparable to traditional ET.

Sporis, Ruzic and Leko (2008) evaluated changes in anaerobic endurance in elite First-league soccer players throughout 2 consecutive seasons, in 2 phases, with and without high-intensity situational drills. Eighteen 59 soccer players were tested before and after the 8-week summer conditioning and again in the next season. The measured variables included 300-yard shuttle run test, maximal heart rate, and maximal blood lactate at the end of the test. During the first phase of the study, the traditional sprint training was performed only 2 x weeks and consisted of 15 bouts of straight-line sprinting. In the second year the 4 x 4 min drills at an intensity of 90-95% of HRmax, separated by periods of 3-minute technical drills at 55-65% of HRmax were introduced. Statistical significance was set at $P < 0.05$) with the maximal blood lactate at the end of the test significantly greater (15.4 +/- 1.23 mmol.L vs. 13.5 +/- 1.12 mmol.L. $P < 0.01$). Their findings showed some indication that situational high-intensity task training was more efficient than straight-line sprinting in improving anaerobic endurance measured by the 300-yard shuttle run test.

Arnold, Joke and David (2005) conducted two separate experiments were conducted. In experiment 1, the knee-flexion muscle strength endurance exercise was measured by exercise performed at 60 and 40% of body weight following either a no-stretching or stretching regimen. In experiment 2, using a test-retest protocol, a knee- flexion muscle strength endurance exercise was performed at 50% body weight on 4 different days, with 2 tests following a no stretching regimen (RNS) and 2 tests following a stretching regimen (RST). For experiment 1, when exercise was performed at 60% of body weight, stretching significantly ($p < 0.05$) reduced muscle strength endurance by 24%, and at 40% of body weight, it was reduced by 9%. For experiment 2, reliability was high (RNS, intraclass correlation 5 0.94; RST, intraclass correlation 5 0.97). Stretching also significantly ($p < 0.05$) reduced muscle strength endurance by 28%. Therefore, it is recommended that heavy static stretching exercises of a muscle group be avoided prior to any performances requiring maximal muscle strength endurance.

Hughes, et al., (2003) conducted a study on "Six bouts of sprint interval training (SIT) improve intense aerobic cycling performance and peak anaerobic power". For this purpose the researchers recreationally trained Ss (M = 6; F = 2) performed SIT (6 bouts of 4-8 Wingate 30-s tests with 4-min recovery between tests) six times with 1-2 days of rest between sessions over two weeks. Performance was measured by a ride to exhaustion at ~80% VO_2peak. Physiological measures were taken. VO_2peak was unchanged over the training period. Maximum anaerobic work increased by 14% and cycle time to exhaustion increased ~101%. Lactate measures were unchanged as a result of the training. Judiciously applied sprint interval training and recovery resulted in improved intense aerobic work and to a lesser extent, anaerobic work.

Zacharogiannis, et al., (2003) analysed the effects of continuous, interval and speed training on anaerobic capacity. Active men and women were assigned to three training or a control group such as continuous training (N = 10; 70% VO_2max for 30-50 minutes), interval training (N = 10; 85-100% VO_2max 16-35 minutes), speed training (N = 10; 100% maximal speed in 20-50m intervals for 300-400 m total distance per session), and control (N = 8). Training was for three days per week and lasted for eight weeks. Only speed training increased MAOD. It remained unchanged in the other two forms of training. Moderate interval intensity training and continuous training mainly change aerobic power in exercise. Only supra maximal sprint training stimulates improvement in MAOD.

Laursen, et al., (2002), in their study, "Interval training program optimization in highly trained endurance cyclists" examined the influence of three different high-intensity interval training (HIT) regimens on endurance performance in highly trained endurance athletes. Before, and after 2 and 4 wk of training, 38 cyclists and triathletes (mean +/- SD; age = 25 +/- 6 yr; mass = 75 +/- 7 kg; $VO(_2peak)$ = 64.5 +/- 5.2 mL x kg(-1) min(-1)) performed: 1) a progressive cycle test to measure peak oxygen consumption ($VO(_2peak)$) and peak aerobic power output (PPO), 2) a time to exhaustion test (T(max)) at their $VO(_2peak)$ power output (P(max)), as well as 3) a 40-km time-trial (TT(40)). Subjects were matched and assigned to one of four training groups (G(2), N = 8, 8 x 60% T(max) at P(max), 1:2 work:recovery ratio; G(2), N = 9, 8 x 60% T(max) at P(max), recovery at 65% HR(max); G(3), N = 10, 12 x 30 s at 175% PPO, 4.5-min recovery; G(CON), N = 11). In addition to G(1), G(2), and G(3) performing HIT twice per week, all athletes maintained their regular low-intensity training throughout the experimental period. All HIT groups improved TT(40) performance (+4.4 to +5.8%) and PPO (+3.0 to +6.2%) significantly more than G(CON) (-0.9 to +1.1%; $P < 0.05$). Furthermore, G(1) (+5.4%) and G(2) (+8.1%) improved their $VO(_2peak)$ significantly more than G(CON) (+1.0%; $P < 0.05$). The present study has shown that when HIT incorporates P(max) as the interval intensity and 60% of T(max) as the interval duration, already highly trained cyclists can significantly improve their 40-km time trial performance. Moreover, the present data confirm prior research, in that repeated supramaximal HIT can significantly improve 40-km time trial performance.

Young, McDowell and Scarlett (2001) identified whether straight sprint training transferred to agility performance tests that involved various change-of-direction complexities and if agility training transferred to straight sprinting speed. Thirty-six males were tested on a 30-m straight sprint and 6 agility tests with 2-5 changes of direction at various angles. The subjects participated in 2 training sessions per week for 6 weeks using 20-40-m straight sprints (speed) or 20-40-m change-of-direction sprints (3-5 changes of 100[degrees]) (agility). After the training period, the subjects were retested, and the speed training resulted in significant improvements ($p < 0.05$) in straight sprinting speed but limited gains in the agility tests. Generally, the more complex the agility task less the transfer from the speed training to the agility task. Conversely, the agility training resulted in significant improvements in the change-of-direction tests ($p < 0.05$) but no significant improvement ($p > 0.05$) in straight sprint performance. They concluded that straight speed and agility training methods are specific and produce limited transfer to the other. Their findings have implications for the design of speed and agility training and testing protocols.

Tabata, et al., (1997), in their study, “Metabolic profile of high intensity intermittent exercises” evaluated the magnitude of the stress on the aerobic and the anaerobic energy release systems during high intensity bicycle training, two commonly used protocols (IE1 and IE2) were examined during bicycling. IE1 consisted of one set of 6-7 bouts of 20-s exercise at an intensity of approximately 170% of the subject's maximal oxygen uptake (VO_2max) with a 10-s rest between each bout. IE2 involved one set of 4-5 bouts of 30-s exercise at an intensity of approximately 200% of the subject's VO_2max and a 2-min rest between each bout.

The accumulated oxygen deficit of IE1 (69 +/- 8 ml.kg-1, mean +/- SD) was significantly higher than that of IE2 (46 +/- 12 ml.kg-1, N = 9, $p < 0.01$). The accumulated oxygen deficit of IE1 was not significantly different from the maximal accumulated oxygen deficit (the anaerobic capacity) of the subjects (69 +/- 10 ml.kg-1), whereas the corresponding value for IE2 was less than the subjects' maximal accumulated oxygen deficit ($P < 0.01$). The peak oxygen uptake during the last 10 s of the IE1 (55 +/- 6 ml.kg-1.min-1) was not significantly less than the VO_2max of the subjects (57 +/- 6 ml.kg-1.min-1). The peak oxygen uptake during the last 10 s of IE2 (47 +/- 8 ml.kg-1.min-1) was lower than the VO_2max ($P < 0.01$). In conclusion, this study showed that intermittent exercise defined by the IE1 protocol may tax both the anaerobic and aerobic energy releasing systems almost maximally.

Tsutsumi, et al., (1997) examined in medically healthy but sedentary 42 older adults (mean age=68 years). The purpose of this study was to evaluate the effects of high and low intensity resistance training intensity on a) muscular fitness, b) psychological affect, and c) neurocognitive functioning. Subjects were randomly assigned to high intensity/low volume (EXH: 2 sets of 8 to 10 repetitions for 75 to 85% of 1 RM), low intensity/high volume (EXL: 2 sets of 14 to 16 repetitions for 55 to 65% of 1 RM), or no exercise control programs. Prior to and following the 12-week program, subjects underwent comprehensive physiological and psychological evaluations. Physiological assessment included measurements of blood pressure, heart rate, arm and leg muscle strength, body composition, and oxygen consumption (VO_2max). Psychological measures included evaluations of mood, anxiety, and physical self-efficacy as well as cognitive functioning. The results of this study indicated that both high and low intensity strength programs were associated with marked improvements in physiological fitness and psychological functioning. Specifically, subjects in the strength training programs increased overall muscle strength by 38.6% and reduced percent body fat by 3.0%. Favorable psychological changes in the strength-trained subjects included improvements in positive and negative mood, trait anxiety, and perceived confidence for physical capability. The treatment effects of neurocognitive functioning were not significant. In summary, this study 55 demonstrated that participation in 12-weeks of high or low intensity strength training can improve overall physical fitness, mood, and physical self-efficacy in older adults while cognitive functioning remains constant.

2.7. SUMMARY OF LITERATURE

The reviews are presented under the five sections namely, studies related to high intensity interval training (HIIT) with 1:1 work to rest ratio (n = 8), studies related to High intensity interval training (HIIT) with 1:0.5 work to rest ratio (n = 6), studies related to High intensity interval training (HIIT) (n = 6), studies related to Physiological variables (n = 14) and studies related to athletic performance variables (n = 17) and in total fifty one studies were reviewed.

All the research studies that are presented in this section prove that high intensity interval training with 1:1 work to rest ratio and high intensity interval training with 1:0.5 work to rest ratio contribute significantly for better improvement on physiological and athletic performance variables.

In general, from the previous presentation of studies, **(Iacono, Eliakim and Mecke, 2015)**, **(Buchheit and Laursen, 2013)**, **(Esfarjani and Laursen, 2007)**, **(Helgerud, et al., 2007)** and **(Burgomaster, et al., 2005)** were carried out related to high intensity interval training with 1:1 work to rest ratio and also **(Harbin, 2014), (Talisa Emberts, et al., 2013),** (**Rozenek, et al., 2007**), (**Millet, et al., 2003),** (**Billat, et al., 2001)** and **(Meyer, et al., 1990)** were carried out related to high intensity interval training with 1:0.5 work to rest ratio to improve the physiological and athletic performance variables.

Hence, in the present investigation, the researcher intended to find out the effect of tabata interval methods of various durations on selected physiological and athletic performance variables of school students.