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Long term adaptations and mechanisms of different protocols of "concurrent" training in recreationally trained male adults

Author:
Sanjaya Othalawa

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Murcia, March of 2023

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Dr. Pedro Emilio Alcaraz Ramón as Director of the Doctoral Thesis titled “Long term adaptations and mechanisms of different protocols of "concurrent" training in recreationally trained male adults” carried out by Sanjaya Othalawa Othalawe Gedara in the Doctoral Program in Sports Sciences, authorize for submission since it has the conditions necessary for its defence.

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DEDICATION

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පුදමි … !!!

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"You cannot travel the path until you have become the path itself."

~ Buddha

From this thesis, Section 01 has been published in a peer-reviewed journal and several abstracts have been submitted to national or international conferences, where oral communications and posters were presented. Below lists the references of the dissemination of the work:

- Othalawa S, Alcaraz PE. Long-term neural adaptation following three distinct protocols of "concurrent" training, Journal of Culture, Sience and Sport, 2023, under review.

- Ramos-Campo DJ, Martínez-Guardado I, Rubio-Arias JA, Freitas TT, Othalawa S, Andreu L, Timón R. and Alcaraz PE. Muscle Architecture and Neuromuscular Changes After High-Resistance Circuit Training in Hypoxia, J Strength Cond Res, 2019, DOI: 10.1519/JSC.0000000000003275

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- Othalawa S, Freitas TT, Carlos-Vivas J, Rubio Arias JA, Alcaraz PE. Long term adaptation of different protocols: high intensity resistance circuit-based training (HRC) and sprint interval training (SIT) and traditional concurrent training (TCT). V doctoral research conference – ciencia sin frontera (2019). Universidad Católica San Antonio de Murcia, Spain.

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ABSTRACT

The combination of resistance and endurance solicitations within the same training program or session appears to be a compulsory path to achieving high performance in many sports. Those performances are highly dependent on multiple physical qualities that must be developed simultaneously, whereas having appropriate concurrent training allows for better neuromuscular adaptation. Thus, the identification of a single form of physical training that promotes broad physical fitness adaptations within less time would be of great benefit to physical training specialists. Therefore, the general objective was to evaluate and compare the neuromuscular, metabolic, cardiorespiratory, structural (body composition and muscle architecture), and mechanical long-term adaptations between the three different concurrent training methods; Traditional Concurrent Training (TCT), Sprint Interval Training (SIT), and High-intensity Resistance Circuit-based training (HRC) in young recreationally training athletes. In addition, the specific objectives were to identify the long-term neuromuscular, metabolic, cardiorespiratory, structural (body composition and muscle architecture), and mechanical adaptation and mechanism following three different concurrent training (HRC, SIT, and TCT) in the same sample.

To achieve these objectives, the convenience sampling method was used for a single-blinded randomized controlled trial experimental research design to recruit thirty-four young recreationally training male athletes (24±5.8 years, 174.9±5.9 cm height, and 73.4±7.9 kg) and randomly assigned to three training groups (HRC: 13, SIT: 10, and TCT: 11). The study consisted of five total visits to the laboratory: Visit #1 – Initial assessment for requirement test and familiarization session, Visit #2 – pre-training evaluation, Visit #3 – continuation of pre-training evaluation, Visit #4 – post-training testing, and Visit #5 – continuation of post-training testing. The entire study has taken approximately ten weeks but all subjects exercised twice a week for 8 weeks during the intervention. During Visits # 2, 3, 4, and #5 neuromuscular, metabolic, cardiorespiratory, structural (body composition and muscle architecture), and

mechanical variables were assessed. Standard descriptive statistics were used to characterize the study population. A mixed analysis of variance with repeated measures and the Bonferroni post hoc test were used to investigate the interaction effect and significant differences within and between groups.

The findings of the study are explained through five sections and the main findings of section 01 showed each training procedure had a unique neuronal adaptation that was most particular to its training character. Whereas SIT and TCT protocols demonstrated spinal adaptation throughout the intervention, HRC demonstrated supraspinal and spinal adaptation. It follows that while theoretically all of these adaptations exhibit both quantitatively positive and negative changes, both changes are crucial to improving athletic performance. Furthermore, the main findings of section 02 revealed that although no training approach is superior to the others, following three distinct concurrent training regimens caused different metabolic improvements in blood lipid profiles. Particularly, the TCT protocol was an ideal training method to lower total cholesterol levels and increase HDL-C, but SIT protocol is a time-effective method for performance-based programs that induced a decrease in cholesterol, triglycerides, and LDL-C, whereas HRC also induced positive and negative alterations. Thus, each user could be able to select any training protocol following their needs.

Moreover, section 03 exposed that the TCT protocol is much better than the other two concurrent training methods (HRC and SIT); in terms of enhancing the cardiorespiratory variables in recreationally trained individuals. However, following HRC and SIT also induced an increase in VO_2 max and RMR, but the time consumed by the training sessions is lesser than TCT. Since HRC and SIT are very time efficient and contribute to enhancing cardiorespiratory adaptations, it would be advantageous to use a single mode of an exercise training protocol to improve cardiorespiratory variables. Hence, it is depending on the needs and desires of each individual in terms of their available time for exercising as well as the training plans.

In addition, section 04 observed that HRC, SIT, and TCT offered different body composition and muscle architecture benefits after the 8 weeks training period but no single program was better than another, but the time spent on the training sessions differed. Hence, depending on the necessity of the subjects they can select the training method for their training schedule. Need to write about the body composition

Interestingly, section 05 revealed that the HRC training program is better than other concurrent training protocols (SIT and TCT) for enhancing force and power in young recreational male athletes. Although HRC is recommended since it is so time-effective, the athlete's or coach's preferences may also call for the use of the other two training protocols throughout their training sessions.

Finally, it revealed that all training protocols enhance more or less adaptation respective to each other but some training methods are very time efficient than other training protocols. Thus, depending on the necessity of each athlete and their coaches they can select the training protocol for their training schedule.

Keywords: Concurrent training, HRC, SIT, TCT, neuromuscular, blood lipid profile, cardiorespiratory, body composition, muscle architecture, force and power

RESUMEN

La combinación de solicitudes de resistencia y resistencia dentro de un mismo programa de entrenamiento o sesión parece ser un camino obligatorio para lograr un alto rendimiento en muchos deportes. Estas actuaciones dependen en gran medida de múltiples cualidades físicas que deben desarrollarse simultáneamente, mientras que tener un entrenamiento concurrente adecuado permite una mejor adaptación neuromuscular. Por lo tanto, la identificación de una forma única de entrenamiento físico que promueva amplias adaptaciones de la aptitud física en menos tiempo sería de gran beneficio para los especialistas en entrenamiento físico. Por lo tanto, el objetivo general fue evaluar y comparar las adaptaciones neuromusculares, metabólicas, cardiorrespiratorias, estructurales (composición corporal y arquitectura muscular) y mecánicas a largo plazo entre los tres diferentes métodos de entrenamiento concurrente; Entrenamiento Concurrente Tradicional (TCT), Entrenamiento por Intervalos Sprint (SIT) y Entrenamiento Basado en Circuito de Resistencia de Alta Intensidad (HRC) en jóvenes atletas que entrenan recreativamente. Además, los objetivos específicos fueron identificar la adaptación y el mecanismo neuromuscular, metabólico, cardiorrespiratorio, estructural (composición corporal y arquitectura muscular) y mecánico a largo plazo tras tres entrenamientos simultáneos diferentes (HRC, SIT y TCT) en la misma muestra.

Con el fin de lograr estos objetivos, se utilizó el método de muestreo por conveniencia para un diseño de investigación experimental de ensayo controlado aleatorio con enmascaramiento simple para reclutar a treinta y cuatro jóvenes atletas varones entrenando recreativamente (24±5,8 años, 174,9±5,9 cm de altura y 73,4±7,9 kg) y se asignaron aleatoriamente a tres grupos de entrenamiento (HRC: 13, SIT: 10 y TCT: 11). El estudio consistió en cinco visitas totales al laboratorio: Visita #1 – evaluación inicial para la prueba de requisitos y la sesión de familiarización, visita #2 – evaluación previa al entrenamiento, visita #3 – continuación de la evaluación previa al entrenamiento, visita #4 – prueba posterior al entrenamiento, y visita #5 – continuación de las pruebas posteriores al entrenamiento. Todo el estudio ha tomado aproximadamente diez semanas, pero todos los sujetos se ejercitaron dos veces por semana durante 8 semanas durante la intervención. Durante las visitas # 2, 3, 4 y # 5 se evaluaron variables

neuromusculares, metabólicas, cardiorrespiratorias, estructurales (composición corporal y arquitectura muscular) y mecánicas. Se utilizaron estadísticas descriptivas estándar para caracterizar la población de estudio. Se utilizó un análisis mixto de varianza con medidas repetidas y la prueba post hoc de Bonferroni para investigar el efecto de interacción y las diferencias significativas de dentro y entre los grupos.

Los hallazgos del estudio se explican a través de cinco secciones y los principales hallazgos de la sección 01 mostraron que cada procedimiento de entrenamiento tenía una adaptación neuronal única que era más particular a su carácter de entrenamiento. Mientras que los protocolos SIT y TCT demostraron adaptación espinal a lo largo de la intervención, HRC demostró adaptación supraespinal y espinal. De ello se deduce que, si bien teóricamente todas estas adaptaciones exhiben cambios tanto positivos como negativos cuantitativamente, ambos cambios son cruciales para mejorar el rendimiento deportivo.

Además, los principales hallazgos de la sección 02 revelaron que aunque ningún enfoque de entrenamiento es superior a los demás, seguir tres regímenes de entrenamiento simultáneos distintos provocó diferentes mejoras metabólicas en los perfiles de lípidos en sangre. En particular, el protocolo TCT fue un método de entrenamiento ideal para reducir los niveles de colesterol total y aumentar el HDL-C, pero el protocolo SIT es un método eficaz en el tiempo para los programas basados en el rendimiento que indujeron una disminución del colesterol, los triglicéridos y el LDL-C, mientras que HRC también indujo alteraciones positivas y negativas. Así, cada usuario podría seleccionar cualquier protocolo de entrenamiento de acuerdo con sus necesidades.

Además, la sección 03 expuso que el protocolo TCT es mucho mejor que los otros dos métodos de entrenamiento concurrentes (HRC y SIT); en términos de potenciar las variables cardiorrespiratorias en individuos entrenados recreativamente. Sin embargo, seguir HRC y SIT también indujo un aumento en el VO2 máx y la RMR, pero el tiempo consumido por las sesiones de entrenamiento es menor que el TCT. Dado que HRC y SIT son muy eficientes en el tiempo y contribuyen a mejorar las adaptaciones cardiorrespiratorias, sería ventajoso utilizar un único modo de protocolo de entrenamiento para mejorar las variables cardiorrespiratorias. Por lo tanto, depende de las necesidades y deseos de cada individuo en cuanto a su tiempo disponible para hacer ejercicio, así como los planes de entrenamiento.

Además, la sección 04 observó que HRC, SIT y TCT ofrecieron diferentes beneficios en la arquitectura muscular después del período de entrenamiento de 8 semanas, pero ningún programa fue mejor que otro, pero el tiempo dedicado a las sesiones de entrenamiento fue diferente. Por lo tanto, dependiendo de la necesidad de los sujetos, pueden seleccionar el método de entrenamiento para su horario de entrenamiento. Necesito escribir sobre la composición corporal.

Curiosamente, la sección 05 reveló que el programa de entrenamiento HRC es mejor que otros protocolos de entrenamiento concurrentes (SIT y TCT) para mejorar la fuerza y la potencia en atletas masculinos jóvenes recreativos. Aunque se recomienda HRC ya que es muy efectivo en el tiempo, las preferencias del atleta o del entrenador también pueden requerir el uso de los otros dos protocolos de entrenamiento a lo largo de sus sesiones de entrenamiento.

Finalmente, reveló que todos los protocolos de entrenamiento mejoran más o menos la adaptación entre sí, pero algunos métodos de entrenamiento son muy eficientes en el tiempo que otros protocolos de entrenamiento. Así, dependiendo de la necesidad de cada atleta y sus entrenadores pueden seleccionar el protocolo de entrenamiento para su horario de entrenamiento.

Palabras clave: Entrenamiento concurrente, HRC, SIT, TCT, neuromuscular, perfil de lípidos en sangre, cardiorrespiratorio, composición corporal, arquitectura muscular, fuerza y potencia

ABBREVIATIONS

The abbreviations of the units from the International System Units are not included in the following list as there are internationally accepted standards for their use.

HRC	:	High Intensity Resistance Circuit-based Training
SIT	:	Sprint Interval Training
TCT	:	Traditional Concurrent Training
CT	:	Concurrent Training
HIIT	:	High Intensity Interval Training
HIIE	:	High Intensity Intermintent Exercise
MICT	:	Moderate Intensity Continuos Training
CWT	:	Circuit Weight Training
HIPT	:	High Intensity Power Training
RT	:	Resistance Trainig
CRT	:	Circuit Resistance Training
BMI	:	Body Mass Index
BMD	:	Bone Mineral Density
BMC	:	Bone Mineral Content
MVC	:	Maximal Volantary Contraction
EMG	:	Electromiography
H – Reflex	:	Hoffmen Reflex
M wave	:	Motor Wave
RFD	:	Rate of Force Development
MN	:	Motor Neuron
α- MN	:	Alpha Motor neuron
EMD	:	Elector Mechanically Delay
CMJ	:	Counter Movement Jump
NTLM	:	Neural Tension-Limiting Mechanism
CNS	:	Central Nervous System
RBC	:	Red Blood Cells
RBCV	:	Red Blood Cells Volume
WBC	:	White Blood Cells

Hb	:	Himoglobin
EDTA		Ethylenediamine Tetraacetic Acid
PLT	:	Platelets
Hct	:	Hematocrit
LPL	:	Lipo Protien Lipase
BG	:	Blood Glucose
TC	:	Total Cholesterol
TG	:	Triglyceride
FFM	:	Fat Free Mass
GH	:	Growth Hormone
HDL-C	:	High Density Lipoprotein Cholesterol
LDL-C	:	Low Density Lipoprotein Cholesterol
VLDL	:	Very Low Density Lipoprotein
Pcr	:	Phospho Creatine
MCH	:	Mean Capsular Hemoglobin
CBC	:	Complete Blood Count
PV	:	Plasma Volume
HR	:	Heart Rate
MHR	:	Maximum Heart Rate
Q	:	Cardiac output
Q max	:	Maximum cardiac output
SV	:	Stroke Volume
VO_2 Max	:	Maximal oxygen consumptionn
VO_2 R	:	Oxygen consumption reserve
EPOC	:	Execess of Post Oxygen Consumprtion
RMR	:	Resting Metabolic Rate
VT2	:	Ventilation threshold 2
ATP	:	Adenosin Three Phosphate
RSA	:	Repeated Sprint Ability
PDec	:	Power Decrement
DEXA	:	Dual Energy X-ray Absorptiometry
CSA	:	Cross Sectional Area
ACSA	:	Antomical Cross Sectional Area
PCSA	:	Physiological Cross Sectional Area

ACSM	:	American Colleage of Sports Medicine
VL	:	Vastus Laterales
% PPO	:	% Peak Power Output
FABPpm	:	plasma membrane Fatty Acid Binding Protein
WOD	:	Work Out of the Day
PO_2	:	Partil pressure of Oxygen
PIO_2	:	Partial pressure of Inspired Air
P_AO_2	:	Partial Presure of O_2 in Alveoli
P_aO_2	:	Partial Presure of O_2 in arterial
P_vO_2	:	Partial Presure of O_2 in Venous Blood
a_vO_2	:	Arteriovenous Oxygen difference
FIO_2	:	Fractional Concentration of Oxygen
EIMD	:	Exercise Induced Muscle Damage
LV	:	Left ventrical
IGF	:	Insulin Growth Factor
BMR	:	Basal Metabolic Rate
1 RM	:	One Repetition Maximum

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I - INTRODUCTION

I - INTRODUCTION

Studies performed over the past decade have yielded new information related to the physiological and metabolic adjustments made in response to both short and long-term exercise training. Hence, it is clear that when the body engages frequently under the supervision of proper exercise training sessions, each of the physiological systems undergo specific responses, which assist to increase the human body's efficiency and capacity. Therefore nowadays, many scientists are willing to investigate physiological benefits which improve the performance of athletes as well as a patient by conducting proper and well-planned training schedules vs time, which would be able to prevent cardiometabolic disease, as well as delaying of the adverse effects of aging. Therefore the most crucial factor is the relationship between performance and time invested to realize exercise. Therefore it always needs to apply ideal stimulus for the optimum performance or expected performance through the training sessions.

Long-term (chronic) physiological adaptations are a vital part of the human ability to develop and improve over time. It is allowed to manage various human body systems more efficiently by imposing different changes and demands of exercise. Under this premise, the current physical exercise programs are most successful than traditional exercise programs which imply a few minutes lower than traditional exercise programs to secure the same benefits. Hence, the present investigation will propose to study the chronic effects of different concurrent training protocols on neuromuscular, metabolic, cardiovascular, structural (body composition and muscle architecture), and mechanical parameters of recreationally trained young male athletes.

According to the above-mentioned matter, the present investigation will direct with the following hypothesis, is the exercise workouts which include strength and endurance sessions like High Resistance Circuit (HRC) training will be able to produce different benefits such as decrease the cardiovascular risk profile of patients, improving the control of blood pressure, cholesterol and blood sugar levels, and Body Mass Index (BMI). Improvements in Bone Mineral Density (BMD), muscle mass, and quality. Besides, this type of training greatly reduces the training time, so it is a great application for any kind of sport where physical preparation is of special relevance and when it has limited time.

Therefore, the present investigation will consist with following objectives, is to describe the adaptations of three different type of concurrent training [HRC vs. Sprint Interval Training (SIT) vs. Traditional Concurrent Training (TCT)] response after 8 weeks training sessions: neuromuscular [Maximal Volantary Contraction (MVC), EMG (Electromyography) peak, EMG (Electromyography) mean, H reflex (Hoffmann reflex) and M wave (muscle response), H max/ M max ratio, RFD (Rate of Force Development) 50, RFD 200, RFD peak, EMG 50 and EMG 200), metabolic [Red blood cells (RBC) or Erythrocytes, Hemoglobin (Hb), Hematocrit (Hct), Basal blood sugar (BG), Total blood cholesterol (TC), Triglyceride (TG), High-density lipoprotein cholesterol (HDL-C), Low-density lipoprotein cholesterol (LDL-C)], cardiorespiratory (Maximum heart rate, Maximum velocity, Maximal Oxygen Consumption (VO_2 max), Maximal Oxygen Consumption Reserve (Max VO2R)) structural (Modification of BMD, lean mass, fat mas, total fat %, thickness and diameter changes in ventricular, muscle architecture, etc.) as well as on mechanical parameters (strength production and power or potential) responses in different population, and as well to compare the adaptations among the three types of concurrent training systems.

Background

In the present day, it is completely demonstrated that physical exercise has been clinically proven the positive effects on people's health due to the proper intervention of training programs and in many cases prevents the health burdens associated with many chronic diseases. However, the effects of the training workout depend largely on parameters related to the own training workout and to the persons who are given it. In this sense, the physiological impact induced by the activity will depend on the magnitude of the load. It means, the type of exercise, volume, frequency of application, intensity, recovery, etc.…, as well as the contribution of general health state and age of the persons also will depend according to the above-mentioned factor (1). However, there are common potential benefits for all the population which are directly related to the enhancement of health state performance, and prevention of cardiovascular and metabolic diseases associated with sedentary lifestyles (2-3).

However, the benefits of exercise are well-established scientifically through a bunch of theories and practical investigation. But one of the most common specific problems in the current society all around the world is the absence of time available for realizing physical exercise (4). When considering the sport context, also shows the same issues in different categories of athletes like semiprofessionals and novices/amateurs, facing a short time period available for their training schedule due to different reasons like education, work…etc. On the other hand, the dynamic changes in rules and regulations of each category of sports also have pushed strongly all the athletes to train hard but in relatively less time period. Even the competition calendar of many sports has been changed, increasing the number of competitions per year at both ways national and international levels. It means forcing the athlete to keep maintaining the peak level during a short time period of time for a higher performance level. Hence, literally, all athletes are now in the critical phase of training duration compare with the time which exactly they need to be at peak level. It means literally according to the number of competitions, competition standards, rules, regulations, etc. the training time has been reduced but the demands of the competition level or performance level are still being increased dynamically.

Therefore, for the above-mentioned different reasons athletes have to maximize practice time to train the largest number of physical qualities, and technical and tactical determinants in their discipline in the shortest time possible. For example, in the majority of sports training athletes dedicate there a training time period to improve their physical capacity, including aerobic capacity, maximum strength, speed, and mechanical power. As an example, Bangsbo et al 1994 (5) explained that athletes who play 90 minutes of a football match with medium intensity just showed close relation with anaerobic threshold or 80 – 90 % of their maximum heart rate of them. Besides football match which is played during high-intensity period normally consisted of the most relevant actions of the games, therefore those actions are provoking to produce the maximum accumulation of lactic acid (6).

According to Franchini et al. (7) explained that typical maximal oxygen uptake values are around 50–55mL/kg/min for males and 40–45mL/kg/min for female judo athletes. Some authors recommended that to improve an athlete’s VO_2 max is better to train with 90-95 % of the maximum heart rate of the athlete and maximum strength training with a heavy load like 85% of one repetition maximum (1RM) (8). Normally the training programs for the physical condition in Judo, include a combination of strength and endurance training sessions for execution. Nevertheless, as has been mentioned in advance, this aspect could make an issue due to the limited access to the instructors and equipment during the workout, as well as when there is limited time available for physical preparation. Thus, the unique form of training development which promotes extensive physical adaptations with less work time could be a great benefit for coaches and athletes.

It is important to have an idea about almost all sports and training activities (Judo, football, etc.) that show similar metabolism profiles like realizing a very high intensity of repeated movements with constant effort, inserted with the recovery period. Like these kinds of exercises, the intensity required in each action is much higher than the maximum power that which aerobic energy system can maintain. According to that the last research published by the American College of Sports Medicine (ACSM) in 2014 shows that the more demanded training workout suggested by the population was, those were produced high levels of profits within a short time of work period. Some of these training types, characterized by the attempt to integrate the improvement of both energy processes anaerobic as well as aerobic (concurrent training), are High-Intensity Interval Training (HIIT), Circuit Training, and High Resistance Circuit training already been shown to the similar adaptation of strength and endurance … etc. than traditional training of strength, endurance or combination of both (Traditional Concurrent Training).

According to Alcaraz et al (9-10), Gibala et al. (11) explained that the main character of this new training tendency is the combination of high-intensity exercise with incomplete recovery between different exercises and series. This kind of manipulation will allow stressing the aerobic and anaerobic metabolic systems appropriately through the training session. It is based on the concept of the possibility to realize more work with high-intensity exercise within the same or less fatigue than continuous training workouts. One of the possible physiological justifications is the Excess of Post Oxygen Exercise Consumption (EPOC). It means when someone stops the training at a high-intensity level, but still, his or her metabolism can continue by using oxygen and burning more calories up to the body being rested or stabilizing the conditions previous to the exercise (re-synthesis of Adenosine Three Phosphate - ATP) stores, phosphocreatine, glycogen re-synthesis, restoration of oxygen in cellular, etc.) during a period which depends on the intensity and duration of the activity.

Another possible character is the relationship between exercise and inflammation. This could happen after intense exercise is related to three vascular components like Monocyte, Endothelium, and Platelet which have demonstrated fundamental role in the development of inflammatory responses that occurs after intense exercise. Micro-particles (MPs) are subcellular vesicles released by these vascular elements and supposed that those elements could be important modulators of inflammatory response and later adaptations in the aerobic system after the training of anaerobic. Hence, documenting the specific activation of these cells after high-intensity exercise is expected to study the effect of new training workouts on the current MPs profile and inflammatory molecules of athletes.

One of the clearest examples of maximizing training time to achieve optimal results is HIIT, it is characterized by very short periods of duration and very high-intensity of exercise with rest periods or low-intensity exercise which serves as recovery (1). HIIT can make potential stimulus for the new athlete who doesn't have the proper experience, and higher training athletes as well as physically active persons will produce similar adaptations to aerobic traditional exercise which include the heavy volume of work and long duration of training sessions (12, 1, and 13). The benefits of HIIT have been also tested on different populations with cardiovascular and metabolic diseases, as well as with obese people (14 - 15).

The idea of amalgamating different stimuli, such as strength and resistance in the same training workout is not something new anymore. Different studies have shown positive effects on cardiorespiratory, neuromuscular, and skeletal parameters during the HRC (9, 10, 16). Many studies have demonstrated that this type of training workout can receive muscle hypertrophy decreases the percentage of body fat, and the greatest improvement of strength and power, due to the major metabolic impact. In addition Alcaraz et al. (10) explained that HRC training can produce a similar range of benefits of physical condition than combines strength and resistance training, but with a shorter duration of workout in which adults are trained.

Moreover many studies prove that EPOC of post-exercise is significantly higher than the results of traditional training. Concerning the different adaptations explained that significant improvement of maximum strength, mechanical power, acceleration capacity, decrement of body fat with a moderate increment of muscle mass, lactic anaerobic capacity, and VO_2 max during 8 weeks of training (17). However, there is a certain sign about the physiological cause that produces the gran magnitude of adaptation, even though there are a lot of studies, still exists the scarcity of conducting major deepening studies about the mechanism of reasons for the same adaptation mentioned. Recent studies have intended to apply strength training with together HIIT training (18).

For everything exposed in advance and due to the absence of studies that have determined and compared the chronic adaptations of the different protocols of training presented between themselves (HRC; SIT; TCT) in recreationally trained athletes, It raises the following research questions: What are the physiological mechanisms which are activated with each type of "concurrent training", are there differences between any other different mechanisms that occur in three type of training, What adaptations produce each of the training, which of the three protocols of training produces the largest number of adaptations concerning the dedicated time of work.

II - LITERATURE REVIEW

II - LITERATURE REVIEW

2.1. Definition of concurrent training

Combining strength and endurance training within the same regimen is aptly referred to as "concurrent training". Hence, it is crucial to understand the meaning of the word "concurrent". According to the Oxford dictionary, it is "happening, existing or done at the same time", while Merriam-Webster dictionary explains that it is "operating or occurring at the same time". Therefore, the majority of authors it was interpreted it in different ways but practically used it as two training programs that included "resistance" and "endurance" training modes in the same training session, either on the same day or on separate days as concurrent training.

According to (19), concurrent training was incorporating strength and endurance training within the same training session or on separate days. Later, Leveritt et al. (20), and Wilson et al. (21) were defining concurrent training as a concomitant integration of resistance and endurance training within a periodized training regime. While Fyfe and associates (22) defined it as the simultaneous integration of both resistance and endurance exercise within a coherent training plan. However, among all of them, concurrent training is commonly defined as the simultaneous integration of both resistance and endurance exercise within a periodized training regime, as well as concurrent resistance and aerobic training refers to stimulating both strength and aerobic development in the same training session.

Furthermore, Williams (23) says concurrent training is the simultaneous physical preparation of two or more exercise modalities. By the way, with time through the different studies, Fyfe and Lonneke in 2018 (24) revealed that the goal of concurrent training is to get the most out of benefits simultaneously associated with both resistance and endurance training, achieved by either exercise mode in isolation. In another way, it could be explained that, enhance the athlete's performance and health variability at once through the same training protocol or isolation protocol. Eventhough it is traditionally defined as a concomitant integration of resistance and endurance training within a periodized training regime. Therefore to the understanding of the authors, this term should be reconsidered. The goal of concurrent training according to Fyfe and Lonneke (24) is to simultaneously maximize the effects connected with both endurance and resistance training (i.e. enhanced metabolic health, functional capacity, and athletic performance) above that achieved by either exercise mode in isolation. Consequently, any protocol which is able to full fill these purposes might be considered concurrent training, which is corresponding with the meaning of words explained by different dictionaries.

2.2. Types of concurrent training

In this regard, according to the perspective of Fyfe and Lonneke (24) in the context of sports training it could be identified different types of concurrent training which are given almost equal benefits simultaneously both endurance and resistance training, such as metabolic health, functional capacity (VO_2 max), muscle hypertrophy and athletic performance … etc but in isolation mode.
Therefore, especially if the protocol is in isolation format or even any protocol that is able to fulfill the aims of concurrent training then it should be considered as "concurrent training". According to this notion, some of the best-known concurrent protocols are HIIT and SIT, HRC, and unquestionably, TCT.

2.2.1 Traditional concurrent trainings (TCT)

2.2.1.1 Introduction to traditional concurrent training

Since the revolutionary investigation conducted by Hickson (19) regarding concurrent training, it has been documented that training to increase the performance of resistance and endurance physical qualities simultaneously, the results might compromise the strength adaptation. This blunted results occurrence was described by him as an "interference phenomenon" (19, 25). However, with time the widespread research regarding the contribution of this mechanism was interpreted as an "interference effect" too. It was mainly indicated that endurance training was discouraging or decreasing the development of strength, power, and hypertrophy when compared to strength training in isolation, even though still researchers are trying to be fully elucidated. However to prove the above-mentioned phenomenon he was using a strength group, an endurance group, and a combined strength and endurance group. The strength group exercised 30-40 min/day with load > 80% of 1 RM within 5 days/week and recovery periods were separated by 3-min, while the endurance group performed interval training on cycling and continuous running 40 min/day, during 6 days/week with 2min of rest intervals, and lastly strength and endurance group exercised the same daily exercise schedules as the strength and endurance groups. All training protocols were extended alone by 10 weeks.

Interestingly during 7 weeks, strength development was increased by approximately 34% in strength and endurance groups how is usually happens in the strength group. However, within the last three weeks, it plateaued and decreased by approximately ~25% in strength and endurance groups while the strength group continued to enhance by ~10%. As well as after completing the training intervention of 10 weeks both the training endurance group and strength and endurance groups' VO_2 max was increased by approximately 25% during bicycle exercise and 20% during treadmill exercise. Hence these results were the first study that explained that when concurrently training for strength and endurance will result in a lower capacity to improve strength (Figure 01), but will not impede the magnitude of improvement in maximal oxygen consumption (VO_2max).

Based on this preliminary information it has been conducted several studies about the effects of concurrent training up to the present day in a variety of different settings or types of concurrent training. There were a number of methodological applications used within different studies, and most of the studies interpreted that an 'interference phenomenon' occurred during these investigations, like Hickson (19, 25), Kraemer et al. (26, 27), Dolezal and Potteige (28), Hakkinen et al. (29) were observed decrement of strength capacity, while Hickson (19, 25), Kraemer et al. (26), McCarthy et al. (30) were analyzed reduction in hypertrophy, and Hunter et al. (31), Leveritt et al. (32); Hakkinen et al. (29) were depicted that reduction of muscular power following concurrent-training (CT).

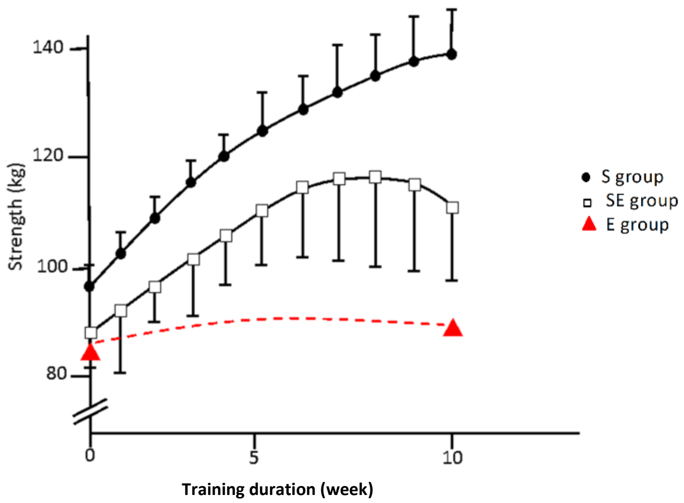

Figure 1. Strength changes of three different training types. Hickson (19)

To better understand of interference phenomenon and the reason of generate such effects it might be important to investigate the effects of different concurrent training programs which were using different training methods. On the other hand, if it is able to identify the methodological designs of those studies it probably supports the creation of theoretical concepts with the purpose of minimizing interference effect during any kind of concurrent training. After profound observation of those studies of CT, it is depicted that a variety of methodologies was used, and it was making difficult to analyze and compare the final findings to create conclusions because of the discrepancy of the studies, thus the results are still inconclusive.

As an example, different investigators have used verities of resistance training (RT) methods, such as circuit-based RT (33), isokinetic RT (35), 'free-weight RT' (30), 'machine RT' (27), isoinertial strength training and finally the combination of some training methods of above with the purpose of improve muscle strength either lower or upper body. Whereas different endurance training method was performed to increase aerobic capacities, such as running (35), cycling (36), rowing (37), arm-cranking (38), and a combination of running and cycling have all been performed in the endurance training components of various concurrent training studies with Sub-maximal (31), high-intensity (33) and a combination (26) of low and high training intensities have been used to improve both strength and aerobic capacity.

Furthermore, training frequency differed according to the studies; Abernethy and Quigley (38) were instructed to train 3 days per week while Santtila et al. 2009 (39) were trained 6 days per week for the duration of the training program. Moreover, sequences of training were also highlighted, some used strength prior to endurance others used endurance prior to strength and especially some of them mentioned the sequences, and those who mentioned training sequences did not care to mention the recovery during the period between training programs (40). Moreover, some studies have failed to report the 'order' or 'sequence' of concurrent training (41) and those who reported training sequence did not always report the recovery period between training sessions (40). Lastly, the training age and state of study participants differed among studies which were investigated the effect of CT, but the majority of studies used untrained participants for their investigations. To complicate matters further, most CT protocols differ in the volume, intensity, and speed of muscular contraction, which makes it impossible to propose any training recommendations with the purpose of minimizing the interference effects.

Therefore, at least it is useful to verify why it occurs interference effect strength development. Hence some of the authors also report why it is blunted strength development, following session will discuss the theoretical models which explain why interference occurs, which is literally important to design further CT programs with deeper understanding.

2.2.1.2 Strength training

Over the past fifty years, strength training has gained widespread acceptability as an important component of a physical conditioning program for the healthy individual preparing for sports participation or seeking greater physical fitness and health (42). Therefore, it can be used as a method of improving muscular strength by progressively increasing the ability of the neuromuscular system to generate and/or resist force through the use of free weights, machines, or the person's own body weight (43). It encompasses short-duration activity at high or maximal exercise intensities (44) and increases the capacity to perform high-intensity, high-resistance exercises of a single or relatively few repetitions such as Olympic weightlifting, and powerlifting to name but a few.

In addition, over time strength training has been shown to result in a variety of physical and physiological adaptations, elicited by strength training as an exercise 'stressor' (45). Improved strength-related performance is accomplished through neuromuscular learning and increased fibre-recruitment synchronicity, muscle cell hypertrophy (i.e. CSA), and possibly, hyperplasia without changes in VO2max or in the capacity to generate ATP via oxidative metabolism (46). Those adaptations are solely dependent on the acute variables of the strength training program which was redefined by Kraemer, 1983 (47), such as repetition maximum load, number of sets, choice of exercises, order of exercises, and rest periods. A recently published position stand by the ACSM, 2002 (440) followed a revision of the above program variables. The revised acute program variables are as follows: (i) muscle action; (ii) loading and volume; (iii) exercise selection and order; (iv) rest periods; (v) repetition velocity; and (vi) frequency. The implementation of these acute program variables ultimately determines the nature of performance, neuromuscular, biochemical, and cell signaling responses to strength training (45) (Table 01).

The term strength is identified as the maximal force or torque that could be developed through muscle contractions of particular movements. Those contractions at maximal effort could be either isometric, concentric, or eccentric actions or the two dynamic actions performed at a wide range of velocities. Thus, strength is not just the results of an assessment executed under a single set of conditions since it the involvement of different variables and conditions, likewise determined the strength of muscle or muscle group as the maximal force generated at specified or determined velocity (48).

Table 1.Recommendations for acute programme variables to different strength training adaptation. Adapted from Baechle and Earle (19).

Training goal	Load (% 1RM)	Goal reps	Sets	Rest Period
Strength	≥85	≤6	2-6	2-5 min
Power				
Single-effort event	80 - 90	1-2	3-5	2-5 min
Multiple-effort event	75 - 85	3-5		
Hypertrophy	67 - 85	6-12	3-6	30s -1 min 30s
Muscular endurance	≤67	≥12	2-3	≤30s

2.2.1.3 Endurance training

Any sports exercise that makes the body more muscularly or cardiovascularly resilient is referred to as endurance training. To engage in physical activity for prolonged periods with decreased risk of injury, endurance training helps the bodies respiratory and muscular systems grow. Cardiovascular endurance training focuses on aerobic exercise, which entails exercises that enhance how well the body uses oxygen to provide energy for athletic performance. Muscles will become more able to endure extended durations of use as a result of muscular endurance training. For those wishing to improve their athletic ability, there are a variety of endurance training activities they may do. Basically, running intervals or Fartlek training can help athletes like cyclists or distance runners increase their cardiovascular endurance. Increased muscular endurance can be achieved through resistance and strength training.

Endurance training is induced to increase the oxidative capacity of muscle, thereby allowing the muscle to use more oxygen (O2) and thus achieve a higher O2max. The primary requirement for endurance performance is the capability to sustain repeated muscular contractions at a given submaximal intensity (50). Therefore, according to Jones and Carter (442), endurance was interpreted as "the capacity to sustain a given velocity or power output for the longest possible time".

2.2.1.4 Mechanisms to explain the interference phenomenon

As it is mentioned previously, the higher plasticity nature of human skeletal muscle response to the training program and always induced particular adaptations depending on the training stimulus (51). Thus, strength and endurance training is two different methods that involved contrasting training methodologies, following developed vastly different biochemical, neural, and performance adaptations as responses to the different training methodologies. Several investigations have been conducted regarding the effect of concurrent training protocol on strength and endurance performance as well as muscle progress. On the other hand, some other researchers also conducted studies regarding the physiological mechanism of interference phenomenon. Looking forward to an answer regarding the question of why the inhibition of strength, power, and hypertrophic responses may occur when conducting strength before endurance training.

Since the study conducted by Hicksons in 1980 up to now there were different suggestions explained by different authors regarding the interference phenomenon. Among them, Docherty and Sporer (52) explained the consequences of deficit adaptability for different training intensities. Besides, contradictory hormonal issues (53), molecular signaling environment (54) the training sequences (33), the recovery time between training bouts or sets (55), the aerobic-training frequency (21), and the effects of overtraining (56). How all those explanations are interconnected could be able to categorize into two hypotheses such as acute and chronic (443).

The endurance component of concurrent training-induced residual fatigue caused an interferential effect which is resulting in the incapability to develop tension effectively in the strength component of CT due to the overtraining (28), identified as an acute hypothesis. While chronic hypothesis explained that the effects of the acute intramuscular event create a conflict situation on skeletal muscle adaptation (i.e. metabolically or morphologically), which was blocking chronic adaptation because the adaptations to endurance training are often inconsistent with adaptations observed during strength training. For example, the activity of aerobic enzymes used to increase after endurance training (57). However, aerobic enzyme activity can be decreased after strength training (58). Therefore it is unable to receive optimal muscle adaptation of either strength or endurance stimulus through the training sessions. Therefore, skeletal muscle shows a different adaptation as a response to CT than each training mode performed in isolation normally. Specially, exercise training stimuli depend on the execution of the exercise and the way of organization, according to that it could be influenced by both categories.

2.2.2 High-intensity interval training (HIIT)

2.2.2.1 Introduction to High-intensity interval training (HIIT).

High-intensity interval training, also known as high-intensity intermittent exercise (HIIE), is a short, intense workout type of cardiovascular exercise usually lasting from 4-30 minutes; applying alternate exercise periods between high and low-intensity exercise or between high-intensity anaerobic exercise and short periods of rest (59, 60). According to Keating and associates (61) in 2014, HIIT involves repeated bursts of vigorous-intensity exercise combined with low-intensity recovery. Besides HIIT is essentially what the name describes: High-intensity exercise split up into intervals, focusing to get the heart rate up for brief bouts of high-intensity exercise, followed by less intense periods of active rest, or slower-paced exercise. The main purpose of HIIT is to increase speed, glucose metabolism, cardiovascular fitness, and fat burning (62 - 64). The major principles of HIIT are that exercise should be brief, infrequent, and intense.

On the other hand, HIIT induced specific physiological adaptations in limitless variables and it is determined by uncountable factors of the exercise stimulus. Such as intensity, duration, and the number of intervals performed, as well as the duration and activity patterns during recovery (1). Furthermore, it can be used as an effective substitute for traditional endurance training, which probably achieves similar or even better adaptation in a range of physiological, performance, and health-related biomarkers in both healthy and diseased populations (1, 65).

Therefore, for the aforementioned reasons and due to the quick results and effective use of time, it has become a popular within few years. How it is in the shape of interval training that alternates between intermittent bursts of vigorous high-intensity activity with periods of low-Intensity active rest periods whereas high and low-intensity intervals could range between 10 seconds to 4 minutes long. To enhancement of anaerobic capacity, shorter high-intensity interval activity ranges between 10-30 seconds, while to develop aerobic capacity could use longer high-intensity interval activities whereas apply exercise more than 30 seconds. Thus commonly the entire workout including warm-up and cool-down could be completed within 30 minutes; of course, it depends on the intensity of the workout. Even it is like that interestingly HIIT provided similar health benefits to steady-state moderate-intensity exercise in much less time. Therefore, it is well known that following this training method could be produced greater adaptation in musculoskeletal, metabolic, and cardiorespiratory improvements. Only the other hand, it has gained a lot of momentum in the fitness context due to the tissue adaptations it produces, it was equal to the adaptation elicited by traditional aerobic training.

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On the other hand, strength and aerobics exercises that are used for HIIT protocol could be also adjusted according to the requirements of the individual. While, among the different studies conducted by using traditional cycling or sprinting protocols (64, 68) there is a new trend of HIIT circuits including bouts of body weight exercises. Performing this kind of exercise routine could be able to remove varies barriers and increases adherence to an exercise program, and makes weight loss goals more attainable. (Se

Nevertheless, according to Buchheit and Laursen 2013a (69) to maximize the physiological adaptation it's always required the manipulation of programming variables (i.e., participant-related factors and protocol-related factors). In the same study, they explained nine variables that could be manipulated to prescribe different HIIT training protocols (Figure 02). The intensity and duration of work and relief intervals were the crucial factors, while the number of intervals, series, and between series recovery duration and intensity determine the total work performed. Intensity is one of the key factors to prescribe training sessions there are different ways to manipulate it, like based on absolute or relative power output, speed, heart rate, or perceived exertion.

A simpler classification scheme of interval training distinguishes two main types: HIIT, usually defined as relatively intense but "submaximal" or "near maximal" efforts that elicit ≥80% of maximal heart rate, and SIT, a more intense version in which bouts are performed in "all out" manner or "supra-maximal" intensity (≥100% VO2max) (70, 71). However, based on the current studies comparing other concurrent training with HIIT, as well as the proper understanding of the most common barriers and limitations still requires to continue the research, particularly in this area.

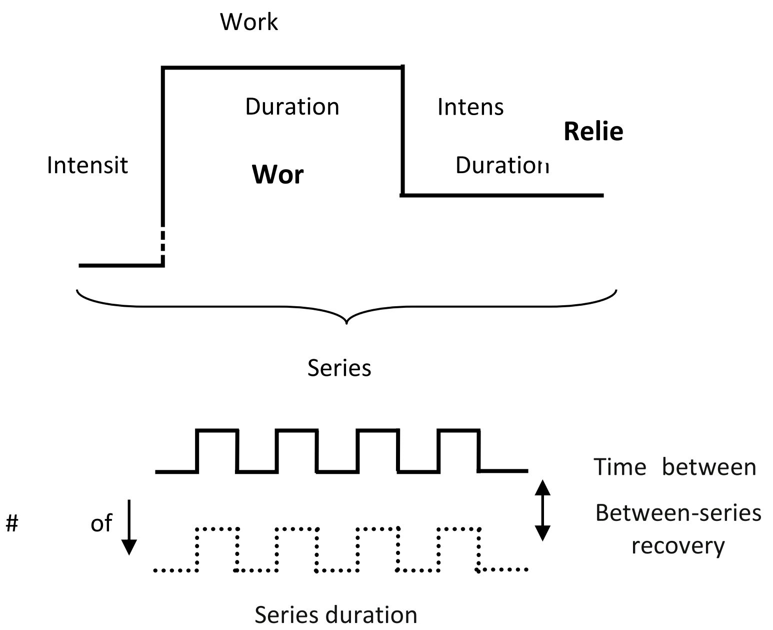
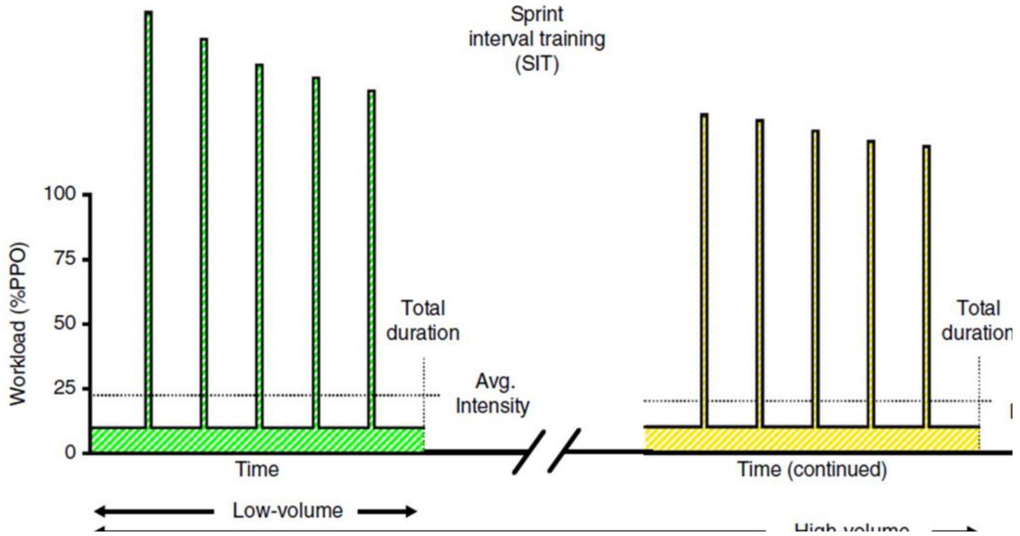


Figure 2. Suggested nine variables of HIIT, Buchheit and Laursen (69).

2.2.2.2 Types of HIIT training

2.2.2.2.1 Sprint interval training (SIT)

Sprint interval training was introduced by Woldermar Gerschler over 70 years ago to enhance athletic performance (72). In the past few years, there has been a renaissance of scientific interest in SIT, it has been applied with the purpose of improving the clinical issues and athletics performance for both disease and healthy populations (1). It is defined as repeated bouts of high-intensity exercise, commonly employed SIT protocol consisting of repeated bouts of 30-s maximal efforts performed on a cycle ergometer, separated by four minutes of recovery (1). This high-intensity low volume model of exercise seems to elicit similar metabolic and cardiopulmonary adaptations that are typically associated with endurance training (12, 1). This training could be applied in two forms: low and high volumes. Most recent studies of SIT used a low-volume protocol (e.g. 12), whereas earlier studies of SIT used a high-volume protocol (Figure 03).



Low-volume SIT	Freq./Dur. (3x/week, 30 min); Inten.-%PPO (90 W); Weekly Trai. Vol. (486 kJ)
High-volume SIT	Freq./Dur. (3x/week, 75 min); Inten.-%PPO (80 W); Weekly Trai. Vol. (1080 kJ)

Figure 3. A graphical depiction of the main types: low and high volumes of sprint interval training (SIT). %PPO = % peak power output. MacInnis and Gibala (71).

Among the researchers who were investigating improving performance on this type of training method, Professor Izumi Tabata is one of the best-known pioneers in this particular area. It was noted that SIT induced significant enhancement of VO_2 max and anaerobic capacity of skeletal muscle (59). In this study, he used an ergonomic stationary cycle at 170% of VO_2 max which is might consider a very high intensity, then ergonomic stationary bikes have been started to use for studies to apply the Wingate test or some variation (74 -75). This test consisted of 4 to 6 repeats of ‘all-out’ maximal efforts around 30 seconds in duration followed by a rest period of low-intensity cycling to prevent the pooling of blood in the venous of the legs, which is allowed to conduct a prescribed amount of times (76). Counting the “rest” period among the sprints one session could last around 10 minutes in length (12, 77).

With regards to metabolic syndrome for a healthy life as well as better athletic performance maintaining body composition is vitally important (78 - 79). Thus, it is remarkable that following SIT training sessions induced a very low level of direct caloric expenditure (80) when compared with traditional endurance training (12), but interestingly evidence turn up that SIT induced a greater margin of fat oxidation and fat loss than the traditional type of endurance training (81). Later these consistent results have been backed up by many studies. On the other hand, Talanian et al. 2007 (82) reported that increase in whole-body fat oxidation of 36%, while maximal activities of mitochondrial oxidation enzymes β-HAD and Citrate Synthase was increased by 32% and 20% respectively. As well as, they detected increased plasma membrane fatty acid binding protein (FABPpm) from 25%, while improved fatty acid transport and oxidation of fatty acids were analyzed too. Thus, continuing virtuous metabolic fitness is always connected with enhancing body composition.

During the SIT training sessions embraced very high force and power contraction movements. Hence, it looks like SIT produced muscle adaptation identical to endurance training, but there is very little information is available regarding the SIT training encourages adaptations equal to resistance training. Among the few available, Astorino et al. 2012 (83) reported non-alteration of isokinetic force production following 2 weeks of sprint interval training in young males and females. The adaptation of long-term SIT training on peak muscular force information still needs to be investigated due to the lack of information.

However, different studies (e.g., 4, 84 - 85) depicted why people adhere to SIT more than traditional endurance-type training. However, when those studies were analyzed the greater barrier was the recruitment of subjects for related studies. The majority of them mainly focused on university students and narrowly selected groups such as the obese or overweight population, as well as relatively short-term training programs. Therefore, more still to be conducted more research representing the general population with different perspectives.

2.2.2.2.2. Tabata training

The Tabata training method was discovered by the Japanese scientist Izumi Tabata in 1996. The study conducted by Tabata and his colleagues in 1996 (59) compared two modes of training sessions, such as Moderate Intensity Continuous Training (MICT) at 70% of VO_2 max for 60 minutes, and HIIT at 170% of VO_2 max. The latter method consisted of 8, 20-second all-out exercise bouts followed by 10 seconds of rest for a total of 4 minutes of exercise. They revealed that following the HIIT training method induces a greater degree of aerobic capacity than MICT (7 ml/kg/min versus 5 ml/kg/min). Furthermore, it was capable to produce an enhancement of 28% in aerobic capacity, whereas aerobic training couldn't achieve.

Commonly majority is getting confused about the difference between Tabata and HIIT training. Thus the principal difference between them, Tabata consisted of four minutes increments and completed with greater intensity than HIIT exercises. In addition, the rest period also is differed from the HIIT training method. Tabata consisted of a shorter rest period (lasting 10 seconds) than HIIT. Generally, HIIT contained longer recovery periods, sometimes up to two minutes. Tabata training and its outcomes are directed to develop a wide range of HIIT programs. Even though there are different types of HIIT programs, all training methods were developed under the same umbrella. Therefore all of those programs are characterized by periods of all-out effort combined with periods of complete rest or low to moderate recovery periods (86). VO_2 max is a common and effective measurement of having an idea about the overall physical fitness level of an individual playing an advanced role in the physical fitness context. Thus, an increment of VO_2 max following HIIT training is well established by different authors (87 – 88, 74).

On the other hand, it has been identified that HIIT induced increment of insulin sensitivity (80, 74), HDL-C level (or "good" cholesterol) (65), and blood pressure (86, 74), as well as decrement of body fat % (441). Furthermore, it does not focus to enhance athletic performance only, but it provides benefits for a trained individual to achieve clinical purpose also (75), such as an increment of health and fitness levels in sedentary (80), overweight/obese (74), and cardiac populations (88, 74).

Moreover, insufficient time availability for physical fitness training, as well as adherence is common concerns to take into account when prescribing exercise. Otherwise, people are more interested in high-intensity workouts than moderate long-term training (445). Hence, the Tabata method is perhaps the most effective and powerful workout tool to achieve the personal targets of physical fitness. The interesting matter is Tabata is willing to improve both main energy systems (i.e., anaerobic and aerobic). It focuses on an increment of the anaerobic energy system that is responsible for short and high-intensity exercise (i.e., sprints), and the aerobic energy system that is responsible for endurance exercise (i.e., long and slow running). Nonetheless, there is little information regarding the exercise intensity and energy expenditure of the Tabata training method and many more are yet to be investigated.

2.2.3. High Intensity Resistance circuit-based training (HRC)

2.2.3.1. Introduction to High Intensity Resistance circuit-based training (HRC)

Circuit training as a distinctive training method was developed by Morgan and Adamson in 1953 while they were given they are serving as staff of the University of Leeds in England (446). It is a versatile training model, as it can be adapted to many situations and different populations with different levels of physical condition. The exercises are arranged in a pattern of circular that can be modified on the basis of the objective, the motivation, or the level of the participants (447). Hence it has been designed to develop a series of components of the physical conditions, such as strength, muscle power, and cardiorespiratory capacity.

Traditional circuit training consists of a number of different exercises, commonly between 10 and 15, that are carefully selected in order to train each muscle group with minimum recovery between exercises (15 – 30s) (16). The stimulation of the main muscle groups occurs alternately (i.e. Legs, abdomen, and arms) so that while one muscle group is stimulated, another muscle group actively recovers. Due to the alternation of large muscle groups, it is possible to short rest periods between exercise and another exercise, which makes the load that the cardiorespiratory system receives higher than in conventional strength training (448).

Each isolated exercise conducted in the circuit is mentioned as a station (449). One of the crucial factors of circuit training is the design of the training method; it is consisted of lifting low weights with relatively short rest periods between the stations (450). Romero- Arenas and associates in 2013 (16) reported that most of the time these periods do not exceed 30 seconds. For the reason that traditional circuit training circulated of at least 10 different exercises and the athlete or participant should perform a higher number of repetitions possible in each of these exercises within the given time period, with brief rest periods between them, thus it makes this protocol appropriate for introducing an aerobic component to the training workout (16,450). Additionally, according to the interpretation of ACSM, 2009 (451) circuit training is an effective training method to enhance local muscular endurance, due to the own characteristics of the same training method, such as high continuity and minimal rest between the stations. Thus, the circuit training method integrated with resistance and aerobic exercise blended training, further as a response shows a positive effect the muscular and aerobic fitness (452, 449).

2.2.3.1.1. Circuit training induced physical fitness benefits.

Over the years, a growing body of research extended to identify the benefits of this highly efficient training method. Investigators have studied how to increase the intensity, especially in this particular training method by using different exercises which significantly increase the heart rate and regulating rest time could provoke even greater adaptation during the shorter overall training time (89, 11, 77, and 59).

There are a bunch of studies regarding the circuit training method and its effect on physical fitness performance as well as the human body. Those studies have shown that this training method is the most prominent and effective training method to enhance muscular endurance, as well as it has met the credential for an effective muscular and cardiovascular workout. Moreover, by conducting the circuit training method were given the most effective results to improve explosive power for all kinds of sports including combat sports. Hence it has also been considered that circuit training is the best way to enhance muscular strength and endurance which determined the athlete’s success in the sport context.

Therefore, by being included in the training session many benefits could be achieved during the training program, indeed these benefits would be able to receive if participants were moved continuously thorough out the workout. There were possibilities to enhance at the same time (i.e. concurrently) strength and cardiovascular fitness. One of the prime benefits of this training method is its versatile characteristics. It is possible to include whatever exercises need into the circuits; it means there is the freedom to adjust exercises according to the participant's desires, as well as according to their fitness, coordination, and ability level. Thus, participants could work with what they have instead of worrying about multi functions machines, or expensive equipment. On the other hand instead of expensive equipment there is the possibility to use their body weight and any improvised equipment (i.e. jump ropes) which can increase motivation and as well as decrease the monotony of training. According to the fitness level of participants and their goal, there is a possibility to decide the number of circuits and exercises that variability allows to the participants keep interested in their workout and makes them reach their fitness targets, and conversely, makes them less likely to stop before reaching their targets.

Some researchers described that circuit training is remarkably effective for the increment of pulmonary ventilation and functional capacity in healthy young people (i.e. VO_2 max) (10, 90). Circuit training is already attached to the heart rehabilitation programs (453) because it decreases the stress on the heart (454), even compared with aerobic exercise (455), and in addition to causing an improvement based on the muscles respiratory based on high ventilation (455).

Thus, circuit training is a time-efficient exercise mode that caused changes in factors related to health and physical condition. Circuit training achieves force improvements using relatively low intensities (~40% del 1RM) (91). These intensities allow for strength gains in sedentary people. But unfortunately, the enmity to get adaptations of strength, muscle mass (92), and bone mass (456) is minimal. However, new evidence and exercise strategies have indicated that working with high volume (i.e. 6RM) could influence the magnitude of the neuromuscular and cardiovascular adaptations of the elderly (92). To optimize the prescription of circuit training, it seems reasonable to identify the most effective combination of training load, volume, work/rest relationship, weekly frequencies, and sequence of exercises to promote neuromuscular, cardiorespiratory, and body composition adaptations

2.2.3.1.2. Circuit Weight Training

In the late 1970s, Circuit weight training (CWT) came into the fitness context based on circuit training; it takes the general concept of circuit training and through that rebuilds the training sessions. Thus within less time it took the attention of people and rose the popularity because of the use of strength apparatus, as well as numerous participants conducted CWT because of its capability to enhance different fitness components simultaneously, such as muscle strength, muscular endurance, cardiorespiratory endurance (93, 457) and body composition. However, circuits can be altered to emphasize one fitness component over another.

At the very beginning, authors such as Gettman et al. (94) create training sessions with lighter resistance (40-60% 1 RM) and small-scale rest periods to no rest periods between exercises, and it was defined as resistance training in form of CWT. Later, Kraemer, 1997 (458) was given another interpretation of CWT. He creates stations (same as circuit training), a set of prearranged exercises accomplished within a certain period of time with 10 to 15 repetitions interspaced with 15 - 30 s of rest. According to the necessity of the participant, there was a possibility to repeat the circuits.

However, the modern interpretation of CWT was rearranged by different practitioners who utilized CWT with free weights. Thus, currently, it is defined as where the subject moves from one to another exercise and conducts exercises according to the predetermined certain time and number of repetitions with a limited rest period between sets and circuits (95 - 96). While, Romero- Arenas et al. (16) explained each series of different exercises consists of 12 - 15 repetitions, whereas used moderate loads (approximately 40 – 60% of 1RM) with a relationship between working and rest time usually 1:1 (30:30 s). The total duration of a training circuit is 30 min, which makes it a very efficient exercise modality over time. The number of the circuit is repeated once to three times, depending on the level of physical conditions of the participants. Moreover, the exact number of exercises, the volume, the load, the duration of the rest interval and the session, as well as the weekly training frequency will depend on the physical condition of the subjects and the training objective.

2.2.3.1.3 Traditional Strength Training:

It is well established and well known strength training and it is benefits. Just enhancing strength along there is a possible increment of power, size, and body composition. Indeed depending on the athletes' experience and physical state. These changes stem originate from a high training load (i.e. ~85%). The traditional strength training consisted of high loads, and low repetitions (~6RM) ranging between 2 to 6 sets, interspersed with a long rest period between sets (i.e. 2 – 5 minutes) and between blocks 5 minutes, with the purpose of decreasing the acute fatigue effect on remaining sets.

However, now a day everyone looking forward to the benefits of strength training but unfortunately no one has enough time to spend by training hours in the gym or any other place. On the other hand with the limited time that they have in their time schedule trying to train both resistance and endurance physical components at the same time. But actually, the question is does anyone really achieve the targets within their short time period?. Because training both strength and endurance in a single session is very time consuming. Probably it could be done either in separate training sessions or else in one long time training session, also called concurrent training (See 2.2.1). Therefore High intensity resistance circuit-based training has been created to counter the above mentioned problem.

2.2.3.1.4 High intensity resistance circuit based training:

It has been designed to produce the greater benefits of strength training in a considerably short period of time. Thus it is a time-efficient resistance model of training method that used low rest periods with the purpose to increase the hormonal (97 - 98), metabolic (99), neuromuscular and cardiovascular responses to the strength exercises. It has been shown to elicit even greater benefits than traditional circuit training (92, 101).

As the name depicted, it is heavy-weight training in a circuit training format which is consisted of characteristics of traditional strength training, circuit training, and CWT. Along this line, a new version of CWT has been proposed recently by using higher loads (i.e., 6RM) and shorter rest periods (i.e., 35 s). Each training session focuses on all major muscle groups and is fragmented into mini circuits which are containing 3 exercises (i.e. first circuit or block: bench press, knee extension, and lat-pull down). Following the proper warm-up, 6RM of each exercise will perform with minimal rest between exercises (35 seconds). Between 3-5, times could perform this circuit followed by 3 minutes rest between sets and 5 minutes between blocks. Each session could include 2 -5 mini circuits or blocks.

Furthermore, a common characteristic of the circuit training program is that it opens the possibility for a large number of people to take part in the same training session. This fact corresponds to the wide variety of exercises, as well as the amplified possibility of increasing interpersonal relationships during exercise practice, which leads to a higher level of motivation during the exercise.

2.2.3.3. Types of HRC training

2.2.3.3.1. Crossfit

CrossFit training is a core strength and conditioning program, designed for being able to elicit as broad adaptation responses as possible. On the other hand, CrossFit is not a specialized fitness program for any particular movements or sports actions but a thoughtful attempt to optimize physical competence in a wide range of fitness domains which is recognized already, such as cardiovascular and respiratory endurance, stamina, strength, flexibility, power, speed, coordination, agility, balance, and accuracy.

However, it is one of the exceptionally popular variations of high-Intensity Power Training (HIPT), whereas conducting resistance training according to the instruction of HIIT principles. Thus, it has increased in popularity interestingly among enthusiastic trainers who are willing to improve both musculoskeletal and aerobic fitness (102). This almost new training approach consists of weight training using a variety of multiple-joint exercises (i.e. squat, back press, deadlift), to execute all exercises at the rapid pace possible, or with the highest number of possible repetitions during the limited predetermined time (103).

According to Butcher et al. (104), Crossfit is defined as a resistance training model where both cardiovascular and musculoskeletal exercises are conducted together with many types of functional movement patterns within a single exercise session. Usually, these types of exercise sessions are called "Workouts of the Day" (WOD), otherwise, these exercises are conducted in the circuit training format (i.e. consecutive completion of ≥3 exercises, performed back-to-back), with little to no rest periods, usually lasting 10-20 minutes in duration. However, the structure of the "workout of the day" depends on the fitness level of the participants. Typically each session wrapped within an hour consisted of the warm-up principal part (10 - 30 minutes) and cool down part (104), perhaps these exercises (workouts) could be repeated, combined, or attached with warm-up, cool down, and/or flexibility drills (103).

While, designing these WODs exceptionally focused on three different elements: mono structural metabolic conditioning (cardio), Gymnastics, and weightlifting (459). All of these elements have consisted of a variety of movements that are allowed to be functional, multi-joint movements that are executed from the core to the extremities (459). These elements differ in the exercises, intensities, reps, sets, and rest periods used, as well as the predominant energy system(s) stressed during exercise. Furthermore, when designing a CrossFit training program take into consideration three different standards for assessing and controlling fitness, such as ten general physical skills (mentioned previously), the performance of a variety of athletic tasks, and three energy systems (459).

However, within a few years, CrossFit has gained considerable attention from practitioners due to several reasons: easy access to programming, a short time commitment, and higher entertainment than traditional training (460). Even though it is popularity expanded among practitioners still there is lack of information regarding the physiological responses following CrossFit due to the limited research performed. Howbeit, according to the available information depicted that CrossFit has induced a higher acute cardiovascular response and significant increment of fitness levels (i.e., aerobic and anaerobic performance) (103 - 105). On the other hand, the famous variations of CrossFit routines (e.g., exercise types, intensity, velocity, and muscular groups) and less accessible regulation of workouts create disadvantages on the performance, because workouts are often posted in detail, perhaps it could be excessively for participants or vice versa (106). Hence, it creates difficulty to have a clear idea about the acute and chronic responses to this activity.

CrossFit Training induced acute and chronic adaptation.

Recently, Fernández-Fernández and associates (107) studied the CrossFit training-induced acute perceptual and physiological response using middle age healthy subjects who have around one year of CrossFit training experience, and they found that significant cardiovascular responses following “FRAN [barbell front squat, overhead press, and pull-up exercises, performed continuously three round (21 reps, 15 reps, and 9 reps) without rest (between movements or rounds)]” and “CINDY [5 pull-ups, 10 push-ups, 15 body weight squats, to conduct continuously as many rounds of circuit as possible within 20 minutes]. On average, participants in this study reached 61.5% of VO_2 max and 96.4% of their maximal heart rate (HRmax) while performing these CrossFit WODs (respectively). Hence, these findings depicted that surpasses the minimum requirements which are established by ACSM previously, to promote aerobic fitness in the adult population (108). Furthermore, exercise-induced cardiovascular and physiological adaptation has been explained in the cardiorespiratory adaptation and endurance training sector.

Furthermore, the physiological effects following long-term (10 weeks/ 5 days per week) intervention of CrossFit training on healthy subjects of both genders were investigated by Smith and colleagues (103). They reported increased average relative VO2max of all male participants (a 14% increases relative to baseline), and female (a 12% increase relative to baseline); during the same time period, while decreased the average body fat % of men (from 22.2% to 18.0%) and female (from 26.6% to 23.2%) over time. These findings demonstrate an increment in VO_2 max from pre- to post-intervention, even in subjects possessing VO_2 max values well above average. Thus, it has been suggested that the CrossFit training method could be an effective training method to substitute for endurance athletes to improve an already elevated aerobic fitness profile.

Therefore to date, the investigations conducted regarding the CrossFit training-induced physiological variables have established that CrossFit WODs acutely elicit cardiovascular adaptation and those numerical values exceed the minimum requirement for enhanced aerobic fitness in the adult population which is published by ACSM. This elucidates that's why the long period of CrossFit training has been shown to significantly increase aerobic fitness across recreational practitioners with a wide range of initial fitness levels and training experience.

The training should be performed at high intensity and even it has been highlighted in the training guide because the intensity is the crucial factor that is related to maximizing favorable adaption to exercise (459). Even though it is recommended, the intensity levels depending on the ability and fitness level of each individual.

2.2.3.3.2 HRC training in Hypoxia

Aerobic exercises always assist to deliver the proper amount of oxygen (O2) to mitochondria in working muscle to be able to function properly the aerobic metabolism (461). Therefore, maximal oxygen uptake or maximal aerobic capacity is frequently interpreted as an individual's maximal rate of oxygen consumption (VO_2 max); it reflects the maximal rate of O2 which could be used by the body during maximal work. Therefore optimal aerobic exercises elicit to increase in the correspondence between the requirement and delivery of O2 by the cardiopulmonary system. Acute and chronic adaptation following altitude training imposes different physiological challenges that prejudice aerobic performance by depriving required O2 to the working muscles for aerobic metabolism.

The mechanisms and implications of these changes happened due to the inverse relationship between barometric pressure and altitude [if altitude increases barometric pressure decrease (hypobaric)] when altitude is the high partial pressure of oxygen (PO_2) is low (462). Following figure 16 described how the low level partial pressure of inspired air (PIO_2) at altitude guided to low level partial pressures of O_2 in the alveoli (PAO_2), as well as arterial blood (PaO_2) and venous blood (PVO_2) effectively decreasing the PO_2 gradient that drives O_2 circulation from atmospheric air to mitochondria in working muscle (109). Although the fractional concentration of oxygen (FIO_2) remains the same as at sea level, 20.93%, the reduced PO_2 results in less oxygen available at altitude. The decrease in partial pressure of oxygen in the blood or tissues is defined as "hypoxia" (110) (Figure 04).

However, taking into account all aforementioned, traditional aerobic training in the hypoxia method has been demonstrated to enhancement of O_2 transport capacity by increasing erythropoietin secretion and hemoglobin mass and improving VO_2max (463), anaerobic threshold (464, 111), and exercise performance. Thus, it has garnered much attention among practitioners. On the other hand, high-intensity resistance circuit training method was expanded already in the physical fitness context as a training method that could improve aerobic, body composition, and mechanical performance with a shorter volume and duration of the session. Therefore, recently there is growing interest in HRC training in hypoxia. Some of the authors have reported constructive responses in anaerobic metabolism and metabolic stress (112 - 113) and an increase in anaerobic performance following HRC in hypoxia.

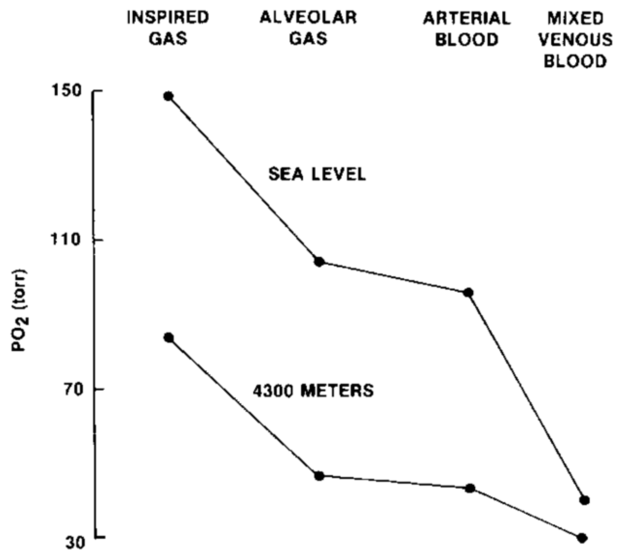


Figure 4. Differences in PO_2 at sea level and altitude (4,300 meters) (Hypoxia and Exercise, 2006)

Furthermore, one of the crucial advantages of resistance training in hypoxia is higher metabolic stress (114) under such conditions, it has been described in several investigations (111 - 113), mainly because of a greater reliance on the anaerobic metabolism via an increment on blood lactate concentration and alterations in the acid-base balance (114). Metabolic acidosis has been associated with some potential mediators for muscle hypertrophy such as higher motor unit recruitment, and cellular swelling as well as increased growth hormone concentrations (114) As a consequence, following hypoxic training could be expected higher hypertrophic and muscle structural adaptations (115).

Additionally, following resistance (116) and HRC training (17) programs induced enhancement of resting energy expenditure. As well as, HRC in hypoxia-induced higher energy consumption following training sessions (112 - 113), it could be due to the higher phosphocreatine turnover, replacement of O2 in circulation and in the muscle, elevated ventilatory rate, elevated cardiac activity, oxidation of lactate, glycogen resynthesize, and sodium-potassium pump activity. Also, HRC in hypoxia increases energy consumption after a training session (112) This fact can be to higher phosphocreatine turnover, replacement of O2 in circulation and in the muscle, elevated ventilatory rate, elevated cardiac activity, oxidation of lactate, glycogen resynthesize, and sodium-potassium pump activity (117). However, inconsistent results of resting energy expenditure were reported after hypoxic treatments. While Westerterp et al. (118) described training in hypoxia decreases resting energy expenditure; some others show increment (119) or no changes (120) after chronic exposure to simulated hypoxia.

2.2. Specificity of exercise induced adaptation

The main significant factors of any training program are the training load (i.e. Intensity and volume) and frequency of training sessions. Hence, the levels of adaptive responses, either enhancement or decrement of the exercise capacity are determined by these "training impulses" (50). Otherwise, a long-lasting observation is that the training response/adaptation is directly associated with the volume of exercise assumed (121). Additionally, different contractions and metabolic stimulation just provoke contrasting performances through physiological adaptation. Thus, it is crucial that trainees have a clear objective before starting their training sessions. Moreover, Rhea and associates (2008) explained that when focusing on the physiological adaptations to training some training methods may actually be considered incompatible. The physiological responses, performance and specificity of training responses are well documented (19, 27, 53, 123, 124) as skeletal muscle is a highly workable soft tissue that could be adapted to a different kinds of exercise stimuli (125). As result repeated muscular contraction elicit a cascade of response which over time could alter the skeletal muscle characteristics of both trained and untrained muscle (Figure 05).

According to the anecdotal experience known that exercise-induced adaptation exists, it has been started in the 1960s to properly understand the complex processes of exercise-induced adaptation. During that time reported the precise mechanism which exists behind the exercise-induced adaptation to the different exercise stimuli. Among them, Goldberg (126) identified the mechanism which is support to improve cross-sectional area (CSA) following strength training. He explained the role of amino acid in protein synthesis and how it could affect the skeletal muscle to develop Cross Sectional Area (CSA).

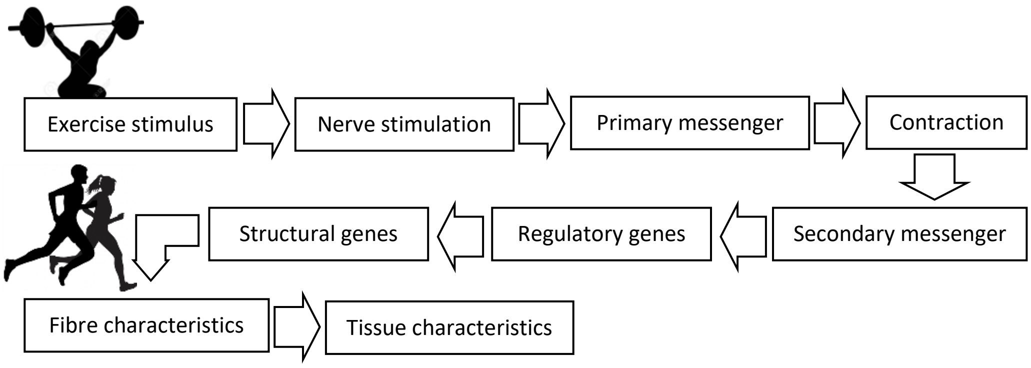


Figure 5. Different steps by which motor nerve activity leads to skeletal muscle adaptation, Williams and Neufer (547).

Additionally, it also provokes the potential increase of maximal contraction strength of trained muscle. While Holloszy 1967 (127) described the endurance exercise-induced physiological adaptation. He reported when performing prolonged exercise on a regular basis different physiological adaptations are induced, such as an increased number of mitochondrial in the muscle, and enzyme activity which is subsequently caused to improve aerobic capacity. These adaptations were long-established by different research through different exercise stimuli. Later, observed that these adaptations and their functions are primarily determined by the intensity, volume, and frequency of the muscle contraction activity performed (128), recently explained by Izquierdo and associates (128) these adaptations may also be dependent on the mode of exercise executed.

Therefore different sports required different physiological conditions to improve sports performance or for successful performance. Thus using different intensities, volumes, and frequencies with different modes of exercise to increase sports performance, while past decades have been wildly considered, and conduct research regarding the behavior of science behind this mechanism, causing the understanding of stimulus magnitude which is needed for particular physiological adaptation has been greatly improved. Training in different sports activities at the extremes of force-velocity or strength-endurance continua such as Olympic lifting and marathon events is comparatively straightforward and associated with sports and events that require a combination of strength and endurance capabilities (Figure 06).

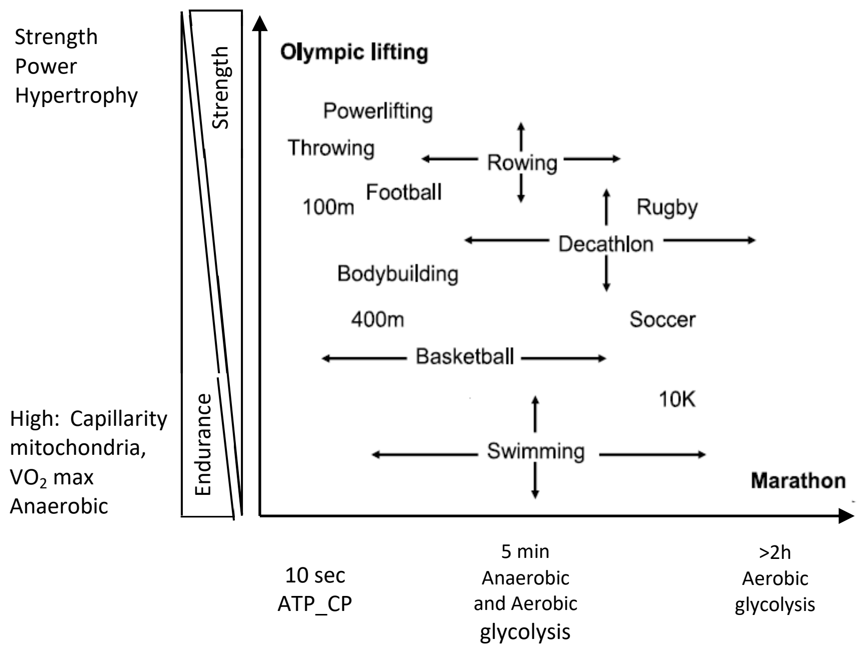


Figure 6. The relation of strength-endurance continuum and sport specific physical performance, Nader (44).

In this regard, individuals are forced to mix different training methods with the purpose of eliciting contrasting physiological and performance responses (130). Therefore, how it is previously mentioned concurrent training creates different training stimuli following strength and endurance training which is caused by blunted strength related adaptation when compare with strength training adaptation alone. (19, 27, 53, and 123).

2.3. Exercise training induced neuromuscular adaptation

2.3.1. Neural adaptations following strength training

The cooperation between muscles and the nervous system allowed for producing the 'strength' performance. Whereas muscle functions as an engine to generate the force and the nervous system provide the engine controller. A few years ago, it has been assumed that CSA was the main trigger point to determine muscular strength because eventually after weight training increases muscle hypertrophy. However, since the 1980s different authors such as Bompa, and Zatsirosky have been open a new point of view through their strength training studies regarding the neural component of strength adaptation. In addition to that in 1984 Lamb DR (465) explained that CSA was only one single best predictor to produce muscle hypertrophy.

Therefore, increment of muscular strength could be dependent on numerous adaptations in the muscles, or in the nervous system, the engine controller. Thus those adaptive responses of training-induced changes in the nervous system were referred to as neural adaptations. On the other hand, for the increment of strength performance motor act has a main role challenging to the nervous system, such as fully activating the agonist (prime mover) muscles, appropriate activation of synergist (assisting) muscles, and muscles which oppose the action of the agonists (antagonists) (Figure 07). Hence, the more difficult challenges probably lend greater scope for neural adaptations to increase the probability of success. The final goal of training in meeting these challenges is to produce the greatest possible force and/or rate of force development in the intended direction of movement which means an increment of strength performance. Thus, the increment of agonist muscle activation following training is considered the most obvious mechanism of neural adaptation.

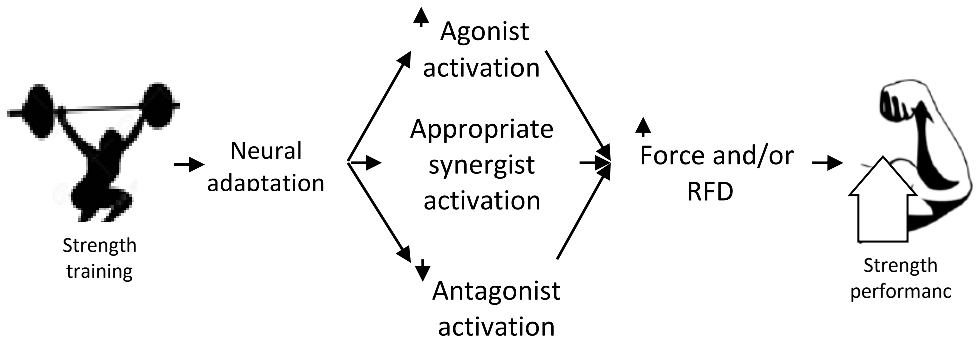


Figure 7. Strength training induced neural adaptations may increase agonist muscles activation, appropriate activation of synergist muscles, and decreased activation of antagonist muscles. Sale (548).

Neural adaptations to strength training involve disinhibition of inhibitory mechanisms, such as Golgi tendon organs, Renshaw cells, and supraspinal inhibitory signals, as well as intra- and intermuscular coordination improvements: synchronization, recruitment, and rate coding. Whilst morphological changes in human skeletal muscle induced by resistance training, such as increases in anatomical muscle cross-sectional, physiological muscle fibre area (PCSA), increased percentage of IIA fibres with a corresponding decrease in 2X fibres, and precipitous muscle fibre pennation angles are also significant factors.

When intermuscular coordination improves properly through the specific motor pattern, the adaptation of an intramuscular coordination transfer process from one exercise to another will increase. As an example, the athlete who executes sport specific skills (techniques) properly can achieve better performance by the transmission of maximum voluntary recruitment of motor units developed during the maximum strength training. Thus, for that reason, the maximum strength macrocycles have an objective of improving motor unit recruitment of the prime movers, while power macrocycles work mainly on rate coding. Therefore, recruitment and rate coding (intramuscular coordination) have a greater contributing role than synchronization does in muscular force production.

In this perspective, when an athlete performed proper sport specific skills the nervous system is more willing and efficient to coordinate the kinetic chain than previously since some movement patterns (i.e. lifting 30 Kg of a biceps curl) are new to the nervous system the recruitment of motor unit is higher and fatigue level also is higher, contrary if same movement pattern is well established the recruitment of motor unit is less and fatigue level also is low, because with time nervous system learns the motor pattern and leaving more motor units available for the advanced motor pattern (i.e. lifting 50 Kg of bench press) (Figure 08, A and B). Hence, intermuscular coordination training is the fundamental factor in being able to perform advanced movement patterns (i.e. biceps curl with 60 Kg) over a long period of time.

Therefore, intermuscular coordination training through the sport specific skill (i.e. biceps curl) over a long period of time is the fundamental factor to increase performance (i.e. biceps curl with 60 Kg or more). Even though the training-induced increment of the "neural drive" of muscle fibres contributes to increased strength performance (131). It has been explained that the initial strength gain following resistance training (< 6 weeks) is due to the neural adaptation, through the improvement of coordination and/or increment of neural recruitment of muscle fibres in advance of any hypertrophic adaptation (132 - 134). Increased activation of the specific prime mover muscles involved in the strength training intervention is a primary mechanism behind the neural induced strength increases (131). Therefore, the basic matter is that these adaptations are not absolutely stable, to maintain or increase strength over time, it is crucial to keep training always. For the same reason, it proves that truth which brings under the intermuscular coordination, which is system, is allowed to increase the load with time on the basis of system efficiency improvement (135).

Furthermore, the factors of the neural firing frequency and the number of motor units recruited seem to be controlled by both acute and chronic neuromuscular responses following strength training (45). It was well established after proposed the "size principle" by Henneman and associates (136). They explained that under load, motor units are recruited from smallest (type I) to largest (type II). In the practical scenario, this means that slow-twitch (type I, low-force, fatigue-resistant muscle fibres) are activated before fast-twitch (type II, high-force, less fatigue-resistant muscle fibres). During the heavy resistance exercise the force requirement increase, thus higher threshold motor units are activated. As such, it appears that heavy to near maximal loads activate the full spectrum of motor units following resistance exercise (137).

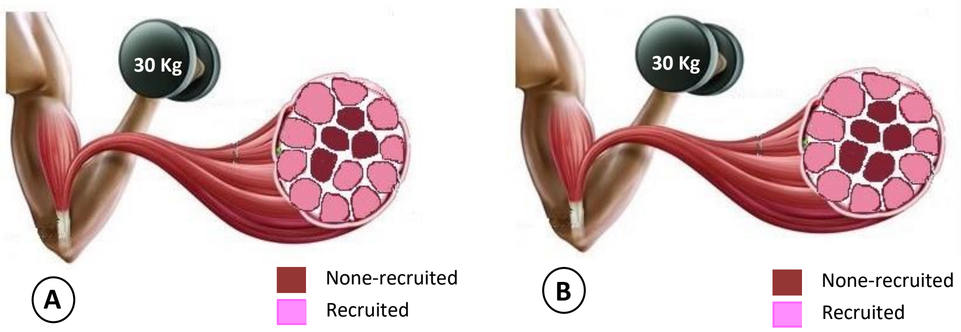


Figure 8. Over time, strength training induced less motor unit activation through intermuscular coordination to execute same load, as a results leaving more motor units available to execute higher loads. Bompa and Buzzichelli (135).

The central nervous system (CNS), adjusts the firing rate of neural impulses traveling down the motor neuron (rate coding). Thus, depending on that neuromuscular system is able to recruit muscle fibres in response to resistance. Hence when intensity is high following strength training, obviously firing frequency is high therefore occurred greater motor unit recruitment allowing more forceful contractions to be produced more force (138). For instance, when executing explosive high velocity contraction (i.e. Olympic lifting) increase neural firing frequency and rate of force development (RFD) to a greater extent than slower less forceful contractions. Therefore Behm (139) explained that to perform motor action effectively with high force and velocity it is necessary to recruit high force motor units more fastly, such as occurred in the neuromuscular system during the explosive type movements' execution. Furthermore, it is known that recruitment thresholds and firing rates of motoneurons depend on the amount of afferent input (140).

The majority of scientific literature used integrated EMG technology as a quantitative indicator to measure the changes in the efferent neural drive after resistance training (141 - 142). As usual, some researchers successfully reported that increase in EMG activity following a strength training intervention (131, 142) while some others reported contradictory results that integrated EMG does not increase following strength training (143, 466). These incongruous results could be occurred due to the methodological constraints associated with the way of recording surface muscle EMG during MVC (142), such as surface preparation, electrode placement, prescribed range of motion of contraction, and sampling frequency.

In addition, even though adaptation of muscle morphology followed by strength training is well examined, still some authors have thought of something more deep justification regarding the specific neural mechanisms responsible for the training-induced increase in maximal muscle strength. As result, they used the Hoffman reflex which was originally described by Paul Hoffmann in 1910, and later given his name, the Hoffmann reflex (H-reflex) which is an electrically induced reflex analogous to the mechanically induced spinal stretch reflex (144), allowing to measure the efficacy of synaptic transmission as the stimulus travels in Ia sensory (afferent) fibres through the motor neuron (MN) pool of the corresponding muscle to the efferent (motor) fibres (145). When electric stimulation is given start the action potential of H-reflex from the point where received stimulation travel along Ia afferent (sensory) fibres until they reach and synapse on alpha motoneurons (αMNs). Then αMNs generated action potential on the efferent (motor) fibres of the H-reflex pathway, allowing them to travel along efferent fibres until they reach the neuromuscular junction and create a twitch response in the electromyography (the H-reflex). When it (action potentials) reaches the neuromuscular junction, a synchronized twitch is produced in the muscle. This twitch is a synchronized contraction.

The H-reflex is a compound action potential or a group of almost simultaneous action potentials from several muscle fibres in the same area. In addition to the afferent and efferent pathways that contribute to the H-reflex, electric stimulation of the peripheral nerve causes direct activation of the efferent fibres, sending action potentials directly from the point of stimulation to the neuromuscular junction. This efferent arc produces a response in the EMG known as the muscle response (M-wave) (Figure 09) (144).

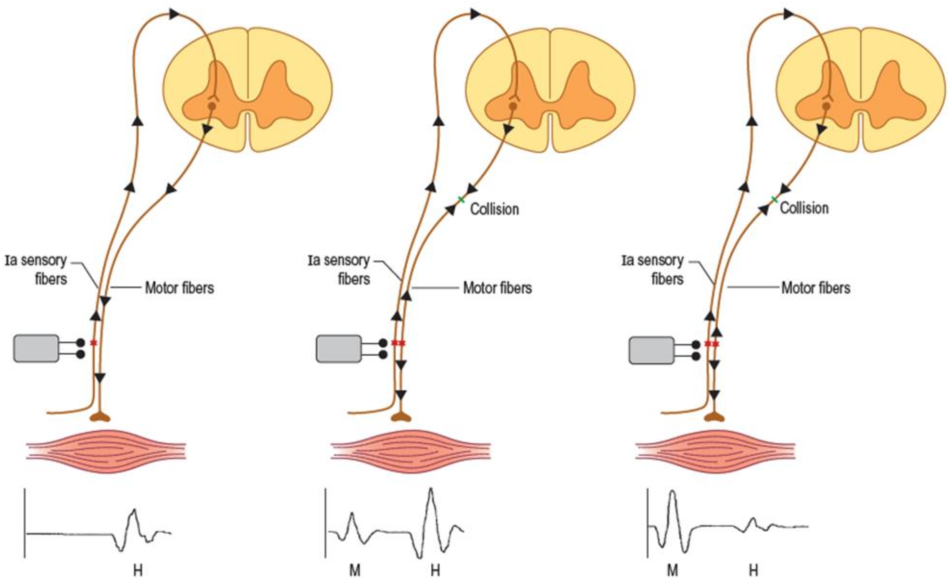


Figure 9. Integrated circuit system of H reflex, Preston and Shapiro (146).

The afferent pathway is formed from Ia sensory fibres and the efferent pathway is from motor axons, with an intervening synapse in the spinal cord. At low stimulation intensity (left), the Ia sensory fibres are selectively activated, yielding an H reflex without a direct motor (M) potential. With increasing stimulation (middle), more Ia sensory fibres are activated, as are some of the motor fibres. The motor fiber stimulation results in a small M potential and some collision proximally of the descending H reflex by the antidromic motor volley (Figure 10). At higher stimulation (right), the selective activation of the Ia sensory fibres is lost. Both sensory and motor fibres are stimulated at high levels. The higher motor stimulation results in an increasingly larger M potential. However, the H reflex decreases in size as there is greater collision proximally of the descending H reflex from the antidromic motor volley (146).

Additionally, Vangsgaard and associates (147) suggested increased net excitability of the H-reflex following 5 weeks of eccentric training protocol, the intervention has resulted in a significant positive correlation between the adaptation of MVC force and the change in EMG voluntary activity in the training group. Furthermore, only a few studies have evoked spinal motoneuron responses to examine more closely the adaptive change in neural function induced by resistance training. On the other hand, the lack of consistency amongst the studies may reflect limitations of the H-reflex measure, which is highly modifiable and influenced by a variety of factors (148).

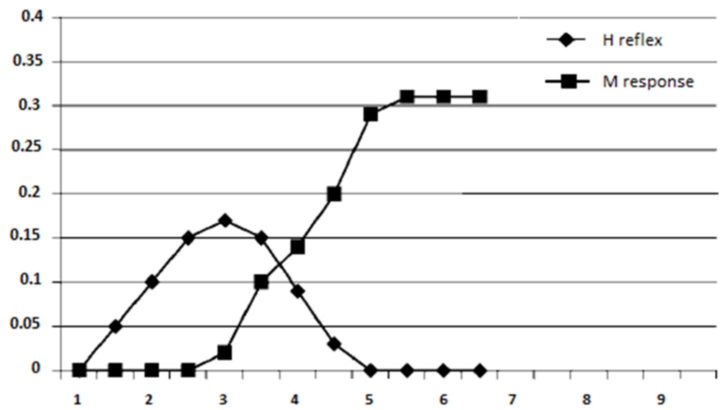


Figure 10. Recruitment curve. The intensity of stimulus is start from 0 and it will increase gradually until maximum H-reflex amplitude and maximum muscle response amplitude are discovered, Palmieri et al. (144).

2.3.2. Endurance training induced neural adaptation

Generally, endurance training is always concentrated on improving muscle fatigue resistance for being able to exercise of longer duration (149). Thus, fatigue is an important factor, which sends stimulus to decrease the capacity of producing force and velocity to inhibit the actions. Hence, fatigue is described as a loss of the ability for emerging force and/or velocity of a muscle but it is reversible by rest. Performance in endurance base activities is dependent on the muscles' capability to produce enough ATP through the aerobic energy system. This process needs an interaction of neuromuscular, respiratory, and cardiovascular cooperation.

Basically, endurance training and activities corresponding to the aerobic energy system enhance the oxidative capacity and metabolic efficiency of skeletal muscle. Those are achieved through mitochondrial adaptation (O_2 utilization), angiogenesis (O_2 delivery), and the availability of local substrate (149). On the other hand, following endurance training-induced different neuromuscular adaptations, such as a decrease in motor unit discharge rate (150), decrement in motor unit recruitment thresholds (149), and as well a slower rate of decline in motor unit conduction velocity during sustained contractions is found after endurance training (151). Moreover, Zghal and colleagues (152) reported that voluntary activation percentage or EMG of the knee extensor muscles in sedentary or previously untrained subjects has not changed following long-term endurance training (153).

Furthermore, corresponding research and similar data on the conceivable effects of endurance training on muscle performance and neuromuscular adaptations are notably limited. However, some studies have suggested that increased rate of muscle activation and possibly increased strength in adult athletes who followed endurance training compared with untrained adults (154). As well as, Konopka and associates in 2014 (467) suggested that aerobic exercise training has minimal effects on skeletal muscle size and they demonstrated that aerobic exercise acutely and chronically alters protein metabolism and induces skeletal muscle hypertrophy. On the other hand, Carter et al. (155) reported that endurance training does not appear to significantly affect muscle fibre size, area, or type I/II distribution in either males or females, at least following running training interventions.

On the other hand, endurance training-induced favorable activation of the slow, stiffer muscle fibres, this leads to a decrease in electromechanical delay (EMD) and to an increment of stiffness index (156). Basically, EMD was interpreted as proceed time between the beginning of muscle electrical activation and the commencement of force production, reflecting both electrochemical processes and mechanical processes. Electrochemical processes mean synaptic transmission, propagation of the action potential, and excitation-contraction, while mechanical processes mean force transmission along the active and passive parts of the series of elastic components (157).

How it is explained previously, due to the lack of research and information still it is difficult to conclude the general idea about some extended endurance training induces neural adaptations, such as some authors revealed an increased rate of muscle activation and others reported a decrease in electromechanical delay. Hence, identifying factors like that requires conducting more investigation regarding the aforementioned field of the recreationally trained healthy population.

2.3.3. Neuromuscular adaptation following TCT

According to the suggestions given by Dolezal and Potteiger (28), TCT makes available similar benefits to strength training produced alone, but to a minor extent. Furthermore, the study conducted by Mikkola et al. (158) observed that performance could be also improved; besides in some cases improved hypertrophy was equal to training mode alone and perhaps it was shown even greater extent than training modes alone. Therefore, Häkkinen et al. (159) suggested that there is the possibility to occur various adaptations in the neuromuscular system due to the rapid muscle actions and micro-level hypertrophy adaptations following TCT which could differ from those of single-mode strength training. After long observation of different studies, most of them were shown some interference in rapid actions, while some of them reported increased maximal strength concurrently. As well as, it is possible to observe the trend of the interference effect on hypertrophy and endurance performance, whereas the neuromuscular system is more likely to be affected to suffer unfavourable adaptations. Thus, it seems true irrespective of how the traditional concurrent training routines are structured.

TCT induced blunted strength development was avoided by using moderate to low volumes and frequencies of training programs. There are plenty of studies with different designs of training programs enforcing that increased maximal strength to similar extents as with strength-only training, such as strength and endurance performed in immediate sequences (468,469), same day but 2 hour recovery between both modalities (160), on different days (159). Even so, still, there was plenty of evidence reported with compromised adaptations of other neuromuscular variables. Generally, speed/velocity related variables were adversely interfered with or remained unchanged during the intervention. Like RFD (159), Counter Movement Jump (CMJ) (161), and power (162). Furthermore, isometric (53) and unilateral muscle actions (470), as well as fibre conduction velocity (161) were also been reported that it has been compromised by TCT.

Even though compromised neuromuscular variables performance following TCT is well established matter, the exact mechanism undergoing this process remains unclear. On the other hand, cardiorespiratory performances were not compromised by interference effect (159), but as explained previously force and velocity related performances were compromised. Therefore, it seems like it is crucial to focus on the interference effects on the neuromuscular system following TCT. As well as after analyzing the other studies (163) and their inconsistent results regarding the strength and velocity related variables adaptation may be due to neural rather than metabolic activation. The neural, tension-limiting mechanism (NTLM) regulates by the central nervous system (CNS) to minimize potential damage to the muscle and associated connective tissues in response to the higher force potential (164). Thus, it has been shown greater importance when realizing strength training with high force and slow contraction velocity, while other neural factors are responsible for the enhancement of fast contraction (165). Therefore, after analysing numerous studies and their results of TCT were coincidences with the blunted performance of velocity related variables, hence these results depicted that TCT could not be able to enhance the adaptation process of fast contraction speed like strength training alone. On the other hand, as explained previously cardiorespiratory performance has not been compromised by interference effect (159), which means TCT has been activated the slow, stiffer muscle fibres favourably, this leads to decreased EMD and to an increment of stiffness index (156). Whereas decreased synaptic transmission, propagation of the action potential, and excitation-contraction (157).

The specificity training principle plays a major role to reach desired adaptation for maximizing sports performance; more information has been given in section 2.2. (Specificity of exercise induced adaptation). It is always underpinned by the volume, intensity, frequency, and mode of contractile activity, after undertaking either prolonged endurance or resistance training-induced results were shown contrasting characteristics of divergent phenotypes, a probably neuromuscular mechanism also responsible for these adaptations. There is plenty of literature evidence to support the aforementioned, such as compromised hypertrophy results following TCT due to the molecular signalling process (22), while some studies reported the absence of hypertrophy following combined training (166 - 167).

On the other hand, a number of studies reported increased muscle CSA following different TCT intervention protocols (158 - 159, 53, 163). Therefore, even if there are differences in fibre type-hypertrophy may not be impaired itself the hypertrophy in muscle CSA (e.g. macro-level hypertrophy). It has been enforced by McCarthy et al. (30) who reported that following strength and strength endurance groups induced similar enhancement of type II fibre area in quadriceps muscles but only strength training increased the area of type I fibres (163). As well as, intervention time also seems to be played an important role in sufficient muscle hypertrophy, hence sufficient prolonged intervention time is required to be achieved certain adaptations (53). Therefore, maybe TCT intervention time is more important for macro or micro-level hypertrophy, rather than a differential response to strength versus combined training (53). Alternatively, differences in the high force and slow contraction velocity and time course of adaptations may explain the discrepancy which exists among the reported results.

2.3.4. Neuromuscular adaptation following SIT

It is well established matter that increases in muscle strength go along with the increment of motor unit discharge rate (150), high and low frequency motor unit consistency (168), conduction velocity (150), and alterations in recruitment threshold during explosive contractions (169), while decrement of discharge rate variability (170) has been associated with improvement of force steadiness during sustained submaximal contractions after strength training (170). In contrast to resistance training studies, there is limited information regarding endurance training-induced alterations in motor unit behaviour. Thus, that information depicted that opposite adaptations regarding motor unit behaviour mean discharge rate and discharge rate variability) (150, 170), motor unit peripheral properties (motor unit conduction velocity) (171), and functional outcomes such as MVC force (150) and time to task failure (151). Hence as a conclusion, these studies revealed that endurance training-induced to decrease in the discharge rate, diminish decline rate in conduction velocity during fatiguing contractions, and increment the time to task failure without changing the MVC force. Thus these results are not unexpected, according to the training paradigms induced muscular and neural adaptations are highly specific and may vary (172, 150). Certainly, following the training specificity principle, it is always possible that different training protocols observing divers' motor tasks, training volume, and intensities show different neuromuscular adaptations (172).

However, the study conducted by Buchheit and Laursen (69) explained that the intensity of HIIT is capable to induce a considerable acute neuromuscular load, and high levels of muscular fibre recruitment (46), consequently providing a stimulus for neuromuscular adaptation (173). Even though resistance training represents the major approach to enhancing muscle morphology, preceding investigations depicted following HIIT induced increment of lean mass (fat free) (2) and muscle cross sectional area (CSA) (471). Furthermore, increment of protein synthesis and satellite cell activity may be responsible for the aforementioned observed changes too. However these changes are not universal (174), and the capability of HIIT to produce more adaptations like muscle mass neuromuscular contribution remains largely unknown, thus still to be investigated.

On the other hand, considerable enhancement in mean and peak power output has been observed following SIT by different authors, such as Whyte LJ (75), Burgomaster KA (73), Astorino, et al. (472) and anaerobic enzyme activity MacDougall et al. (473), Rodas G (175). While there is a possibility to determine the power output during the Wingate test (short-duration cycling bouts), it may primarily represent metabolic, not neuromuscular power. However, Hurst et al. (474) suggested HIIT induces explosive muscular power increment and it has been assessed via leg extension and standing broad jump (475). Muscle strength enhancement following HIIT also was reported (85, 173) with small-moderate increases (~7%) in knee extensor strength following 6 sessions of cycle-based HIT performed at 100% peak power output (173). These conclusions reaffirm the potential for HIT as a training strategy capable of improving cardiorespiratory and neuromuscular fitness simultaneously.

2.3.5. Neuromuscular adaptation following HRC training

So far, there is little information available regarding the neuromuscular demand related to HRC training on recreationally trained healthy young individuals, and therefore it is yet to be investigated to identify properly whether HRC training-induced peripheral or central fatigue mechanisms. However, in 2017 Gonzalo and associates (476) investigated the acute effect of HRC and explained that higher lactate concentration after HRC probably impaired excitation-contraction coupling, indicating larger peripheral fatigue than after TST. In addition, in the same study, they discovered no differences in the peak-to-peak amplitude of M max before and after the HRC and TST sessions, and in the end, they conclude that membrane excitability of the motor nerve remained unchanged after HRC and TCT.

However, there is plenty of evidence established already regarding the neuromuscular adaptation after strength or heavy resistance training which is already explained in the 2.3.1 paragraph. In addition, resistance training-induced spinal adaptation, specially modification of H-reflex explained by different authors (14, 176). Precisely, many researchers observed that improvement of H reflexes upon a voluntary contraction following chronic resistance training protocol, as well as acute adaptation following resistance training, was the same results that were facilitated to increases H reflex (477). On the other hand, Casabona et al. (177), Nielsen et al. (178), and Maffiuletti et al. (179) suggested through the cross-sectional studies also chronic resistance training may modify spinal circuitry.

Moreover, adaptive neural adaptations at both spinal and supraspinal levels are suggested by results indicating strength training produces a greater ability to activate muscles, or heavy-resistance strength training potentially connects changes in α-motoneuron excitability and descending motor drive (141 - 142). Further, there were explanations regarding the resistance training-induced α-MN adaptations, like increases in neurotransmitter release at the neuromuscular junction or changes in biophysical properties of the motor neuron. On the other hand, the previous data (141) reported that unchanged H reflex data continues even after resistance training. However, Vila-Cha et al. (151) found something in contrast to previously reported data regarding the affected H reflex adaptation following endurance training. Ramos campo et al. (115) applied HRC in hypoxia and the same protocol in normoxia. However, according to the research, the H-max amplitude was not explained as the result of resistance training-induced adaptation, but instead, by the potential of HRC in hypoxia to lead to adaptations similar to those found after endurance exercise and associated with changes in H-max responses (151). Notably, it has been previously reported to be an effective method (HRC hypoxia) to improve endurance capacity (Ramos-Campo, D. J. et al. 2018).

Furthermore, Ramos-Campo et al. (90) observed that increased MVC following HRC in hypoxia; has been somehow associated with the H-max responses attained during the study. The fact that improvement in H-max amplitude was recognized after training indicates that neural adaptations occurred at the spinal level (141), potentially contributing to an enhancement of motor unit recruitment and to an increase of motor unit discharge rate (176) (explained in 2.3.1 section).

2.4. EXERCISE TRAINING INDUCED METABOLIC ADAPTATION

2.4.1. Metabolic responses following strength training

Commonly, it is a well known matter that regular exercise induced an adaptation of haematological parameters. Adaptations in blood haematological characteristics have been related to resistance exercise, acute resistance exercise was studied in young people by Ramel and associates (180), and they reported that increment of white blood cells (WBCs –leukocytes) count with different variations between subpopulations of WBCs (neutrophils, lymphocytes, and monocytes). Moreover, transient changes in blood rheological variables were found by Ahmadizad and El-Sayed (181) following acute resistance exercise, and the changes that occurred due to the RT was returned to pre-exercise values by the end of recovery (30 minutes). They conclude that these changes could be attributed to exercise-induced alterations in hemoconcentration. Thus, decrement of plasma volume is headed to increase red blood cells (RBCs), as well as Hb and Hct. However, WBCs counts were not changed in elder adults (sedentary) following 8 weeks of resistance training (182).

Furthermore, Murray-Kolb and colleagues (183) found unchanged haematological parameters in older men and women following 12 weeks of resistance training, as well as Fujitsuka et al. (184) reported no significant changes in platelets (PLT) and increased Hb and RBCs. Correspondingly, Ahmadizad and El-Sayed (181) reported no significant differences in RBC, Hb, and Hct values among trained and untrained healthy young males before and after RT. As well as, Cakir-Atabek and associates (185) reported an increase in RBC deformability and aggregation immediately after 6 weeks of weight lifting resistance training exercise. On the other hand, WBC, Hb, and Hct values were considerably increased following the resistance training on the first and last day of the program only in the moderate intensity group of subjects (185). However, they observed the alterations that occurred in RBC aggregation seem not to be related to the intensities of resistance training and suggested that it seems to be more influenced by the lower intensity of resistance training. However, still it remains unclear.

Furthermore, regular physical exercise always helps to enhance lipid and glucose metabolism by increasing insulin levels and HDL-C, while decreasing serum LDL-C and triglycerides (186). As well as, acute resistance exercise has been also shown to improve lipid profile (187). Reductions in total and LDL cholesterol have been reported in premenopausal women after resistance training at 70% of one repetition maximum (1-RM) (188). A study conducted by Elliott, and associates (189), reported no significant changes in lipid profile after 8 weeks of resistance exercises.

Rigorous exercise training in the presence of high serum lipid levels may even aggravate the development of atheromatosis by releasing catecholamines which damage the vascular walls, leading to their susceptibility to lipid deposition (478). Therefore, resistance training brings lots of advantages by improving lipid and lipoprotein levels. Subsequently, an increase in muscle lipoprotein lipase (LPL) and a disparate decrease in hepatic LPL, might result in constructive lipid and lipoprotein alterations. The increased muscle LPL and the decrease in hepatic LPL following resistance training may result in increased very low-density lipoprotein cholesterol catabolism and decreased HDL-C breakdown, respectively (190).

However, conflicting findings from intervention trials have been documented. A rise in plasma HDL-C and/or a decrease in total cholesterol, LDL-C, and triglycerides have been reported as benefits of endurance or strength training, respectively (479, 480). The relationship between physical activity and cholesterol and lipoprotein levels is still unclear because of the variety of exercise treatments, experimental methods, and participant characteristics (481).
Several factors may be used to explain the variation in training responses on blood lipids and lipoproteins. First, those with more significant dyslipidemia at baseline often have more beneficial improvements in response to training (191). Loss of body fat may also be necessary for physical training-related changes in lipid profiles (480). Those having a worse baseline body composition profile have been seen to experience higher increases in HDL-C and greater decreases in TC (Kelley et al., 2004).

Additionally, it's not entirely apparent how resistance training affects blood lipids and lipoproteins. Resistance training has resulted in substantial reductions in LDL-C ranging from 5 to 23% in fewer than half of the investigations (192). Only a little more than one-fourth of the resistance training trials have demonstrated improvements in TC, TG, or HDL-C. Additionally, there has been some discrepancy in research comparing aerobic and resistance exercise. Other research (186) did not discover changes in blood lipids in either the aerobic or resistance training groups, although other studies observed benefits in both groups (193; 482).

2.4.2. Endurance training induced metabolic adaptation

Indeed, it is well established that regular aerobic exercise-induced mitochondrial biogenesis and the activity of oxidative enzymes are also shown an important role in aerobic endurance capacity. In addition, aerobic exercise leads to an increase in VO_2 max, therefore, increasing total Hb (194), which positively affects the performance as well as the mean life expectancy of subjects. Blood volume changes induced to enhance VO_2 max with chronic endurance exercise training. This has been proved through the investigations conducted with endurance trained athletes versus sedentary controls; endurance trained subjects were shown higher blood volumes and VO_2 max values than sedentary controls. As an example, Krip et al. (195) found 16% greater total blood volume and a 54.4% higher VO_2 max in cyclists (male) compare with the same age untrained male control group. In this perspective, endurance training induced hypervolemia (expansion of blood volume) has been well recognized. An increment of plasma volume could account for nearly all of the exercise-induced hypervolemia for up to 2-4 weeks; after this time expansion may be dispersed equally between plasma and red cell volumes. This higher plasma volume is mainly achieved through a higher renal sodium reabsorption rate due to aldosterone (196), higher plasma protein production (197), and a plasma protein shift into the intravascular space (198).

Transportation of O_2 and CO_2 as the main function of red blood cells hemoglobin has major importance. It also contributes to the blood's buffering capacity and vasodilatation which improved blood flow to working muscle.

These tasks call for sufficient amounts of RBC (erythrocyte) in circulation. Enforcing that, Bizjak and associates (199) explained that non-endurance trained healthy participants has been shown increased RBC properties following a regular moderate running training program and resulting in improved performance-related parameters.

Therefore, systematic endurance exercise induces an increment of the RBC number and Hb in the blood. Hemoglobin is a protein found in the red blood cells, thus when increasing the RBCs hemoglobin concentration also increases. Therefore, Nicole Prommer and associates in 2018 (483) reported that elite endurance athletes are characterized by markedly increased hemoglobin mass.

On the other hand, Mousavizadeh and associates (200) found that 8 weeks of endurance exercise produced a significant reduction in hematocrit (Hct), Hb, and RBC. As well as, increased plasma and red blood cell volume (RBCV) (201). It has also been reported that decrement in RBC deformability following endurance training (202 - 203) and following Wingate anaerobic power test (204). In the same study were described the decrement of RBC deformability during exercise in subjects with low physical fitness. However, Gürcan and associates (205) observed increased RBC deformability in trained athletes (5 years experience) following submaximal cycling exercise, based on 75% of VO_2 max for 30 minutes.

As well as Rodrigues dos Santos, J. A. (484) 2019 reported that prolonged endurance training significantly reduced hemoglobin, mean corpuscular hemoglobin (MCH), and increased lymphocyte (subtypes of a white blood cell) count (485). While some authors reported that more dilute blood characteristics of endurance athletes attributed to higher blood volume expansion, predominantly plasma volume as a consequence of chronic training (206). How it is explained previously, consistent exercise training-induced an increment of RBCs number in the blood. As well as enhance plasma volume in the resting state as an adaptation to training. This volume expansion induced lower Hct (the percentage of RBCs in the blood) and Hb levels than in non-athletes. Therefore, lower hematocrit and hemoglobin levels are reflected in plasma volume on a complete blood count (CBC). Hence, Hb will be roughly 0.5g/dl lower than normal in most runners, while it could be 1g/dl lower in highly trained runners. As well as El-Sayed associates (206) reported that decrease in hct and an increase in Hb content or platelet number in young and old individuals following long term aerobic training.

Highly endurance trained athletes show lower Hct levels, when aerobic exercise program start, blood volume increases rapidly during the first few weeks, and then eventually levels off. This primary expansion is due mostly to an increase in blood plasma, resulting in a decline in hct, which is normally called "sports anemia", but it is a normal response to exercise (207). After about a month of training, red blood cell numbers also begin to increase to match the increase in plasma volume. However, the mechanism enforced to increase total RBC mass following training is not fully understood. Thus, according to the previous studies and their inconsistent findings are evident, whereas making it difficult to assemble conclusions.

On the other hand, a number of reports recommended that regular endurance activities allow for increasing the lipid profile, which just means that decrement of total cholesterol, triglyceride, and LDL-C and increased HDL-C (208 - 209), whereas some others reported that there were no changes in these parameters following endurance training (210, 200). According to Banz and associates (211), increasing the HDL-C levels following endurance exercise with the proper intensity and duration is the most effective method than resistance exercises. Furthermore, Randomized controlled trials were conducted by Kelley et al. 2004; Kelley and Kelley 2006 to observe the effects of aerobic exercise on blood lipids and lipoproteins. It was revealed that statistically significant increases in all lipids and lipoproteins in women (Kelley et al. 2004), as well as in men's TC, HDL-C, and TG, as well as a tendency toward LDL-C, decreases. LDL-C and TC both decreased by 3% and 2% in men and women, respectively (Kelley & Kelley 2006). TG levels were reduced by around 5% and 9% in men and women, respectively, whereas HDL-C levels increased by 3% and 2%.

2.4.3 Metabolic adaptation following traditional concurrent training

It is well-known matter that the blood lipid profile of each individual is always adaptable according to the particular exercise program, adaptations such as reductions in total cholesterol, triglycerides, LDL, and increases in HDL (Mann, S. et al. 2014). In this sense, particularly there is plenty of evidence to prove that endurance training is effective (212) while the majority of studies conducted regarding concurrent training and its consequences mainly compared with endurance training. However, some studies conducted by Libardi and associates (213), used 50% for the endurance training volume of CT protocol intervention to maintain the equal duration of training sessions between groups. Hence, contrasting one training mode or protocol with another is difficult. Authors like Dutheil et al. (214), and Schjerve et al. (215) reported that following the higher intensity of endurance training protocol induced faster and higher improvement of body composition and lipid profiles because Mann and colleagues (212) reported that there is dose-response relationships arise between training amount and improvement in blood lipid profile. However, contrasting the effectiveness of CT protocol outcome to single-mode training outcome is especially challenging, as well as there is also a lack of research on this specific area. There is more research associated with the elderly (166 - 167), obese individuals (216), and type 2 diabetics (217) rather than recreationally trained healthy adults. Therefore, the prevailing knowledge relies on the outcomes from these precise subject populations.

Thus, Sillanpää et al. (167) reported decreased total cholesterol in elderly women following 8 weeks and 21 weeks of CT interventions, and also in adult sedentary men (218). In addition, Libardi et al. (213), Damaso et al. (216), and Ghahramanloo et al. (218) observed decreased LDL and triglycerides in obese (adolescents and adults) and as well as healthy adult men. On the other hand, Sillanpää et al. (166) reported no major alterations in blood lipids in older men, while LeMura et al. (219) reported the same in young women. However, endurance-only training groups of these respective studies were shown some constructive alterations to the blood lipid profile. How it is explained previously these discrepancies in the results between different studies could be related to a subject training background, the baseline and physiology characteristics of the subjects, etc. Though Laaksonen and associates (191) suggested that individual who shows dyslipidemia at their baseline level could be achieved more constructive adaptations in blood lipid following exercise training. However, based on the existing knowledge, it is reasonable to assume that combined strength and endurance training could have a beneficial effect on blood lipid concentrations.

Some studies suggest that strength training in addition to aerobic exercise may have a bigger effect on a healthy person's lipoprotein profile than aerobic exercise alone (486). There aren't many studies looking at how combined strength and endurance training affects blood cholesterol levels. While TC and TG improvements have been less common, combined training has been shown to enhance LDL-C or HDL-C levels (220). LeMuraet al. (219) and Boardley (479) discovered no intervention effects in any of the training groups when compared to the control groups.

It is currently unknown how different training volumes and intensities impact serum lipids, despite the fact that it has long been known that exercise may improve the lipid profile in the blood. For example, the differences in physical performance improvements can be utilized to explain the diversity of exercise responses. As VO_2 max has raised, HDL-C has risen more proportionately than the other way around (487). According to a recent investigation, training intensity may significantly modify how training affects changes in blood lipids and lipoproteins (192). Improvements, notably an elevation in HDL-C, were more commonly seen after high-intensity exercise programs. 21% of trials with a moderate intensity demonstrated improvements in blood lipids, compared to 60% of high-intensity research.

Furthermore, there is a lack of evidence that could be found regarding the blood serums following CT intervention in the recreationally trained healthy population. Hence, it is recommended to investigate the different blood serum factors levels following CT in those particular subjects' populations.

2.4.4. Metabolic adaptation following SIT

There are numerous definitions of HIIT by various authors, among them, it was described by Gibala and McGee (86) as a potent time-efficient approach to induce various metabolic adaptations which are usually related to traditional endurance training. In addition, it has been guided to increase the level of glycolysis, glycogenesis, and lactate transport proteins in skeletal muscles (221). Very few minutes approximately 15 minutes of intense HIIT workout or a few sessions such as six sessions of HIIT over 2 weeks could increase endurance or skeletal muscle oxidative capacity during aerobic base exercise (86). While Abe and associates (221) were hypoxia-inducible factor-1α (Hif-1) and the major transcription factor regulating the expression of genes related to anaerobic metabolism adaptation following HIIT. With the purpose of deciphering the mechanism leading to the improvement of skeletal muscle glycolytic capacity. Then they were suggesting that Hif-1 is a key regulator in the metabolic adaptation to high-intensity training.

According to Belviranli et al. (222) reported acute haematological adaptation following the Wingate test (HIIT). They reported increased hematocrit percentage, hemoglobin values, red cell count, mean cell volume, platelet count, total white cell count, and counts of the white cell subgroups' following the acute HIIT intervention and interestingly their values started to reappearance to resting levels 3 hours after exercise, and complete recovery was shown 6 hours after exercise. The study conducted by Oliveira-Child et al. (223) reported lower red blood cell count and hemoglobin concentration comparing pre and post-training following two weeks of HIIT training. On the other hand, increased lactate (224) and plasma glucose levels (225- 226) were reported, as well as decreased PCr/(Cr + PCr) ratio (225) were detected following high-intensity exercise.

However, numerous adaptations could be able to achieve following consistent endurance training, such as enhanced functional performance, improve health, and reduce risk for chronic disease. As well as physiological alterations are complex and involve multiple organ systems, metabolic adaptations in skeletal muscle play a critical role in the beneficial effects of endurance training.

However, more details have been described under the endurance training sector (2.2.1.4). Specially, increased glucose transportation and muscle oxidative capacity following exercise are supposed to contribute to fat burning after exercise and as well as decrease the risk of diseases such as insulin resistance and type 2 diabetes (T2D). Therefore, recent results following different studies have been described that following HIIT intervention induces various metabolic and performance adaptations that are remarkably similar to traditional endurance training, even though lower total training volume and time commitment observed (86).

2.5. EXERCISE TRAINING INDUCED CARDIORESPIRATORY ADAPTATION

2.5.1. Cardiorespiratory adaptation following strength training

In order to satisfy the increased metabolic needs of the working muscles, the shift from rest to activity necessitates modifications in both respiratory and cardiovascular function. Changes in heart rate (HR), cardiac output (CO), stroke volume (SV), and blood pressure (BP) are among the cardiovascular reactions that take place after an intense bout of exercise (565, 566). Although both resistance and aerobic exercise cause similar cardiovascular changes, several significant discrepancies occur that allow both forms of exercise to continue.

Strength exercise is a powerful stimulus for muscular growth and strength improvement, which cannot be disputed. When the initial VO_2 max at the outset of the training is lower than the typical values of VO_2 max for the corresponding age, this training also results in an improvement in VO_2 max. The improvement in oxygen use in hypertrophied muscles may be linked to the RT-induced rise in VO_2 max. Consequently, when young and elderly people have initially low fitness levels, RT may be anticipated to simultaneously enhance both musculoskeletal (muscle hypertrophy and functional ability) and cardiovascular (VO_2 max) fitnesses within a single modality of resistance training. Therefore, further research is required since there is lack of study examining the dose-response relationship between baseline VO_2 max and the rise in VO_2 max following traditional strength training.

2.5.2. Endurance training induced cardiorespiratory adaptation

Human studies in the 1960s and onward demonstrated that leading consistent training of endurance exercise induced significant increases in VO_2 max adaptation with time (231), as well as increases in cardiac output, vascular conductance, a greater perfusion capacity of the muscle, and greater oxygen extraction, with a consequent increase in aerobic power (232). VO_2 max allows to increase in the number and size of mitochondria in skeletal muscle fibres, as well as the enzyme mechanism involved in the aerobic exercise for ATP degradation from fat and carbohydrate substrates; subsequently both of these factors ended by increasing the energy production during the aerobic training sessions (233 - 234).

Furthermore, it has also been reported that endurance training induced an increment of cardiac output through the increment of stroke volume. It is defined as hypertrophy of the heart, specially hypertrophy adaptation of the left ventricle which ended by increasing the amount of blood leaving the heart with each contraction. Therefore, enhance the O_2 delivery to exercising muscle, consequently increasing VO_2 max (235). As well as Saltin and Rowell (236) reported that cardiac output will increase from 30% when training nears maximal rates of endurance workout. Thus, Fick's Principle suggested that once O_2 consumption increases must improve cardiac output, and the same study proposed that following endurance training could be able to achieve a positive cardiorespiratory outcome. An increment in the maximal rate of pulmonary ventilation is the major respiratory system adaptation following endurance training, which means an increment of both tidal volume and respiration rate, an increase in pulmonary diffusion at maximal rates of work, and an increase in pulmonary diffusion at maximal rates of work, primarily due to increases in pulmonary blood flow, particularly to the upper regions of the lung.

On the other hand, Sawka and colleagues (201) reported, following endurance training induced an increment of plasma volume up to 20%, thereby could increase VO_2 max adaptation by improving stroke volume and O_2 transport (237 - 238). In addition to that, they also reported improved circulatory reserve, enhanced diastolic volume, and temperature regulation during exercise may also contribute to enhancing aerobic fitness following endurance training (237 - 238).

Enhanced capillarization is also explained as another crucial theory following sustained endurance training. It improves the O_2 delivery to working muscles thus causing to increase in VO_2 max. It has been reinforced through the study conducted by Murawska-Cialowicz and associates (239). They reported a substantial increment of VO_2 max (14%) following Cross Fit training. They suggested that training intervention has been affected to improve the oxygen pressure in arterial blood (PaO_2), thus it has been backed to improve O_2 saturation in the blood following exercise and during the rest period. Otherwise, when it is combined with the fact that expression of vascular endothelial growth factor (VEGF) increases in the brain, lungs, and skeletal muscles during physical exertion (240), these findings suggests that endurance exercise may improve aerobic power through enhanced O_2 saturation of circulating blood and improved delivery of this O_2 rich blood to exercising muscles.

Moreover, almost all studies conducted regarding the O_2 max following endurance training has been reported increased VO_2 max and endurance performance. It is very difficult to define an optimal level of intensity and volume that assist to enhance endurance performance. There is however evidence proposed that during the long term training, aerobic exercise will become stable and therefore increase endurance performance, such as exercise economy and lactate threshold (174).

Exercise economy has been defined as required oxygen uptake at a given absolute exercise intensity, or "the steady state O_2 measured in ml/kg/min at a given absolute exercise intensity". Thus, enhanced exercise economy (i.e., minor VO_2 for a given absolute running speed and power output) always represents the higher endurance performance due to the lower % of VO_2 max for any particular exercise intensity (242 - 243). Thus, Morgan et al. (243) have reported that there is an inverse relationship between VO_2 max and running economy in well trained runners. Coyle and associates (244) explained that corresponding to the increased exercise economy following endurance training may result in increased oxidative capacity and associated changes in motor unit recruitment patterns. As well as decreased exercise ventilation and heart rate for the identical exercise intensity (245) and improved technique (246). This progress could be achieved due to the increased utilization of fat as substrate (fat metabolism) and a greater amount of O_2 which is required for energy production (ATP re-synthesis) than carbohydrate metabolism. However, the levels of these alterations essentially depend on the person's initial fitness levels, such as mode, intensity, duration, and frequency of exercise; and on the length of training.

2.5.3. Cardiovascular adaptation following traditional concurrent training

Generally, the combined strength and endurance training within the same training program and if the total number of weekly training sessions is high it has been mostly reported compromised results of strength development and muscle hypertrophy (19, 21). However, Nelson and associates (468) in 1990 at the first time reported different results than previous. They observed that perhaps VO_2 max was compromised following a prolonged period (20 weeks) of combined endurance and strength training. Even so, the majority of studies have reported controversial results to Nelson et al. (468), it was non-attenuation effects of VO_2 max following concurrent training (21). It seems like the prime objective of conducting studies regarding concurrent training is muscular capabilities and performance. These muscular capabilities could be independent of VO_2 max, which shows a well-established relationship between exercise intensity and exercise duration. However, Mikkola et al. (158) were observed not much large increases in VO_2 max from subjects who already physically active following concurrent training, while (247 - 248) were reported greater effect on BP, arterial stiffness, body composition, and VO_2 max than performing either type of exercise independently.

On the other hand, Dolezal and Potteiger (28) compared different training protocols: combined, endurance, and strength training, and observed increased VO_2 max after comparing both the combined training group (7%) and endurance training group (13%). While 1RM of bench press and parallel squat were in the strength training group (24 and 23%, respectively) compared with combined training (19 and 12%, respectively), and endurance training group recorded no changes in strength values. It is contrary to the other investigation (19, 34); they reported a significant impedance of strength development than endurance development when incorporating combined training protocol (28).

Further, methodological differences between studies can increase heterogeneity. Thus, the interference level could depend on the intensity and the nature of particular strength and endurance training program. Like Dolezal and Potteiger (28), Nelson et al. (468), (250) and Kraemer et al. (27) described a lower percentage growth in VO_2 max for a CT group compared to an endurance-only group. Conversely, Nelson et al. (468), Dolezal and Potteiger (28), and Kraemer, W. J. et al. (27) reported reduced endurance alterations following TCT in some studies when compared to the same endurance training in isolation. In these studies, it was proposed that muscle fiber hypertrophy induces decreases in capillary and mitochondrial densities as well as oxidative enzymes, which could be an underlying cause for attenuated VO_2 max gains due to an increased diffusion distance (468).

On the other hand, some studies were reported in contrast to the above. No interference effects were reported following TCT intervention compared with endurance training isolation (19, 30, 34, and 53). However, the majority of these studies have used untrained subjects that have simultaneously started strength and endurance training for the sample. Thus, perhaps it could alter the level of adaptation compared to either already strength or endurance trained subjects, therefore some caution must use when interpreting this research finding (251).

2.5.4. Cardiovascular adaptation following SIT

A greater number of studies published regarding the HIIT training method compared to non-exercise controls have reported that HIIT has been guided to enhance cardiorespiratory fitness. Authors like Burgomaster et al. (12), and Astorino et al. (252) revealed that HIIT training has an effective approach for enhancing VO_2 max. It has been proven through the different meta-analyses conducted with healthy (253, 254, 255), and clinical populations (70, 256). However, Gibala et al. (11), Burgomaster et al. (12), and some others reported that HIIT could be induced similar adaptation compared to the MICT, while Helgerud et al. (257); Matsuo et al. (258) and others informed that HIIT could be able to achieve even greater adaptation than MICT (259) despite a substantially reduced time commitment. Thus, Daussin et al. (260) say corresponding all the above analyses could differ due to their underlying physiological mechanism; however, still these remain to be determined.

On the other hand, Reyes-Amigo et al. (261) explained that HIIT has the potential to improve cardiorespiratory fitness in preadolescents. Thus, there is plenty of evidence to conclude that children and adolescents should engage in high-intensity physical activity to enhance their cardiorespiratory fitness. Therefore, Dobbins and associates (262) in 2013 also reported that HIIT could be able to achieve similar or better cardiorespiratory adaptation compared to traditional endurance training, even in a short period of time.

There are different variations of HIIT protocols, thus different studies have emerged to support the efficacy of this type of training (70, 255), it appears to be effective when performed in a variety of ways; although all protocols of this training method frequently require to training with an intensity of 75% VO_2 max or greater with 3-5 times of training sessions per week. The meta-analysis conducted by Milanovic and associates (255) determined that different types of HIIT were more effective in terms of enhancing cardiorespiratory fitness than standard endurance training in healthy adults (up to 45 years of age). However, there are plenty of published studies that described that if the required intensity is attained, the physiological responses following the HIIT protocol seem to be equal to the physiological adaptation induced by SIT protocol in healthy individuals (1).

On the other hand, not only HIIT but also SIT as another form of interval training and both of them (i.e. HIIT and SIT) induced the classic physiological adaptations characteristic of MICT such as increased aerobic capacity ($\dot{V}O_2$ max) and mitochondrial content. However, few studies suggested that mitochondrial development is greater following HIIT training compared to MICT, at least when matched-work comparisons are made within the same individual. On the other hand, it is well established that the increase of mitochondrial content following SIT is similar to MICT even though exercise volume is different between both training methods. Thus, HIIT improves greater VO_2 max adaptation than MICT for a given training volume, whereas SIT and MICT induce equal VO_2 max adaptation despite differences in training volume (71). Generally, these studies and their results propose that HIIT/SIT is a vital training method to improve mitochondrial activity (mitochondrial respiration and function), while the increase of mitochondrial mass is possible when a greater training volume is available (Figure 11) (264). Whereas prolonged low-intensity and high-volume (long slow-distance [lsd] training) endurance exercise seems to be encouraged to increase the mitochondrial content within skeletal muscle (265).

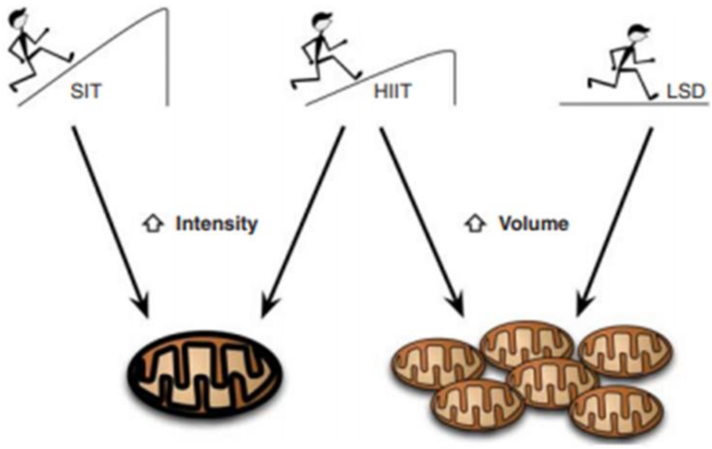


Figure 11. Schematic diagram of training intensity and volume on mitochondrial respiration versus content adaptations through endurance training, Hughes et al. (265).

Exercise at both ends of the intensity continuum could be able to produce considerable developments (e.g., 10–15%) in VO_2 max following short term training programs (266, 258). While the mechanism accountable for HIIT training elicit enhancement of cardiorespiratory adaptation still remain difficult to track down, both peripheral (e.g., increased mitochondrial content and function) and central adaptations (e.g., increased cardiac output) may contribute to increased VO_2 max (267, 12, 252). On the other hand, MacPherson et al. (266) suggest that achieving a certain total exercise volume is necessary to increase central adaptation while higher-intensity exercise targets peripheral adaptation.

With regards to SIT, evidence corresponding to the effects on maximal cardiac output (Qmax) is limited and equivocal. The study conducted by Raleigh et al (269) reported that even performed repeated 20 s intervals at 170% of work rate at VO_2 max during four weeks, Qmax has not changed, despite improved VO_2 max by 10%. However, Zhang et al. (270) found that SIT improved stroke volume during submaximal exercise, but Vella and Robergs (271) revealed that stroke volume at submaximal exercise may not be an accurate reflection of Qmax, thus SIT-induced improvements in submaximal stroke volume do not necessarily indicate that SIT is improving Qmax (272).

2.5.5. Cardiorespiratory adaptation following HRC training

Generally, it is well established that resistance training-induced muscular force production, not only that they have also been reported resistance training-induced cardiorespiratory adaptations. Alcaraz and associates (9) explained that HRC and TCT sets are quantitatively similar but cardiovascular load is significantly higher than TCT. Therefore, they concluded that to promote both strength and cardiovascular adaptation concurrently, perhaps the HRC training method is an effective training strategy within a short period of training. Therefore, maybe high-intensity circuit training (HICT) could be the most effective and efficient training method to improve VO_2 max in individuals which is a well-established marker of cardiopulmonary health. When comparing the HICT and steady state training protocol induced adaptation, HICT induced similar or sometimes greater adaptation in VO_2 max, despite significantly lower exercise volume (11, 56).

In addition, training sessions always provoked to increase in the heart rate immediately as an acute response and it is affected by the amount of resistance, number of repetitions, and the muscle (agonist and antagonist) involved in the contraction (488). Therefore, Katch et al. (263) explained that after a prolonged period of resistance training, there is an increment of cardiorespiratory adaptation due to the elevated heart rate and O_2 consumption that occurred during the training sessions. Moreover, some other researchers also detected changes in cardiac output following resistance training (273, 274).

On the other hand, resistance training not produced only fibre hypertrophy and also induced to make changes in the mechanism which is responsible for the transport and utilization of O_2. These mechanisms are comprised of an increase in capillary density per fibre and an increase in the oxidative capacity of the muscle cell, as reflected by an increased citrate synthase activity (275). As well as, it has also been described modifications in the way in which muscles use energy, such as the increase in the degradation of phosphagen and glycogen and better utilization of intramuscular triglycerides. It is possible that all these changes may explain the improvements in oxygen consumption in people who perform resistance circuit training, including older adults. (16).

Some researchers have shown that following 10, 12, and 20 weeks of circuit-based strength training is very effective for increasing maximum oxygen consumption, VO_2 peak, maximum pulmonary ventilation, functional capacity, and strength while improving body composition (91, 93, 229, 276), while Allen et al. (277) reported no change in VO_2 max over 12 weeks of training. Therefore it is given an idea that training program length is not crucial, particularly when considering the enhancement of VO_2 max has been shown to occur in 10 to 20 days of training. This argument is reinforced by the review study conducted by Wenger (278) and Swain and Franklin (279) which has reported that exercise intensity is probably the most important factor to improve VO_2 max. Thus, to optimize the circuit weight training prescription, it seems reasonable to identify the most effective combination of intensity, volume, work-to-rest ratio, weekly frequency, and exercise sequence to promote muscular, cardiorespiratory, and body composition adaptations. It was depicted through the study conducted by Gormley et al. (489) which had been explained higher intensities of exercise are more effective to increase VO_2 max than lower intensities of exercise when the volume of exercise is controlled in healthy, young adults. As well as athlete's current training status will certainly influence cardiorespiratory and strength training adaptation.

On the other hand, the direct linear relationship between oxygen consumption and heart rate always helps to detect exercise intensity, thus heart rate has long been considered reliable information of the athlete's physical state during the training sessions. Furthermore, heart rate data imposed in the HRC condition were reported by Alcaraz et al. (9) and it would likely be important for stimulating adaptations that improve cardiovascular function. Thus, they found that the HR max achieved in the HRC was approximately 71% of the maximum, which was they interpreted HR values found in the study fell within the ACSM guidelines (60–90% range) for the development of cardiorespiratory fitness and promotion of body composition changes.

However, Skidmore and associates (280) examined the heart rate responses to different types of CWT methods, such as Traditional CWT, aerobic CWT, and combined CWT interval training. Thus, they found different heart rate responses and mentioned that should be attentiveness when using HR to determine intensity during CWT. Nonetheless, Collins and associates (281), and Gotshalk and colleagues (282) explained that HR values perhaps within the suggested range for enhancing cardiovascular fitness, but oxygen consumption could not follow a linear path in this particular training, especially when the load is above 70% 1RM. It is totally in contrast to the findings of Alcaraz et al. (9). However, above 75% of 1RM workloads are still to be investigated due to the lack of information.

2.6. Exercise training induced structural (body composition and muscle architecture) adaptation

2.6.1. Structural adaptation following strength training

The research by Ramos-Campo, D. J. et al. (490), notably in adult males, convincingly demonstrates that circuit training alone may induce considerable changes in body composition, characterized by fat loss and increasing muscle mass. Regarding fat mass, Chtara et al. (33) similarly found a loss of 9.2% in body fat with just 2 sessions per week in active adults, even though the majority of research has shown substantial reductions in body fat with a frequency of training of 2-3 times per week. Additionally, Paoli et al. (92) discovered a larger reduction in body fat in the high-intensity group utilizing comparable training volumes and frequencies for low-intensity circuit and high-intensity circuit groups. It might be associated with the lipolysis linked to low intensity and large volume (283), as one explanation for these findings.

Due to the fact that there was no change in body mass, these data also show a gain in muscle mass rather than just muscle mass maintenance. As a result, the increase in muscle mass and the decrease in fat mass, which encourages body mass maintenance, may have an impact on how circuit training affects weight. The primary cause of increased muscle development could be related to intramuscular anabolic signaling, maximizing the response of muscle fiber recruitment, time under strain, and metabolic stress (284) that resistance exercise, such as resistance circuit training, promotes.

Furthermore, other investigations have discovered differences between untrained and trained people. Even after only a little time of training, the range of improvement is often substantially larger compared to trained participants because, among other things, untrained subjects are more easily able to display changes in body composition (285). This might be because, in untrained people, exercise causes a bigger increase in total energy expenditure than can be explained by the energy cost of a training program (286), independent of the training parameters. Therefore, larger energy expenditure will result in a bigger loss of fat mass.

A number of interrelated factors, such as pennation angle (the angle at which muscle fibers are oriented between each tendon), muscle thickness (size: the distance between the superficial and deep borders of a muscle), and fascicle length (the length of bundled muscle fibers in series between each tendon), define the structure of human skeletal muscle (552). All characteristics of muscle architecture are changed by strength training in a way that is expected to increase overall muscular function (317, 320, 416, 551, and 553). After only three weeks of a progressive resistance workout program, significant improvements in muscle thickness, pennation angle, and fascicle length have been seen (320, 553). Across a number of resistance training protocols, increases in muscle mass have been seen (317, 320, 416, 551, and 553). Hence, it is not unexpected when Abe et al. found that after 12 weeks of traditional resistance training; muscles had thickened significantly (317). Studies after that revealed comparable results along with a 16%–25% increase in fascicle length in response to a resistance-training regimen. In addition, the authors found a modest decrease in pennation angle, however it was not significant (320, 416).

2.6.2. Structural adaptation following endurance training

Training for endurance is frequently done to encourage weight loss. The amount of the decrease depends on the total weekly energy used for exercise and the total amount of calories consumed throughout the intervention period (287). Additionally, additional variables, such as initial body composition and degree of fitness, may influence weight fluctuations during the training period (287). Additionally, older adults and males may be more likely than younger people and women to lose weight as a result of exercise training (288).

Additionally, aerobic exercise is linked to modest or insignificant gains in skeletal muscle mass, with a comparable response in both men and women (288). Both walking/jogging exercise and high-intensity cycling have been found to be helpful in boosting muscle growth in previously untrained people (289). Body weight stays the same if the energy cost of exercise is offset by an increase in calorie consumption. But even without weight reduction, body composition changes as a result of endurance exercise. Numerous studies show that aerobic exercise without weight loss reduces visceral and adipose tissue in both obese and lean men and women, as well as total body fat mass (513).

Moreover, endurance training is extensively used by a variety of athletes and appears to recruit ST fibers in particular, supporting the hypothesis of selective recruitment (136). Gollnick et al. (315) discovered that bicycle ergometer-based endurance training caused the ST fibers to hypertrophy. Yet, gross muscle hypertrophy is not often a result of endurance exercise. The ST fibers of orienteers were observed by Jansson and Kaijscr (562) to be tiny and devoid of hypertrophy, lending confirmation to this observation. In a different investigation, muscle regions that had undergone intense endurance training had normal or very modest ST fiber areas, according to Nygaard et al. (563). In contrast, ST muscle fibers in elite distance runners were shown to be considerably bigger than those in untrained individuals (564). Thus, a lack of information regarding the muscle architecture adaptations following endurance training exists in the literature.

2.6.3. Structural adaptation following TCT training

Several researches have examined the impact of concurrent training on total fat mass, and the literature has conflicting findings. Middle-aged and older men who completed three months of endurance training or concurrent training had reductions in their total body fat mass, according to Donges et al. (558), but only those who were assigned to strength trainng or concurrent training programs saw gains in their muscle mass. Others have reported similar benefits of concurrent training in reducing fat mass or percentage of body fat (167, 560, 561), and it has been debatable whether concurrent training is superior to single-mode training routines (such as strength training) in terms of reducing total body fat mass.

This may be due to the concurrent training group performing a larger overall training volume than endurance training or strength training alone in some but not all experiments (i.e., participants in concurrent training performed the sum of each single-mode training routine). Nonetheless, combined data from 21 trials show that concurrent training reduces body fat similarly to endurance training or strength training, but inadequate data prevented an examination of different concurrent training volumes in comparison to single modalities in terms of body fat reduction (21). However, according to certain research (559, 560), people who participate in long-term concurrent training don't see any changes in their body fat.

However, the researcher believes that while there is a wealth of research on concurrent training-induced muscle architecture (such as fascicle length, muscle thickness, pennation angle, etc.) in the literature, there is little information on the traditional concurrent training (endurance training followed by strength training)-induced muscle architecture. Yet, as a result of endurance exercise, the pennation angle increases (317). On the other hand, strength training raises fascicle length (416), and pennation angle (317, 416, 320) their fore improves muscle thickness, thus literally boosting maximum force-generating ability and skeletal muscle hypertrophy. Due to these drastically dissimilar reactions, the concurrent training provides a substantial level of complexity in the exercise prescription (417).

2.6.4. Structural adaptation following SIT training

Best of the author's knowledge, a lack of information regarding the SIT-induced body composition adaptation in a recreationally healthy young male are exist in the current literature. However, some investigations were reported with different samples like obese males and females, Postmenopausal Women, and intellectually disabled persons. SIT, in contrast to aerobic exercise, has improved lean mass and lowered fat loss in young overweight men and women. A 15-week SIT program with premenopausal women includes three 20-minute sessions each week (554). During a continuous 20 minutes, women pedaled at a low effort for 12 s after an 8-second sprint. A 40-minute cycling routine for aerobic exercise was followed by the control group throughout each session. SIT caused women to lose 2.5 kg of subcutaneous fat, but the steady-state aerobic exercise had no effect. Moreover, women who exercised also demonstrated a notable 0.6 kg gain in lean mass. Using the identical SIT protocol, similar outcomes with young, obese men (556, 557) and women have been seen (555).

The effects of run training on skeletal muscle architecture are rarely investigated. The leg muscles of sprinters and distance runners, however, have different muscle architectural structures. As compared to endurance runners, sprinters' vastus lateralis and lateral gastrocnemius are thicker, more finely pennated (with a lower angle relative to the aponeuroses), and have longer fascicles (316). These findings suggest a connection between architectural adaptability and running specialization. The greatest sprinters also showed the most severe architectural traits when grouped based on ability, suggesting that fascicle lengthening allows better muscle-shortening velocity and running speed. However, it is not clear whether these architectural variations are due to a genetic predisposition or a training adaptation.

2.6.5. Structural adaptation following HRC training

Now a day, athletes and their coaches are acutely aware of the meaning of achieving and maintaining optimal body composition for peak performance in a particular sports event. Thus, appropriate body size and composition are extremely required to be a success in almost all athletic endeavors. It is true that vigorous exercise can significantly change body composition. Such adaptations could be the most important in succeeding in optimal performance.

To be able to achieve optimal adaptation exist different types of training methods, among them, the characteristics of circuit-based resistance training methods have been shown significant interest due to their results. Subsequently, Alcaraz and associates (10) reported that high-intensity resistance circuit-based training has been shown to be an effective training method for reducing % of body fat (1.5%) and increasing lean mass in healthy men while using shorter training session duration. The decrease in body fat percentage resulted from a simultaneous increase in lean mass (+1.5 kg) and decrease in fat mass (21.1 kg) with the circuit training, which compared to lean and fat mass changes of +1.2 and 20.8 kg, respectively, with traditional heavy strength training. In addition, circuit training, where lighter loads are lifted with minimal rest, has proven very effective for reducing body fat and improving body composition (91).

On the other hand, using a similar volume and training frequency, Paoli, A. et al. (92) compared low and high-intensity circuits. In this study, a great decrease in body fat was observed in the group of participants who train with high loads, and the authors attribute this to an increase in EPOC in the hours following exercise. This increment of EPOC could be a great decrement in fat in circuit training. Meanwhile, these results are similar to the other results observed by other authors who studied with higher intensities and also reported a greater increment of EPOC with standard intensities (336).

Furthermore, Murphy and Schwarzkopf (336) and Wernbom (337) reported that high-intensity resistance circuit training could be a fast and efficient way to reduce body fat and excess body weight. As well as Scott et al. (338) reported that integrating resistance training comes up with a significant effect to increase fat burn during workouts. However, when resistance training is designed to be used in large muscle groups with micro rest between sets, they would be able to produce aerobic and metabolic benefits (339, 336, and 340). Thus researchers have found that these benefits could appear up to 72 hours after completing the high-intensity exercise training sessions (341).

In addition, some researchers such as Murphy and Schwarzkopf (336) and Moller et al. (342) explained that following high-intensity circuit-based training may produce a greater influence on subcutaneous fat reduction than traditional resistance training or traditional steady-state aerobic workout. This happens probably due to the increased catecholamines and growth hormone (GH) levels in the blood at both times such as during and after the high-intensity resistance training exercise with a very little rest period (<30 s). Thus, this little rest period together with shorter total exercise time is always attractive to people who are frustrated to improve their performance within minimum time wasting of exercise program.

2.7. Exercise training induced mechanical (force and 6 RM) adaptation

2.7.1. Mechanical adaptation following strength training

Generally, both terms "strength" and "resistance" training are used for the same purpose, even though there is a small difference between them. However both training results were the same adaptation, thus traditionally both terms have been used to express the outcomes corresponding to each particular training program. Basically, strength training is when the participant is lifting heavy at low reps specifically training to get stronger. Whereas resistance training consisted of more reps using free weight machines, free weights, isokinetic devices, vibration devices, medicine balls, resistance bands, stability balls, sandbags, ropes, and exercises involving one's body weight to introduce resistance in the workout (291).

Therefore, both "strength" and "resistance" training use resistance to muscular contraction to build the strength, anaerobic endurance, and size of skeletal muscles, of course when it is performed repeatedly and consistently. Thus, it is well documented that Heavy strength training typically induces increases in maximum force production and muscle mass (46, 292 - 295). A review of the more than 100 studies, depicted that muscular strength increased approximately 40% in untrained, 20% in moderately trained, 16% in trained, 10% in advanced, and 2% in elite participants over periods ranging from 4 weeks to 2 years (440). On the other hand, identical strength training programs may cause different responses between individuals, and it has been demonstrated that 1RM and muscle CSA increases may differ or even not respond at all in some individuals undergoing training (296).

Commonly, a well-rounded fitness program includes strength training to improve joint function, bone density, and muscle, tendon, and ligament strength. However, there are variables identified already that can impact the results including Sets, repetitions, exercises undertaken, intensity (weights used), frequency of sessions, and rest between sets. If resistance training programs vary through the number of repetitions and sets performed, exercises undertaken, and weights used, will be able to maintain any strength gains.

Moreover, following traditional resistance training may induce an increment of muscle power. However, Häkkinen and Komi (297) and Newton and associates (298) reported that the most effective method for increasing power is the use of ballistic resistance exercise with light to moderate loading, 30% to 60% of 1 RM at maximal velocity throughout the full range of joint motion combined with traditional strength training. As well as following strength or resistance training-induced neuromuscular adaptation, fibre type transformation, and type of muscle contraction directed to increase the rate of force development (299).

More than a few authors suggested that success in sports depends on the improvement of strength and power. Therefore enhancement of strength and power is vitally important. In this sense, strength training is crucial that it assists to enhance strength power as well as vertical jump performance. The research conducted previously has revealed that the vertical jump is a reliable predictor of success in a number of sports. As well as, scientific evidence proposed that the best way to improve vertical jump height is through the combination of plyometric training with weight training. It literally means following strength training could achieve higher performance (height) of CMJ. Thus, strong correlations have been found between the one repetition maximum squat (300) and power during CMJ and static vertical jumping (301) Furthermore, training-induced increases in measures of maximum strength have been shown to result in vertical jump height and power output increases (301-302).

The muscle fibres have different metabolic functions; physiologically, some are better suited to work under aerobic conditions, whereas others work better under anaerobic conditions. The fibres which are used and depend on O_2 to produce energy are called aerobic, slow-twitch (slow-oxidative), type I, or red fibres. Fibres which are not required O_2 to produce energy are called anaerobic, fast-twitch (fast oxidative glycolytic), type II, or white fibres. Fast-twitch muscles are further divided into IIA and IIX (21). Sometimes IIX has been referred to as IIB, though the IIB phenotype is practically non-existent in humans (303). Type I (slow-twitch) fibres have greater mitochondrial volume, densities, and capillary-fibre content than other both kinds of type II fibres (304). For that reason, compared with type II fibres these fibres have greater fatigue resistance and energy maintenance (305).

On the other hand, generally, type IIA and IIX muscle fibres produce greater peak power and contractile velocities than type I fibres (306). According to the understanding of researchers, hypertrophic adaptation to strength training is greater in type II than in type I fibres, as well as increases fibre size, which generates greater force production. Moreover, studies conducted by the Danish researchers Andersen (307) and Aagaard (308 - 309) explained that IIX fibres develop the characteristics of IIA fibres when subjected to voluminous training or training that is lactic in nature because the myosin-heavy chain of these fibres gets more efficient and slower at dealing with lactic exertion, but if the training volume is reduced (tapering) the adaptation could be reverse too. As a result, IIX fibres could be adapted to their original character as the fastest-contracting fibres (307, 21). There is also research demonstrating the transformation of type I to type II fibres (or vice versa depending on the nature of the exercise) (27, 310). Additionally, type II has been shown greater rates of ATP re-synthesis following contracting activity compared with slow type I fibres (491).

Strength training-induced morphological adaptation is normally coupled with increased strength production during the contraction of trained muscle, whereas increasing the percentage of both IIA and IIX fibres while decreasing the percentage of slow type I fibres (492). In contrast, different authors reported that no fibre transformation occurred from slow to fast twitch or fast type IIA to IIX following strength training (493, 494, 495). These contradictions of findings are perhaps explained by characteristics of exercises, specifically, the speed at which contractions in the respective intervention are performed. After fast isokinetic resistance exercise, Paddon-Jones et al. (492) observed significant slow to fast twitch fibre type transformations. While some other authors, such as Adams et al. (493), Harridge et al. (494), and Carroll et al. (495) reported that no fibre transformation after the intervention of slower contractile speeds. Therefore, it seems like fibre transformation direction may be dependent on the intensity and/or velocity/speed of contractile muscle actions performed during the training.

Energy expenditure is elevated during resistance training, which is affected by increased lean body mass, increased requirements of metabolically active lean tissue (496, 497), and amplifies the energy required to perform exercise during the training. Strength training-induced body composition adaptation is showing crucial aspects among the rest of the other adaptations and those adaptations mostly vary since the difference in a training program. The nature of the program defines the type of adaptation such as local and entire body adaptation. If training programs focused only on small muscle groups resulted in local adaptation while those programs which include large muscle groups resulted in larger changes in body composition. Specially, the main consequence of strength training on body composition is transference from fat to muscle mass with individuals remaining in caloric balance (116). Several studies reported that strength training induced decrement in fat mass and concurrently increase fat-free mass without changes in body weight (496 - 498).

Furthermore, high-intensity strength training induced an increment of fat-free mass, muscle fiber area, and muscle CSA. Usually, a 5 - 10% increment of muscle CSA is always possible whereas the major part is caused by neural factors (499 - 502). Besides both type I (slow) and Type II (fast) fibers adapt to strength training by increasing their size. In addition, more than above mentioned fat mass to fat-free mass transference, strength training help to transform body composition by decreasing abdominal fat (503, 505). Particularly, well planned total body strength training programs with progressive training loads appear to be a success in the sense of modifying body composition. While Treuth et al. (505) and Ibañez et al. (503) reported that increment of muscle strength from 17% - 65% following successful strength training.

2.7.2. Endurance training induced mechanical adaptation

To achieve steady state endurance performance, endurance training-induced favourable adaptation of type I slow oxidative fibres and relative structural changes of slow myosin. Subsequently, the consequences of the adaptation affect muscle force production. Thus, Malisoux and co-workers (311) reported that after endurance training-induced composition changes of type II fast muscle fibres to type I slow muscle fibres, for that reason decline the force producing capabilities of the muscle. Certainly, this adaptation makes a negative impact on the performance of a particular event that is required higher force production rapidly, like power related events, middle-distance running events to short distance high-intensity events (sprints) whereas required rapid force production for successful performance (Figure 06).

Furthermore, following endurance training, there is a possibility of a modest increase in muscle strength, particularly in untrained subjects. Thus, the type of endurance training may play a crucial role in the development of muscle strength. Perhaps, it appears that cycling training-induced greater muscle strength than walking or treadmill endurance training in people who need to develop strength in a lower body extremity with lower body multi-joint exercise (i.e. leg press or squat) (312). In response to the changes in functional demand, skeletal muscle shows higher plasticity.

Prolong contractile activity of skeletal muscle, such as endurance exercise, directs to a multiple of biomechanical and physiological adaptations in skeletal muscles, together with fibre type transformation, angiogenesis, and mitochondrial biogenesis. These adaptive modifications are the basis for the enhancement of physical performance as well as other health benefits. How it is explained previously, type I (slow-twitch) oxidative muscle fibre contain both greater mitochondrial volume densities, and capillary-fibre content and rich in oxidative enzyme expression than other both forms of type II (fast-twitch) fibres (304). On the other hand type I slow, oxidative fibres are more fatigue resistant than type II (fast-twitch) fibres (305), therefore obviously slow oxidative fibres exhibit higher O_2 max values and are associated with other verities of factor that shows higher endurance performance (305).

Following endurance training also could be able to reform fibre type structures within trained muscles such as occurred during strength training. It has been proved by different authors such as Jansson et al. (506), Howald et al. (507), Sale et al. (313)...etc. they informed that aerobic training like cycling and running based intervention protocols was induced to improve the percentage of type I slow oxidative fibres coupled with a decreased percentage of type II fast oxidative and fast glycolytic fibres, besides Fitts et al. (508) proposed that increased expression of slow myosin in type II fast oxidative fibres, so that decrease the contraction speed which leads to decrease the energy expenditure following endurance training. This may not apply to all endurance exercise modalities however as the increased expression of slow myosin has primarily been reported in swimming. As well as, a study conducted by Luden et al. (314) showed that 16 weeks of moderate marathon training for recreational runners induced the size of the muscle, contractile properties, and fibre type distribution.

It is a well known matter that mitochondria are considered the power generators of the cell, converting oxygen and nutrients into ATP. Therefore, among the many investigators Hoppeler and Flueck (234) has been pointed out that it is the primary subcellular structure that makes an impact on the oxidative capacity and fatigue resistance to repeated contractile activity of skeletal muscle. Mitochondrial biogenesis refers to the process of increasing the response to a stimulus (upregulation) of mitochondrial mass (production and degradation of free radicals) and function and is one of the primary and most crucial adaptations to endurance training (509). It was first reported by Holloszy (127). He explained following endurance training induces mitochondrial biogenesis in human skeletal muscle. Although exercise unavoidably affects all organs in the body, the foremost positive impacts are believed to adapt directly from skeletal muscle adaptations.

Further, different authors confirmed their findings about the mitochondrial adaptations to endurance training (510). Additionally, later research has suggested that the proliferation of mitochondria in skeletal muscle is mediated by contractile movement rather than external stimuli, of a kind that alteration in the metabolic and endocrine environment. Perhaps it is evidenced through the observations that were done following endurance training such as limited adaptations of mitochondrial to the specific muscle fibres that are recruited during the endurance training (315; 510; 511).

Commonly, endurance training is undertaken to encourage the decrement of body weight; the degree of reduction of body weight always depends on the total energy intake and the total energy expenditure via exercise, measured per week or day within the invention period (287). Not only that but also body composition, and fitness level may affect change in weight during the exercise period (287). Furthermore, there is more possibility to lose body weight in men and old persons following exercise training than in younger people and women (288). Even body weight does not change if the exercise induced energy expenditure is compensated by increased energy intake. However, there is evidence that body composition changes following endurance training without losing body weight. Some studies conducted by different authors such as Lee et al. (512); Ross et al. (513); Ross et al. (514) reported that reduction of total body fat mass following aerobics training without weight loss, as well as in visceral and adipose tissue both in obese and lean men and women.

Usually, weight loss and Fat-Free Mass (FFM) following moderate exercise is preserved. While body fat could be reduced following training until total energy expenditure and energy intake are equal. As well as, aerobic training is also connected with moderate improvements in skeletal muscle mass, with a similar response in both men and women (288). Both high-intensity cycling (289) and walking/jogging training (515) have been shown to be effective in improving muscle mass in previously untrained individuals. On the other hand, some other studies have shown that following longer distances running could be achieved lean muscles with shorter fascicle lengths and smaller pennation angles (316 - 317). These findings support the idea that training mode favours specific muscle characteristics or that these characteristics are the result of prolonged specific training.

2.7.3. **Mechanical adaptation following traditional concurrent training**

Muscle hypertrophy describes as the increment of strength following resistance training due to the mechanism of neural adaptation, thus strength and skeletal muscle size are extremely correlated (318 - 319). Muscle strength has the main role as a crucial factor for producing whole muscle power, while force and velocity also is the product of power. Thus, the increment of muscle mass following concurrent training must be paralleled to the capacity of producing whole muscle force and power, but it is not always proportionate with hypertrophy following CT (21 - 163). Otherwise, there is limited information to able to justify this discrepancy, however different adaptations of muscle architecture (320 - 321) or maximal neuromuscular activation (29, 163) do not appear to be played a role. As well as due to the resistance stress created through the CT-induced greater tendon thickness may contribute to relative functional deficits with concurrent exercise, but the evidence is limited (322).

Furthermore, similar results about the TCT versus strength training alone were reported frequently. Strength training alone induced different fiber-type hypertrophy, lean mass adaptation on a whole body level (28), and muscle CSA (159, 163). On the other hand, running exercise as one endurance exercise could interfere with lean mass adaptation as opposed to cycling (e.g. in 323), which could even be considered to enhance hypertrophy (21, 158). However, Izquierdo et al. (129) reported that prolonged low-frequency combined resistance and endurance training-induced great gains in maximal dynamic strength, and power-load characteristics of the leg and arm extensors muscles. Identical results were reported previously by different authors, such as Hakkinen et al. (29), and McCarthy et al. (163).

However, according to the ultimate results CT induced strength and power adaptations were not comported with the magnitude of hypertrophy. A remarkably, long period of CT intervention-induced strength training decrement has not been reported; therefore authors like McCarthy et al. (163), and Glowacki et al. (324) it was characterized as the early adaptive response to concurrent exercise. However, interfered with explosive strength development (158) and force at high velocities (34), further highlighting the decrement of maximal power production following CT (21). Therefore, it has been suggested three key factors which allow for achieving maximal strength and hypertrophy following CT by Murach, K. A., and associates in 2016. That was longer recovery periods (i.e. 6–24 h) between exercise sessions, minimizing endurance frequency to ≤ 3 days per week and integrating cycling rather than running as the endurance exercise mode (to minimize muscle damage), and incorporating post-exercise nutritional strategies.

The study conducted by Lundberg and colleagues in 2014, with unilateral consecutive bouts of knee extensor of aerobic exercise within 45 minutes and resistance exercise (4 sets of 7 reps) interspersed by 15 min recovery. The contralateral limb was subjected to resistance exercise only within 5 weeks. According to the results, they analyzed the activation of AMPK, decrease glycogen stores, and defective progression of concentric force following aerobic exercise. However, resistance exercise-induced muscle hypertrophic responses that seem like not been compromised. Thus finally they suggested that non-contractile volume expanded more than myofibrillar volume within 5-week concurrent versus resistance exercise training.

2.7.4. **Mechanical adaptation following SIT**

HIIT can effectively increase cardiovascular fitness (255), as well as it has induced skeletal muscle adaptations, as observed e.g. elevated levels of the markers of mitochondrial content and oxidative capacity (12, 11), glycolytic capacity (175, 325), intramuscular glycogen and triglyceride stores (175, 11, 325), and capillary density (325, 326, 327). However, there is still a lack of knowledge regarding the impact of HIIT training on muscular fitness (strength, power, endurance). This lack of evidence could be due to the traditional aerobics exercise characteristics of most HIIT protocols used for investigations. Which is mostly using running, cycling, and rowing rather than strength training (lifting weights) exercises, which are commonly related to muscular hypertrophy and fitness? Therefore, to fill the research gap which exists already needs to be conducted more research in a particular context.

According to the studies conducted by Costigan and associates (328) in 2015 and Logan and colleagues (329) revealed that HIIT could be able to induce to decrease in body fat percentage and improve BMI in preadolescents and children. However, Racil et al., (330) explained that evidence which is corresponding to preadolescents groups is not clear enough when comparing HIIT to other training methods. Although, the review study conducted by Reyes-Amigo et al. (261) reported that body composition results are very inconsistent in BMI and even body mass, however, body fat shows a decrease in most studies.

On the other hand, the study conducted by Dobbins et al. (262) with a young population, explained that the HIIT training method effectiveness was considerably larger than other interventions on body composition but the effectiveness of HIIT in preadolescents on body composition is still unclear (331). However, Sultana et al. (259) reported that low-volume HIIT is inefficient for the changeover of total body fat mass or even total body fat percentage in comparison with MICT and non-exercise control. Even though other studies explain that it was tendered to favour enhancement in lean body mass with low-volume HIIT versus MICT (259), they revealed non-significant effects on their study.

Furthermore, SIT and endurance training protocol was applied to a young healthy recreationally active population by MacPherson and associates (266) and analyzed that following SIT and endurance training induced to increase in total mass, lean mass, and BMC. In addition, the same study suggested that despite a fraction of the time commitment, SIT elicits similar body composition and performance adaptations as endurance training, but with no effect on maximal cardiac output. Thus, these data suggest that adaptations with endurance training are origin primarily central, whereas those with SIT are more peripheral. On the other hand, a part from mitochondrial adaptations (264), both training (i.e., HIIT and SIT) induced enhancement in other factors of skeletal muscle that may contribute to enhanced oxygen extraction and oxidative energy metabolism such as increased capillary density (269, 252), including in both type I and type II fibres (332).

With regards to the CSA, there are very limited data available related to HIIT or SIT training. Estes and associates (333) conducted research regarding the hypertrophy of the vastus lateralis in a young population following a running protocol, and they revealed that increased whole muscle size of the quadriceps following an effective HIIT mode running intervention whereas improved cardiorespiratory fitness also. As well as Harber and colleagues (229) found that reduced type I fibre following HIIT intervention without affecting the contractile properties in competitive cross-country runners. However, there has been shown a tendency to decrease the fibre type II following HIIT. Hence, it is still unclear why the CSA of fibre has been shown a tendency to decrease following HIIT, therefore future investigation on this context is still to be continued. Although Kohn, T. A. and researchers (516) in 2010 reported that perhaps faster release of lactate from the fibres and faster uptake of oxygen from blood are positive effects on that.

2.7.5. Mechanical adaptation following HRC training

Resistance training has long been established for enhancing and maintaining muscular strength, power, endurance as well as muscle hypertrophy (muscle mass) (334). However, its advantage related to clinical context and chronic disease has been accepted recently by the US Department of Health and Human Services. Physical Activity and Health: A Report of the Surgeon General. Until 1990, resistance training was not in the recommended guidelines given by both the American Heart Association and ACSM. Thus, ACSM 1990 firstly recognized resistance training as a crucial factor for an inclusive training program for healthy adults of all ages (ACSM 1990), because it has provided greater development of muscular strength, mass, and endurance. Coyle and associates (335) reported why resistance training frequently involves muscle mass to develop considerable force. According to them, it happens due to the exaggerated blood pressure reaction following resistance training, such high, isolated force leads to compression of the smaller arteries and results in substantial increases in total peripheral resistance.

Furthermore, Alcaraz and colleagues (9) compare the acute effects in young adults following two training protocols, and they found that with equal loading (i.e. 6 RM), strength, power, and total workload was similar between both protocols (HRC and TST) sessions. As well as Alcaraz et al. (10) reported that HRC training was effective in improving 1RM and peak power performance as TST. Thus, the exceptional thing is HRC training promoted a similar force, power, and muscle adaptation as TST while using a shorter duration of the training session.

On the other hand, Romero-Arenas, S. et al. (513) found significant improvements in the walking economy in the HRC group ($p<0.049$) compare with TST, and isokinetic strength gains were similar in both groups when older adults performed. However, Paoli et al. (92) reported that the HRC training method was more effective than low-intensity circuit training to improve muscle strength in older adults (50 - 65 years old).

III – HYPOTHESIS

III - HYPOTHESIS

3.1. GENERAL HYPOTHESIS

- Across all recreationally trained young male subjects from three different concurrent training groups (HRC, SIT, and TCT), there would be no difference between groups in neuromuscular, metabolic, cardiorespiratory, structural, and mechanical adaptations following 8 weeks of training intervention.

3.1. SPECIFIC HYPOTHESIS

- Across all recreationally trained young male subjects from three different concurrent training groups (HRC, SIT, and TCT) there would be no difference between groups in neuromuscular variables adaptations following 8 weeks of training intervention.

- Across all recreationally trained young male subjects from three different concurrent training groups (HRC, SIT, and TCT) there would be no difference between groups in metabolic variables adaptations following 8 weeks of training intervention.

- Across all recreationally trained young male subjects from three different concurrent training groups (HRC, SIT, and TCT) there would be no difference between groups in cardiovascular variables adaptations following 8 weeks of training intervention.

- Across all recreationally trained young male subjects from three different concurrent training groups (HRC, SIT, and TCT) there would be no difference between groups in structural variables adaptations following 8 weeks of training intervention.

- Across all recreationally trained young male subjects from three different concurrent training groups (HRC, SIT, and TCT) there would be no difference between groups in mechanical variable adaptations following 8 weeks of training intervention.

IV – OBJECTIVES

IV - OBJECTIVES

4.1. GENERAL OBJECTIVE:

To evaluate and compare the neuromuscular, metabolic, cardiorespiratory, structural, and mechanical long term adaptations between the three different concurrent training methods (HRC vs. SIT vs. TCT) in young recreationally training athletes.

4.2. SPECIFIC OBJECTIVES:

- To identify and explain the long-term neuromuscular adaptation and mechanism following three different concurrent training (HRC, SIT, and TCT) in young recreationally training athletes.
- To identify and explain the long-term metabolic adaptation and mechanism following three different concurrent training (HRC, SIT, and TCT) in young recreationally training athletes.
- To identify and explain the long-term cardiorespiratory adaptation and mechanism following three different concurrent training (HRC, SIT, and TCT) in young recreationally training athletes.
- To identify and explain the long-term structural adaptation and mechanism following three different concurrent training (HRC, SIT, and TCT) in young recreationally training athletes.
- To identify and explain the long-term mechanical adaptation and mechanism following three different concurrent training (HRC, SIT, and TCT) in young recreationally training athletes.

V – METHODS

V - METHODS

This chapter provides information regarding the methodology of the study conducted during this doctoral thesis. This doctoral thesis consists of five different sub-sections aligned under one methodology, which measured long-term adaptation following three different concurrent training interventions. Details of all these assessments, analysis procedures, research methods, research population, sampling and sampling method, source of data, research procedure and procedure of data collection, exercise training protocol, method of data analysis, validity and reliability of the instrument, ethical issues and code of conduct employed are presented in this overarching chapter on methodology.

5.1. Study Design

To compare the effectiveness of different training protocols on neuromuscular, metabolic, cardiorespiratory, structural, and mechanical variables, a single-blinded randomized controlled trial with pre and post-tests was conducted. Participants were randomly allocated into three experimental groups: HRC, SIT, and TCT. All training sessions were supervised by an experienced instructor who encouraged the subject to achieve volitional fatigue safely and control the rest period and adjust of training load.

This study consisted of five total visits to the laboratory (Figure 12): Visit #1 – Initial assessment for requirement test and familiarization session, Visit #2 – pre training evaluation, Visit #3 – continuation of pre training evaluation, Visit #4 – post training testing, and Visit #5 – continuation of post training testing. The entire study has taken approximately ten weeks but the intervention only lasted eight weeks. All testing and exercise sessions took place at approximately the same time of the day. To be included in the study, subjects must meet several requirements which are measured during Visit #1: Regular physical activity practice, to have a BMI >20 and < 27, being able to complete an intense workout of at least 20 minutes, as well as to have >35 ml/kg/min of VO_2 max capacity. On the other hand, to safeguard participant protection, a number of exclusion criteria were applied. Such as being less than 18 years of age, having significant cardiovascular, respiratory, metabolic, or other neurological or orthopedic disorders that limit the exercise, present any other medical conditions that counter indicate the practice of exercise.

The study was conducted within the premises of Catholic University of Murcia. The following investigation counted only healthy recreationally trained subjects residing within a radius of 50 km of the city of Murcia and voluntarily wanting to participate in the study. It was highly considered that at least fifteen (15) subjects for each group must be participated to be analyzed statistically, further it necessarily formed by recreationally trained healthy male participants who are between 18 to 35 years of age.

Visit #1 – Initial testing and familiarization session:

During the first visit, all the subjects were informed of the characteristics of the study, advantages, and disadvantage which is could occur during their participation and as well as their role during the study. Therefore they were well-versed in the study and their participation.

Hence, at the very beginning, all subjects completed the informed consent (annex 1), exercise risk assessment, the behaviour of nutrition ingested, and a health history questionnaire. Besides Height (cm), age and weight (kg) was recorded. After that, all participants conducted the ECG test to verify whether he is suitable or not to conduct at least 20 minutes of intense workout or a VO_2 max test. Based on the advice of the medical doctor about the ECG report and the rest of the other relevant data, participants were excluded who were not being able to complete the entry requirements. During this visit, all participants were familiarized with the testing to avoid the alteration that could be occurred during the real testing time and later randomly divide all participants into three training groups. Finally, each participant experienced their own training procedure to understand the nature of exercises of three different "concurrent" training protocols a week prior to the start of training.

Visit #2 pre training evaluations:

The second visit (first pre training testing session) was conducted after 24h of the first visit; the measurements were realized according to the following order: blood test, resting metabolic rate (RMR), the maximum amplitude of Hoffman reflex (H max), the maximum amplitude of M wave (M max), CMJ, push-up, MVC, RFD, ultrasound scan, repeated sprint ability (RSA) and lastly the strength training load determination (6RM).

Visit #3 continuations of pre training evaluations:

During visit #3 was continued the measurements were with VO_2 max and DXA. Participants who got approval after the ECG assessment were only allowed to conduct the VO_2 max test if anyone disqualified based on the ECG assessment was excluded from the study. They had 24 hours recovery period after the previous measurement to avoid fatigue involvement due to the RSA and 6 RM test.

Visit #4

The 4th visit was conducted after the completion of sixteen training sessions within 8 weeks; the same testing procedure which was applied during the 2nd visit was repeated during the 4th visit and it was called after 48 hours of recovery from the cessation of the training program. Subjects were informed to assist in fasting again for the blood test and RMR test. The rest of them followed similarly to 2nd visit.

Visit #5

During visit #5 were continued the measurements with VO_2 max and DXA. In this visit, they do not have to conduct the ECG test because subjects who accomplish the requirement only participated in the intervention programme. They had 24 hours recovery period after the previous measurement to avoid fatigue involvement due to the RSA and 6 RM test.

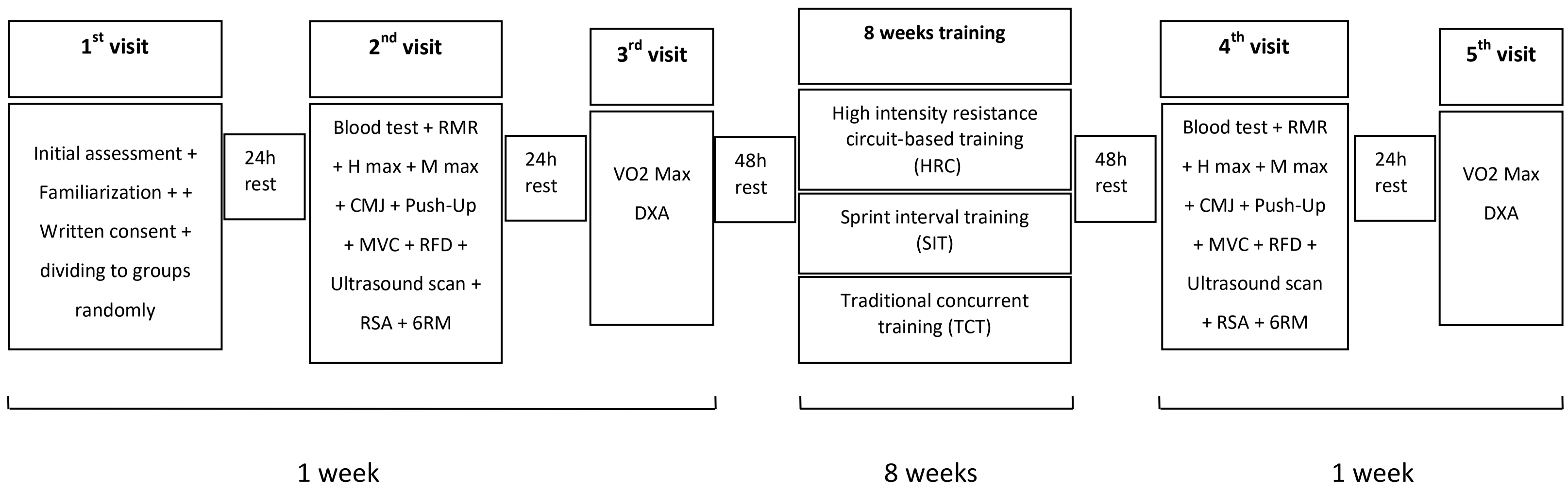


Figure 12. Research design.

RMR = resting metabolic rate, H max = maximum amplitude Hoffman reflex, M max = maximum amplitude of M wave, MVC = maximum voluntary contraction, RFD = rate of force development, CMJ = counter movement jump, RSA = repeated sprint ability, RM = repetition maximum, VO_2 Max = maximum oxygen consumption, DXA = Dual-energy X-ray absorptiometry.

Measured variables

Three levels of the independent variable were raised: HRC, SIT, and TCT. The purpose of the applied experimental method is to establish the cause-effect relationships of independent variables on analyzed dependent variables, which are:

Neuromuscular variables: H max, M max, H max M max ratio, MVC, RFD (RFD 50ms, 200ms), RFD peak, EMG (EMG 50, EMG 200), EMG peak, EMG mean.

Metabolic variables: Erythrocyte (x10^6/mmc), hemoglobin (gr/100), hematocrit (%), basal glycemic (mg/dl), total cholesterol (mg/dl), triglycerides (mg/dl), cholesterol High-density lipoprotein (HDL - mg/dl), cholesterol LDL (and Low-density lipoprotein - mg/dl)

Unites: International unit per liter (IU/L), Milligrams per decilitre (mg/dL)

Cardiorespiratory variables: maximum heart rate (MHR), maximum velocity, maximum oxygen uptake (VO2 max), maximum oxygen uptake reserve (Max VO_2R), maximum time, respiratory exchange ratio (RER), oxygen uptake (VO_2), oxygen uptake reserve (VO_2R), efficiency.

Structural variables:

Body composition: Body Fat %, Total Fat Mass, Lean Mass (g), Fat Mass (g), Bone Mineral Content (BMC g), Bone Mineral Density (BMD).

Muscle architecture: Fibre longitude, pennation angle, muscle thickness of proximal, medial, and distal regions measurement of vastus lateralis.

Mechanical variables: Height of Counter Movement Jump (CMJ), Maximum potential of CMJ (Pmax_CMJ), Maximum force of push-ups (Fmax_Pushup), power decrement (PDec), 6RM (bench press, leg extension, lat pull-down, deadlift, biceps curl, ankle extension), and Body weight.

In order to maintain constant factors that could affect the dependent variables were established the following control variables: were extra strenuous physical activities, extra supplements habits, and assistance. (Advised to avoid strenuous strength exercise program a part from the intervention, they were not allowed to take any supplements during the intervention time, once enter to the investigation he has to complete 100% of compliance rate if in case anyone does not complete then exclude from the data analysis.)

Subject:

The sample consisted of healthy subjects within the city of Murcia, Spain. The participants voluntarily participated in the investigation. All subjects were randomly divided into three different groups and each group corresponded to a different type of training like HRC, SIT, and lastly TCT groups. All interested recreationally trained healthy male subjects who are between 18 to 50 years old were invited to the high-performance sports centre (CIARD-UCAM)

where they were informed (verbally and in different written formats) of the activities to be carried out, the characteristics of training protocols, side effects of the test, benefits of training and possible lesions, and the responsibility of investigators. In addition, they were clear that at any time they could leave the study, if they wished, without having to give any kind of justification and without causing any harm to his person. After the explanation, they completed an informed consent form (Annex 2) that was signed by all participants before they begin. It details that the study was carried out in accordance with the Helsinki Declare, and all the ethical aspects required by the research ethics committee of the Catholic University of Murcia had been taken into account to accomplish the study.

After signing the informed consent, it was opened a file for each person who included all details of the subjects regarding the appointment time, measure variables, physical status, and nutrition status at the very first electrocardiogram of all participants was done and read by a qualified medical doctor. Therefore according to the medical doctors' advice participants just allow entering to the investigation.

5.2. Instrument

The Catholic University of Murcia is administrating High-performance Sports Centre (CIARD- (Centro de Investigaciones de Alto Rendimento Deportivo) and Sports Centre which is functioning independently. However, all laboratory evaluations were conducted in the biomechanical laboratory which belongs to high performance sports centre except for blood analysis and all training sessions with different types of intervention, as well as some of the measurement, was conducted in the sports centre by using the same equipment and indoor track.

In addition, the laboratory belongs to the faculty of nutrition and infirmary of UCAM, where it drew blood, centrifuged it, and froze it at -80oC. Furthermore, the analysis of skeletal muscle oxidative capacity was conducted at the Virgen del Valle Hospital (Toledo). Therefore, for the proper data collection and intervention were disposed of the material listed below (Table 02):

Table 2. Testing equipment list

No	Material	Availability
1.	Force plate tri-axes (Kistler, Switzerland)	Biomechanics Laboratory, CIARD - UCAM
2.	Photocell (Witty, Microgate, Italy)	
3.	Biodex System 3 chair (Biodex Medical Systems, Shirley, NY, USA),	
4.	Gas analyser	
5.	Treadmill ergometer	
6.	Isoinertial rotary Encoder	
7.	Electrocardiograph Ergometry	
8.	Dual energy X ray absorptiometry (XR-46, Norland Corp., Fort Atkinson, WI, USA)	
9.	Ultrasound scanner (Edan dus 60, Shangai International Holding Corp. Hamburg, Germany)	
10.	D360 8-Channel Amplifier Digitimer	
11.	Direct current stimulator for the neurophysiological evaluation (Digitimer, model	

	DS7A, Garden City, UK)	
12.	MR 3.4 Noraxon software	
13.	Centrifuge for biological samples (Material removal-conservation)	Faculty of Science and health, UCAM
14.	Freezer - 80^0	
15.	Flow of cytometry	Hospital virgen del valle, Toledo
16.	Ergometry (Technogym selection 900, Eleiko disc and bar, biceps curl cable machine, body-solid seated calf raise machine) and indoor track.	Sports centre

5.3. Method and Procedure

Prior to data collection and the start of the training program, all participants carried out a familiarization session with the evaluation protocols. Later, they were informed about the guidelines that all of them should follow before and during evaluations, on the other hand, they were informed to wear comfortable footwear, not to drink supplement beverages, and avoid conducting intense physical activities before 48 hours of the evaluations.

All measurements were conducted in the High-performance sports centre – UCAM, except for blood analysis, but the blood sample collections also were done at the same place as well as the rest of them. It was a complete place where the necessary instruments were located in the proper place with space and the right environment to perform the tests.

Hence, both the initial and final assessments were made by the same research investigator with help of assistants. Each research investigator was responsible for a particular test, explaining the way of realizing the test and how to assist the participant to conduct the test smoothly, making a practical demonstration (if necessary), and collecting the data. Furthermore, they had previously been instructed in the use and calibration of the measuring instruments to be used during the testing time. They all are well prepared research investigators who have at least 5 years of experience in the particular measurement field. The experimental test and exercise procedure were strictly administered and standardized in terms of administration, organization, and implementation conditions using workloads of mainly cardiorespiratory endurance, muscular strength exercises and neuromuscular assessment, and other tests. All pre and post-tests were carried out by the same investigator in the same format and they did not know which group the participants belonged to.

5.4. Independent variables

The training sessions were conducted during the eight weeks. All participants in three training groups had to train twice per week according to the time possible, but at least 48 hours of rest period between two training sessions were required. On the other hand, the training sessions were held at UCAM sports center, Murcia. The equipment for training sessions used the Technogym model (TGYM, Italy).

All three training programs realized an undulating periodization; the strength part of TCT and HRC worked with 6RM (intensity has been changed by weekly) and realized the same exercises, while SIT training protocol used 20 m running with the subject's maximal effort. Each treatment group had its own training protocol and all subjects were supervised by an experienced instructor to ensure that volitional fatigue was achieved safely and rest periods were strictly controlled. The training program performed over the course of the 8 weeks of the intervention consisted of two training sessions per week, separated by at least 48 hours, which were completed by each participant. Exclusively all subjects were informed to avoid any other strenuous exercise or supplements as well as to maintain their normal daily routines and eating habits.

The warm-up session consisted of two blocks: general and specific warm-up. The general warm-up consisted of 5 min of submaximal running on the treadmill at 8.5 km/h, then stretching and mobility exercise of all major muscle groups was conducted before the workout. The general warm-up was equal for all training groups (i.e: HRC, SIT, and TCT). But specific warm-up of HRC and TCT has differed from SIT training group. The specific warm-up of HRC and TCT consisted of two steps, 1st step was to conduct the 10 repetitions of 50% from their 6RM of all 6 exercises and the 2nd step is measure the 6RM with the purpose of adjusting the training load in case they changed their 6 RM. Subsequently, subjects rested for 3 minutes prior to starting the particular training session. The 6RM load was adjusted for the later training sessions; if the subject performed ±1 or ±2 reps approximately 2.5% or 5% of the training load was adjusted (518). The special warm-up was conducted on the 20-m track with different numbers of attempts of sprints, which consisted of the normal run, fast run, run fast and change the direction followed by a slow run, and finally fast run and change the direction followed by a fast run-up to the original position.

5.4.1. High-intensity resistance circuit-based (HRC) training:

HRC training (112 - 113) protocol was consisting two blocks, which contained three exercises in each block. The 1st block was composed of bench press, leg extension, and lat pull-down exercises while the 2nd block was comprised of the deadlift, biceps curl, and ankle extension (calf raise). There were 5 minutes of rest between two blocks, and between each set, there were 3 minutes of rest (Figure 13). Lastly, six repetitions of each exercise interspersed with 35s rest which allowed sufficient time for the subject to shift from one exercise to the next. The eccentric and concentric exercising velocity ratio was 3:1and within 8 weeks training load was undulated (Table 03).

Table 3. Distribution of the training load

Weeks	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Series	2	3	3	2	3	3	4	2
Load (6RM)	90%	95%	100%	100%	100%	100%	100%	100%

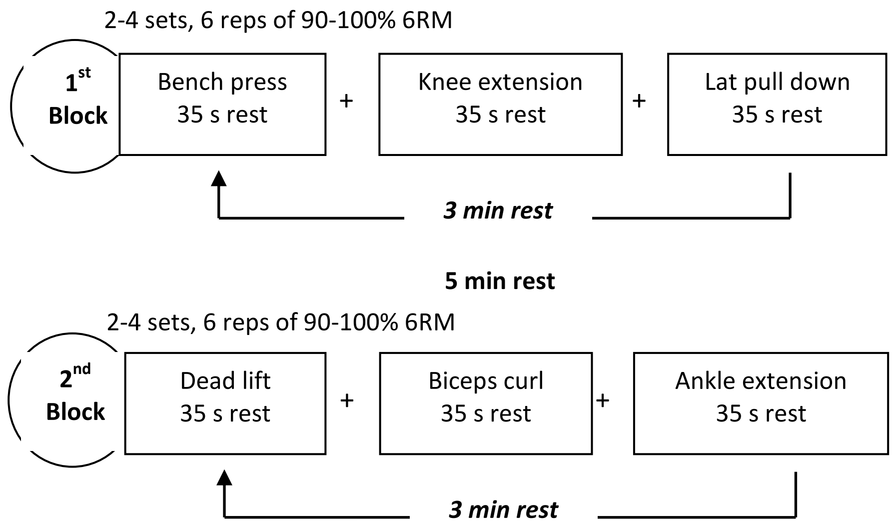


Figure 13. High-intensity resistance circuit training (HRC) protocol

5.4.2. Sprint interval training (SIT):

Training for the sprint interval group consisted of two blocks. Each block involved six repeated 20-m of running in track with 100% of maximum velocity to obtain VO_2 max. Each repetition is interspersed by 15 seconds of recovery and followed by 3 minutes of rest between each set. A 5 minutes rest period is allowed between two blocks (Figure 14). The set was undulating for 8 weeks, and to define the number of sets per block, the total sets were divided by two. In the case of fractions, the entire set was allocated to the 1st block. Subjects were encouraged to achieve 100% of their VO_2 max during the active recovery time and the movement of executing the repetitions. The special warm-up was conducted on the 20-m track with different numbers of attempts of sprints, which consisted of the normal run, fast run, run fast and change the direction followed by a slow run, and finally fast run and change the direction followed by a fast run-up to the original position.

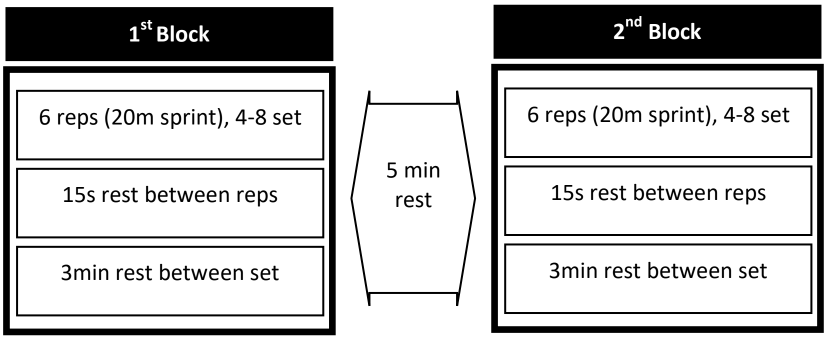


Figure 14. Sprint interval training

Table 4. Distribution of the training load

Weeks	1	2	3	4	5	6	7	8
Series	4	5	6	4	6	6	8	4
Reps	6	6	6	6	6	6	6	6

5.4.3. Traditional concurrent training (TCT):

Traditional Concurrent Training (TCT): TCT consisted of two blocks of strength training and 15 to 25 min of endurance training in which the endurance part was realized on the treadmill. The strength training contained the same two blocks and the exercises used for HRC training, but the recovery period between repetitions was different. There were 3 and 5 minutes of passive rests between two sets and two blocks respectively (Figure 4).

The heart rate of the subject was maintained at a pre-decided value according to the percentage of ventilation threshold two (VT2) throughout the endurance training session. General and specific warm-ups were the same as the HRC training group and the training sequence was strength training followed by endurance training. Both types of training load were undulated for 16 sessions of 8 weeks. The eccentric phase of each exercise was performed for approximately 3 seconds, whereas the concentric phase was performed at maximum velocity. This sequence was standardized in the first week of the training and eccentric phase duration was regularly timed as feedback from the subjects. The subjects were supervised by an experienced instructor to ensure that the volitional fatigue was safely achieved, and the rest was strictly controlled.

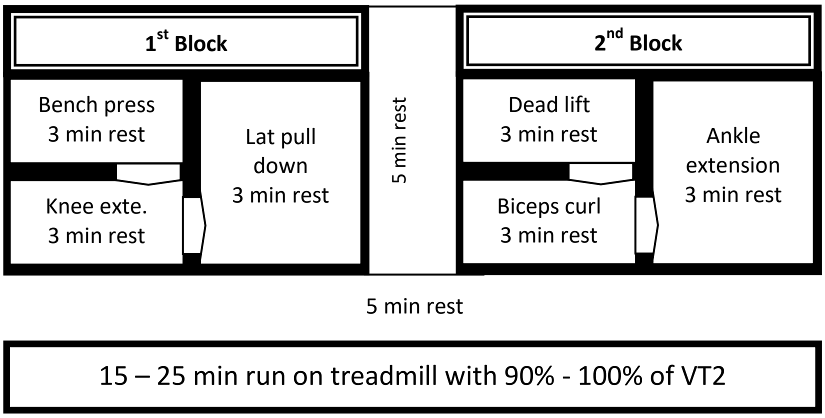


Figure 15. Traditional concurrent training

Table 5. Distribution of the endurance training load

Weeks	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Series	2	3	3	2	3	3	4	2
Load (6RM)	90%	95%	100%	100%	100%	100%	100%	100%

Table 05 A: Distribution of the strength training load

Weeks	1	2	3	4	5	6	7	8
Series	15 min	15 min	20 min	15 min	20 min	20 min	25 min	15 min
Intensity	90%	95%	VT2	VT2	VT2	VT2	VT2	VT2

5.5. Dependent variables:

5.5.1. Neuromuscular assessment:

5.5.1.1. H-reflex test:

It is also known as Hoffman's Reflex, which is the electrical correspondent of the monosynaptic stretch reflex and assessing the response using electromyography. Usually, it is provoked by giving electrical stimulation to the muscle fibre (Ia afferent) of the posterior tibial or median nerve. The electrical stimulation which is applied externally travels along sensory fibres (Ia afferent) by crossing the dorsal root of the ganglion, and finally, it is transmitted to the muscle fibre to produce movements through the alpha motor axon after crossing the central synapse and the anterior horn of spinal cord.

Therefore, it is important to measure the athlete's reflex in order to increase the athlete's performance. Hence, the following variables were measured during the study: H max, M max, H max M max ratio, MVC, RFD (RFD 50ms, 200ms), RFD peak, EMG (EMG 50, EMG 200), EMG peak, EMG mean.

Instrument for realizing H-reflex test

To measure the spinal α-motoneuron excitability (H-reflex) and the motor response (M-wave) used electrical constant-current stimulator (Digitimer model DS7A, Garden City, UK), EMG electrodes, EMG mobile receiving sensors (Noraxon INC, Scottsdale, AZ, USA) and Biodex System 3 chair (Biodex Medical Systems, Shirley, NY, USA). In addition, the MR 3.4 Noraxon software was used to measure the neuromuscular parameters.

Testing Protocol

Spinl α-motoneuron excitability (H-reflex) and the motor response (M-wave) were measured from the soleus muscle of the right leg of each subject in the rest position. It is composed of two main steps: preparation of the subject and taking the measurements. In the preparation part, the subject was measured the 1/3 distal part of the length between the medial malleolus and the medial epicondyle of the tibia (Figure 21 A, B), then the previously measured place was cleaned with an alcohol gauze, and remove the dead skin. Then the two electrodes of electromyography (EMG) and two EMG mobile receiving sensors (Noraxon INC, Scottsdale, AZ, USA) were set following the SENIAM recommendations and guidelines (Maximum distance between two electrodes not higher than 20 mm) ((519). Then the Subject was seated securely on a Biodex System 3 chair (Biodex Medical Systems, Shirley, NY, USA) setting their right foot on a 30º plantar flexion position (Hugon, 1973). The MR 3.4 Noraxon software was used to measure the neuromuscular parameters such as the H reflex and M wave.

As the measurements of soleus H-reflex and M-wave were obtained by posterior tibial nerve stimulation with the motor point electrode (the cathode) located in the popliteal fossa, while the anode was placed over the patella. By stimulating the posterior tibial nerve, using an electrical constant-current stimulator (Digitimer model DS7A, Garden City, UK) determined the M-wave and H-reflex recruitment curves. To define the optimal stimulation point of H max and M max were using various test stimuli, hence used a stimulus which was gradually increased the intensity (0.5 mA, every 2-5 seconds) to find the greatest point of 'Ia afferent' recruitment (H-reflex). To obtain the M-wave or the greatest point of efferent recruitment curve (maximum direct muscle response), the intensity was progressively increased at intervals of 1 mA and further increases in intensity did not produce increments in M-wave amplitude. Through the unrectified EMG signals were obtained the highest peak-to-peak amplitude for the H max (H reflex) and M max (M-wave). Then, the maximal H-reflex was normalized to the corresponding maximal M-wave (Hmax/Mmax ratio).

5.5.1.2. MVC test:

It was conducted subsequently to the CMJ and push-up test (Figure 21 and 22), hence they have completed the warm-up previously. The preparation was done at the same time as when prepared for the H- reflex and M wave. Two EMG electrodes and EMG mobile receiving sensor were located on the vastus lateralis. According to SENIAM guidelines, two electrodes were placed 20 mm apart on the 1/3 distal part of the line between the anterior superior iliac spine and the lateral part of the patella bone (Figure 16 C, D) at the same preparation time done for H-reflex test. The subject was sitting on the Biodex System 3 chair with the legs flexed at 90º position and fully strapped their upper limb to the Biodex chair and above the two malleoli of the right ankle directly with a load cell (SML500, Interface Scottsdale, AZ, USA) (Figure 16 E).

The specific warm-up consisted of two submaximal isometric knee extensions for 5 seconds, with their arms crossed on the chest. Three different trials were conducted given by three minutes of rest between each of them. They were encouraged verbally with the purpose of assessing their maximum effort and also were instructed to conduct the movement with as much force and fast as possible to determine their MVC and rate of force development. Between three trials of MVC, the highest trial of MVC was used for analysis.

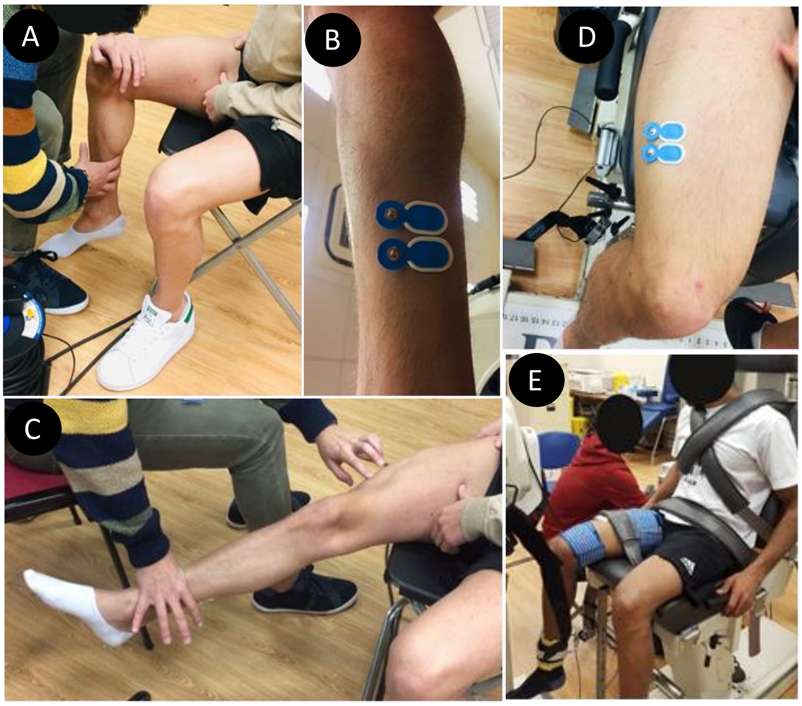


Figure 16. Prior preparation of individual for neuromuscular test

5.5.1.3. Rate of force development (RFD) measurement:

RFD was assessed during the isometric contractions of the knee extensors, following the recommendations by Maffiuletti et al. (299). Subjects were instructed to apply "as much force as possible, as fast as possible" and were verbally encouraged to ensure a maximal explosive effort. Previous literature on the methodological considerations for the assessment of RFD stated that trials used to measure MVC force should be separated from those used to measure RFD (299). In this regard, even though RFD was assessed in the same contractions used to measure MVC, the RFD data used for analysis consisted of the average of the highest value obtained in each trial performed (i.e., even in the trials that did not coincide with the contraction in which the greater MVC value was obtained). The onset of contraction of each repetition was identified manually from the data extracted from the MR 3.4 Noraxon software, using a customized spreadsheet. To maximize the reliability of manual onset detection, a systematic approach that identified and considered "the last through before force deflects above the range of the baseline noise" was used (299).

5.5.2. Metabolic variables:

5.5.2.1. Blood test:

Before the RMR test, blood extraction was performed while the subject was seated. A portion of each blood sample (3 mL) was introduced into a tube with Ethylenediamine Tetraacetic Acid (EDTA) to determine haemoglobin concentration and hematocrit and erythrocytes count using a hematology analyzer (Sysmex XS-1000i, Kobe, Kansai, Japan) by an experienced nurse.

5.5.3. Cardio respiratory variables:

5.5.3.1. VO_2 max test:

It is also known as maximal oxygen uptake. Basically, it measures the maximum amount of oxygen an individual can utilize during intense exercise. In addition, it is one of the gold standard tests which are able to determine the cardiovascular fitness and performance capacity of athletes. Otherwise, it is given the numerical measurement of the body's ability to consume oxygen, indeed by calculating the ventilation, concentration of oxygen, and carbon dioxide of the inhaled and exhaled air.

Hence, the following variables are discussed during the study in order to analyze the cardiovascular fitness and performance of each subject and their training method: MHR, maximum velocity, VO_2 max, Max VO_2R, and maximum time.

Instrument for realize the VO_2 max test:

The VO_2 max test using a treadmill (Run Med Technogym, Cessena, Italy), which was programmed with special soft wear in a real-time show all details. As well as the subject was wearing a mask that is connected to a gas analyzer machine. A Polar RS800CX heart rate monitor (Polar Electro, Kempele, Finland) also were placed on the chest to measure the heart rate.

VO_2 max test testing protocol:

The test was programmed to function automatically after being given the start by the research investigator. It was programmed to five levels. Whereas at the 1st level subject walks or runs on the treadmill at 4.5 Km/h for 3 minutes, and continues it with another three minutes running on the treadmill at 8 Km/h, then it will keep increasing the speed to 10 Km/h which is subject must increase the running speed on the treadmill, then after again the speed increase to 12 Km/h during three more minutes. Subsequently, as the last level again the work rate was increased by 1 km/h every minute in a progressive manner until exhaustion to obtain the value of maximum oxygen consumption (VO_2 max) (Figure 17). The corresponding heart rate was also determined by a Polar RS800CX heart rate monitor (Polar Electro, Kempele, Finland). Verbal encouragement was given to ensure maximum physical effort.

The subject would be prepared with a face mask that is linked with a gas analyzer machine which analyzes respiratory rate and volume together with O_2 concentration and CO_2 in inhaled and exhaled air. Therefore, every subject was informed not to talk during the test, instead of talking they were informed to raise their hand to aware the research investigator of any incidence, as well as if the subject needed to stop the test due to fatigue or any other matter was used the same action. Finally, the test was concluded according to traditional physiological criteria, such as the occurrence of a plateau despite an increase in speed; elevated respiratory exchange ratio ($r \geq 1.0$); elevated heart rate (≥90% of [220-age]); and maximal perceived exertion.

Inflection points over time were used to determine thresholds of the ventilatory equivalent (VE) of carbon dioxide (VE/VCO_2), the ventilatory equivalent of oxygen (VE/ VO_2), and the VE. The second increase in VE with a concomitant rapid increase in VE/VO_2 and VE/VCO_2 was defined as VT2. Specially all subjects were informed not to ingest caffeine for four hours before the test, to ingest a light meal two hours before, and to avoid intense physical efforts the day before.

Figure 17. VO_2max test

5.5.3.2. RMR test

The individual should arrive after a 12-hour fast for the best RMR test results. It is advised that the subject arrive calm in mind and well rested because the purpose of this test is to determine the individual's resting metabolic rate. Athlete orientation for the exam will begin when they arrive. The athlete will breathe in unmodified room air while being monitored by a metabolic cart as he exhales through an expiratory tube attached to a facemask. After the apparatus is in place, the subject will lie down, and over the next 20 minutes, a program running on the connected computer will record his heart rate, respiratory exchange ratio, the volume of oxygen consumption, and volume of carbon dioxide production. It is advised that athlete keep their eyes closed during the test and maintain calm while trying not to sleep off, as this will affect the result. Calculations will utilize the average of the five minutes of testing that were the most consistent.

5.5.4. Structural variables

5.5.4.1. Body composition:

The analysis of body composition deals with the quantification of the body components, the quantitative relationships between the components, and the quantitative changes in them. On the other hand, it is used to describe the percentages of fat, bone, water, and muscle mass in human bodies. Therefore body composition is one of the main fitness components that many athletes need to maintain for their success in many sports, as well as it is a crucial factor to maintain or enhance body composition for healthy life and clinical purpose.

For many athletes as well as normal people, this is an area that they worry about and concentrate on to reach an optimal level of their body component for their success in sports and day to day life. Subsequently, many training methods or exercise programs are specially available to modify body composition in some way. Physical activity and systematic training can be very effective in altering muscle and fat distribution and amount within the body, whereas significantly affect sporting performance.

To carry out a proper analysis of the body composition determined following components during the study:

Body weight: it refers to a person's mass or weight. Body weight is measured in kilograms (Kg).

Body fat percentage (%): is the total mass of fat divided by total body mass, and multiplied by 100; generally body fat includes essential body fat and storage body fat.

Lean mass (g): Lean Mass is overall body mass after Fat Mass has been subtracted (Lean mass = Total weight – Fat mass). It contains bone, organs, the brain, water, and contractile muscle. Generally, the changes in the first three components do not occur often; changes in lean mass are assumed to either be muscle tissue, glycogen (energy storage), or water.

Fat mass (g): the portion of the human body which is composed strictly of fat, on the other hand as opposed to fat-free mass. It represents grams.

Bone mineral content (BMC g): a measurement of bone mineral found in all body, it represents the total bone content of each participant, interpreted by grams (g).

Bone mineral density (BMD): it represents the amount of bone mineral in the bones of each participant.

Overview of Dual Energy X-Ray Absorptiometry

Competitive successes in a range of sports have been influenced by the physique traits of the athlete. In athletic settings, several situations occur during the training measurement of body composition may be of importance to define the athlete's performance. Therefore nowadays a Dual-energy X-ray absorptiometry (DEXA or DXA) scan will be used to assess overall skeletal changes that often occur in the athlete's body.

Mostly DXA is used to assess overall skeletal changes that often occur with age, by measuring BMC and BMD. It is one of the body fat testing methods that have been scientifically validated and thus, is considered a "gold standard" test. Two X-ray beams with different energy levels are aimed at the subject's bones. When soft tissue absorption is subtracted, the BMD can be determined from the absorption of each beam by bone. Hence, it is the most widely used and most thoroughly studied bone density measurement technology.

During the past years, DXA has become widely accepted due to the availability of measuring the body composition of the whole body. DXA provides a rapid and easy technique to estimate fat and lean mass plus BMC for the total body. And even it allows us to measure the above-mentioned compositions in the regions of the body such as the left and right sides of arms, legs, trunk...etc. according to the interest of the person.

In a real scenario, to complete the test will be taken at least 10 to 15 minutes while the machine slowly moves from head to toe, covering the whole body of the subject, when the subject lay down on a machine with feet together and arms by the athlete side (Figure 18). It could be heard the machine "clicking" as the little ray goes back and forth across every inch of the body. The athlete doesn't feel anything either hurt or sting. The athlete doesn't need to wear any protective garments, as it's not a dangerous scan. It measures everything, bone mass, muscle mass, fat mass, and height. Moreover, it measures the weight of the head, torso/truck, and each of the legs and arms. A DXA scan will describe how dense the bones are. In fact, a DEXA scan interprets how much visceral fat and subcutaneous fat have.

DXA instrument

All measurements of body composition mentioned before were assessed from a whole-body scan and analysis performed by using the DXA machine (XR-46, Norland Corp., Fort Atkinson, WI, USA). The DXA was calibrated with phantoms as per the manufacturer's guidelines before assessment.

Figure 18. Dual energy X-Ray absorptiometry scan test

Standardized operational protocol of DXA

Before undertaking this study, have been developed and pilot-tested a protocol for undertaking whole-body scans, which was given an emphasis on consistency in the positioning of subjects on the scanning area of the DXA instrument. All DXA scans should be done and analyzed by a well-trained technician who has the special authority to conduct the test. The technician might inform all athletes to might remove all metallic items, pieces of jewelry, or any other external items before entering the DXA machine. After setting up the machine by entering the all necessary data into the computer, let to athlete lay down on a machine in a mid-prone position with a standardized gap (3 cm) between the palms and trunk. It is crucial to be aligned centrally in the scanning area. Between feet and scan might keep the 15 cm of the constant distance of each scan. It is most important to inform the athlete to avoid unnecessary movements during the test and before the start, the test technician should verify again the position of the athlete. The scans were analyzed automatically by following the data inserted by the technician according to the interest of the researcher. After the scan is completed, in computer screen shows the skeletal features of the athlete appear. View the scanned image to determine if the quality of the scan is satisfactory. The scan may be repeated once under certain circumstances if the athlete agrees.

5.5.4.2. Muscle Architecture Data Collection.

To collect the data regarding the muscle architecture of subjects, ultrasound scan test were used. It is a medical test that uses high-frequency sound waves to detect live images from the inside of particular person. It is also called as sonography and through this could be able to collect current and accurate information of the subjects. To measure the muscle architecture of the participants following variables were measured in at proximal, medial and distal of three places in the same muscle (i.e. vastus lateralis): fibre longitude, pennation angle and muscle thickness.

Instrument to realize ultrasound scan test

A real-time B-mode computerized ultrasound system (Edan dus 60, Shangai International Holding Corp. Hamburg, Germany) with a linear array probe of 7.5–12 MHz wave frequency was used to record longitudinal ultrasonic images. Water gel was applied to the probe to avoid the negative effects of muscle deformation. As well as a marker pen and measurement tape (Figure 19).

Figure 19. Equipment's of ultrasound scan

Testing protocol:

Firstly subjects were prepared in order to measure the above-mentioned variables of the vastus lateralis (VL) muscle of the right leg of each subject in a rest position. It was two main steps: preparation of the subject and then taking the measurements. In the preparation part, the length of the VL muscle of the right leg was measured (from the greater trochanter to the lateral epicondyle of the femur) of each subject and it was divided into three to define distal, medial, and proximal parts of the VL muscle. Then, each part is measured and calculated.

A real-time B-mode computerized ultrasound system (Edan dus 60, Shangai International Holding Corp. Hamburg, Germany) with a linear array probe of 7.5–12 MHz wave frequency was used to record longitudinal ultrasonic images from three different parts of the VL of the right leg. To obtain the sonography, subjects lay supine with legs and muscles relaxed. To aid acoustic contact and remove the need to directly touch the skin, eliminating the deformation of the muscle, a water gel was applied to the probe, positioned parallel to the muscle fascicles and perpendicular to the skin. The assessment was performed by the experienced examiner in muscle ultrasound and the same examiner conducted both pre and post-tests. According to the previous recommendations (521), all frames were obtained at proximal, medial, and distal sites on VL. Analysis was done by using 1 best frame of each part of the muscle and analyzing images using image J java 8 programs to determine fibre longitude, pennation angle, and muscle thickness quantitatively (Figure 20).

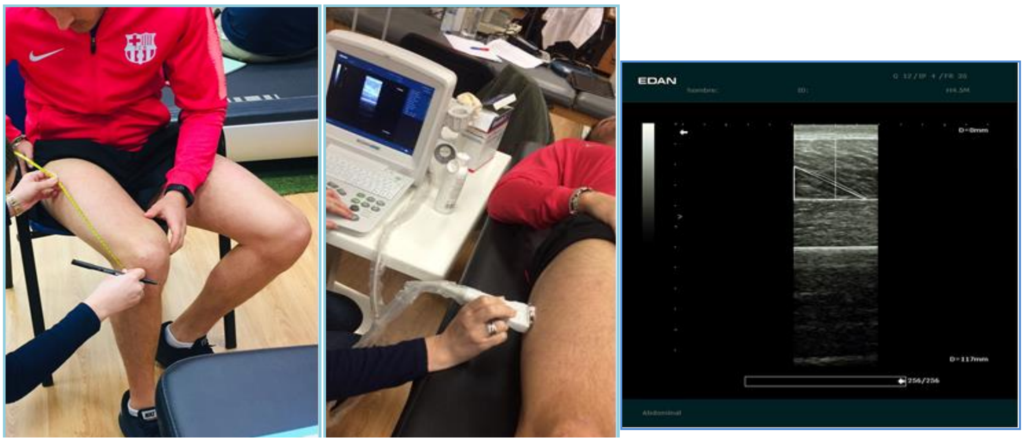


Figure 20. Execution of ultrasound scan test

5.5.5. Mechanical variables*:*

To measure the variety of mechanical variables were applied a different kinds of instruments and methods. Subsequently explain the testing method, the instrument used, and their protocol.

5.5.5.1. Power and force measurements:

To measure the power and force of recreationally trained healthy male participants used force plates. The force plate is useful and modern high-technological equipment which mostly used to measure the kinetic characteristics of an athlete's movement. It provides information about external forces and power involved in a particular movement. Sports scientists or coaches and even athletes could be used that information to evaluate the excursion of the skills of athletes quantitatively with the purpose of physical development.

For the following investigation to measure the athlete's lower and upper body maximum potential we used a tri-axes force plate with CMJ and push-up test. The CMJ and push-ups are a simple, practical, valid, and very reliable measure of lower-body and upper-body power. As a consequence, it has become a cornerstone test for many strength and conditioning coaches and sports scientists. Specially the CMJ test when compared with other jumping tests was shown the most reliable measure of lower body power. Moreover, it has been shown to have a relationship between CMJ and the 1 RM maximal strength test, as well as the explosive strength test. This suggests that performances in the CMJ are linked with maximal strength, maximal speed, and explosive strength.

Even though there are plenty of other materials which can provide a valid and reliable measure of CMJ and push-up performance, force platforms are considered the gold-standard test. Therefore, following CMJ and Push-up test we measured the following variables of athletes during the study: Height of CMJ, Maximum potential of CMJ, and Maximum force of push-ups.

Instrument for realizing Countermovement Jump (CMJ) and Push-up

To measure the maximum force and potential have been used the Kistler 9286 BA (Switzerland), Connection cable Type 1760A, DAQ system (USB 2.0) Type 5691A1, and a computer with BioWare version 5.2.02. BioWare software is the engine behind the force plate system. It collects data from the force plates and converts the trials into useful information and later plots the results. The force plates and charge amplifiers are completely remote-controlled by BioWare thus making the system extremely flexible and easy to use.

Testing Protocol

Before the assessment, each athlete performed a warm-up in the gym consisting of 10 minutes of ergo metric cycling at 75 W, mobility exercises specially legs, arms, and hip, then continue with bench press with 22kg two times and followed by standard stretching exercises. One of the most important factors was when the test is performed as well as other fitness tests; it was used in consistent environmental settings at all times. Thus, it was not affected by no any other factors like weather or surface…etc.

In the present investigation have was applied CMJ without an arm swing (keep tightly their both hands on the hip level) throughout the test. Then with the test administers signal subject just enters the force plate and stays straight legs. Later respect to the administer signal perform a vertical jump by making an impulse of getting down to the 90 degrees of knee angle. This 90 degree knee angle depends on the athlete's desire because some athletes make a maximal height of jump without making the 90 degree angle. But anyway some literature says 90 degrees (Figure 21). One of the crucial key mechanisms of the test is to maintain all athletes always take off and land in the same position in the force plate. Besides bending the knees in the air when performing the vertical jump can affect the real information by increasing the flight time. Otherwise, some athletes just tend to hit hard feet on the force plate when landing. It also facilitates to make of wrong results due to unnecessary movements.

Figure 21. Executing countermovement jump (CMJ)

The same protocol of CMJ was applied to the push-up test (Figure 22). Previously the familiarization session also explained how to localize the hands-on force plate. According to the administers signal subject just positioned his hands on the force plate and subsequently in order to the administers signal performed a push-up in form of a vertical jump making an impulse against the force plate and landed absorbing the upper body weight by bending the arms at 90 degrees or more but without touching the force plate from the chest. Each athlete had three attempts for CMJ and Push-up test and finally selected the best results of each one for the further process of the analysis.

5.5.5.2. Repeated sprint ability (RSA) test:

The RSA describes the ability of an athlete to reproduce sprints without a significant decrease in sprint speed. On the other hand, it is explained as the capability of an athlete to recover and maintain maximal effort during following sprints; it is well-accepted as an important fitness component, specially in team-sport performance. It literally means that subjects with good RSA would be likely to perform better than subjects who are less able to repeat sprint efforts at a similar intensity. In the present study was applied 20m of RSA test was assessed following variables: power decrement, fatigue Index and lactate.

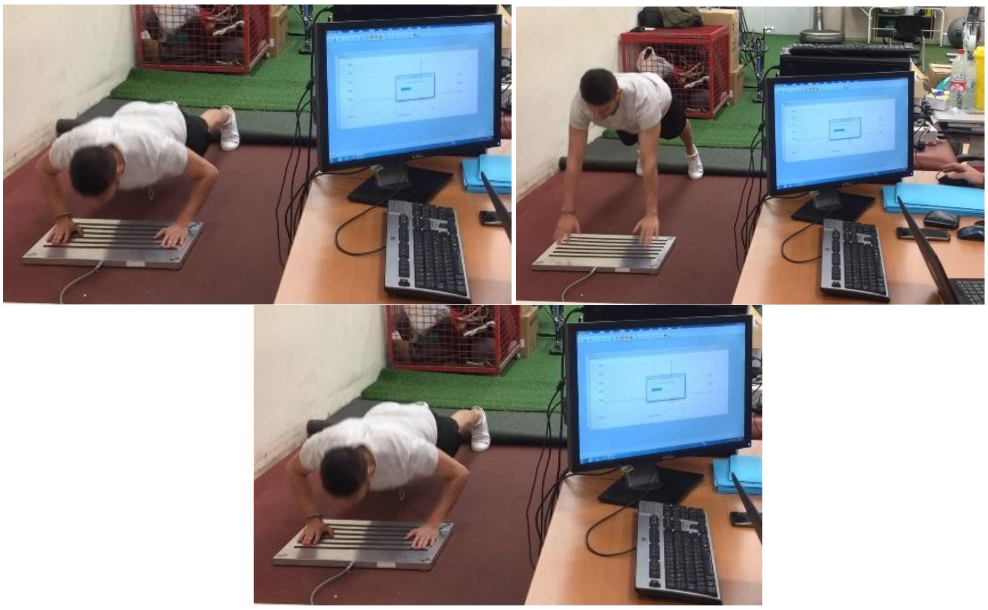


Figure 22. Executing push-up test

Instrument for realizing repeated sprint ability (RSA) test

To conduct the RSA test was used photocell (Witty, Microgate, Italy), due to the integrated transmission system, which has a range of 150 meters, the photocells are highly reliable. Redundant radio transmission ensures that the data acquired is transmitted to the timer with the maximum precision (±0.4 thousandths of a second) even if the signal is disturbed. The Witty timer remotely recognizes the photocell ID number, so the user can easily set the signal type on the photocell: start, stop, and intermediate times. Besides one traffic corn and tape to measure 20 m were used.

Testing protocol

After completion of all laboratory tests RSA test were conducted. It was conducted on an indoor track that had enough space for 20 m of running and recovery, the floor was made of wood, therefore, it was also made a friendly environment for short time high speed sprints events. The RSA test consisted of

10 × 20 m sprints with a 180º turn at the 10 m mark separated by 15 seconds of passive recovery (Figure 23).

Figure 23. Repeated Sprint Ability (RSA) test

The subject started 0.5 m behind the start line, which was marked by a photocell (Witty, Microgate, and Italy). Before starting, the subject was instructed to run as fast as possible to the end of the 20 m course. Before testing, a warm-up consisting of 5 minutes of running at 10 km/h followed by active stretching and three submaximal sprints was performed. Following each sprint, athletes decelerated and walked to the starting line ready for the following sprint.
The 10 sprint time was recorded as the performance of subjects, and later fatigue index was calculated according to the equation proposed by Spencer et al. 2005 where RSA total is the total time of the 10 sprints and RSA best is the best sprint time (Figure 24).

Capillary blood samples for blood lactate concentration analysis were collected from a finger prick 5 minutes after the end of the RSA test and analyzed using a Lactate Pro analyzer (Lactate Pro, Arkay, Inc, Kyoto, Japan).

$$\text{Fatigue Index} = \left(\left(\frac{RSA_{total}}{RSA_{best} \times 10} \right) \times 100 \right) - 100$$

Figure 24. Fatigue index equation

5.5.5.3. Six-Repetition Maximum (6RM) Determination:

Generally, the purpose of the 6RM test is to measure the maximum strength of a particular subject by using different muscles and actions (i.e. chest, biceps, and quadriceps) for this repetition range. It is an alternative to the 1RM test and is considered much safer due to the lighter loads that will be lifted. Therefore, it is also recommended to be used for clinical purposes also due to their safety.

Instrument to realize 6EM test

Technogym selection 900 machines, such as chest press, leg curl, and lat machines were used, as well as for deadlift were used Eleiko disc and bar. Furthermore, the biceps curl cable machine body-solid Seated calf raise machine was used to conduct the calf raise exercise in pre and post-both tests.

Testing protocol

It was conducted after the recovery of the RSA test. The 6RM loads for all exercises of the training program [Bench press, leg extension, lat pull down, deadlift, biceps curl, and ankle extension (calf raise)] were determined according to standard procedures (9) by an experienced instructor with the purpose of evaluate muscular strength. In addition, measured 6RM loads were used as a base of the training protocol. It was determined through the 3 sets of sequences: such as (1) 10 repetitions at 50% of the perceived 6RM following 1 minute of rest, (2) 8 reps at 75% of estimated 6RM, 2 minutes of rest, and (3) 1 set of the exercises to volitional fatigue at 100% of estimated 6RM. If the subject performed ±1 or ±2 reps approximately 2.5% or 5% of the training load was adjusted (518, 521). Within 5 attempts subjects were allowed to take their maximum of 6RM following a maximum of 5 minutes of recovery between attempts and 5 minutes of rest were programmed between exercises. Before the 6 RM test warm-up sessions were conducted, it was considered with the 10 repetitions of 50% from their 6RM of all 6 exercises (Figure 25).

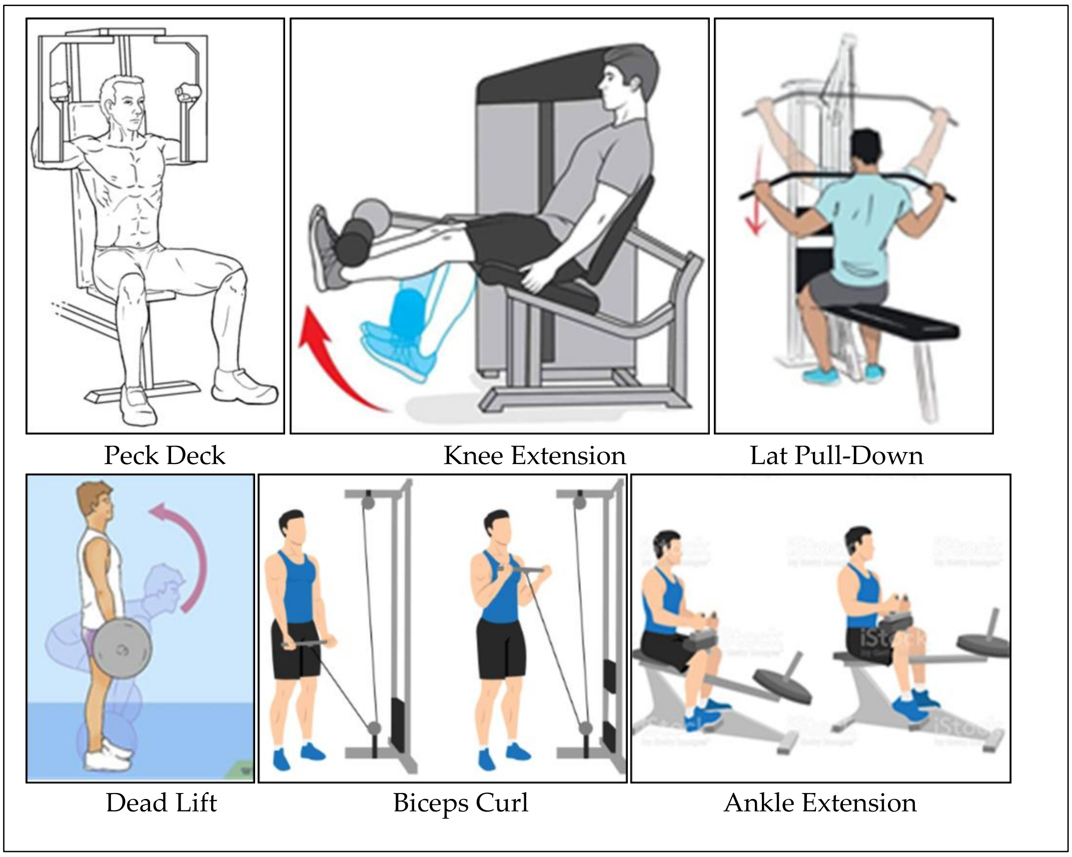


Figure 25. Resistance training and 6 RM test exercise

5.5.6. Data analysis

There were prepared in excel sheets (Excel Office 2010) where registered the obtained all information of every group of the study to proceed later to the statistical analysis. The data analysis was performed with the IBM SPSS version 23 (IBM corp., New York, USA) statistical package for Windows. The descriptive statistical values of the sample were first established, and their values were expressed as mean and standard deviation. Subsequently, the Shapiro - Wilk test was used as the normality test and the Levene test was used to check the homogeneity of variances of the sample. Furthermore, all assumptions were checked before conducting the statistical test.

To analyze significant interaction between-groups and within-subjects factors on dependent variables of all three different concurrent training protocols were used mixed analysis of variance (Mixed ANOVA) was, and as well as to analyze the pairwise comparison of both factors on dependent variable were used Bonferroni posthoc measurements.

For all tests, the level of minimum statistical significance was set to $p < 0.05$.

VI - RESULTS

VI - RESULTS

In this chapter, the results of the experimental study are presented. Accordingly, this chapter is divided into five main sections. The first section presents neuromuscular adaptation (Section 1), the second section presents the metabolic adaptation (Section 2), the third section is about the cardiorespiratory adaptation (Section 3), and the fourth section will present structural (muscle architecture and body composition) adaptations (Section 4), while the other section (5th) presents the results of the mechanical adaptation (Section 5) following three different concurrent training protocols (HRC, SIT, and TCT).

Furthermore, the results of the experimental study are presented under several subsections: neuromuscular, metabolic, cardiorespiratory, structural and mechanical parameters, performance variables, and physical functions, on the other hand, their group*time interaction, main effects analysis, and subgroup analysis with post hoc results were explained.

6.1. Participants

Overall, ninety-one (n = 91) participants volunteered for the study, but after application of the inclusion and exclusion criteria selected forty-five (45) recreationally trained athletes were randomly divided into three (03) different concurrent training protocols allocating fifteen (15) subjects per each training protocol. However, only thirty-four (n = 34) participants have completed the study (HRC = 13, SIT = 10, and TCT = 11) with a 100 % complaints rate, the rest of the others quit the study due to personal issues and their tight academic schedule.

However, the participants were informed about the study procedures, possible risks, and benefits and instructed not to consume caffeine- and alcohol-containing products during the study period. They were also asked to maintain their daily activities and eating habits but avoid vigorous physical activities or training during the study. All of the participants signed an informed consent form. The study was conducted according to the Declaration of Helsinki, and the study was approved by the Ethics committee at the Universidad Católica San Antonio de Murcia Spain Participants' characteristics are shown in Table 8.

Table 6. General characteristics of the participants

Training protocol	N	Age (years)	Height (cm)	Body Mass (kg)	BMI (kg/m2)
HRC	13	23.31± 6.63	172.86± 5.49	70.90 ± 8.80	23.7 ± 1.2
SIT	10	26.20± 6.34	177.92± 7.18	78.03 ± 8.35	24.9 ± 0.5
TCT	11	23.27± 4.38	174.09± 4.18	69.89 ± 7.71	22.8 ± 1.2

Data are expressed as mean ± standard deviation.

Abbreviations: BMI = Body mass index (kg/m2)

6.2. SECTION 01:

6.2.1. Training interventions induced different neuromuscular adaptation.

The neuromuscular variables' responses to training are presented in the table 7 and 8. There were no significant group and time interactions identified for any measured variable.

A significant main time effect was found when assessing the changes in MVC (N) $F (1, 31) = 15.384$, $P < 0.001$ (Table 7A), RFD 50 N·s-1 $F (1, 27) = 8.773$, $P < 0.05$ and RFD 200 N·s-1 $F (1, 27) = 6.775$, $P < 0.05$ (Table 8) from Pre to Post (within-subjects factor). However, according to the Bonferroni post hoc pairwise comparison analysis on MVC (N) following HRC and TCT methods, as well as RFD 50 (N·s-1) following TCT and RFD 200 (N·s-1) following HRC were shown a significant mean difference ($P < 0.05$) between two-time points.

Moreover, there was a significant main effect across the between groups on the M max (mV) $F (2, 31) = 10.778$, $P < 0.05$ (Table 7A), H max (mV) $F (2, 30) = 10.107$, $P < 0.05$ (Table 7) and H/M ratio $F (2, 30) = 3.778$, $P < 0.05$ (Table 7) were detected. In addition, according to the Bonferroni post hoc analysis, there was a significant difference ($P < 0.05$) shown on M max and H max when comparing the HRC training method from the TCT method ($P < 0.05$), and SIT method from the TCT method ($P < 0.05$). Furthermore, after considering all mean differences in M max and H max following three training methods HRC training method was shown a greater mean difference than the other two training methods (Figure 26, 27, 28 and 29). Rest of the other variables, even though their training methods were shown some improvement in a particular variable it was not significant between groups.

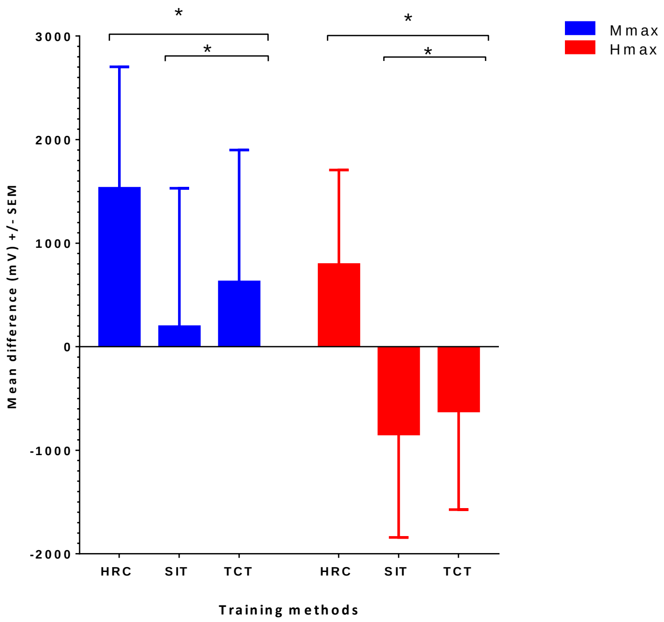


Figure 26. Neuromuscular variables changes (H max/ M max) according to the different training methods (p<0.05*)

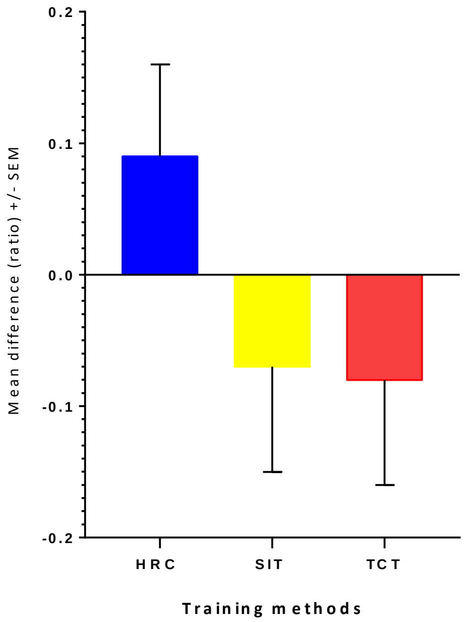


Figure 27. H max: M max ratio changes according to the different training methods (p<0.05*)

Table 7. Neuromuscular results before and after training in all three training groups.

Variable	ANOVA (F, p)						Time effect (Bonferroni)							Group effect (Bonferroni)	
	Time*group effect		Time effect		Group effect			Pre		Post					
	F	*p*	F	*p*	F	*p*	Group	Mean	SD	Mean	SD	*p*	Δ%	Group	*p*
MVC (N)	2.547	0.095	15.384	**0.001***	0.219	0.804	HRC	683.54	173.68	729.41	186.40	**0.013***	6.71	HRC vs SIT	*
							SIT	700.87	115.51	710.65	115.02	0.624	1.40	HRC vs TCT	*
							TCT	637.25	106.97	708.47	97.07	**0.001***	11.18	SIT vs TCT	*
EMG Peak (mV)	0.758	0.478	0.018	0.893	0.802	0.459	HRC	391.11	179.41	398.05	114.10	0.893	1.77	HRC vs SIT	*
							SIT	405.50	157.24	436.31	94.85	0.530	7.60	HRC vs TCT	*
							TCT	490.44	197.56	441.32	120.63	0.297	-10.02	SIT vs TCT	*
EMG mean (mV)	0.552	0.582	0.032	0.860	1.522	0.236	HRC	224.15	98.74	243.76	71.56	0.574	8.75	HRC vs SIT	*
							SIT	258.57	115.60	273.09	66.50	0.660	5.62	HRC vs TCT	*
							TCT	304.97	108.63	280.98	72.85	0.448	-7.87	SIT vs TCT	*
Mmax (mV)	0.305	0.739	1.155	0.291	10.778	**0.001***	HRC	8411	2476	9942	2766	0.201	18.20	HRC vs SIT	*
							SIT	8927	4377	9120	2610	0.886	2.16	HRC vs TCT	**0.037***
							TCT	11954	2500	12580	1690	0.627	5.24	SIT vs TCT	**0.008***
Hmax (mV)	0.897	0.418	0.164	0.689	10.11	**0.001***	HRC	3667	2405	4461	2533	0.391	21.65	HRC vs SIT	1.000
							SIT	5365	3572	4522	2223	0.406	-15.71	HRC vs TCT	**0.005***
							TCT	8911	3844	8290	3058	0.519	-6.97	SIT vs TCT	**0.008***
H/M ratio	1.540	0.231	0.183	0.672	3.778	**0.034***	HRC	0.41	0.21	0.50	0.28	0.240	21.95	HRC vs SIT	*
							SIT	0.61	0.20	0.54	0.28	0.431	-11.48	HRC vs TCT	0.455
							TCT	0.74	0.30	0.66	0.21	0.300	-10.81	SIT vs TCT	0.938

MVC = Maximum voluntary contraction, EMG = Electromyography, M max= Maximum amplitude of M wave, H max= Maximum amplitude of Hoffmen reflex

* The P value is reported as 1.000 according to the way significant figures are calculated in SPSS.

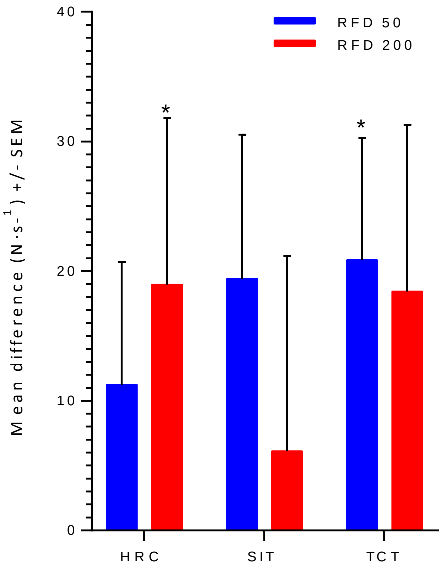


Figure 28. RFD 50 and RFD 200 changes upon different training methods ($p<0.05$*).

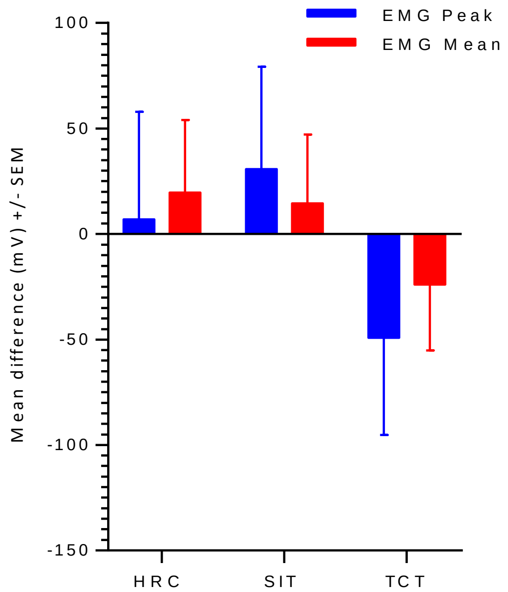


Figure 29. EMG Peak and EMG Mean changes upon different training methods ($p<0.05$*).

Table 8. Neuromuscular results before and after training in all three training groups.

Variable	ANOVA (F, p)							Time effect (Bonferroni)						Group effect (Bonferroni)	
	Time*group effect		Time effect		Group effect			Pre		Post		p		Group	p
	F	p	F	p	F	p	Group	Mean	SD	Mean	SD		Δ%		
RFD 50	0.291	0.750	8.773	**0.006***	0.239	0.168	HRC	86.60	30.83	97.84	28.75	0.245	12.98	HRC vs SIT	0.865
(l Table 8.														HRC vs TCT	*
														SIT vs TCT	0.431
R														HRC vs SIT	*
(N·s^{-1})							SIT	397.90	54.44	403.82	55.16	0.765	1.49	HRC vs TCT	*
							TCT	384.46	66.89	412.25	68.14	0.108	7.23	SIT vs TCT	*
															*
RFD Peak	1.109	0.345	1.249	0.274	0.686	0.512	HRC	1771	613.14	1963	605.31	0.815	10.84	HRC vs SIT	
							SIT	1988	462.76	1892	342.02	0.920	-4.83	HRC vs TCT	0.779
							TCT	1815.72	448.25	3387	4718	0.063	86.54	SIT vs TCT	0.832
EMG 50	1.341	0.277	1.390	0.248	1.916	0.165	HRC	288.16	134.53	277.62	88.67	0.773	-3.66	HRC vs SIT	0.855
(mV)							SIT	253.94	67.85	326.99	84.65	0.064	28.77	HRC vs TCT	0.211
							TCT	348.21	135.58	360.79	130.02	0.731	3.61	SIT vs TCT	*
EMG 200	0.572	0.571	0.004	0.948	2.335	0.115	HRC	244.65	105.33	235.05	78.54	0.801	-3.92	HRC vs SIT	0.314
(mV)							SIT	267.01	94.78	298.01	83.34	0.437	11.61	HRC vs TCT	0.146
							TCT	336.33	172.05	310.60	95.09	0.498	-7.65	SIT vs TCT	*

RFD = Rate of force development, EMG = Electromyography
* The P value is reported as 1.000 according to the way significant figures are calculated in SPSS.

6.3. SECTION 02:

6.3.1. Training interventions induced different metabolic adaptation.

The following tables 9 and 10 represent the metabolic variables after conducting the statistical analysis. It denotes the interaction and main effect between the subject (group) and within-subject factor (time) factors. Further, the Bonferroni post hoc test depicted the comparison between training groups and within-subject for each variable measured during the blood test analysis. Following the statistical result only High-Density Lipoprotein Cholesterol (HDL-C) was shown a significant interaction between the time of measurement and the groups of training methods $F (2, 28) = 6.385$ $P < 0.05$.

Furthermore, there was a significant main effect across the two-time points on Basel blood Sugar (BG) $F (2, 28) = 4.564$ $P < 0.05$. While among all variables HDL-C following SIT training induced a significant difference ($P < 0.05$) between pre and post.

Remarkably, there were non-significant main effects were shown between groups for all variables. Neither, Bonferroni post hoc comparison between groups was shown a significant difference for all variables. However, TCT intervention was shown much better (numerically) increases of mean differences in RBC (0.95 Δ%), Hb (0.60 Δ%), Hct (1.53 Δ%), BG (3.80 Δ%), and decrease in LDL-C (-12.98 Δ%), TC (-05. 98 Δ%) rather than other both (HRC and TCT) training protocols even though mean differences of groups were not significant (Figure 30, and 31).

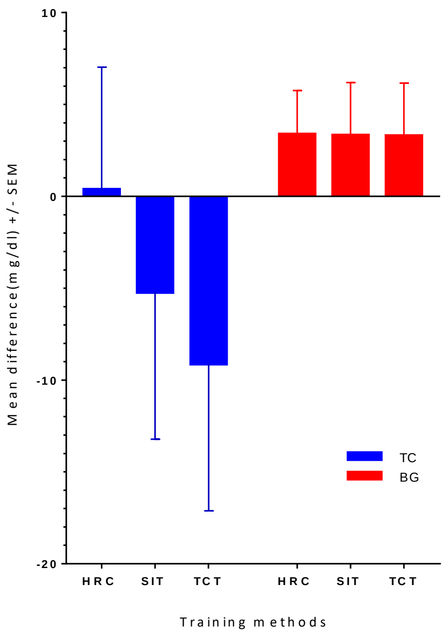


Figure 30. TC and BG changes upon three training methods (p < 0.05*)

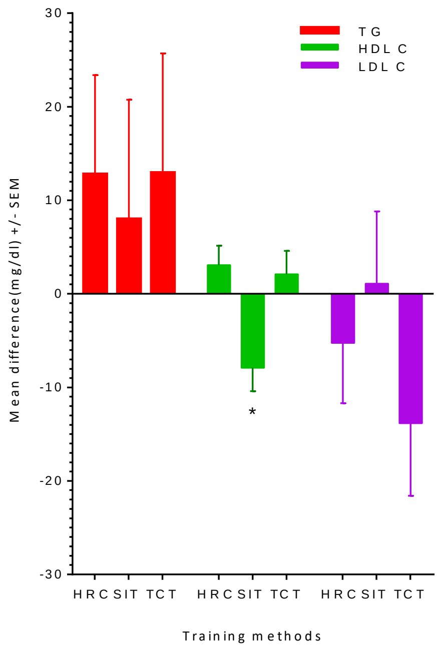


Figure 31. TG, HDL-C and LDL-C changes upon three training method (p < 0.05*)

Table 9. Blood test

Variable	ANOVA (F, p)						Time effect (Bonferroni)							Group effect (Bonferroni)	
	Time*group effect		Time effect		Group effect			Pre		Post					
	F	*p*	F	*p*	F	*p*	Group	Mean	SD	Mean	SD	*p*	Δ%	Group	*p*
RBCs	0.004	0.996	0.648	0.427	1.588	0.222	HRC	5.09	0.25	5.14	0.28	0.562	0.98	HRC vs SIT	*
x10*6/mmc							SIT	5.18	0.32	5.24	0.33	0.707	1.16	HRC vs TCT	0.410
							TCT	5.27	0.34	5.32	0.18	0.654	0.95	SIT vs TCT	*
Hb	0.028	0.972	0.119	0.733	0.462	0.635	HRC	15.25	0.82	15.34	0.92	0.743	0.59	HRC vs SIT	*
(gr/100)							SIT	15.38	1.17	15.43	0.91	1.000	0.33	HRC vs TCT	*
							TCT	15.04	0.91	15.13	0.39	0.774	0.60	SIT vs TCT	*
Hct	0.049	0.952	0.836	0.368	0.976	0.389	HRC	43.90	2.60	44.25	2.73	0.649	0.80	HRC vs SIT	0.574
(%)							SIT	45.16	3.00	45.59	2.34	0.715	0.95	HRC vs TCT	*
							TCT	44.34	2.97	45.02	1.44	0.460	1.53	SIT vs TCT	*
BG	0.000	1.000	4.564	**0.042***	1.446	0.253	HRC	91.15	7.05	94.54	8.12	0.166	3.72	HRC vs SIT	*
(mg/dl)							SIT	90.60	4.43	93.56	7.83	0.253	3.27	HRC vs TCT	0.681
							TCT	86.94	7.14	90.24	8.05	0.258	3.80	SIT vs TCT	*

RBCs = Red blood cells or Erythrocytes, Hb = Hemoglobin, hct = Hematocrit, BG = Basal blood sugar
* The P value is reported as 1.000 according to the way significant figures are calculated in SPSS.

Table 10. Blood test

Variable	ANOVA (F, p) Time*group effect		Time effect		Group effect		Time effect (Bonferroni)							Group effect (Bonferroni)	
								Pre		Post					
	F	*p*	F	*p*	F	*p*	Group	Mean	SD	Mean	SD	*p*	Δ%	Group	*p*
TC (mg/dl)	0.434	0.652	1.132	0.296	0.228	0.798	HRC	175.00	39.05	175.38	39.91	0.954	0.22	HRC vs SIT	*
							SIT	177.50	38.88	163.89	23.95	0.519	-7.67	HRC vs TCT	*
							TCT	181.13	50.00	172.01	30.11	0.264	-5.04	SIT vs TCT	*
TG (mg/dl)	0.051	0.950	2.593	0.119	0.460	0.636	HRC	73.00	26.86	85.77	55.69	0.239	17.49	HRC vs SIT	*
							SIT	74.00	30.35	73.11	23.97	0.536	-1.20	HRC vs TCT	*
							TCT	62.94	27.06	75.89	35.47	0.319	20.58	SIT vs TCT	*
HDL C (mg/dl)	6.385	**0.005***	0.514	0.098	0.163	0.850	HRC	58.85	13.83	61.92	12.46	0.150	5.22	HRC vs SIT	*
							SIT	65.80	9.28	58.33	12.56	**0.004***	-11.35	HRC vs TCT	*
							TCT	62.00	13.14	64.10	7.20	0.408	3.39	SIT vs TCT	0.858
LDL C (mg/dl)	0.934	0.405	2.009	0.167	0.219	0.805	HRC	101.55	34.53	96.31	34.63	0.422	-5.16	HRC vs SIT	*
							SIT	96.90	36.33	90.93	25.49	0.891	-6.16	HRC vs TCT	*
							TCT	106.55	52.34	92.72	32.01	0.085	-12.98	SIT vs TCT	*

TC = Total blood cholesterol, TG = Triglyceride, HDL-C = High-density lipoprotein cholesterol, LDL-C = Low-density lipoprotein cholesterol
* The P value is reported as 1.000 according to the way significant figures are calculated in SPSS

6.4. SECTION 03:

6.4.1. Training interventions induced different cardiovascular adaptation.

Table 11 (VO_2 max) presents the results of the different cardiovascular variables, for the experimental groups, in the pre-test and the post-test. Furthermore, resting metabolic rate was measured before and after the training intervention and those data was present in Table 12.

In order to measure the different variables related to maximum oxygen consumption, VO_2max tests were conducted in laboratory premises and their statistical analysis results were presented in table 09. However, among all the other variables only maximum velocity at VO_2max was shown as a significant interaction between groups of training methods and the time of measurement $F (2, 29) = 3.909$ $P < 0.05$.

Interestingly, there was significant main time effects were detected across the within-subject factors of all variables except maximum heart rate at VO_2 max. Thus, the variables which were shown a significant main effect, in order: Maximum velocity at VO_2 max: $F (2, 29) = 14.104$ $P < 0.05$, VO_2 max: $F (2, 29) = 8.141$ $P < 0.05$], Max VO2R: $F (2, 29) = 12.869$ $P < 0.05$ and Maximum time at VO_2 max: $F (2, 29) = 20.005$ $P < 0.05$. On the other hand, through pair-wise comparison of the Bonferroni post hoc test were detected significant differences ($P < 0.05$) between two-time points on maximum velocity, VO_2 max, Max VO_2R, and maximum time at VO_2 max following TCT intervention, as well as maximum velocity and maximum time at VO_2 max following SIT intervention were also shown significant difference ($P < 0.05$) between pre and post-test results.

However, there was a non-significant main effect were shown across the between groups on any variables, but the comparison between HRC from TCT and SIT from TCT on VO_2 max were detected with significant difference ($P < 0.05$) through Bonferroni post hoc test (Figure 32, 33, 34, and 35). According to the mean differences of HRC vs TCT and SIT vs TCT, TCT was shown a higher mean difference than HRC and SIT which means TCT is more likely to induce higher VO_2 max adaptation than HRC and SIT training methods.

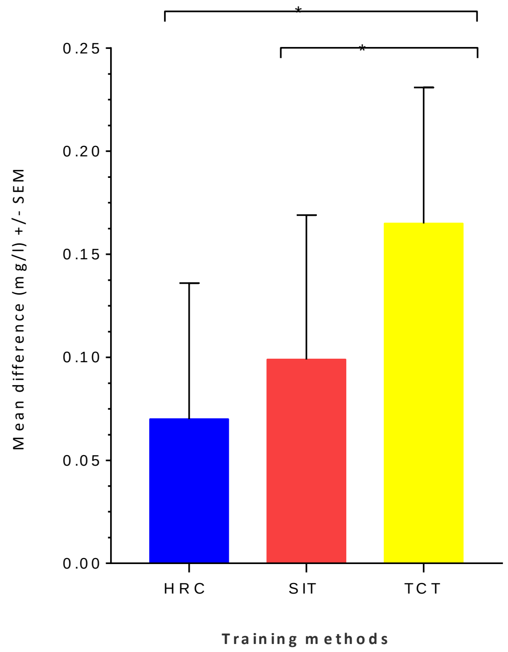


Figure 32. VO_2 max at maximum changes upon three training methods ($p < 0.05$*)

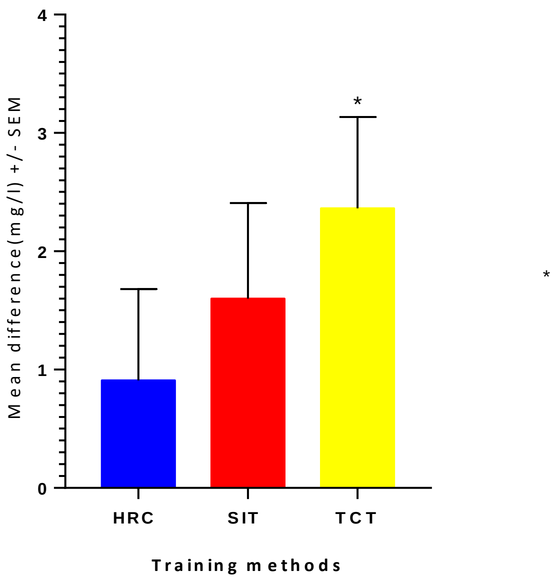


Figure 33. VO_2 max R at maximum changes upon three training methods

Table 11. VO_2 max: maximum

Variable	ANOVA (F, p) Time*group effect		Time effect		Group effect		Group	Time effect (Bonferroni) Pre		Post				Group effect (Bonferroni)	
	F	*p*	F	*p*	F	*p*		Mean	SD	Mean	SD	*p*	Δ%	Group	*p*
Max HR	0.309	0.737	1.298	0.265	0.166	0.848	HRC	197.45	8.43	196	7.50	0.316	-0.73	HRC vs SIT	*
							SIT	196.33	10.44	196.33	9.10	1.000	0.00	HRC vs TCT	*
							TCT	194.55	10.63	193.80	9.95	0.324	-0.39	SIT vs TCT	*
Max. Vel.	3.909	**0.031***	14.104	**0.001***	1.089	0.350	HRC	16.69	1.49	16.67	1.37	0.926	-0.12	HRC vs SIT	*
							SIT	16.09	1.35	16.78	1.32	**0.002***	4.29	HRC vs TCT	*
							TCT	15.47	1.66	16.09	1.77	**0.004***	4.01	SIT vs TCT	0.912
VO_2 max	0.531	0.594	8.141	**0.008***	5.285	0.011	HRC	3.87	0.31	3.94	0.26	0.300	1.81	HRC vs SIT	*
							SIT	3.88	0.53	3.98	0.41	0.166	2.58	HRC vs TCT	**0.042***
							TCT	3.37	0.45	3.53	0.41	**0.019***	4.75	SIT vs TCT	**0.026***
Max VO_2R	0.889	0.422	12.869	**0.001***	2.393	0.109	HRC	54.82	5.96	55.73	5.41	0.248	1.66	HRC vs SIT	0.781
							SIT	51.50	6.11	53.10	6.64	0.058	3.11	HRC vs TCT	0.214
							TCT	49.18	4.85	51.55	3.27	**0.005***	4.82	SIT vs TCT	*
Maximum time	3.313	0.051	20.005	**0.001***	1.09	0.350	HRC	16.45	1.22	16.56	1.32	0.605	0.67	HRC vs SIT	*
							SIT	15.93	1.39	16.75	1.27	**0.001***	5.15	HRC vs TCT	*
							TCT	14.83	1.92	15.98	1.86	**0.002***	7.75	SIT vs TCT	0.775

Max HR = Maximum heart rate, Max. Vel. = Maximum velocity, VO_2 max = maximum rate of oxygen consumption, Max VO_2R = Maximum oxygen uptake reserve.
* The P value is reported as 1.000 according to the way significant figures are calculated in SPSS.

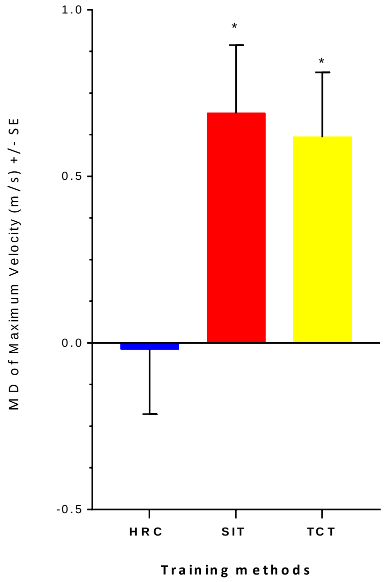


Figure 34. Maximum velocity changes upon three training methods ($p < 0.05$*)

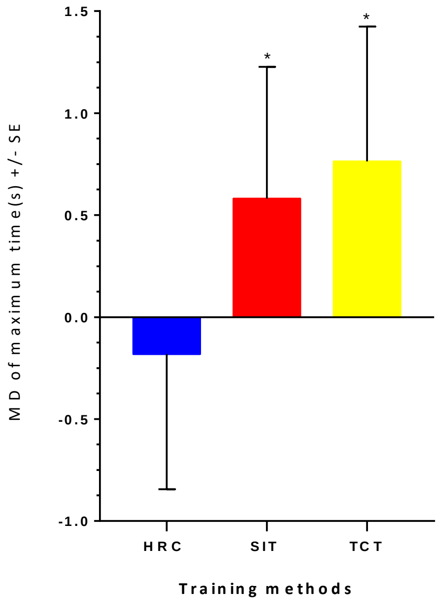


Figure 35. Maximum time at VO2 max changes upon three training methods ($p < 0.05$*)

6.4.2. Training interventions induced different resting metabolic adaptation.

Table 12 (RMR) presents the results of the different cardiovascular variables measured during and after the intervention of three different concurrent training protocols.

According to the statistical analysis, there were only Respiratory Exchange Ratio (RER) was shown a significant interaction between groups of training methods and the time of measurement $F (2, 28) = 3.396$ $P < 0.05$.

Interestingly, there were significant main time effects were detected across the within-subject factors for only RER, $F (1, 28) = 5.273$ $P < 0.05$. On the other hand, through pairwise comparison of the Bonferroni post hoc test were detected significant differences ($P < 0.05$) between two-time points on RER following TCT intervention.

However, there was a significant main effect was shown across the between groups on O2, $F (2, 28) = 9.424$ $P < 0.05$ and CO2, $F (2, 28) = 3.678$ $P < 0.05$. Additionally, the comparison between HRC from SIT and SIT from TCT on O2 was detected with a significant difference ($P < 0.05$) through the Bonferroni post hoc test (Figure 36 - 40). According to the mean differences of HRC vs SITT and SIT vs TCT, SIT was shown a higher mean difference than HRC and TCT which means SIT is more likely to consume higher O_2 adaptation than HRC and TCT training methods (figure 36, 37, 38, 39 and 40).

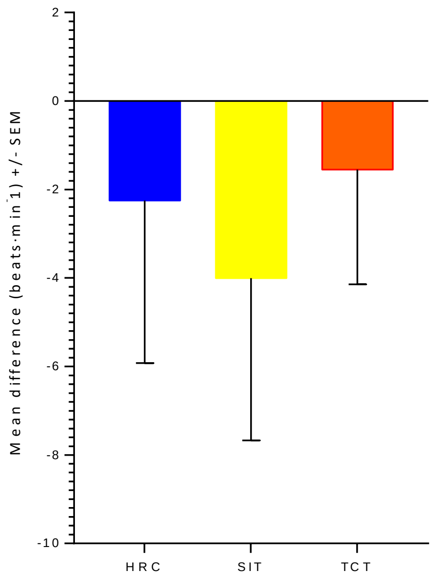


Figure 36. HR changes upon three training methods ($p < 0.05$*).

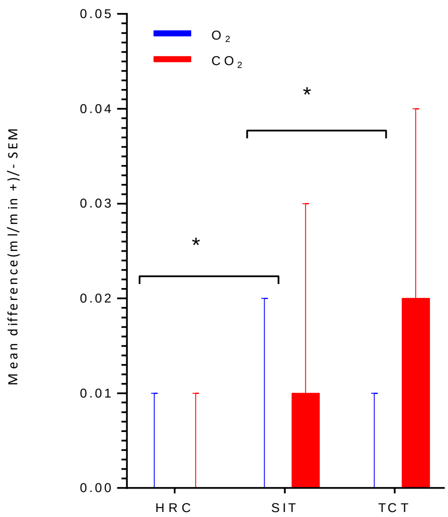


Figure 37. O_2 and CO_2 changes upon three training methods ($p < 0.05$*).

Table 12. Resting Metabolic Rate (RMR)

Variable	ANOVA (F, p)						Time effect (Bonferroni)							Group effect (Bonferroni)	
	Time*group effect		Time effect		Group effect			Pre		Post					
	F	*p*	F	*p*	F	*p*	Group	Mean	SD	Mean	SD	*p*	Δ%	Group	*p*
O_2 ml/min	0.015	0.985	0.021	0.887	9.424	**0.001***	HRC	0.29	0.06	0.29	0.03	0.954	0.00	HRC vs SIT	**0.043***
							SIT	0.32	0.04	0.32	0.03	0.882	0.00	HRC vs TCT	0.228
							TCT	0.26	0.02	0.26	0.03	0.885	0.00	SIT vs TCT	**0.001***
CO_2 ml/min	0.472	0.629	0.692	0.413	3.678	**0.038***	HRC	0.26	0.06	0.26	0.04	0.789	0.00	HRC vs SIT	0.212
							SIT	0.28	0.04	0.29	0.02	0.539	3.57	HRC vs TCT	*
							TCT	0.24	0.03	0.25	0.04	0.332	4.17	SIT vs TCT	0.113
HR beats·min−1	0.149	0.863	1.807	0.202	0.450	0.647	HRC	59.00	2.16	58.38	7.61	0.550	-1.05	HRC vs SIT	*
							SIT	64.50	4.65	60.50	6.35	0.295	-6.20	HRC vs TCT	*
							TCT	62.56	8.52	60.95	12.12	0.561	-2.57	SIT vs TCT	*
VO_2R ml/kg/m	0.074	0.929	0.120	0.732	2.122	0.139	HRC	4.06	0.43	4.04	0.40	0.902	-0.49	HRC vs SIT	*
							SIT	4.01	0.55	4.02	0.42	0.985	0.25	HRC vs TCT	0.232
							TCT	3.86	0.49	3.71	0.44	0.612	-3.89	SIT vs TCT	0.425
RER	3.396	**0.048***	5.273	**0.029***	0.964	0.394	HRC	0.91	0.10	0.89	0.08	0.510	-2.20	HRC vs SIT	*
							SIT	0.86	0.05	0.90	0.04	0.110	4.65	HRC vs TCT	0.178
							TCT	0.90	0.04	0.95	0.07	**0.011***	5.56	SIT vs TCT	0.436
MET	0.019	0.982	0.062	0.805	1.916	0.166	HRC	1.16	0.12	1.15	0.11	0.903	-0.86	HRC vs SIT	*
							SIT	1.15	0.16	1.15	0.12	0.982	0.00	HRC vs TCT	0.310
							TCT	1.10	0.14	1.07	0.11	0.766	-2.73	SIT vs TCT	0.534

O_2 = Oxygen, CO_2 = Carbon dioxide, HR = Heart rate, VO_2R = Volume of oxygen reserve, RER = Respiratory exchange ratio,
MET = Metabolic equivalent (the amount of oxygen consumed at rest)

* The P value is reported as 1.000 according to the way significant figures are calculated in SPSS.

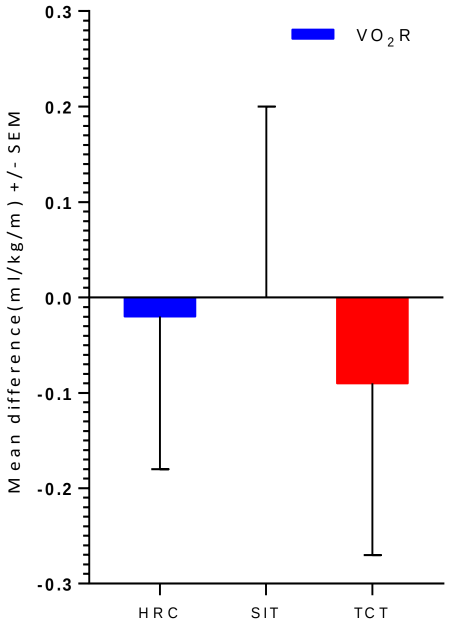


Figure 38. VO_2R changes upon three training methods ($p < 0.05$*).

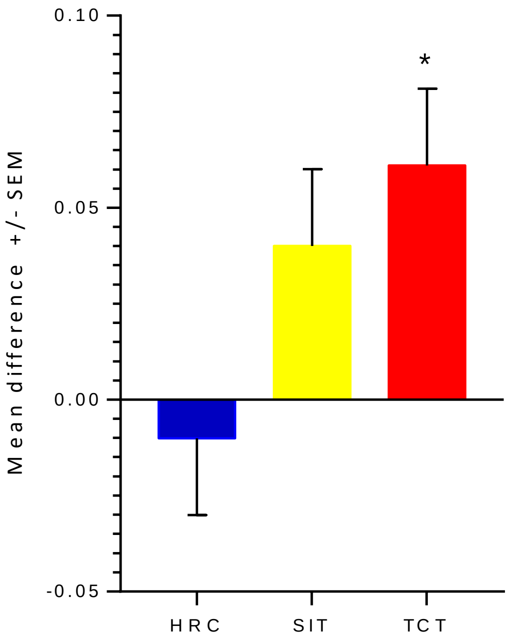


Figure 39. RER changes upon three training methods ($p < 0.05$*).

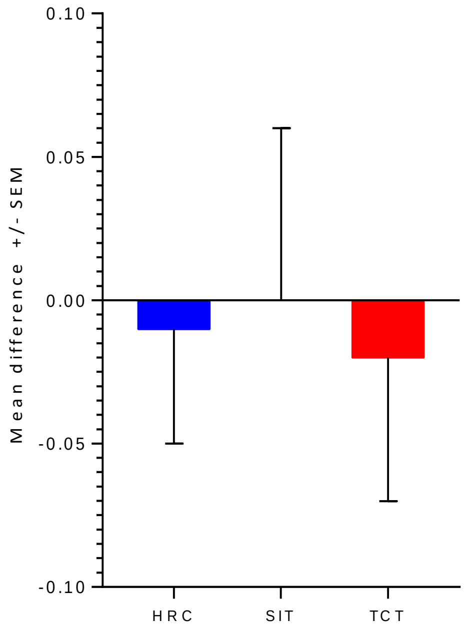


Figure 40. MET changes upon three training methods ($p < 0.05^*$).

6.5. SECTION 04:

6.5.1. Training interventions induced different structural adaptation.

6.5.1.1. Body composition variables:

Table 13 presents the summary of body composition data which were extracted after the statistical analysis. In order to the given data BMC $F(1, 31) = 6.394$, $P < 0.05$, and BMD $F(1, 31) = 4.721$, $P < 0.05$ were shown significant interaction between the time of measurement and the groups of training methods.

Further, there was a significant simple main effect across the two-time points (within-subject factor) on lean mass $F(1, 31) = 25.860$ $P < 0.001$ and BMD $F(1, 31) = 4.278$, $P < 0.05$ were detected. Subsequently, significant differences ($P < 0.05$) between two-time points (Pre-Post) were detected through Bonferroni pairwise comparison on lean mass, BMC, and BMD variables following SIT, while lean mass and BMC following TCT were also shown significant differences ($P < 0.05$) between Pre-Post measurement (Figure 41 - 44).

However, according to the statistical analysis, there were non-significant main effects across between groups on all variables of body composition. Neither has detected a significant difference from a pairwise comparison among training groups on any variables measured during body composition assessment. Moreover, after considering all mean differences in body composition following three training sessions, all training protocols induced considerable changes; however, the TCT method was shown much higher positive adaptations, when compared to the mean difference between SIT and HRC. In contrast, the data depicted that SIT even induced much better adaptation than HRC when comparing the mean differences of each variable following three training protocols.

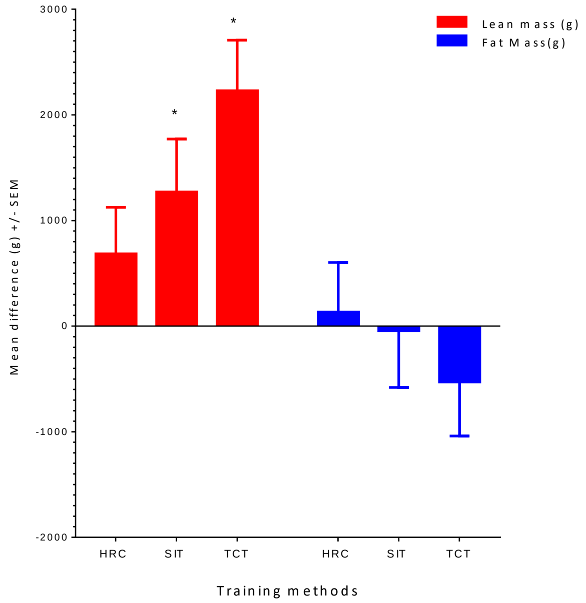


Figure 41. Lean and fat mass changes upon three training methods ($p < 0.05$*)

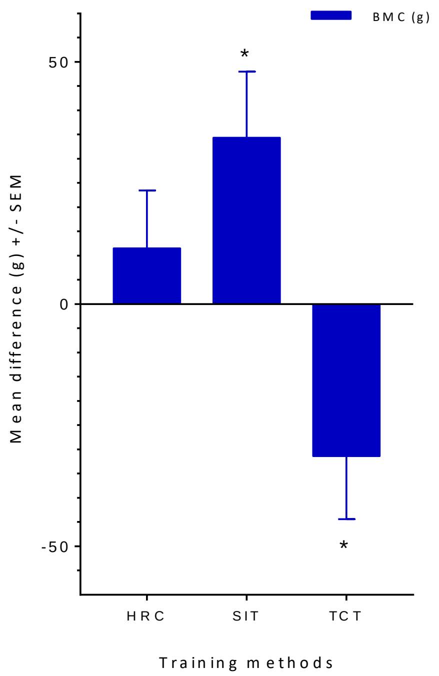


Figure 42. BMC changes upon three training methods ($p < 0.05$*)

Table 13. Body composition variables

Variable	ANOVA (F, p)						Time effect (Bonferroni)							Group effect (Bonferroni)	
	Time*group effect		Time effect		Group effect			Pre		Post			Δ%	Group	*p*
	F	*p*	F	*p*	F	*p*	Group	Mean	SD	Mean	SD	*p*			
Body Weight (Kg)	1.392	0.264	0.250	0.620	2.828	0.074	HRC	70.90	8.80	71.58	8.50	0.099	0.96	HRC vs SIT	0.253
							SIT	78.03	8.35	77.76	8.18	0.558	-0.35	HRC vs TCT	*
							TCT	69.89	7.71	69.85	7.94	0.934	-0.06	SIT vs TCT	0.107
Total Fat %	0.872	0.428	2.261	0.143	0.464	0.633	HRC	16.29	5.54	16.2	5.57	0.884	-0.55	HRC vs SIT	*
							SIT	18.22	5.43	17.87	5.82	0.596	-1.92	HRC vs TCT	*
							TCT	18.78	5.82	17.61	5.53	0.069	-6.23	SIT vs TCT	*
Lean mass (g)	2.834	0.074	25.860	**0.001***	2.967	0.066	HRC	56399	5035	57083	4733	0.131	1.21	HRC vs SIT	0.432
							SIT	59425	7785	60694	7915	**0.017***	2.14	HRC vs TCT	*
							TCT	52840	4621	55068	4298	**0.001***	4.22	SIT vs TCT	0.096
Fat mass (g)	0.472	0.628	0.250	0.620	0.459	0.636	HRC	11940	5422	12073	5552	0.780	1.11	HRC vs SIT	*
							SIT	14125	5135	14081	5291	0.936	-0.31	HRC vs TCT	*
							TCT	13299	5181	12770	4975	0.309	-3.98	SIT vs TCT	*
BMC (g)	6.394	**0.005***	0.427	0.518	1.311	0.284	HRC	2942	337.9	2954	332.7	0.342	0.41	HRC vs SIT	0.310
							SIT	3195	477.8	3229	496.3	**0.017***	1.06	HRC vs TCT	*
							TCT	3069	349	3038	344.68	**0.022***	-1.01	SIT vs TCT	0.810
BMD (g)	4.721	**0.016***	4.278	**0.047***	0.69	0.509	HRC	1.06	0.08	1.07	0.08	0.078	0.94	HRC vs SIT	0.665
							SIT	1.10	0.11	1.12	0.12	**0.006***	1.82	HRC vs TCT	*
							TCT	1.09	0.09	1.08	0.09	0.229	-0.92	SIT vs TCT	*

BMC = Bone mineral content, BMD = Bone mineral density
* The P value is reported as 1.000 according to the way significant figures are calculated in SPSS.

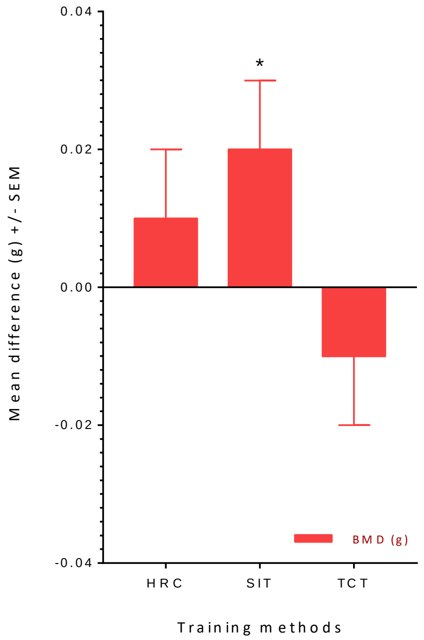


Figure 43. BMD changes upon three training methods (p < 0.05*)

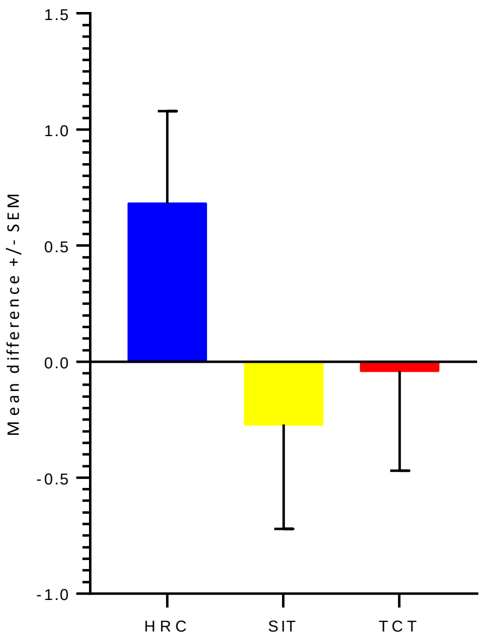


Figure 44. Bodyweight changes upon three training methods (p < 0.05*)

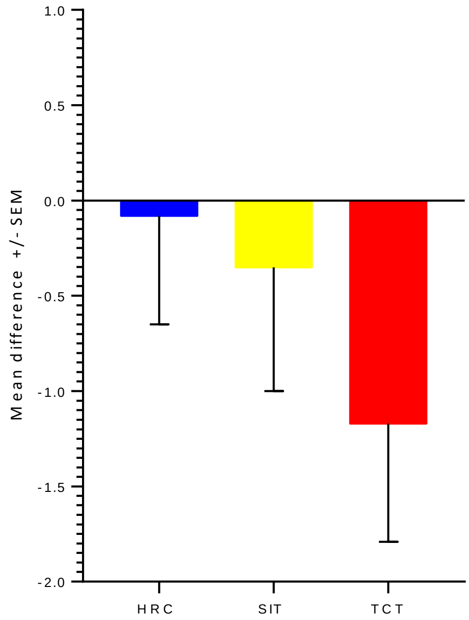


Figure 45. Total fat % changes upon three training methods ($p < 0.05$*)

6.5.1.2. Ultrasound scan results of Vastus lateralis

The table 14 and 15 present the summary of muscle architectural variables data which were concluded after the statistical analysis. Following the statistical results there was a significant interaction effect between the time of measurement and the groups of training methods on proximal fiber length $F(2, 26) = 4.184$ $P < 0.05$.

Interestingly, there was a significant simple main effect across the within-subject factor found only on proximal fiber length $F(1, 26) = 4.481$, $p = 0.044$ among all the variables of muscle architecture measurements. On the other hand, following a pairwise comparison between two-time points only the proximal fibre length following the HRC training protocol was shown a significant difference ($P < 0.05$) (Figure 46 - 48).

Moreover, there was a significant main effect across the between groups only on proximal fibre length $F(2, 26) = 4.685$, $p = 0.018$ of muscle architectural variables. However, there were non-significant differences were identified following Bonferroni post hoc pairwise comparison between groups for all variables. However, each training protocol induced different adaptations depending on the particular training protocols. Considering only the numerical value it might be able to consider TCT shows a better mean difference than the other two training methods (HRC and TCT).

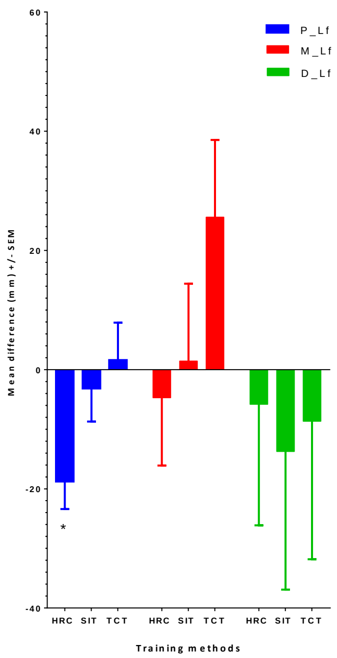


Figure 46. Fl changes of different regions on VL upon three training methods ($p < 0.05^*$)

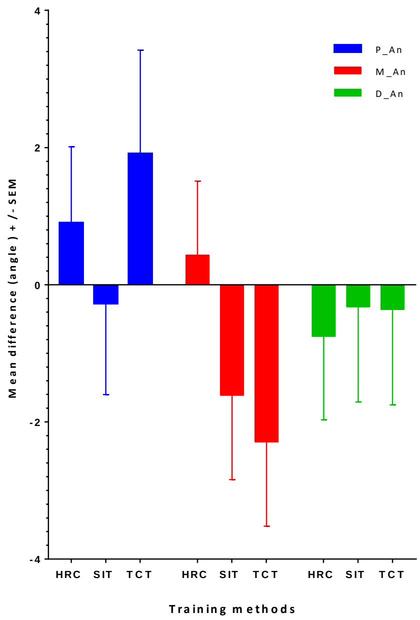


Figure 47. An changes of different regions on VL upon three training methods ($p < 0.05^*$)

Table 14. Ultrasound scan of Vastus lateralis

Variable	ANOVA (F, p) Time*group effect		Time effect		Group effect			Time effect (Bonferroni) Pre		Post			Δ%	Group effect (Bonferroni)	
	F	*p*	F	*p*	F	*p*	Group	Mean	SD	Mean	SD	*p*		Group	*p*
P Fl	4.184	**0.027***	4.481	**0.044***	4.685	**0.018***	HRC	97.64	18.87	78.87	11.81	**0.001***	-19.22	HRC vs SIT	*
							SIT	78.29	16.79	75.12	8.10	0.576	-4.05	HRC vs TCT	*
							TCT	73.27	10.13	74.86	12.02	0.804	2.17	SIT vs TCT	*
P An	0.597	0.558	1.225	0.279	1.151	0.332	HRC	17.32	2.26	18.21	1.70	0.423	5.14	HRC vs SIT	*
							SIT	17.93	4.54	17.66	2.10	0.841	-1.51	HRC vs TCT	*
							TCT	15.16	3.43	17.07	5.33	0.217	12.60	SIT vs TCT	*
P Th	0.643	0.534	0.155	0.697	0.19	0.828	HRC	23.59	3.83	24.21	3.64	0.271	2.63	HRC vs SIT	*
							SIT	25.05	4.52	24.69	4.51	0.594	-1.44	HRC vs TCT	*
							TCT	24.68	4.72	24.87	4.21	0.804	0.77	SIT vs TCT	*
M Fl	1.642	0.211	1.065	0.310	0.122	0.885	HRC	82.12	17.14	77.40	8.73	0.681	-5.75	HRC vs SIT	*
							SIT	75.90	19.01	77.33	14.39	0.913	1.88	HRC vs TCT	*
							TCT	69.10	9.01	94.67	74.28	0.058	37.00	SIT vs TCT	*
M An	1.553	0.228	2.862	0.101	0.413	0.665	HRC	18.13	2.93	18.57	2.44	0.691	2.43	HRC vs SIT	*
							SIT	19.96	4.44	18.34	4.07	0.201	-8.12	HRC vs TCT	*
							TCT	20.55	2.56	18.25	4.50	0.073	-11.19	SIT vs TCT	*
M Th	1.100	0.346	1.264	0.270	1.695	0.201	HRC	26.07	3.56	26.56	2.66	0.914	1.88	HRC vs SIT	*
							SIT	25.58	4.60	25.39	3.98	0.971	-0.74	HRC vs TCT	0.469
							TCT	26.77	3.58	36.12	28.09	0.080	34.93	SIT vs TCT	0.406

P = Proximal, M = Medial, Fl = Fibre length (mm), An = Pennation angle, Th = Muscle thickness (mm).
* The P value is reported as 1.000 according to the way significant figures are calculated in SPSS.

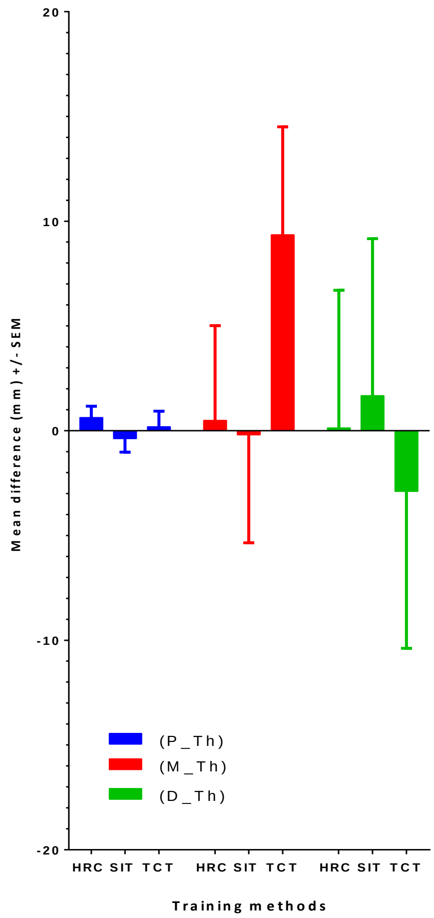


Figure 48. The changes of different regions on VL upon three training methods ($p < 0.05$*)

Table 15. Ultrasound scan of Vastus lateralis

Variable	ANOVA (F, p) Time*group effect F	p	Time effect F	p	Group effect F	p	Group	Time effect (Bonferroni) Pre Mean	SD	Post Mean	SD	p	Δ%	Group effect (Bonferroni) Group	p
D Fl	0.993	0.382	0.754	0.392	1.192	0.317	HRC	87.05	17.83	81.25	10.49	0.956	-6.66	HRC vs SIT	*
							SIT	111.87	79.64	98.14	63.34	0.909	-12.27	HRC vs TCT	0.531
							TCT	103.13	70.93	94.49	666.26	0.118	-8.38	SIT vs TCT	0.721
D An	0.035	0.966	0.386	0.539	2.075	0.143	HRC	19.97	1.36	19.24	1.78	0.542	-3.66	HRC vs SIT	*
							SIT	20.12	3.02	19.79	2.40	0.819	-1.64	HRC vs TCT	0.401
							TCT	21.90	4.76	21.54	5.64	0.795	-1.64	SIT vs TCT	0.838
D Th	0.096	0.909	0.007	0.932	1.296	0.289	HRC	25.82	3.35	25.95	3.07	0.984	0.50	HRC vs SIT	0.819
							SIT	31.37	16.52	33.03	23.05	0.826	5.29	HRC vs TCT	*
							TCT	33.52	26.15	30.63	14.67	0.704	-8.62	SIT vs TCT	
															*

D = Distal, Fl = Fibre length (mm), An = Pennation angle, Th = Muscle thickness (mm).
* The P value is reported as 1.000 according to the way significant figures are calculated in SPSS.

6.5. SECTION 05:

6.5.1. Training interventions induced different mechanical adaptation.

Following tables: Table 16 force plate test (Maximum power, maximum force, and CMJ height), Table 17 RSA test (% power decrement, lactate, fatigue index), Table 18 6RM (strength) present the all mechanical variables results which were measured during the experimental study following three training groups, in the pre-test and the post-test. As well as, it includes the time * group interaction, the main effect within-subject (time), the main effect between subject (group), and Bonferroni post hoc analysis.

6.5.1.1. Test for power and force

Table 16 (force plate), In order to the statistical data there was a significant interaction between the time of measurement and the groups of training methods, on maximum force output (Push-up) $F (2, 29) = 4.675$ $P = 0.017$.

However, following the three training methods none of them were shown a significant simple main effect across the within-subject factor for all variables, though maximum force output (Push-up) following TCT intervention was shown a significant difference ($P < 0.05$) between two-time points (Pre-Post). Moreover, non-significant main effects across the between-subject factors were detected through the analysis. Neither, Bonferroni post hoc comparisons of training interventions from any variables were significant (Figure 41). Though non-significant differences between times were detected, HRC training induced higher MD on height CMJ, as well as Pmax CMJ and Fmax following TCT than other both training methods (figure 49, 50 and 51).

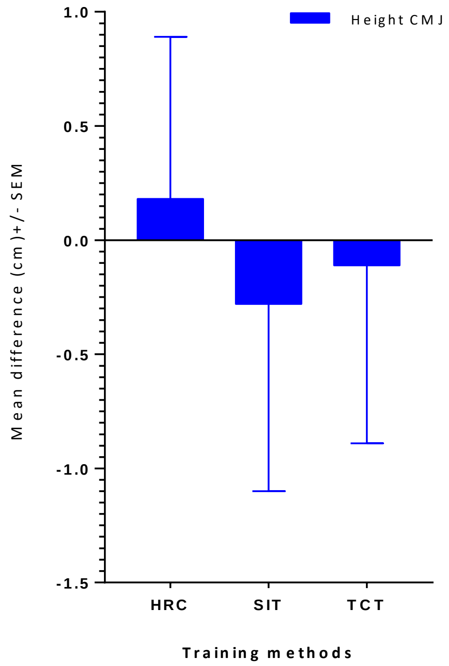


Figure 49.Height CMJ changes upon three training methods ($p < 0.05^*$)

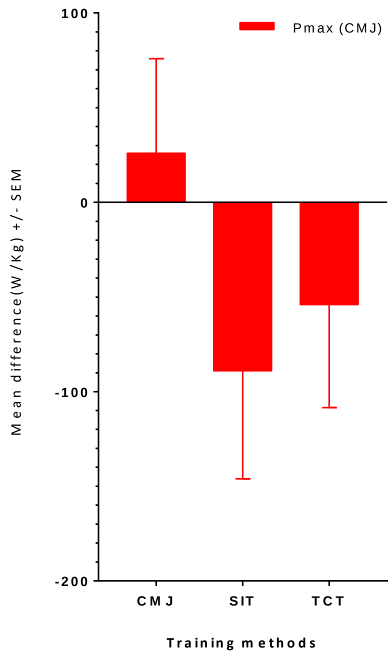


Figure 50. Pmax (CMJ) changes upon three training methods ($p < 0.05^*$)

Table 16. Mechanical variables (Force plate).

Variable	ANOVA (F, p)						Time effect (Bonferroni)							Group effect (Bonferroni)	
	Time*group effect		Time effect		Group effect			Pre		Post					
	F	*p*	F	*p*	F	*p*	Group	Mean	SD	Mean	SD	*p*	Δ%	Group	*p*
Height	0.094	0.911	0.026	0.872	0.701	0.504	HRC	31.16	6.26	31.34	5.78	0.807	0.58	HRC vs SIT	0.804
CMJ							SIT	29.13	3.76	28.85	4.01	0.731	-0.96	HRC vs TCT	*
							TCT	31.37	5.38	31.26	5.55	0.889	-0.35	SIT vs TCT	0.904
Pmax	1.25	0.301	1.577	0.219	0.379	0.688	HRC	3461	506.18	3487	540.29	0.609	0.75	HRC vs SIT	*
CMJ(W/Kg)							SIT	3721	579.13	3632	490.32	0.129	-2.39	HRC vs TCT	*
							TCT	3575	617.09	3508	671.59	0.328	-1.87	SIT vs TCT	*
Fmax (N)	4.675	**0.017***	2.032	0.165	0.31	0.736	HRC	835.32	124.07	884.16	142.46	0.202	5.85	HRC vs SIT	*
							SIT	929.41	278.92	862.41	138.64	0.147	-7.21	HRC vs TCT	0.590
							TCT	847.46	133.96	968.85	175.09	**0.008***	14.32	SIT vs TCT	0.418

Height CMJ = Height of Counter movement jump, P max CMJ = Maximum power output, F max = Maximum force output (Push-up)

* The P value is reported as 1.000 according to the way significant figures are calculated in SPSS.

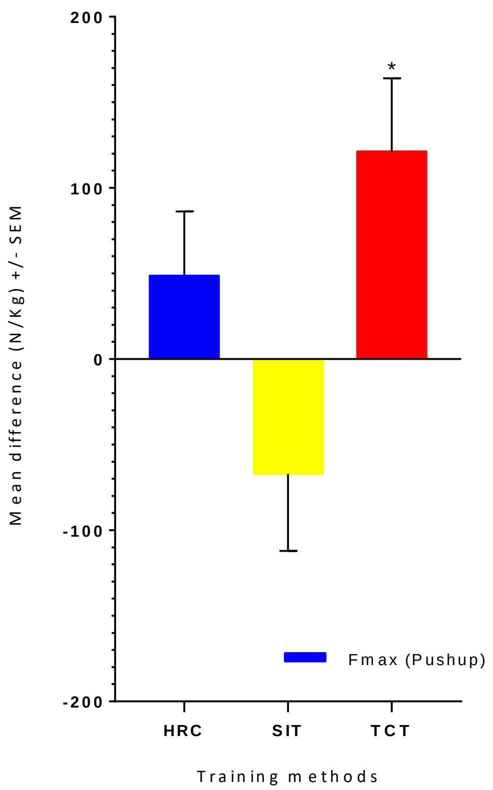


Figure 51. Fmax (pushup) changes upon three training methods ($p < 0.05$*)

6.5.1.2. Repeated sprint ability test (RSA)

Table 17 presents the repeated sprint ability test results composed after the statistical analysis. In order to the statistical data, there was a non-significant interaction effect between the time of measurement and the groups of training method, on any variables measured in RSA.

However, there was a significant simple main effect across the within-subject factor on power decrement $F (1, 30) = 15.918$, $P < 0.001$, and fatigue index $F (1, 30) = 20.076$, $P < 0.001$. Subsequently, both variables were shown significant differences ($P < 0.05$) between two-time points (Pre-Post) following SIT, TCT (power decrement), and HRC, SIT, and TCT (fatigue index) (Figure 52, 53 and 54).

Furthermore, there was a non-significant simple main effect across the between group on any variable measured, neither has been detected the significant difference of training method comparison on any variables measured from RSA.

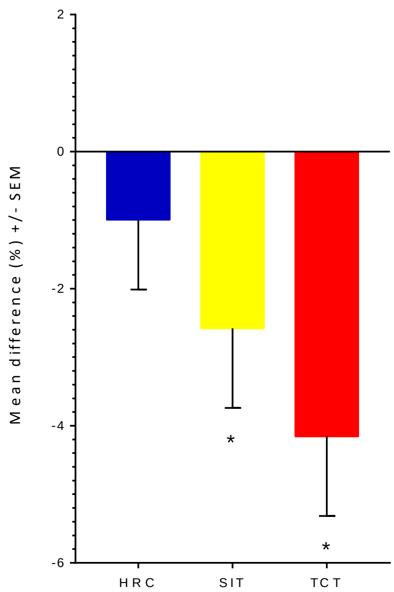


Figure 52. % power decrement changes upon three training methods ($p < 0.05$*)

Table 17. Repeated sprint ability test (RSA)

Variable	ANOVA (F, p)						Time effect (Bonferroni)							Group effect (Bonferroni)	
	Time*group effect		Time effect		Group effect			Pre		Post				Group	*p*
	F	*p*	F	*p*	F	*p*	Group	Mean	SD	Mean	SD	*p*	Δ%		
% Power	2.113	0.138	15.918	**0.001***	0.400	0.674	HRC	4.28	2.26	3.30	1.20	0.341	-22.90	HRC vs SIT	*
Decrement							SIT	5.24	3.16	2.66	1.13	**0.034***	-49.24	HRC vs TCT	*
							TCT	6.72	4.84	2.57	4.05	**0.001***	-61.76	SIT vs TCT	*
Fatigue	0.429	0.655	26.076	**0.001***	0.181	0.835	HRC	-9.87	4.22	-6.73	2.53	**0.014***	-31.81	HRC vs SIT	*
index							SIT	-10.67	4.82	-5.87	2.45	**0.001***	-44.99	HRC vs TCT	*
							TCT	-10.79	4.71	-7.11	2.06	**0.012***	-34.11	SIT vs TCT	0.746
Lactate	1.124	0.338	0.289	0.595	0.948	0.399	HRC	15.08	5.50	14.12	3.92	0.528	-6.37	HRC vs SIT	0.157
(mmol/L)							SIT	15.11	2.86	17.54	4.87	0.168	16.08	HRC vs TCT	0.797
							TCT	15.97	4.03	16.04	3.11	0.968	0.44	SIT vs TCT	*

* The P value is reported as 1.000 according to the way significant figures are calculated in SPSS.

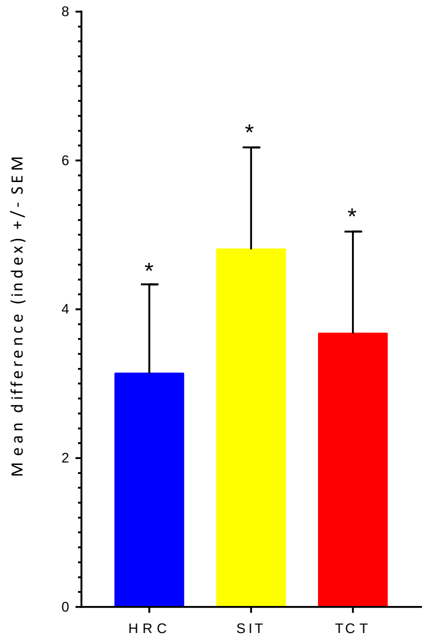


Figure 53. Fatigue index changes upon three training methods (p < 0.05*)

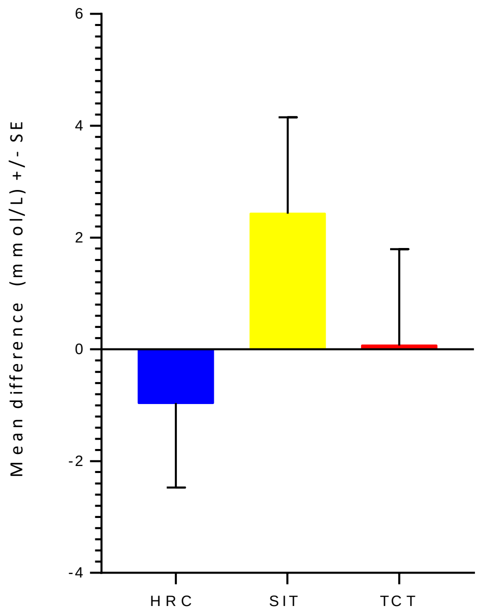


Figure 54. Lactate changes upon three training methods (p < 0.05*)

6.5.1.3. Repetition Maximum (RM)

Table 18 presents the strength parameters which are measured through the 6 RM test. According to the statistical analysis bench press $F (2, 29) = 9.163$ $p < 0.001$, leg extension $F (2, 29) = 6.700$ $p < 0.001$, and biceps curl $F (2, 25) = 10.739$ $p = 0.001$ were shown significant interaction between the time of measurement and the groups of training methods.

Interestingly there was a significant simple main effect across the two-time points (within subject factor) shown on all variables, such as bench press $F (1, 29) = 37.805$, $p < 0.001$, leg extension $F (1, 29) = 105.306$, $p < 0.001$, lat pull-down $F (1, 25) = 34.120$, $p < 0.001$, deadlift $F (1, 23) = 33.859$, $p < 0.001$, bicep curl $F (1, 25) = 45.816$, $p < 0.001$ and ankle extension $F (1, 25) = 46.315$, $p < 0.001$.

While, Bonferroni post hoc analysis detected significant differences in Pre-Post measurement ($p < 0.001$ and $p < 0.05$) of all variables except bench press, lat pull-down, bicep curl, and ankle extension following SIT protocol On the other hand, there were non-significant main effects between groups on all variables of the 6RM, the comparison of biceps curl following HRC vs SIT and SIT vs TCT were shown significant differences between groups ($p < 0.05$), Moreover, after considering all mean differences on all variables of the 6 RM test, all training methods were shown some improvement in particular variables even though it was not significant between groups. However, the HRC method induced greater adaptation on all variables except deadlift than other training methods but those differences were not significant (Figure 55).

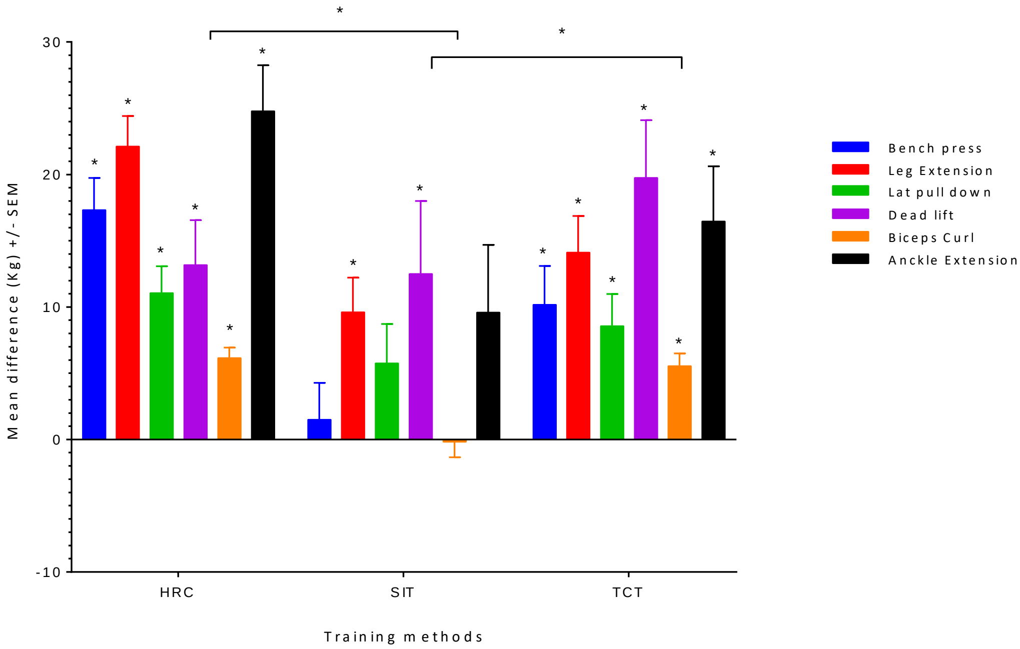


Figure 55. 6 RM changes upon three training methods ($p < 0.05$*)

Table 18. 6 RM

Variable	ANOVA (F, p) Time*group effect		Time effect		Group effect		Time effect (Bonferroni)							Group effect (Bonferroni)	
								Pre		Post					
	F	*p*	F	*p*	F	*p*	Group	Mean	SD	Mean	SD	*p*	Δ%	Group	*p*
Bench Press	9.163	**0.001***	37.805	**0.001***	0.480	0.624	HRC	64.04	14.42	81.35	13.40	**0.001***	27.03	HRC vs SIT	0.164
							SIT	68.10	17.50	69.60	13.85	0.593	2.20	HRC vs TCT	0.426
							TCT	62.06	12.09	72.22	14.81	**0.002***	16.37	SIT vs TCT	*
Leg Extension	6.700	**0.004***	105.306	**0.001***	0.223	0.802	HRC	67.50	9.90	89.62	9.25	**0.001***	32.77	HRC vs SIT	0.338
							SIT	72.75	12.04	82.35	11.30	**0.001***	13.20	HRC vs TCT	0.438
							TCT	68.67	10.46	82.78	11.49	**0.001***	20.55	SIT vs TCT	*
Lat pull down	1.126	0.340	34.120	**0.001***	0.886	0.425	HRC	60.87	10.52	71.92	8.22	**0.001***	18.15	HRC vs SIT	0.365
							SIT	58.58	8.25	64.33	14.87	0.065	9.82	HRC vs TCT	0.655
							TCT	58.11	8.27	66.67	6.96	**0.002***	14.73	SIT vs TCT	*
Dead lift	0.845	0.443	33.859	**0.001***	0.527	0.597	HRC	68.85	16.73	82.00	17.48	**0.001***	19.10	HRC vs SIT	*
							SIT	74.00	5.48	86.50	19.17	**0.033***	16.89	HRC vs TCT	0.541
							TCT	72.75	22.91	92.50	14.33	**0.001***	27.15	SIT vs TCT	*
Biceps Curl	10.739	**0.001***	45.816	**0.001***	3.26	0.055	HRC	22.88	3.04	29.04	3.31	**0.001***	26.92	HRC vs SIT	**0.002***
							SIT	22.50	3.16	22.33	2.77	0.888	-0.76	HRC vs TCT	*
							TCT	23.66	4.23	29.2o	4.21	**0.001***	23.42	SIT vs TCT	**0.003***
Ankle Extension	3.256	0.055	46.315	**0.001***	2.090	0.145	HRC	67.31	12.85	92.08	16.26	**0.001***	36.80	HRC vs SIT	0.439
							SIT	69.25	7.18	78.83	11.84	0.073	13.83	HRC vs TCT	0.087
							TCT	57.67	21.89	74.11	22.74	**0.001***	28.51	SIT vs TCT	*

* The P value is reported as 1.000 according to the way significant figures are calculated in SPSS.

VII – DISCUSSION

VII - DISCUSSION

This chapter will discuss, substantiate, and compare the present doctoral thesis findings with previous research. The chapter is organized into five sub-sections: discussions regarding the findings of Section 1 (Neuromuscular adaptation), Section 2 (Metabolic adaptation), Section 3 (Cardiorespiratory adaptation), Section 4 [Structural (Body composition, muscle architecture) adaptation] and Section 5 (Mechanical adaptation).

All five sections of the study in this Ph.D. thesis are based on the findings following 8 weeks of three different concurrent training protocols intervention. To the best of the authors' knowledge, most studies examine traditional concurrent training studies, specially strength prior to endurance or endurance prior to strength training, rest in between two training modalities and sessions as well as interference effects. On the other hand, others compare the acute and chronic adaptation of contemporary concurrent training methods such as HIIT, HRC, Tabata… etc.). However, no studies compared the three different concurrent training methods and their neuromuscular, Metabolic, Cardiorespiratory, Body composition, muscle architecture, Mechanical adaptations respective to the training times, and other training benefits.

Therefore, when it reads from the practical perspective, it is important to understand the changes and time to take the changes according to the demand of the sports and the desires of each athlete. Thus, all sub-sections of the following thesis had two main objectives, the first of which was to identify and explain the neuromuscular, metabolic, cardiorespiratory, structural, and mechanical long-term adaptations and mechanisms following three different concurrent training in young recreationally training athletes. The second objective was to evaluate and compared the neuromuscular, metabolic, cardiorespiratory, structural, and mechanical long-term adaptations between the three different concurrent training methods (HRC vs. SIT vs. TCT) in young recreationally training athletes. The following discusses the major results of each objective.

7.1. SECTION 01:

7.1.1. Neuromuscular adaptation following different training protocols

Similar to many exercise-induced adaptations, it is believed that motor system changes take place both centrally and peripherally (143). It is useful to conceive of everything in the neuromuscular system proximal to the neuromuscular junction as central and everything distal to it as peripheral. Although the neuromuscular junction does not always neatly fit into this plan, muscle tissue and muscle mechano-receptors are obviously peripheral. When a resistance overload is present, the contractile proteins multiply and the muscle is better equipped to respond to any amount of brain activity (143).
Concerning the previous investigation it is well established that endurance training-induced neuromuscular adaptation was contrasted to the adaptation of resistance training.

Endurance training induces angiogenesis in the motor cortex and resistance training alters spinal motor neuron excitability and induces synaptogenesis within the spinal cord (343). Moreover, Aagaard et al. (141) reported following resistance training increased H reflex and increased efferent motor drive. In contrast, endurance training induces central and peripheral adaptations that decrease the H reflex amplitude of ballet dancers (Nielsen, J. et al. 1993). However, the adaptations of the reflex responses following endurance training are quite ambiguous when discussing the previous investigations, Maffiuletti et al. (179) reported the highest amplitude of the H max potential in the endurance-trained athletes, while Bertschinge et al. (344) reported from their findings have not been further supported the assumption that long-term aerobic training leads to a general increase of the H-reflex.

The most crucial factor of the human sensory system is always highly sensitive to be able to adapt as an answer to a particular training system (Vera-Ibañez, A. et al. 2017). Hence, exercise training may cause adaptive changes within the nervous system that allow a trainee to more fully activate prime movers in specific movements and to better coordinate the activation of all relevant muscles (46). Therefore, it is well known that neural adaptation could have occurred at a different level, such as motor cortex, spinal cord, and neuromuscular junctions following systematic training, which allows a trainee for proper muscle activation with better coordination, by this mean always showed better performance in the intended particular action (346).

Furthermore, time is currently very expensive and is scarce for exercise owing to the high demand for each sport and game as well as other factors. As a result, when athletes use time-related training regimens to increase performance or health in a short amount of time, it is typically warmly embraced. Hence, this section will examine the potential neuromuscular adaptation that might come from three alternative training methods, with the purpose of comparing the neuromuscular adaptation brought on by three different training protocols (HRC, SIT, and TCT) in order to ascertain which one promotes the greatest adaptations.

7.1.2. HRC induced neuromuscular adaptation.

Frequently, it has been explained the initial strength gain following resistance training is due to neural adaptation (132, 133, 522). Those adaptations of the neural training concept were studied with different training protocols by different authors, and it was explained that adaptation within the central nervous system was the anchor aspect to initial strength gain (142, 523 - 525), which resulted in the enhancement of motor unit recruitment and discharge rate (142, 523, 525), decrement of recruitment threshold (526) and enhancement of doublet discharges (527). More specifically, the modulation of motor unit recruitment and discharge rate with training must involve an enhanced net excitatory post-synaptic input to the motoneuron pool or increased motoneuron excitability.

The primary results demonstrated that HRC training protocol induced a significant main time effect on MVC (N) $F (1, 31) = 15.384$, $P < 0.001$ (Table 7A), RFD 50 N·s-1 $F (1, 27) = 8.773$, $P < 0.05$ and RFD 200 N·s-1 $F (1, 27) = 6.775$, $P < 0.05$ (Table 7B) from Pre to Post (within-subjects factor). However, MVC (N) and RFD 200 (N·s-1) following HRC were shown a significant mean difference between the two-time points. Moreover, following HRC intervention observed significant increases in EMG peak (1.77 Δ%), EMG mean (8.75 Δ%), M max (18.26 Δ%), H max (21.65 Δ%), H/M ratio (21.95 Δ%), RFD 50 (12.98 Δ%) and RFD peak (10.84 Δ%), but only MVC (6.71 Δ%) and RFD 200 (12.34 Δ%) were shown statistical significant ($P < 0.05$) differences, while EMG 50 (- 3.66 Δ%) and EMG 200 (- 3.92 Δ%) were decreased but it was not significant. Therefore, the purpose of the present section is to compare the pre and post-intervention effect of HRC (concurrent) training protocols over 08 weeks on neuromuscular adaptation in young recreationally trained male athletes following 8 weeks and will discuss the mechanism behind the changes that occurred following particular training protocol.

However, few studies were conducted directly regarding the HRC training-induced neural adaptation even though it has been revealed following HRC-induced increment of H max, MVC, RFD peak, EMG peak, and EMG mean (115), as well as strength and cardiovascular adaptation (9). Hence, the present study result shows that there was a significant effect between within group of MVC (6.71 Δ%) and RFD 200 (12.34 Δ%) following HRC protocol, the rest of the others such as H max, M max, RFD peak, RFD mean, EMG peak and EMG mean have been shown increased but it was not significant, whereas those results are congruent with the results reported in a previous study of resistance training and their neural adaptation (142, 523 - 525). Preciously, this neural training concept enhanced net excitatory post-synaptic input to the motoneuron pool or increased motoneuron excitability through modulating of motor unit recruitment and discharge rate with training (176), and increases in efferent neural drive could be affected due to the increment in EMG signal amplitude and rate of EMG rise in the early phase of muscle contraction (142). Thereby causing the maximum direct muscle response (M max) to increase, causing the extrafusal muscle to contract, which is resulted to increase maximal force or MVC and RFD.

The findings obtained in the present study may not be only explained by resistance training adaptations, but also by adaptations associated with endurance exercise too because HRC often leads to improving both resistance and endurance adaptation (10, 100). According to the general accordance, increased H reflex amplitude during the voluntary sub-maximal force levels is well established (142, 528). However, an H reflex result following HRC was detected conversely. There was a non-significant ($P > 0.05$) effect between pre and post-through the pairwise comparison (Bonferroni) but have been shown considerable mean differences: H max (21.65 Δ%), M max (18.26 Δ%) and H max M max ratio (21.95 Δ%). Interestingly, the main effect within the group was showed non-significant (P > 0.05) as well.

However, Agaard et al (142) was suggesting that for the precise data of training-induced neural motor function, H – reflex should be measured during actual muscle contraction, not in the rest physical state. Moreover, Aagaard et al. (142) and Lagerquist et al. (528) proved that changes in H-reflex might not consider being related to gain in maximal force or RFD when specially H reflex data collected in rest position because fibre recruitment and discharge rate are totally different. On the other hand decrement in H-reflex, excitability may also represent a beneficial adaptation (78). Furthermore, H-reflex amplitude could be affected during the modulate muscle activation (178), thus between recording attempts the strength of effective stimulus should remain invariant (141).

Moreover, the level of reflex excitability of the motor pool (H max/ M max ratio) which is the facilitation of the transmission between the Ia fibers and the alpha motor neuron (α- MN) following HRC increased, probably due to the methodological characteristics of the particular training method, as well as the training-specific sensorimotor control of the concurrent training itself might differently affect the responsiveness of spinal motoneurons on Ia-afferent inputs. Alterations in the H max/M max ratio following training indicate altered susceptibility of α- MN pool in response to Ia-afferent signals (529). Improved H max/M max ratios following HRC-directed enhanced motor neuron excitability and/or reduced presynaptic inhibition of Ia-afferent terminals (141). Mutually those mechanisms increase α- MN output and subsequently, the neural drive to the muscle. This could beneficial for generating high muscular forces (141).

On the other hand, when muscle electrical activity during muscle contraction, which reflects the functional status of muscles was shown to decrease the mean difference at EMG 50 (-3.66 Δ%) and EMG 200 (-3.92 Δ%), but still the rate at which the muscle's contractile components can generate force (RFD) has been increased significantly (P < 0.05) at RFD 200 (12.34 Δ%), and increased at RFD 50 (12.98 Δ%). It means, even decreased muscle electrical activity during muscle contraction rate of force development has been increased. Parallel to that the EMG of maximal activity of the given muscle during the exercise (EMG peak: 1.77 Δ%) and EMG mean (8.75 Δ%) increased, as a result, the RFD peak (10.84 Δ%) was also increased. Basically, the number of recruited motor units and the discharge rate of each activated motor unit determines both the force a muscle exerts and the amplitude of the EMG. More motor units must be enlisted for stronger muscular contraction. It is unclear how force and surface EMG during voluntary contractions relate to one another. For a variety of muscles, some authors have found that the strength of the muscle is directly correlated with the magnitude of the EMG signal for isometric and/or isotonic contractions at a constant speed, but others argue that this relationship is not linear (347 - 350). However, as previously explained by different authors, such as Guimaraes et al. (530), Madeleine et al. (351); Lawrence and De Luca (352); Solomonow et al. (353) in the present investigation following HRC training protocol induced increases of EMG non-linearly with increasing force of muscle contraction.

Hence, according to the present data HRC induced a significant effect of MVC, and RFD 200 adaptation is more likely to express greater development following 8 weeks of intervention, as well as considerable mean differences of H max, M max, H max/M max ratio, RFD peak, EMG peak, and EMG mean are more likely to express better development following HRC training method. Therefore, collectively HRC seems to lead the adaptations of spinal excitability of the α- MN and transmission efficiency of Ia afferent synapses and motor response, which was lead to enhance recruitment rate muscle fibre conduction velocity (maximal force) as well as increment of RFD. Collectively from all those explanations we can conclude that HRC training led to enhance supra-spinal and spinal adaptation during the intervention (141, 343, 346).

7.1.3. SIT induced neuromuscular adaptation

The foundation of SIT is a series of brief, near-maximal, or supra-maximal sprints. Theoretically, it has been demonstrated that SIT applied for brief intervals of a few weeks to a few months causes enzymatic adjustments in the three energy systems. The significance of the neuromuscular adaptation that occurs after SIT has rarely been discussed to date. The human nervous system, on the other hand, is remarkably flexible in response to many forms of training. Both supraspinal and spinal levels of the brain experience these neuronal changes, which are absolutely training-dependent. Therefore, the current research examined how SIT affected neuromuscular adaptation, including spinal excitability, alpha motor neuron excitability, muscle electrical activity during muscle contraction (EMG), the highest possible voluntary force during muscle action (MVC), and how fast an athlete can develop force (RFD) after 8 weeks of intervention.

However, in the literature, little data are available regarding the neural adaptation induced by sprint interval training. Remarkably, the current study is the first that investigates H-reflex and M-wave responses under such conditions. Hence, the primary results demonstrated that SIT training protocol induced a significant main-time effect on MVC (N) $F(1, 31) = 15.384$, $P < 0.001$ (Table 7A), RFD 50 N·s-1 $F(1, 27) = 8.773$, $P < 0.05$ and RFD 200 N·s-1 $F(1, 27) = 6.775$, $P < 0.05$ (Table 7B) from Pre to Post (within-subjects factor). Moreover, a non-significant mean difference effect was reported for any measured variables between two-time points (pre and post). However, following SIT training protocol observed some increases in MVC (1.40 Δ%), RFD 50 (30.91 Δ%), RFD 200 (1.49 Δ%), EMG peak (7.60 Δ%), EMG mean (5.62 Δ%), EMG 50 (28.77 Δ%), EMG 200 (11.61 Δ%) and M max (2.16 Δ%). Other variables reported decreased mean difference, such as H max (-15.71 Δ%), H/M ratio (-11.48 Δ%), and RFD peak (-4.83 Δ%) following particular training protocol. Therefore, the purpose of this subsection is to compare the pre and post-intervention effects of SIT (concurrent) training protocols over 8 weeks on neuromuscular adaptation in young, recreationally trained male athletes. Latter will discuss the mechanisms underlying the changes that happened as a result of a particular training protocol.

Recently, a novel type of high-intensity interval training known as sprint interval training has demonstrated increases in aerobic and anaerobic performance with a very low time commitment. However, the availability of studies regarding sprint interval training is limited but there were some studies conducted under the name of HIIT instead of SIT (345), even though they used training protocols that were closer to SIT mechanism. Interestingly, the current study is the first that investigates spinal reflex excitability such as H-reflex and M-wave responses as well as RFD peak, EMG peak and EMG mean, MVC, RFD 50, and RFD 200 measures under such conditions.

Comparatively, a decrement of H reflex amplitude was reported in some cross-sectional studies for athletes who trained in anaerobic or explosive sports than athletes who trained in aerobic or endurance sports (354, 179). It probably could happen due to several matters, such as muscle fibre differences (141) or genetic or training-induced decreased synaptic strength of Ia excitatory motoneuron of particular motor neuronal pools (290). Moreover, Nardone and Schieppati (531) in 1988 explained slower muscle fibres contribute more to the H reflex responses. On that basis proposed that slow to fast transformation of motor units might be related to decrease H reflex amplitude (177, 532) indicating possible adaptations in neuromuscular functions, which are the motoneurons, reached the threshold within the low action potential to increase the maximal direct muscle response. It is well-known that motoneurons in type I muscle fibres (slow) are more easily excited by a volley in Ia afferents than those in type II muscle fibres (fast) (Ross et al., 2001 and Casabona et al., 1990) due to the Henneman's size principle.

However, a decrement of the H reflex also denotes beneficial adaptations in sports performances, such as presynaptic inhibition and disynaptic reciprocal inhibitions (Neilsen et al., 1993, Casabona et al., 1990). This will be further confirmed by following the present short burst "all-out" effort sprint interval running training, in which subjects need to perform co-contraction of antagonistic, agonistic, and synergistic muscles to maintain balance, speed, and postures during the running phase. Hence, taking into consideration all the above and the own characteristics of the particular training protocols we can conclude that SIT and TCT encourage the decrement of the maximal reflex electromyographic (EMG) response (H-response, H max) and increment of the maximal direct EMG muscle response (M - response, M max) to enhance motor unit recruitment and discharge rate, which caused possible adaptations occurred in efferent motoneuronal output (Aagaard et el., 2002a) (Figure 5).

Moreover, high stimulation intensity causes H-reflex to disappear or become impossible to record due to collisions between antidromic and orthodromic reflex volleys in the Ia afferent. Additionally, the motoneurons become resistant to reflex input due to the antidromic firing of the motor fibres (355). This would make it less useful for evaluating quick twitch units' resting H-reflex. Another explanation for the diminished H-reflex in anaerobically trained muscles is that long-term training may affect the descending effect. Elite ballet dancers exhibit very little triceps surae reflex activation. The increased chronic co-contraction of lower limb muscles during ballet training (and consequent presynaptic inhibition) may cause a long-lasting reduction in synaptic transmission, according to (533). The emphasis on "toe-up" or dorsi flexed ankles in modern sprint training causes the tibialis anterior and the triceps surae muscle group to contract at about the same rates. This offers an alternative to the slow to quick transition of motor units suggested by Casabona and colleagues for the reduced resting H-reflex seen in sprint athletes (534).

However, Mero, A., and associates (1985) explained that it was difficult to distinguish the difference in EMG due to a lack of transfer from cycle sprint training to maximal isometric contractions, on the other hand, Zhou, S. et al. (1996) proposed that perhaps cycle sprint training changes was not pretty enough to overcome isometric intensive contractions demands. Therefore under all the above explanations, we can suggest that that’s why SIT protocol was not helpful to develop significant MVC or RFD ($P > 0.05$) after intervention due to the own training characteristics. Indeed, it is logical that spinal reflex excitability might be influenced by both the amount and the type of activity routine (533) which was not able to produce enough impulses to achieve MVC or RFD requirements. In contrast, a decreased H max/M max ratio during SIT training suggests that the Ia afferent route has been inhibited, which has lowered the participation of the muscle spindles in producing excitement for muscular activation. Practically, this may avoid reflex-mediated (destabilizing) movement and, as a result, improve the movement regulation of supraspinal centres (356).

As was covered in this section, the majority of research involving sprint athletes and reflex studies has been cross-sectional in nature, making it challenging to distinguish between genetic and training-induced variations. The limited longitudinal research in combination with the predominately cross-sectional research, however, suggests that the H-reflex declines in response to sprint training, reflecting a decline in motoneuron activation either brought on by changes in presynaptic inhibition or possibly connected to a slow to fast motor unit transition. Stretch reflexes, however, are either unaffected by the sprint workout or may even become more sensitive, suggesting that the muscle spindle may have become more sensitive to make up for the decreased motoneuron excitability.

Hence, even though SIT induced increases in MVC, RFD 50, RFD 200, EMG peak, EMG mean, EMG 50, EMG 200, and M max, they did not create enough impulses to increase significantly. Therefore, MVC and RFD according to their own characteristics of training do not favour to increase in MU recruitment and discharge rate. Anyhow, increment of all measured variables except H max, H/M ratio, and RFD peak reviled that the muscle which was training mostly during the intervention might have occurred neural adaptation even though there is a possibility to affect other external factors too. Hence, taking into consideration of all the above explanations and the own characteristics of the particular training protocol we can conclude that SIT led to an improved endurance adaptation by showing positive benefits of decrement in H reflex amplitude and motor unit recruitment and discharge rate, which was caused spinal adaptation during the intervention.

7.1.4. Traditional concurrent training (TCT) induced neuromuscular adaptation

The fact that performance in numerous sports and athletic events depends on different physical performance phenotypes makes it clear that adaptations to exercise vary heavily on the type of activity done. It is not unexpected that research has shown a possible contradiction between strength and endurance training because they represent opposite extremities of the physiological spectrum. However, in order to improve athletic and clinical performance, it is crucial to understand how the simultaneous performance of both forms of training (also known as concurrent training) produces neuromuscular adaptation. However, in the literature, little data are available regarding the supraspinal adaptation induced by TCT. According to the best of our knowledge, the current study is the first one which measured spinal excitability following the TCT protocol, but endurance training-induced spinal α-motoneuron excitability is well established. Therefore, the current section explored how TCT affected neuromuscular adaptation, including spinal excitability, alpha motor neuron excitability, muscle electrical activity during muscle contraction (EMG), the highest possible voluntary force during muscle action (MVC), and how fast an athlete can develop force (RFD) after 8 weeks of intervention.

Nonetheless, the primary results demonstrated that TCT training protocol induced a significant main time effect on MVC (N) $F(1, 31) = 15.384$, $P < 0.001$ (Table 7A) and RFD 50 N·s-1 $F(1, 27) = 8.773$, $P < 0.05$ (Table 7B) from Pre to Post (within-subjects factor). Moreover, following pairwise comparison Bonferroni posthoc test reported non-significant mean differences among any measured variables between two-time points (pre and post) except MVC and RFD 50 N·s-1 ($P < 0.05$). However, following the TCT protocol observed some increases in MVC (11.18 Δ%), RFD 50 (25.06 Δ%), RFD 200 (7.23 Δ%), RFD peak (86.54 Δ%), EMG 50 (3.61 Δ%), and M max (5.24 Δ%). Other variables reported decreased mean difference, such as H max (-6.97 Δ%), H/M ratio (-10.81 Δ%), EMG 200 (-7.65 Δ%), EMG peak (-10.02 Δ%), and EMG mean (-7.87.62 Δ%) following particular training protocol. Therefore, the purpose of this subsection is to compare the pre and post-intervention effects of TCT protocol over 8 weeks on neuromuscular adaptation in young, recreationally trained male athletes. Latter will go through the mechanics underlying the modifications brought about by a certain training regimen as well. As previously stated, a number of factors might contribute to a reduction in H reflex amplitude (See the section HRC induced neuromuscular adaptation). As presynaptic inhibition and disynaptic reciprocal inhibition are also examples of positive adaptation, increases in maximum force or RFD were not correlated with changes in the H reflex (533, 354, 177).

Additionally, slower muscle fibres contributed more to the H reflex responses, as indicated by Nardone and Schieppati (531) in 1988. Accordingly, it was suggested that slow-to-fast motor unit transformation may be related to a decrease in the H reflex amplitude (177, 532). This suggested that neuromuscular functions, which are the motoneurons, may have adapted to reach the threshold within the low action potential to increase the maximal direct muscle response. According to Henneman's size principle, motoneurons in type I muscle fibres (slow) are more easily excited by a volley in Ia afferents than those in type II muscle fibres (fast) (290, 177). Therefore, we can summarize that the TCT intervention of the present investigation encourages the reduction of the maximal reflex electromyography (EMG) response (H-response, H max), and the increase of the maximal direct EMG muscle response (M-response, M max), to improve motor unit recruitment and discharge rate, which was caused by potential adaptations occurring in efferent motoneuronal output (141).

Interestingly, even though there were huge differences between the mechanism of TCT and SIT protocols, the supraspinal changes induced by both are almost equal in the present investigation. Combined strength and endurance training following 8 weeks of intervention induced significant increases in MVC and RFD 50. Interestingly, muscle electrical activity during muscle contraction, which reflects the functional status of muscles (EMG) has been decreased in EMG 200 (-7.65 Δ%), EMG peak (-10.02 Δ%), and EMG mean (-7.87.62 Δ%) following training intervention, but still RFD and MVC has been increased.

As previously explained, this implies that even though there is less electrical activity in the muscles during muscular contraction, the rate of force production has risen. That non-linear relationship between force and surface

EMG during voluntary contractions has been discussed by different authors, such as (347 - 350). However, as previously described by many authors, such as Madeleine et al. (351), Lawrence and De Luca (352), Solomonow et al. (352) in the present investigation following TCT protocol induced increases of EMG non-linearly with increasing rate of force development of muscle contraction. In contrast, as a result of the Ia afferent pathway being inhibited during TCT training, the muscle spindles' contribution to generating excitement for muscular activation has diminished, as seen by a decreased H max/M max ratio. Practically, this may prevent reflex-mediated (destabilizing) movement and enhance the supraspinal centers' ability to regulate movement (356).

According to the best of our knowledge, the current study is the first one which measured spinal excitability following the TCT protocol, but endurance training-induced spinal α-motoneuron excitability is well established. TCT-induced H reflex was showing decreased MD Δ% while M max was showing increased MD Δ%. As previously explained that even though the H reflex has not been increased it has positive benefits, otherwise it was collected in a rest position instead muscle contraction phase. Together, these justifications allow us to conclude that HRC training enhanced supraspinal and spinal adaptation throughout the intervention (141, 343, 346).

7.1.5. Comparison between three different training protocols (HRC, SIT and TCT) induced neuromuscular adaptation.

Sports performance is highly dependent on multiple physical qualities that must be developed simultaneously, having appropriate concurrent training-induced neural adaptation is essential and these adaptations may occur at different levels, such as the motor cortex, spinal cord, and neuromuscular junctions, depending on the stimulus imposed. Thus, this study aimed to compare the effects of 8 weeks of three distinct “concurrent” training protocols on neural adaptation associated with spinal reflex.

The primary results of the present study reported that there were no significant group and time interactions identified for any measured variable. Interestingly, a significant main-time effect was found when assessing the changes in MVC (N) $F (1, 31) = 15.384$, $P < 0.001$ (Table 7A), RFD 50 N·s-1 $F (1, 27) = 8.773$, $P < 0.05$ and RFD 200 N·s-1 $F (1, 27) = 6.775$, $P < 0.05$ (Table 7B) from Pre to Post (within-subjects factor). However, MVC (N) following HRC and TCT methods, as well as RFD 50 (N·s-1) following TCT and RFD 200 (N·s-1) following HRC were shown a significant mean difference between the two-time points. While, there was a significant main effect across the between groups on the M max (mV) $F (2, 31) = 10.778$, $P < 0.05$ (Table 7A), H max (mV) $F (2, 30) = 10.107$, $P < 0.05$ (Table 7A) and H/M ratio $F (2, 30) = 3.778$, $P < 0.05$ (Table 7A) were detected.

In addition, according to the Bonferroni post hoc analysis of between groups, there was significant differences ($P < 0.05$) were shown in M max and H max when comparing the HRC training method from the TCT method ($P < 0.05$), and SIT method from TCT method ($P < 0.05$). Moreover, after considering all mean differences in M max and H max following three training methods HRC training method was shown a greater mean difference than the other two training methods (Figure 26 and 27). Rest of the other variables, even though their training methods were shown some improvement in a particular variable it was not significant between groups.

To the best of our knowledge, no study has been previously reported on an investigation of the effect of 8 weeks of “concurrent” training on neuromuscular variables associated with the spinal reflex. Our results mainly demonstrated that (i) no significant interaction among any measured variables (II) significant main effect between groups in H max, M max, and H max/M max ratio, and (iii) a higher mean difference in H max and M max when comparing the HRC with TCT (HRC vs TCT) and SIT with TCT (SIT vs TCT). Therefore, these results revealed that HRC and TCT promote better neuromuscular adaptations that are more commonly associated with resistance training compared to SIT. Further, SIT induced considerable neural adaptation even though it was less than the HRC and TCT.

HRC training induced an increment of the maximum H-reflex amplitude (21.65 Δ%), which is more related to the results reported in a previous study of high-intensity resistance training and it is a neural adaptation (142, 115). In contrast SIT (-15.71 Δ%) and TCT (-6.97 Δ%) induced decreased H max after a particular intervention which was even in line with the previously reported data (533, 354, 177). However, the behaviour of the maximum H-reflex amplitude is quite confused following the different training protocols.

From that perspective, the addition of a high-intensity stimulus to resistance training modulates the motor unit recruitment and discharge rate, whereas enhanced net excitatory post-synaptic input to the motoneuron pool or increased motoneuron excitability (176), causing to motoneurons to reach their threshold and increases in efferent neural drive could be affected due to the increment in EMG signal amplitude and rate of EMG rise in the early phase of muscle contraction (142). Thereby causing the maximum direct muscle response (M max) to increase, causing the extrafusal muscle to contract. However, decrement of the H reflex also denotes beneficial adaptation, such as presynaptic inhibition and it would cause disynaptic reciprocal inhibition too (533, 354, 177), when subjects conducted the short burst "all-out" effort sprint running they need to perform co-contraction of antagonistic, agonist and synergist muscles to maintain balance, speed, and postures during the running phase.

The availability of studies regarding the SIT and TCT-induced neural adaptation associated with spinal reflex are few than HRC. Remarkably, the current study is the first that investigates spinal reflex excitability such as H-reflex and M-wave responses among the different concomitant training protocols under such conditions. However, the post results of the present investigation of SIT and TCT induced the decrement of maximum H reflex amplitude (H max) compared to the pre-data but the results were not significant. Some cross-sectional studies reported that decrement in resting H reflex amplitude of athletes who trained in anaerobic or explosive sports relative to those who trained in aerobic or endurance sports (354, 179). Most probably it happened due to the muscle fibre differences (141) or genetic or training-induced decreased synaptic strength of Ia excitatory motoneuron of particular MN pools (290). On the other hand, H reflex responses contribute more to slower muscle fibres (531). Accordingly, it was suggested that slow to fast motor unit transformation may be related to a decrease in the H reflex amplitude (177, 532). This suggested that neuromuscular functions, which are the motoneurons, may have adapted to reach the threshold within the low action potential to increase the maximal direct muscle response. According to Henneman's size principle, type I muscle fibers (slow) motoneurons are easier to activate by a volley in Ia afferents than type II muscle fibers (rapid) motoneurons (290, 177).

Collectively, the present data suggest that the increase in motoneuronal output induced by resistance (HRC) training may comprise both supraspinal and spinal adaptation mechanisms (i.e., increased central motor drive, elevated motoneuron excitability, reduced presynaptic inhibition) following HRC training intervention (141, 343, 346). On the other hand, taking into consideration of own characteristics of the particular training protocols we can conclude that SIT and TCT encourage the decrement of the maximal reflex electromyographic (EMG) response (H-response, H max) and increment of the maximal direct EMG muscle response (M - response, M max) to enhance motor unit recruitment and discharge rate, which was caused possible adaptations occurred in efferent motoneuronal output (141).

Previously, this neural training concept enhanced net excitatory post-synaptic input to the motoneuron pool or increased motoneuron excitability through modulating motor unit recruitment and discharge rate with training (176) and increases in efferent neural drive could be affected due to the increment in EMG signal amplitude and rate of EMG rise in the early phase of muscle contraction (142). Thereby causing the maximum direct muscle response (M max) to increase, causing the extrafusal muscle to contract, which is resulted to increase maximal force or MVC and RFD. Hence, more motor units must be enlisted for stronger muscular contraction. It is unclear how force and surface EMG during voluntary contractions relate to one another. For a variety of muscles, some authors have found that the strength of the muscle is directly correlated with the magnitude of the EMG signal for isometric and/or isotonic contractions at a constant speed, but others argue that this relationship is not linear (347 - 350). However, in the present investigation following HRC and TCT training protocols induced increases of EMG non-linearly with increasing force of muscle contraction, in line with the results explained by different authors like Guimaraes et al. (530), Madeleine et al. (351), Lawrence and De Luca (352), Solomonow, et al. (353). In contrast, SIT reported increases in EMG and force of muscle contraction assuming that there is a linear relationship between both (EMG and RFD) variables as previously explained.

Moreover, the level of reflex excitability of the motor pool (H max/ M max ratio) which is the facilitation of the transmission between the Ia fibers and the a-MN following HRC increased while SIT and TCT were shown decrement. It is probably amongst methodological characteristics of the particular training, as well as the training-specific sensorimotor control of the concurrent training itself that might differently affect the responsiveness of spinal motoneurons on Ia-afferent inputs. Alterations in the H max/M max ratio following training indicate altered susceptibility of the a-motor neurone pool in response to Ia-afferent signals (535). Improved H max/M max ratios following HRC directed enhanced motor neurone excitability and/or reduced presynaptic inhibition of Ia-afferent terminals (141). Mutually those mechanisms increase a-motor neurone output and subsequently, the neural drive to the muscle. This could beneficial for generating high muscular forces (141, 536). In contrast, reduced H max/M max ratios after SIT and TCT training indicate inhibition of the Ia afferent pathway resulting in less contribution from the muscle spindles in generating excitation to muscular activation. Practically, this may prevent reflex-mediated (destabilizing) movements (537) and consequently enhance movement control of supraspinal centres (356).

Overall, these observations suggest each training protocol induced diverse neural adaptations associated with the spinal reflex specifically to the training demands. In conclusion, the present investigation has demonstrated that all three training protocol was showing different neural adaptation which was most specific to their own training character. HRC showed supra spinal and spinal adaptation while SIT and TCT protocols showed spinal adaptation during the intervention. It means theoretically all those adaptations even show numerically positive and negative changes practically both changes are significant to enhance sports performance.

7.2. SECTION 02:

7.2.1. Metabolic adaptation following different training protocols

The human body should always progress following exercise training. That progress is frequently determined by the metabolic adaptations that the body makes, which is critical. As a result, metabolic adaptations are changes in the body that allow it to use energy more efficiently and effectively. Predominantly, the anaerobic energy pathway is used to train strength, power, speed, and hypertrophy training. Following the anaerobic energy system involved high intensity, short duration training types possible to observe certain metabolic adaptations.

The body improves its ability to store phosphocreatine and carbohydrates in the muscle for the immediate generation of ATP for energy without oxygen. Better storage means the ATP-PC system can work at a higher intensity. On the other hand, anaerobic enzyme activity is a crucial factor as well. The enzyme activities, like the regeneration process of creatine phosphate utilizing the enzyme creatine kinase, synthesize and catalyze the decomposition of ATP (ATPase), and the production of lactate by decomposition of glucose is increased. ATP-PC energy system is enforced by the improved breakdown of phosphocreatine which assists during the strength, power, or speed performances. Moreover, longer-duration training-induced physiological adaptation (i.e. aerobic endurance, anaerobic fitness, and muscular endurance) is highly dependent on oxygen consumption for energy production. In line with that diverse metabolic adaptations could occur, like regulation of temperature, body acidity level, aerobic enzyme activity & production, and lactate removal which help to continue the exercise for long period.

In addition, it is well recorded in the literature that hematological changes occurred during the different types of exercise. It could be also influenced by health status and may impair exercise performance (357). Thus, respective to the prime objective of the athletes' training should be adjusted to have higher physical or health performance. However, now a day due to the demand for each sport and game as well as other factors time is highly required in line with the lack of time for exercise. Thus, it is always warmly welcoming effective use of time-related training protocols where athletes can achieve higher performance or health within a short period. Therefore, this section will discuss what sort of adaptation could be happened metabolically following three different types of training. Furthermore, the main objective of this section is to compare the metabolic adaptation following three different training protocols (HRC, SIT, and TCT) to determine which protocol allows for better adaptations. Furthermore, it will discuss the individual training protocol-induced mechanical adaptation as well.

7.2.2. HRC induced metabolic adaptation

Among the variety of exercise programs, associating both resistance and cardiovascular contemporary training protocol have increased in demand due to their ability to meet exercise procedures in a time effectual way (358). Nowadays, the most challenging fact is the 'lack of time' which is the primary reason people do not exercise (359), thus all exercise training-related persons desire to develop exercise programs that meet both aerobics and strength achievement in athletes and as well as clients. Therefore, newer exercise programs like high-intensity resistance circuit-based training explain more popular whereas commonly integrated aerobics and resistance adaptation to improve exercise performance.
However, following high-intensity resistance circuit-based related training-induced increases of some metabolic markers, as such RBC (x10*6/mmc): 0.98 Δ%, Hb (gr/100): 0.75 Δ%, HcT (%): 0.80 Δ%, BG (mg/dl): 3.72 Δ%, TC (mg/dl): 0.22 Δ%, TG (mg/dl): 17.49 Δ%, HDL-C (mg/dl): 5.22 Δ% and only LDL-L (mg/dl): -5.16 Δ% was detected decreased % of the mean difference between pre and post-test.

Physical exercise generates a series of alterations in the erythrocyte (Red Blood Cells - RBC) system of peripheral blood cells, resulting in an increase in the oxygen-carrying capacity of the blood. The effects of endurance exercise on red blood cell index have been well documented, including an increase in red blood cell count (360). However, according to the best of our knowledge no studies have been conducted following HRC training protocol-induced blood component adaptation, instead of that there were some studies regarding the resistance training-induced blood component adaptation. Nevertheless, authors like Ahmadizad and El-Sayed (181) and Hu et al. (196) showed that resistance training can increase red blood cell counts in young adults; thus, we believe that resistance training is an effective strategy for improving the red blood cell system. In line with those results reported, we found increased red blood cell (0.98 Δ%) counts even though it was not significant after high-intensity resistance circuit-based training in young recreationally trained athletes.

The main function of RBC during exercise is to transport oxygen from the lungs to the tissues and transport carbon dioxide produced by metabolism to the lungs for exhalation, for that process mainly used hemoglobin. Thus, it is logical that when increased the RBC hemoglobin could also be increased. Following the present investigation results depicted the same increase of RBC, Hemoglobin (0.75 Δ%), and Hematocrit (0.75 Δ%) after HRC training as well. On the other hand, hematocrit is the ratio of the volume of red blood cells to the total volume of blood, when RBC increased simultaneously Hematocrit could also increase.
Most of the time, exercise training induced a decrease in blood glucose levels in the blood, specially following endurance training reported decrease blood glucose levels because muscle function during the exercise helps to burn glucose and improve the insulin works. Therefore generally blood glucose level decrease during exercise. However, authors like XieYaping et al. (538), were reported increased blood glucose levels following resistance training. In line with those results, the present investigation also reported increased (3.72 Δ%) blood glucose levels following HRC training. The reason behind the increase in blood sugar was due to the high-intensity resistance training made from the particular training protocol. It has been caused to produce stress hormones, like adrenalin due to high-intensity training; therefore adrenaline raised the blood glucose levels by stimulating the liver to release the glucose levels. As well as, even it could be due to the high intake of nutrition, but fortunately from the present investigation nutrition intake was controlled.

Circuit training as a form of combination training incorporates multi-joint resistance and other types of training which provoke to increase in heart rate during the training session (101). Due to the special characteristics of the training mode (i.e. very little rest) heart rate (HR), blood pressure (BP), and rate pressure product are increased and remain high as the rest intervals between sets and exercises are decreased (62). Therefore, their own characteristics would significantly increase the physiological stress while decreasing the overall exercise time. According to Paoli and associates (92), 12-week high-intensity circuit training (HICT) program induced the greatest reductions in blood lactate and greater improvement in strength, while Paoli et al. (101) and Miller et al. (59) reported greater reductions in blood pressure, total cholesterol, low-density lipoprotein cholesterol, triglycerides, and increases in high-density lipoprotein cholesterol compared to the endurance training alone or low-intensity circuit training.

Therefore, it would be of great interest to determine the impact of a short-duration HRC program on blood profile, and physical performance. In addition, several authors reported that short-duration high-intensity exercise is a time-efficient modality to significantly improve fitness and attenuate hyperglycemia (59 - 61). Conversely, Ludin et al. (58) reported a significant increment in the blood glucose level following 12 weeks of HICT. If the attenuation in insulin resistance is in fact primarily due to local muscle change in response to high-intensity resistance circuit training, then perhaps the larger the number and size of muscles stimulated the greater the improvement in insulin action. However, the literature is sparse regarding metabolic change induced by HRC in healthy recreationally trained individuals. Even so, following HRC induced significant changes in blood markers (i.e., triacylglycerol, cholesterol, and insulin) and as well as time efficient method compared to endurance/strength alone training methods, still, need to be investigated in different parameters in relevant individuals.

Furthermore, most commonly total cholesterol is measured with LDL-C and HDL-C even though it is arguable. However, as previously reported by Aadahl et al. (153) explained significant associations between physical activity and increases in total cholesterol, LDL-C, triglycerides, and HDL-C among 4,039 participants aged 30–60 years. As well as Vatani et al. (152) reported after 6 weeks of resistance training with various intensities on the lipid profile. Healthy male participants (n = 30) were divided randomly into two groups, a moderate-intensity resistance training programme (45–55 % 1 RM) and a high-intensity resistance training programme (80–90 % 1 RM). Both groups were trained three sessions per week under supervision. Significant ($p < 0.05$) decreases in LDL cholesterol and total cholesterol were found in both groups, as well as significant increases in HDL cholesterol, however, it was observed only in the high-intensity group (+5.5 mg/dL). As well as, some intervention studies also reported improvements in HDL cholesterol (154) and decrease triglycerides (155) in exercise in youth. In the present investigation, some of the results were also equal to the previously reported data, like decreased LDL-C (-5.16 Δ%) and increased HDL-C(5.22 Δ%), following HRC training protocol.

In addition to the effects on insulin sensitivity, we observed significant increases in circulating lipids following HRC training. Exercise training has been shown to increase HDL-C levels; a meta-analysis by Kodama et al. (220) reported increases in HDL when following aerobic exercise guidelines. Thus, the action of Cholesterol Esther Transfer Protein (CETP) produces triglyceride-rich HDL2 particles, resulting in an HDL-C increase following the exercise. Suggesting that HRC training just not only enhances resistance adaptations but also improves the cardiometabolic profile as well. Furthermore, some studies reported that low- to moderate-intensity resistance training can help reduce total cholesterol, whereas some other research shows that all types of weight training can help raise total and LDL-C, but the high intensity is required to raise HDL-C. However, according to the literature, there is an inverse relationship between triglycerides and HDL-C levels. In line with that, the present investigation reported increased triglycerides (17.49 Δ%) and total cholesterol (0.22 Δ%), the mechanism behind the increases those are yet to be investigated.

7.2.3. SIT induced metabolic adaptation

Sprint Interval Training is a sub-type of HIIT but differs drastically in a few ways. As lack of time is a generally quoted reason for physical inactivity, HIIT was also getting more popular among practitioners due to the less time consumed in practice and its effectiveness of the performance. Thus, the apparent time efficiency of SIT was a significant suggestion for this practice of exercise (11,12). However, presently several innovative combinations of SIT protocols are used in the sport context but still have not been systematically investigated for their efficiency in sense of the performance of metabolic or blood lipid profile. Thus, during the present investigation sprint interval group consisted of two blocks. Each block involved six repeated 20-m of running in track with 100% of maximum velocity to obtain VO_2 max.

According to our knowledge, this is the first study conducted short distance running SIT protocol-induced blood lipid profile with recreationally trained athletes. Nonetheless, following SIT induced increases of some blood lipid profile markers, as such RBC (x10*6/mmc): 1.16 Δ%, Hb (gr/100): 0.33 Δ%, HcT (%): 0.95 Δ%, BG (mg/dl): 3.27 Δ%, and some other variables were detected decreased, such as TC (mg/dl): -7.67 Δ%, TG (mg/dl): -1.20 Δ%, HDL-C (mg/dl): -11.35 Δ%, LDL-L (mg/dl): -6.16 Δ%. The cardiovascular system has a responsible role to warrant substrate to working muscle during exercise. Exercise regularly could increase the RBC and hemoglobin, because when muscle work further, they required more oxygen and energy to produce more force. Thus, exercise will order to increase RBC cell production in order to increase the oxygen distribution to the muscles. Thus, the primary role of RBC is the transport of hemoglobin to the working muscle, hence when increasing the RBC level hemoglobin level also increases in the blood. As previously expected, following the present investigation results SIT protocol induced increases in RBC (1.16 Δ%) and Hb (0.33 Δ%) in line with the previous results of Bizjak et al. (199). They reported increased RBC levels and improved performance in individuals who are not endurance trained previously. Regular endurance training leads to the up-regulation of catecholamines, cortisol, growth hormone, and insulin-like factors, which stimulate bone marrow activity and rise erythropoiesis (156).

Erythropoiesis leads to a greater number of reticulocytes, which in turn increases the number of young RBCs (157). This adaptation in response to endurance training could be observed with an increased RBC level.

Among the few research examined the effect of HIT or SIT on the blood lipid profile Tsekouras et al. (160) reported no changes in triglycerides but a significant decrease in fasting very low-density lipoprotein and total cholesterol and LDL-C has not been measured following 4-minute intervals of running at 60 and 90% VO_2max for 32 minutes. Furthermore, Musa et al. (242) reported following 3.2 km run at 90% max HR, no changes in TC and significant changes in HDL and TC: HDL, while triglycerides were not measured. Moreover, Nybo et al. (174) and Wisloff et al. (539) conducted studies by using lower intensity, 2 times per week for 12 weeks. Any changes were not detected in HDL, LDL, or TC by Nybo et al.(174) While Wisloff et al. (539) reported a decrease in triglycerides but no changes in total cholesterol and a trend for an increase in HDL and O'Donovan et al., (250) reported improved blood lipid and lipoprotein profiles. However, all the studies mentioned were conducted following HIT form not in the format of SIT, thus it might not be an appropriate comparison considering the much more intense SIT. Nonetheless, Whyte et al. (74) reported no significant differences in TG, HDL, LDL, or TC following SIT who performed 6 training bouts of 4-6 Wingates with 4.5 minutes of rest between each sprint. However, the following present investigation reported SIT-induced decreases in LDL (-6.16 Δ%), TC (-7.67 Δ%), and TG (-1.20 Δ%) while a significant decrease in HDL-C (-11.35 Δ%). However, contrasting findings were detected from the present investigation which is decreased HDL-C. Theoretically, it might increase following intervention; it could be due to the nutrition intake of particular subjects even though it has been controlled by the research assistance.

The results of the current investigation observed a strong trend for the reduction of circulating total cholesterol (-7.67 Δ %) and triglyceride levels (-1.20 Δ %). The amounts of changes are in line with the results reported by Fahlman et al. (193) and Zaer Ghodsi et al. (158), both studies were conducted 3 times per week, Fahlman, M. M. et al. (193) conducted an endurance programme lasting 50 min per session with older adults, and Zaer Ghodsi et al. (158) conducted treadmill-based sprint protocol comprising 10 × 15 s sprints with 30 s rest with inactive females. However, the current investigation's SIT protocol was only carried out twice weekly for a total of eight weeks, which is much less than previous endurance and run-based high-intensity studies. This may indicate that more lipids are being cleared from the blood or that the liver is secreting fewer lipids into the bloodstream. Longer duration SIT protocols have been demonstrated to promote fat oxidation (159), while long duration (4 min intervals) high-intensity training has been shown to lower very low-density lipoprotein (VLDL) secretion (160). However, this short sprint protocol is still up for discussion.

These modifications were similar to those seen with endurance exercises. Only the endurance-trained group saw an increase in cardiac output. Eight weeks of sprint interval running lowered the area under the curve during an oral glucose tolerance test, improved the Homeostatic model assessment cell index (HOMA-cell index), decreased LDL-C, and decreased total cholesterol (240). These changes were similar to those brought on by endurance training. However, increases in cardiac output were only seen in the endurance-trained group. Sprint interval training for eight weeks also improved the HOMA-cell index, decreased LDL-C, and decreased total cholesterol. It also decreased the area under the curve during an oral glucose tolerance test.

Alternative sprint interval running programs have also been demonstrated to be successful. Twelve weeks of sprint interval running with two-minute intervals of near-maximal exertion enhanced VO_2 max more than an endurance training program (174). This sprint interval running regimen improved plasma glucose after a two-hour oral glucose tolerance test in the same way as the endurance-trained group did. Endurance training, on the other hand, lowered resting heart rate, body fat percentage, and total cholesterol to HDL-C ratio, all of which were not detected in the SIT group. Despite no change in TC, sprint interval running has been demonstrated to raise HDL-C and lower the TC/HDL-C ratio (242). The mechanism underpinning sprint interval running adaptations may be the same as that hypothesized to function under SIT done on a cycle ergometer. A single session of sprint interval running at 90% VO_2 max for three minutes elevated Adenosine Monophosphate-activated Protein Kinase (AMPK) and Mitogen-Activated Protein Kinase (MAPK) phosphorylation (243). PPARG coactivator 1 alpha (PGC-1) expression was also increased, indicating the activation of mitochondrial biogenesis pathways.

Moreover, Babraj et al. (80) reported improved blood glucose control in younger adults following SIT which was conducted 3 times per week, 4 -6 30s sprints with 4 min recovery. As well as, Adamson et al. (162) reported decreased blood glucose levels in middle-aged people following SIT protocol consisted 10 × 6 s sprints with 60 s recovery, twice-weekly. However, interestingly blood glucose level observed following the present investigation was the same compared to the previously mentioned results of the studies. Thus, following the current SIT protocol blood glucose level has risen (3.27 Δ %) after 8 weeks of intervention. The motivation behind the spike in blood sugar was the same as what explains already following the HRC training protocol. Due to the high-intensity sprint interval training produced stress hormones, like adrenaline whereas caused to increase blood glucose levels by stimulating the liver to release the glucose levels. However, the present SIT protocol was only performed 2 days per week for 8 weeks, compared to previous SIT protocols with much lower total sprint times per week, still, it has been stimulated to release the glucose levels from the liver.

Henceforth, taking into consideration of all the above explanations and the own characteristics of the particular training protocol we can conclude that SIT led to an improved blood lipid profile by showing positive benefits of increases of RBC, Hb, HcT, BG, and decreases in LDL, TC, and TG. Surprisingly, significant decreases in HDL were detected after 8 weeks of training intervention which is in contrast to the previous literature; hence it's required more investigation to find what mechanism exactly happens in the body and the blood response after SIT intervention.

7.2.4. Traditional concurrent training (TCT) induced metabolic adaptation

Simultaneously performing endurance and resistance exercise within the same training program presents a theoretically optimal training method for improving sports performance, as well as health benefits from both modes of training. However, many studies provide evidence demonstrating that concurrent training can improve the blood lipid profile compared to performing other training alone. Thus, during the present investigation traditional concurrent training protocol consisted of two blocks of strength training and 15 to 25 min of endurance training whereas the endurance part was realized on the treadmill. The strength training was contained with two blocks and for those exercises which were used for HRC training, the recovery period was three (03) minutes of passive rest separated sets and five (05) min followed by blocks. The Set was undulating during the 8 weeks for young recreationally trained athletes.

It is a well-known matter that the blood lipid profile of each individual is always adaptable according to the particular exercise program. Thus, resistance and aerobic exercise induce different adaptations that are specific to the exercise modality performed. In line with that, the present investigation was observed different blood lipid profile markers, such as RBC (x10*6/mmc): 0.95Δ%, Hb (gr/100): 0.60 Δ%, HcT (%): 1.53 Δ%, BG (mg/dl): 3.80 Δ%, TG (mg/dl): 20.58 Δ%, HDL-C (mg/dl): 3.39 Δ% were detected increased while some other variables such as TC (mg/dl): -5.04 Δ% and LDL-L (mg/dl): -12.98.16 Δ% were detected decreased in the blood.

As earlier defined, resistance and aerobic exercise induce different alterations that are explicit to the exercise modality executed. Contractions of various intensities and durations result in different blood lipid responses. Due to the intensity of the workout induced effect has to be answered mainly by the cardiovascular system, whereas responsible to be distributed substrate to working muscles to produce force during the workout. Thus, it needs to be supplied oxygen and energy in terms of increasing force production. Thus, the exercise required to increase in the RBC and hemoglobin levels in the blood to be able to circulate enough oxygen and energy. As previously expected, following the present investigation results of the TCT protocol induced increases of RBC and Hb levels in the blood. Moreover, the results observed from the present investigation, like decreased total cholesterol and LDL-C, as well as increased HDL-C, were reported by Mann et al. (212) as well, but they reported decreased total cholesterol whereas the present investigation observed increased total cholesterol in the blood.

However, Lee et al. (32); Sillanpää et al. (167) reported decreased total cholesterol in elderly women following 8 weeks and 21 weeks of concurrent training interventions, and also in adult sedentary men (218). In addition, Libardi et al. (213), Damaso et al. (216), and Ghahramanloo et al. (218) observed decreased LDL - C and triglycerides from obese (adolescents and adults) and as well as healthy adult men. Interestingly, the results observed from the present investigation were in line with some results reported previously. On the other hand, Sillanpää et al. (166) reported no major alterations in blood lipids in older men, while LeMura et al. (219) reported the same in young women. However, endurance only training groups of these respective studies were shown some constructive alterations to the blood lipid profile. How it is explained previously these discrepancies in the results between different studies could be related to subject training background, the baseline and physiology characteristics of the subjects, etc. Though Laaksonen and associates (191) suggested that individual who shows dyslipidemia at their baseline level could be achieved more constructive adaptations in blood lipid following exercise training. However, based on the existing knowledge, it is reasonable to assume that combined strength and endurance training could have a beneficial effect on blood lipid concentrations.

In this sense, particularly there is plenty of evidence to prove that endurance training is effective (212) while the majority of studies conducted regarding concurrent training and its consequences mainly compared with endurance training. However, the studies conducted by Libardi and associates (213), used 50% for the endurance training volume of CT protocol intervention with the purpose of maintaining the equal duration of training sessions between groups. Hence, contrasting one training mode or protocol with another is difficult. Authors like Dutheil et al. (214), and Schjerve et al. (215) reported that following the higher intensity of endurance training protocol induced faster and higher improvement of body composition and lipid profiles because Mann and colleagues (212) reported that there is a dose-response relationship arises between training amount and improvement in blood lipid profile. However, contrasting the effectiveness of CT protocol outcome to single-mode training outcome is especially challenging, as well as there is also a lack of research on this specific area. There is more research associated with the elderly (166,167, 32), obese individuals (216), and type 2 diabetics (217) rather than recreationally trained healthy adults. Therefore, the prevailing knowledge relies on the outcomes from these precise subject populations.

Shaw et al. (244) investigated the efficacy of a 16-week moderate-intensity mixed aerobic and resistance training program in previously untrained but instead healthy young men. The 45-minute protocol comprised aerobic activity at 60% HRmax with resistance training (two sets of 15 repetitions) at 60% 1 RM. It was observed that LDL cholesterol was considerably lowered after aerobic and resistance training, although even the reduction was not statistically significant when compared to 45 minutes of aerobic exercise alone. As a consequence, combining the two kinds of exercise resulted in no further LDL - C decrease. However, this study found that weight training might successfully compensate for decreases in aerobic activity. Furthermore, the studies suggested that resistance training benefited additional physiological systems, perhaps making it more effective.

On the other hand, for 12 weeks, Ha and So (245) combined 30 minutes of aerobic exercise at 60-80% of maximal heart rate reserve (HR reserve = maximal heart rate at rest) with 30 minutes of strength training at 12-15 repetitions maximum in 16 volunteers aged 20-26 years. The lipid profile improved after exercise, with decreases in total cholesterol, LDL-C, and triglycerides, though the differences were not statistically significant when compared to controls. The authors hypothesized that the participants were too young to produce the clinically and statistically significant effects shown in prior studies of mostly older or middle-aged people.

The evidence presented above demonstrates the effectiveness of both aerobic exercise and resistance training in controlling and improving cholesterol levels in various populations, using various modes, frequencies, intensities, and durations of exercise. There is scant research on the two modalities combined, but Tambalis et al. (192) observed that while some combination protocols were effective in lowering LDL cholesterol and increasing HDL cholesterol, others were not. Furthermore, there is almost no evidence could be found regarding the blood serums following CT intervention in a recreationally trained healthy population. Hence, it is recommended to investigate the different blood serum factors levels following CT in those particular subjects' populations.

Blood glucose levels generally drop during exercise, although researchers such as Yaping et al. (538) found elevated blood glucose levels during resistance training. The explanation for the blood sugar elevations was due to the high-intensity resistance exercise performed using the specific training program. Because of high-intensity exercise, produced stress hormones such as adrenalin, which boosted blood glucose levels by activating the liver to release glucose levels. On the other side, the rationale for the blood sugar increase was that high-intensity exercise produced stress hormones such as adrenaline, which induced an increase in blood glucose levels by activating the liver to release glucose levels. However, the present TCT procedure was only conducted two days per week for eight weeks, but it was still stimulated to release glucose levels from the liver, eventually identifying increased glucose levels in the blood.

Sigal et al. (169) discovered that combined aerobic and resistance training over a lengthy period of time was better than either mode in isolation in improving glycemic control in well-designed research with statistically robust sample size. However, while there was an increase in training intensity in this trial, combined training was only used singly for the first four weeks, and the type, order, and progression of resistance exercises recommended were unclear and poorly defined. Church et al. (170) discovered that a combined exercise training program was more successful in improving HbA1. Although the authors clearly define the intensity of aerobic and resistance training, as well as the types of resistance exercises, the daily training sequence and progression were unclear.

Such details are critical when it comes to optimizing results, especially for short-duration training regimens.

Despite the fact that there have been limited studies on the combined strength and endurance training-induced lipid profile, this is the first study to investigate whether traditional concurrent training can improve or deteriorate parameters of blood and lipid profile capacity in young recreationally trained subjects. Furthermore, it is obvious that a concurrent exercise training program executed for a short period of time might result in good adaptations while taking into account variables such as a personalized training method during supervised sessions, as well as the sequence of application. As a result, addressing these difficulties is the major goal of the current study, which hypothesizes that a well-designed, short-term classic concurrent training program can lead to an improved lipid profile. Finally, as a result of the current study, there was a rise in HDL-C and blood glucose, as well as a decrease in TC and LDL-C in young recreationally trained subjects.

7.2.5. Comparison between three different training protocols (HRC, SIT and TCT) induced metabolic adaptation.

The increase in physical exercise has been suggested from the perspective of improving sports performance and health benefits. On the one hand, aerobic exercise induces considerable improvements in fasting glucose, HDL-C, TG, diastolic blood pressure (DBP), and cardiorespiratory fitness in middle-aged and older persons (246). Resistance training (RT), on the other hand, is an exercise plan that develops muscle mass and strength, improves insulin sensitivity, promotes glucose oxidation (247), and lowers the risk of early mortality (248). Notably, concurrent training, which combines resistance training and aerobic exercise, might provide the advantages of both interventions (248).

The current study, on the other hand, looked at the effects of HRC, SIT, and combined strength and endurance training (TCT) on the serum lipid profiles of young recreationally-trained people. The main findings were that 8 weeks of concurrent training resulted in substantial and non-significant changes in the various serum lipid profile variables depending on the training program. Furthermore, the modes, frequencies, intensities, recovery, and durations of exercise appear to impact the extent of modifications, as diverse gains were reported after the HRC, SIT, and TCT groups.

The main statistical conclusion from this section of the study was that the intensity, volume, and type of exercise in each training program caused distinct levels of blood lipid profile in certain subjects. Interestingly, significant interaction (time*group) was reported on HDL-C: $F(2, 28) = 6.385$ $P < 0.05$. Moreover, non-significant main effects between groups and Bonferroni post hoc test differences were detected for all variables. Conversely, there was a significant main effect across the two-time points on Basel blood glucose (BG) $F(2, 28) = 4.564$ $P < 0.05$, while among all variables and HDL following SIT training induced significant differences ($P < 0.05$) between pre and post-test (within a group). Nevertheless, these results depicted that no training method was better than the other training protocol due to the existence of non-significant between-group differences. However, TCT intervention was shown much better increases of mean differences (numerically) in RBC (0.95 Δ%), Hb (0.60 Δ%), Hct (1.53 Δ%), BG

(3.80 Δ%), and decrease of LDL-C (-12.98 Δ%), TC (-05. 98 Δ%) rather than other both (HRC and TCT) training protocols even though mean differences of groups were not significant.

Blood lipid alterations in exercise regimens of varying intensities have shown conflicting outcomes. It has been argued that high intensities are not necessary if lipid changes are the purpose of training (28); yet, it has been observed that lipid alterations are impacted by exercise intensity (250). Nevertheless, authors like Ahmadizad and El-Sayed (181) and Hu et al. (57) showed that resistance training can increase red blood cell counts in young adults; thus, we believe that resistance training is an effective strategy for improving the red blood cell system. Not only that Bizjak et al. (199), were reported increases in RBC levels and improved performance in individuals who are not trained in endurance previously.

Moreover, Bassi et al. (361) reported following concurrent training (Resistance and endurance training) increases RBC levels. In line with those results reported by different authors following three different training protocols, we found increased red blood cell counts in HRC: 0.98 Δ%, SIT: 1.16 Δ%, and TCT: 0.95 Δ% even though it was not significant after the three different interventions in young recreationally trained athletes. The main function of RBC during exercise is to transport oxygen from the lungs to the tissues and transport carbon dioxide produced by metabolism to the lungs for exhalation, for that process mainly used hemoglobin. Hemoglobin also contributes to the buffering capacity of the blood, and the ATP and NO released by red blood cells help dilate blood vessels and improve blood flow to working muscles Thus, it is logical that when increased the RBC levels in the blood hemoglobin could also be increased. Following the present investigation results depicted the same increase of Hemoglobin HRC: 0.59 Δ%, SIT: 0.59 Δ%, TCT: 0.60 Δ% and Hematocrit HRC: 0.80 Δ%, SIT: 0.95 Δ%, TCT: 1.53 Δ% following a training intervention. On the other hand, hematocrit is the ratio of the volume of red blood cells to the total volume of blood, when RBC increased simultaneously Hematocrit could also increase.

Generally, by increasing catecholamines, cortisol, growth hormone, and insulin-like hormones on a regular basis, endurance exercise stimulates bone marrow activity and increases erythropoiesis (Mairbaurl, H. 2013). More reticulocytes are produced as a result of erythropoiesis, which in turn results in more young RBCs (362). This adaptation in response to endurance training could be observed with an increased RBC level. The circulatory system must ensure substrate delivery to working muscles during activity. As previously explained RBC's primary role during exercise is to transfer O_2 from the lungs to the tissues and to deliver metabolically generated CO_2 to the lungs for expiration. Hemoglobin also adds to the buffering capacity of the blood, and the release of ATP and NO from red blood cells contributes to vasodilation and increased blood flow to working muscles. These tasks need a sufficient number of red blood cells in circulation. Trained athletes, particularly those involved in endurance sports, have a lower hematocrit, which is commonly referred to as "sports anemia." This is not anemia in the clinical sense, because athletes have a higher total mass of red blood cells and hemoglobin in circulation than sedentary people. Training causes a modest drop in hematocrit due to increased plasma volume (PV). The methods by which exercise increases total red blood cell mass are not entirely understood.

On the other hand, following the present investigation three different training protocols induced similar as well as different adaptations. Following SIT protocol decreased TC, TG, HDL-C, and LDL-C were identified. On one hand, following the TCT protocol observed decreased TC, and LDL-C levels in the blood while HRC induced only decreased LDL-C levels in the blood. However, following the TCT protocol HDL-C was increased, and TC, HDL-C was reported to increase in blood level after HRC protocol. Unexpectedly, Triglycerides were observed to increase in blood level following strenuous exercise like HRC protocol, whereas need more studies to understand the underlined mechanism.

The results presented above lend credence to the idea that physical activity and exercise might be used to decrease cholesterol levels. Regular physical exercise has been proven to raise HDL cholesterol while lowering LDL cholesterol and triglycerides, presumably offsetting the increase in HDL cholesterol. The relation between physical activity levels and HDL cholesterol levels appears to be linear (i.e. linear dose–response relationship). However, more exercise is necessary to reduce LDL cholesterol and triglyceride levels. Aerobic exercise at high intensities appears to be more effective than physical activity in changing the lipid profile by beginning the clearance of plasma LDL cholesterol and triglycerides. The dose-response relationship between the lipid profile and energy expenditure appears to be independent of exercise style. Increases in calorific expenditure caused by aerobic exercise (by the higher intensity and/or duration) have been demonstrated to improve lipoprotein lipase activity, HDL cholesterol levels (363), and lipid profile (364). During strength training, increasing the volume of movement via an increased number of sets and/or repetitions has been found to have a bigger influence on the lipid profile than increased intensity (e.g. via high-weight low-repetition training) (365, 366).

Exercise is widely documented to increase skeletal muscle glucose absorption via an insulin-independent mechanism (367), suggesting that muscle contraction has a direct impact on glucose homeostasis. Skeletal muscle plays an important role in glycemic control and metabolic balance since it is the primary site of glucose elimination under insulin-stimulated conditions (368). Although both aerobic and resistance exercise can deliver considerable health benefits, the signaling pathways and physiologic implications differ depending on the training type (369). However, the information uncovered as a consequence of the present study was consistent with previous findings. Every protocol used during the present investigation increased blood glucose levels after their intervention (HRC: 3.72 Δ%, SIT: 3.27 Δ%, and HRC: 3.80 Δ%).

Blood glucose levels typically fall during activity, however, it is possible to increase blood glucose levels after exercise. The blood sugar increase was explained by the high-intensity resistance exercise done applying the specified training regimen. Because of the high intensity of the exercise, stress hormones such as adrenalin were released, which increased blood glucose levels by stimulating the liver to release glucose levels.

In conclusion, the present findings it possible to say no training method is better than the other. However, it is suggested that recreationally trained individuals can improve their blood lipid profile following three different training protocols. However, the TCT protocol was an ideal training method to decrease the total cholesterol levels in the body and increase the HDL-C, but SIT protocol is a time-efficient strategy for performance-based programs that induced a decrease in cholesterol, triglycerides, and LDL-C. High-intensity resistance circuit-based training (HRC) also is induced like other training protocols positive and negative alterations whereas each user could be able to select any training protocol according to their needs.

7.3. SECTION 03:

7.3.1. Cardiorespiratory adaptation following different training protocols

The heart is the principal pump that distributes blood throughout the circulatory system, performing several vital activities in the body. Exercise training causes beneficial anatomical and physiological changes that improve athletic performance. Exercise-induced physiological cardiac hypertrophy improves heart function as compared to pathological cardiac hypertrophy. Exercise-induced cardiac remodelling is linked to gene regulatory systems and cellular signalling networks that are involved in cellular, molecular, and metabolic changes. Exercise training also boosts mitochondrial biogenesis and oxidative capability, which reduces cardiovascular disease and improves sports performance.

Regular exercise training is known to be an effective intervention that improves the quality of life and extends life expectancy (370, 371). Furthermore, the resistance and endurance training have long been known to alter the cardiovascular system. On one hand, endurance training improves cardiac output, vascular conductance, muscle perfusion capacity, and oxygen extraction, resulting in an increase in aerobic power, according to human research done in the 1960s and 1970s. On the other hand, Pearson et al. (372) reported significantly greater absolute stroke volume following resistance training. Moreover, Ozaki et al. (373) reported when young and old people have initially poor fitness levels, resistance training can be predicted to enhance both muscular and cardiovascular fitness within a single mode of RT.

Although the benefits of regular exercise training are multifaceted and reflect integrated adaptations in multiple organ systems (374, 375), many research have been reported volume, intensity, recovery and frequency… etc. for specific cellular and molecular processes personally liable for overturning cardiac adaptation but yet to figure out which exercise protocol could be given more benefits. Furthermore, due to the great demand for each activity and game, as well as other variables, time is now extremely valuable, resulting in a shortage of time for exercise. As a result, it is usually warmly welcomed when athletes are able to obtain improved performance or health in a short period of time through the application of time-related training routines. Therefore, this section will explore what kind of cardiorespiratory adaptation might occur as a result of three different forms of training. Moreover, the primary goal of this part is to compare the cardiorespiratory adaptations following three distinct training protocols (HRC, SIT, and TCT) in order to determine which protocol allows for greater adaptations. Furthermore, it will also go over how the individual training protocol induces cardiorespiratory adaptation as well.

7.3.2. HRC induced cardiorespiratory adaptation

Currently, programs to increase cardiovascular adaptations have begun to replace low-intensity exercise with repeated short-to-long bouts of high-intensity exercise separated by rest intervals (376). Unlike classic endurance-based HIIT, a relatively new variety that adds multi-stimulating, circuit-like, multiple-joint, high-intensity resistance training (HRC) is increasing in popularity among fitness and performance enthusiasts. In addition to allowing for appropriate training prescription design with adequate work-to-rest ratios, order of loading, and distribution of training intensity, with shorter session durations (30-40 minutes) than low-intensity-high volume training, which is appealing, given that insufficient time appears to be among the primary reasons for not exercising. As a result, modern exercise programs, such as high-intensity resistance circuit-based training, are more popular, whilst aerobics and resistance adaptation are widely integrated to increase exercise performance.

Furthermore, Muñoz-Martínez et al. (100) reported that high-intensity resistance circuit training has been used in athlete periodization programs as an initial kind of training for increasing cardiovascular fitness and 1-RM. However, the results of CT in trained athletes are debatable, because some studies like Wilmore et al. (93) conclude that aerobic adaptations may be lower in those who are fitter, whereas other high-intensity resistance circuit training studies like Alcaraz et al. (10), Ramos-Campo et al. (90) conclude that using heavier loads for developing strength and cardiorespiratory fitness is much more likely to improve them. Hence, the present investigation observed the influence of high-intensity resistance circuit-based training on cardiorespiratory variables such as maximum oxygen consumption (VO_2 max), maximum oxygen consumption reserve (VO_2 max R), Maximum heart rate, maximum velocity, and Maximum time data following the exhaustive ramp incremental test (VO_2 max test). Thus, this section describes how HRC intervention has induced the alterations in cardiorespiratory markers during the 8 weeks.

The relative VO_2 max at the onset of training in most resistance training trials in young people varied between 45 and 55 ml/kg/min (373), which is within typical limits for lean untrained young adults (377). According to these investigations, there was no significant change in VO_2 max after resistance training. However, in a few investigations, individuals who had a relatively low VO_2 max at the beginning of the training raised their VO_2 max considerably after the RT program. To exemplify, two studies (30, 378) found that following resistance training, VO_2 max increased by 9 and 6%, respectively, and that starting VO_2 max was around 39 ml/kg/min in both trials. Furthermore, Hu et al. (379) found that after 10 weeks of resistance training, the VO_2 max increased by around 8% (pre-resistance training VO_2 max was 36 ml/kg/min). These findings imply that VO_2 max may increase in young participants after resistance training if their initial relative VO_2 max is less than 40 ml/kg/min.

Hence, in line with the previously reported data present investigation also detected some statistical increases following the HRC training protocol, such as VO_2 max (1.81 Δ%), VO_2 max R (1.66 Δ%), Maximum Time (0.67 Δ%) and some decreases like Maximum Heart Rate: -0.73 Δ%, maximum Velocity (- 0. 12 Δ%) as well but none of them were not statistically significant.

However, possible mechanisms for increasing VO_2 max following resistance training could be the increases in cardiac output (Stroke Volume Maximum and Heart Rate Maximum) and Arteriovenous Oxygen difference (a-VO_2 diff - muscle capillary density and myoglobin concentration) contribute to the Resistance Training-induced improvement in VO_2 max. Other factors that may boost VO_2 max include increases in muscle mass and blood supply to the exercising muscle.

In addition to that, differences in Heart Rate and Stroke Volume maximum were reported by different authors like Frontera et al. (275) and Vincent et al. (380). They reported following resistance training no significant difference in Heart Rate maximum (Max HR) at maximum exercise intensities between pre- and post-resistance training. Perhaps, the changes in Stroke Volume might explain the observed increases in VO2 max, especially in older persons. According to Lovell et al. (540) study, the following 16 weeks of RT resulted in a considerable increase in Stroke Volume. During physical activity, Stroke Volume grew linearly from pre-exercise values and peaked at 40% VO_2 max, and thereafter Stroke Volume is maintained during exercise at the 40% intensity, with no significant difference in Stroke Volume between pre- and post-training at 50% VO_2 max and 70% VO_2 max. Interestingly, the same study (Lovell, D. I. et al. 2009) found that a change in a-vO_2 diff, rather than a change in SV, is a key contributor to boosting VO_2 max. Unfortunately, no study has been conducted to investigate the dose-response connection between beginning VO_2 max and the rise in VO_2 max following traditional resistance training; hence, more research is required.

Hence, the previously mentioned data is in line with the results observed following the HRC training protocol conducted with healthy young recreationally trained subjects. Due to the cardiorespiratory changes that occurred following the particular training protocol blood circulation increased for beat per minute shows that the volume overload-induced left ventricular hypertrophy is most likely the cause of the increased maximum stroke volume (381) and the time taken to conduct the activity has been increased, thus increased VO_2 max and VO_2 max R observed following increased maximum time and decreased maximum velocity of the training actions at peak O_2 consumption (VO_2 max). Moreover, additional factors that might contribute to the rise in maximum stroke volume (SVmax) include improved catecholamine sensitivity and an increase in blood volume. The rise in a-VO_2 diff is primarily brought on by an increase in muscle myoglobin concentration and capillary density (35) as well as quantitative and qualitative modifications to the mitochondria.

Interestingly, in line with the linear relationship between VO_2 max and RMR (549), following HRC training intervention was reported increased RMR and RER. However, resulting RER test, no measured variables were significantly improved or decreased following HRC protocol. Yet, it has induced decreases in VO_2 R (-0.49 Δ%), RER (- 2.20 Δ%), HR (-1.05 Δ%), and MET (- 0.86 Δ%) and while O_2 and CO_2 have not been getting any changes.

Decreased RER depicted that HRC training protocol induced to use of a mix of fat and carbohydrates predominantly during the rest period due to the training intensity but decreasing the heart rate. This means, during the rest period volume of CO_2 being produced by the body is higher than the amount of O_2 being consumed. Therefore the amount of air remaining in the lungs at the end of a normal exhalation (VO_2 R) is increasing during less breath or heart rate. However, the amount of oxygen consumed during the rest period (MET) is remaining the same. This indicates that HRC was induced to work anaerobically whereas during the rest period produced more CO_2 than consumed O_2, which used to burn more calories by using fat and carbohydrate during the rest period than the workout time without increasing the heart rate. The data show that the HRC training may lead to enhancements in cardiorespiratory function during a long-term intervention, according to the HR results. It is therefore possible to conclude that HRC training was linked to a shorter training period and yet a higher intensity in terms of the HR response.

7.3.3. SIT induced cardiorespiratory adaptation

Sprint interval training improves endurance exercise performance and induces a variety of beneficial metabolic and cardiovascular responses (11, 12, 268). Despite a significantly shorter training period and lower training volume, these changes are equivalent to those seen after endurance training (12). On the other hand, it is commonly established that either continuous or interval training programs can increase physical fitness. Traditional endurance training (TET) incorporates both and demands a large time commitment, like ~ 30–60 min.d-1 during multiple days per week (315). Gibala et al. (11) and Burgomaster et al. (12) have recently proven that SIT: four to six bouts of 30-second "all-out" exercise followed by four-minute rest intervals three times per week for six weeks have been induced equivalent muscular and aerobic performance adaptations as TET in less than half the time per session. In addition, to enhance VO_2 max, the American College of Sports Medicine suggests 20-60 minutes of aerobic activity (e.g., walking, running, and cycling) at an intensity of 40-50% VO_2 max or higher, 3-5 days per week (Garber et al. 108)

TET-related physiological adaptations have been extensively studied by different authors, including central: cardiac output (382) and peripheral: skeletal muscle arterial-venous oxygen difference (a-VO_2 difference) adaptations (383, 384), resulting in increased VO_2 max, improved exercise capacity, and improved overall health (11, 315). Remarkably, SIT has been shown to increase not only anaerobic (glycolytic) metabolism but also aerobic (oxidative) metabolism (75, 11, 12). Furthermore, these metabolic adaptations have improved a wide range of performances, including those requiring major aerobic metabolism (e.g., cycling time to exhaustion tests and time trials ranging in distance from 2 to 40 km) (75, 11, 62) These results are rather surprising given the short time commitment required for SIT and imply that some kind of this sort of training might help not just athletes but also the general adult population that appears to lack the time to exercise.

Furthermore, running and cycling SIT programs have frequently been shown to be time-efficient methods of improving endurance exercise capacity, as measured by time to exhaustion or time-trial performance (73, 11).

Cardiopulmonary adaptations are most likely to blame for these gains in endurance performance (1). Reduced exercise heart rate (385, 12) Increased stroke volume (386), lower arterial stiffness (385, 326), better endothelial function (385), and higher skeletal muscle capillarization are all cardiopulmonary adaptations to SIT that may contribute to improved endurance performance. Thus, one component of the adaptive response to SIT is angiogenesis. The angiogenic factors that cause the observed angiogenesis after SIT have not been completely elucidated yet.

However, in line with the previously reported data from different studies, the present investigation also detected some increases following SIT protocol, such as VO_2 max: 2.58 Δ%, VO_2 max R: 3.11 Δ%, while Maximum Time: 5.15 Δ% and maximum Velocity: 4. 29 Δ% were reported statistically significant increases but Maximum Heart Rate was not changed during the pre-post intervention. It means that even though the maximum time of the VO_2 max test and the maximum velocity of the movement has been increased significantly without changing the heart rate during the test. Interestingly, even though the heart rate has not changed the maximum oxygen consumption and maximum oxygen consumption reserve have been increased. Seems like the amount of blood pumped out from the heart per each beat (stroke volume) had been increased, but the heart rate was not been changed. However, following the above reason most probably cardiac output increased and the efficiency of O_2 extraction of muscle from the blood and their consumption increased, therefore as a reason, VO_2 max and VO_2 max R have been increased. Suggested a possible mechanism behind that could be due to the size of the left ventricular chamber having grown or the ability of the heart's muscles to contract having improved.

Furthermore, in line with the increases of VO_2 max following SIT, the increases of RER (4.65 Δ%), VO_2 R (0.25 Δ%), and CO_2 (3.57 Δ%) were detected through RER test, while HR (-6.20Δ%) was decreased. Interestingly, O_2 and MET have not been getting any changes. It is evident that there was a positive relationship between resting metabolic rate and cardiorespiratory fitness. Higher muscle strength and VO_2 max were associated with higher RMR. A linear relation was found between VO_2 max and RMR (549).

This indicates that SIT increased the quantity of oxygen that remained in the lungs and airways after a maximum expiration with fewer heartbeats. Moreover, the amount of energy the body normally burns when at rest (RMR) has been increased following SIT intervention, which is used for metabolism training. The present data depicted that SIT requires a short pause between exercises to optimize calorie burn by using fat and carbohydrate and raising metabolic rate both during and after the workout. Additionally, carbon dioxide generation and oxygen intake are employed as a proxy for metabolic rate. This works because food is broken down by oxygen during cellular respiration, which also increases the creation of water, carbon dioxide, and energy, while the ratio between the metabolic production of CO_2 and the uptake of oxygen (RER) has been increased suggesting mixed carbohydrates and fat used as a predominant energy source, it could be due to the intensity of the training protocol.

7.3.4. Traditional concurrent training (TCT) induced cardiorespiratory adaptation

Individually, strength and endurance training regimens reflect and generate completely different adaptive responses. Strength-training regimens typically comprise broad muscle group activation of high-resistance, low-repetition exercises to develop skeletal muscle force output capabilities (313). Endurance-training regimens, on the other hand, use low-resistance, high-repetition workouts like running or cycling to raise maximal O_2 uptake (VO_2 max). As a result, the adaptive responses in skeletal muscle to strength and endurance training differ and might be contradictory (251). Thus, a variety of researchers studied the probable benefits of combined endurance and strength training on maximum oxygen consumption (VO_2 max) in untrained persons or non-athletes, with varying results. Therefore, the goal of this section is to look at the effects of traditional concurrent training on cardiorespiratory adaptation in young recreationally trained male athletes.

The primary results demonstrated that combined endurance and strength training induced statistically significant increases in VO_2 max: 4.75 Δ%, VO_2 max R: 4.82 Δ%, Maximum Time: 7.75 Δ%, maximum Velocity: 4. 01 Δ%, and decreased statistically non-significant Maximum Heart Rate: -0.39 Δ% in young recreationally trained male athletes.

Interestingly, there were significant main effects were detected across the subject factors of all variables except maximum heart rate at VO_2 max. Thus, the variables which were shown significant main effects such as Maximum velocity at VO_2 max: $F (2, 29) = 14.104$ $P < 0.05$, VO_2 max: $F (2, 29) = 8.141$ $P < 0.05$], Max VO2R: $F (2, 29) = 12.869$ $P < 0.05$ and Maximum time at VO_2 max: $F (2, 29) = 20.005$ $P < 0.05$. On the other hand, through pair-wise comparison of the Bonferroni post hoc test were detected significant differences ($P < 0.05$) between two-time points on maximum velocity, VO_2 max, Max VO_2R, and maximum time at VO_2 max following TCT intervention, as well as maximum velocity and maximum time at VO_2 max following SIT intervention were also shown significant difference ($P < 0.05$) between pre and post-test results.

Following the present investigation, eight weeks of combined strength and endurance training, the intervention group improved their maximum oxygen consumption. The significant differences between PRE and POST readings ranged from 4.75 Δ%. Other researchers have explored concurrent training in active university students, inactive college subjects, and young, healthy subjects during a 6- to 8-week period of time (32, 323, 387). The improvement in endurance performance following concurrent endurance and strength training has previously been reported due to fibre type distributions and properties (increase in size of type I fibres, changes in myofibril contractile properties, and changes in type II subtype ratios) (251, 388, 308), which may have also contributed to our current study.

However, the VO_2 max adaptations in our current study differ from Davitt and colleagues' (323) study, which reported an improvement of 15.6% (Strength + Endurance) and 15.3% (Endurance + Strength) following 8 weeks of combined Strength + Endurance training. In comparison to our Strength + Endurance intervention group's results, the possible effect might be explained by their training volume (2 days per week vs. 4 days per week). Nonetheless, Collins and Snow (389) found that same-session combined Endurance + Strength and Strength + Endurance training increased VO_2 max by 6.2% and 6.7%, respectively, following a 7-week intervention period, which was very close to our current findings, although training volume was not indicated in the publication. The reason behind such variations in performance might be the impact of training volume, as well as the diverse intervention groups (female only in Davitt et al. (323) vs. mixed gender group in Collins, M. A. and Snow, T. K. (389). Furthermore, following 8 weeks, Irving et al. (390) discovered that VO_2 max improvements were comparable in younger persons (12%) but differed in the older group (23%). The disparities might be attributable to age groups (younger subjects: 18-30; older subjects: 65) as well as the intervention approach (mixed method of different days and combined Strength + Endurance training in the same session) (390)

Moreover, effects in VO_2 max can also be detected with extended intervention periods. In male athletes, a 12-week intervention (2 sessions per week) resulted in a 12-14% increase in maximal oxygen consumption (388). Prior fitness levels and gender were found to be the most diverse [Chtaraet al. (388): aerobically fit male vs. Gravelle and Blessing (2000): inactive female], indicating that the analyzed population may have an influence on those disparate values. This assumption is consistent with Kraemer and colleagues' findings (27). They showed 8% improvements in VO_2 max in Endurance + Strength training groups in healthy young untrained subjects (age 23±4) after 12 weeks of training compared to the results of Chtara and colleagues (388) (14%). Despite the fact that both studies were conducted with male volunteers, the preceding level of fitness may have played an influence on the outcomes (healthy untrained vs. sports students). Concurrent training is expected to have a greater effect on trained individuals than on untrained ones (323), even though this has not been proven in a shorter period of time (Psilander, N. et al. 2014).

Häkkinen et al. (159) trained untrained subjects for 21 weeks, resulting in a 19% rise in VO_2 max in the combined strength and endurance training group. Even with somewhat extensive training, the general nature of the interference effect has not been proven, as in prior investigations (19, 21). The concept of central circulation is thought to be dominant, determining largely maximal aerobic power during exercise with large muscles (159). Resistance therapies appear to have a negligible effect on central circulatory adaptations, which are most likely related to endurance performance (30). However, research in trained populations revealed that adding strength training to their endurance training programs had no (significant) influence on VO_2 max regardless of the length of time or volume of the treatments. Thus, numerous factors account for the increases in VO_2 max; training level of the individual and expertise, exercise intensities, the timing of the intervention … etc.

Following the TCT protocol led to substantial increases in VO_2 max: 4.75 Δ%, VO_2 max R: 4.82 Δ%, maximum time: 7.75 Δ%, and maximum velocity: 4.01 Δ% during the pre-post intervention, while non-significant decreases in maximum heart rate: -0.39 Δ%. It indicates that although the maximum VO_2 max test duration and the maximum running speed during the test have both been greatly increased, the heart rate throughout the test has decreased. The maximal oxygen consumption and maximum oxygen consumption reserve have increased, which is interesting because the heart rate has reduced. Although the heart rate appeared to have reduced, it appeared that the amount of blood the heart pumps out with each beat (stroke volume) had increased. However, as a result of the aforementioned factor, cardiac output most likely increased as well as the effectiveness of O_2 extraction of muscle from the blood and their consumption. As a result, VO_2 max and VO_2 max R have increased. Increases in the size of the left ventricular chamber or improvements in cardiac muscle contractility have been suggested as potential mechanisms for this.

Interestingly, according to the liner relationship between VO_2 max and RMR explained by Ebaditabar et al. (549), present investigation results also reported statistically significant increases in RER (5.56 Δ%) and non-significant increases in CO_2 (4.17 Δ%) following TCT protocol, while decreased HR (-2.57 Δ%), VO_2 R (-3.89 Δ%), and MET (- 2.73 Δ%) were detected, whereas O_2 has not been shown any changes. Due to the increases in RER depicted that mixed fat and carbohydrate were used as a predominant energy source during the rest period, it means the volume of CO_2 being produced by the body is higher than the amount of O_2 being consumed during the rest period. In line with that, the amount of O_2 consumed during the rest period (MET) and the amount of air remaining in the lungs at the end of a normal exhalation (VO_2 R) was decreased during the less number of breaths or heart rate were also detected.

This indicates that TCT induced to work aerobically whereas using fat and carbohydrate to produce energy during the rest period, while it allows producing more CO_2 than consumed O_2 with a much more low level of heart rate than before training intervention, therefore obviously decreasing VO_2 R. Moreover, increase VO_2 max and decreased HR were inversely related. Hence, finally, TCT induced better adaptation in resting metabolic rate after 8 weeks of training intervention.

7.3.5. Comparison between three different training protocols induced cardiorespiratory adaptation.

The purpose of the present study was to compare the effect of three different concurrent training protocols over 08 weeks on cardiorespiratory adaptation in young recreationally trained male athletes aged between 18 to 35 years. The study compares the three different training protocols for being able to define which training protocol induces more cardiorespiratory adaptation during the 8 weeks of intervention.

The primary results demonstrated that among all the other variables only maximum velocity at VO_2 max was shown a significant interaction between groups of training methods and the time of measurement $F (2, 29) = 3.909$ $P < 0.05$. Moreover, there was a non-significant main effect were shown across the between groups on any variables, but the comparison between HRC from TCT and SIT from TCT on VO_2 max were detected with significant difference ($P < 0.05$) through Bonferroni post hoc test. Interestingly, there were significant main effects were detected across the subject factors of all variables except maximum heart rate at VO_2 max. Thus, the variables which were shown a significant main effect like Maximum velocity at VO_2 max: $F (2, 29) = 14.104$ $P < 0.05$, VO_2 max: $F (2, 29) = 8.141$ $P < 0.05$], Max VO_2 R: $F (2, 29) = 12.869$ $P < 0.05$ and Maximum time at VO_2 max: $F (2, 29) = 20.005$ $P < 0.05$. On the other hand, through pair-wise comparison of the Bonferroni post hoc test were detected significant differences ($P < 0.05$) between two-time points on maximum velocity, VO_2 max, Max VO_2 R, and maximum time at VO_2 max following TCT intervention, as well as maximum velocity and maximum time at VO_2 max following SIT intervention were also shown significant difference ($P < 0.05$) between pre and post-test results.

This led to the suggestion that the three different concurrent training protocols' effects were observed presuming superior endurance performance when conducting combined strength exercises and endurance exercises rather than other forms of training methods, even though the magnitude of adaptations of HRC and SIT intervention groups were increased the endurance performance, but unfortunately those are not statistically significant.

Moreover, following RMR test O_2 and CO_2 were shown significant main effects across the between groups, respectively $F (2, 28) = 9.424$ $P < 0.05$ and $F (2, 28) = 3.678$ $P < 0.05$. Additionally, the comparison between HRC from SIT and SIT from TCT on O_2 was detected with significant differences ($P < 0.05$) through pairwise comparison, while non-significant differences were detected among any groups following Bonferroni post hoc analysis.

However, different concurrent training protocols have been tested in the literature, but almost all are related to variations of traditional concurrent training, such as strength and endurance performed on the same and different days, in different or within the same training session, sequences of strength and endurance training, but the current study only compares cardiorespiratory adaptation following three different types of concurrent training such as traditional concurrent training and contemporary announced concurrent training protocols: HRC and SIT while using completely different time range for the completion of particular training protocols.

Maximal oxygen consumption is crucial because it is often required for many sports as well as for clinical purposes. It is affected by a number of factors, as such muscle stroke volume, cardiac output, arterial-venous oxygen... etc. Moreover, additional factors that might contribute to the rise in maximum stroke volume (SVmax) include improved catecholamine sensitivity and an increase in blood volume. The rise in a-vO_2 diff is primarily brought on by an increase in muscle myoglobin concentration and capillary density (35) as well as quantitative and qualitative modifications to the mitochondria. Due to the cardiorespiratory changes that occurred following the particular training protocol blood circulation increased for a beat per minute shows that the volume overload-induced left ventricular hypertrophy is most likely the cause of the increased maximum stroke volume (381). In that perspective training volume had more attention regarding the expected outcomes. In addition, not only the training volume and initial performance levels were even taken into consideration, specially concerning the TCT protocol-induced cardiovascular adaptation.

Maximal oxygen consumption is crucial because it is often required for many sports as well as for clinical purposes. It is affected by several factors, as such muscle stroke volume, cardiac output, arterial-venous oxygen... etc. Moreover, additional factors that might contribute to the rise in maximum stroke volume (SVmax) include improved catecholamine sensitivity and an increase in blood volume. The rise in a-VO_2 diff is primarily brought on by an increase in muscle myoglobin concentration and capillary density (35) as well as quantitative and qualitative modifications to the mitochondria. Due to the cardiorespiratory changes that occurred following the particular training protocol blood circulation increased for a beat per minute shows that the volume overload-induced left ventricular hypertrophy is most likely the cause of the increased maximum stroke volume (381). In that perspective training volume had more attention regarding the expected outcomes. In addition, not only the training volume and initial performance levels were even taken into consideration, specially with respect to the TCT protocol-induced cardiovascular adaptation.

Aerobic power (VO_2 max) has been improved following all three protocols (HRC: 1.81Δ%, SIT: 2.58 Δ%, VO_2 max: 4.75 Δ%*) but significant increases were only observed from the TCT group, even though the average time spent on the TCT sessions was substantially greater than the time spent on the HRC and SIT sessions. This finding was contradict the results of previous studies showing that recreationally active individuals obtain similar or larger improvements in VO_2 max and muscle oxidative capacity after low-volume HIIT than after high-volume CT (12,59). However, don’t have to forget that HRC and SIT protocols even increased aerobic power unfortunately their differences were not enough much sufficient to be statistically significant.

However, an effective endurance exercise training program will result in an athlete's increased VO_2 max, capacity to operate at a greater fractional utilization of VO_2 max, and enhanced work economy (392, 393). Hence, the cardiovascular response to exercise is thought to center on classic physiological parameters such as heart rate, stroke volume, cardiac output, mean arterial pressure, and total peripheral resistance. Henceforth, due to the cardiorespiratory changes that occurred following the particular training protocol blood circulation increased by a beat per minute. It shows that the volume overload-induced left ventricular hypertrophy is most likely the cause of the increased maximum stroke volume (381). That probably enhanced the maximum oxygen uptake (VO_2 max), the capacity to work at a high proportion of VO_2 max utilization, and the overall work economy. In that perspective training volume had more attention regarding the expected outcomes. In addition, not only the training volume and initial performance levels were even taken into consideration, specially with respect to the TCT protocol-induced cardiovascular adaptation.

On the other hand, the improvement in VO_2 max is determined mostly by an increase in cardiac output, while VO_2 max has a significant genetic component to potential genotypic expression, the capacity to enhance cardiac output through training is a powerful effector of VO_2 max phenotypic expression, with the maximum cardiac output being 20-50% higher in endurance-trained versus untrained, matched people (393, 394).

The key cardiac adaptations to improve cardiac output from endurance training are increased ventricular filling capacity (end-diastolic volume [EDV] characteristics) and the ability to engage the Frank-Starling mechanism during exercise to boost the ejection fraction. These modifications result in a greater ability to enhance stroke volume. Enhancement in left ventricle (LV) compliance, increased cardiac dimensions (i.e., pre-load LV hypertrophy), increased rate of LV pressure decline, decreased pericardium-mediated diastolic ventricular interactions, enhanced diastolic suction, increased rate of calcium uptake within myocardial sarcoplasmic reticulum, and increased changes in vascular volume are key factors responsible for increased EDV capacity after training. When these modifications are combined, the heart's pumping capacity (cardiac output) improves dramatically (393, 394). Correspondingly, training-induced blood hypervolemia and erythropoiesis result in increased hemoglobin content and, as a result, the oxygen-carrying capacity and a-VO_2 difference (392, 393). In short, all of the parameters influencing VO_2 max capacity changes as estimated by the Fick equations (VO_2 = CO x a-v O_2 difference) are improved, which we can observe following the present investigation results but as previously explained those adaptations were only significant following TCT protocol.

In line with the increases in VO_2 max following three different concurrent training, RMR results also were changed depending on the special characteristics of the particular training protocols. Interestingly there were significant differences were detected among HRC vs SIT and SIT vs TCT on O_2 consumption, whereas SIT protocol showed higher O_2 consumption than the other two concurrent training protocols. As well as, HR also decreased following SIT (-6.20Δ%) rather than the other two training protocols. Given that inter-set recovery during sprint interval training has previously been shown to affect cardiovascular responses, this is most likely because the configuration of the training for sprint intervals may stimulate adaptations that improve cardiovascular function and, ultimately, endurance (549).

An additional indication that HRC training imposed a notable stress on the anaerobic metabolism is the fact that the RER was decreased during this protocol. Again, it appears that there is a greater upregulation of anaerobic metabolism during HRC training. In contrast to that TCT was shown an increase of RER whereas TCt imposed distinguished stress on aerobic metabolism in the fact that the RER was increased during this protocol. hence it revealed that there is a greater upregulation of aerobic metabolism during TCT training intervention. However, In order to enhance the ability to work at a high fractional utilization of VO_2 max following three different intervention groups (HRC, SIT, and TCT), all variables (Maximum HR, Maximum velocity, VO_2 max, VO_2 max R, Maximum time) were measured reported increased except maximum heart rate and maximum velocity following HRC. All three training protocols consisted of almost equal exercise, and actions and including recovery periods, respectively per each training methodology during the same number of weeks, but the time taken for each training protocol differed according to the particular training protocols.

In conclusion, following the present findings, it is possible to suggest that the TCT protocol is much better than the other two concurrent training methods (HRC and SIT); in terms of enhancing the VO_2 max, VO_2 max R, Maximum heart rate, Maximum velocity and Maximum time in recreationally trained individuals. However, the other two intervention groups following HRC and SIT also induced an increase in VO_2 max, but less than TCT. Nonetheless, the average time spent on the TCT sessions was substantially greater than the time spent on the HRC and

SIT sessions. Since HRC and SIT are very time efficient training protocols than TCT protocols, and even both protocols could be able to enhance the VO_2 max, and VO_2 max R, the maximum time we would like to suggest that HRC and SIT be incorporated in their training programs that have less time to prepare, whereas it would be advantageous to concurrently improve VO_2 max within a single mode of exercise training.

On the other hand, related to the RMR results, it was revealed that all three concurrent training protocols intervention was effective at improving most of the cardiovascular performance outcomes, but HRC training protocol imposed notable stress on the anaerobic metabolism, while SIT and TCT induced distinguished stress on aerobic metabolism. Hence, none of them were better than the other training protocols at improving the RMR performance in terms of enhancing cardiorespiratory adaptation. Hence, it is depending on the needs and desires of each individual in terms of their available time for exercising as well as the training plans.

7.4. SECTION 04:

7.4.1. Structural (Body composition, muscle architecture) adaptation following different training protocols

Body composition gathers the study of the human body by means of measurements and evaluations of its size, form, composition, proportionality, biological maturation, and body functions. It is regularly associated with maximum performance, physiological markers, and training-based adaptations. Thus, the assessment of body composition is a significant component; it always provides useful information to update and monitored the training program for those who are interested to improve their performance. On the other hand, muscle architecture, defined as a geometrical arrangement of the fascicle affects muscle function (395) which even can develop through exercise training. The relationship between muscle architecture and performance and how training could alter the architecture of muscles have been revealed. Thus, the identification of a single form of physical training that promotes broad physical fitness adaptations within less time would be of great benefit to physical training specialists.

We analyzed the effects of three distinct protocols of "concurrent" training on structural adaptation such as body composition and muscle architecture. Briefly, body composition was taken on Total Fat %, lean mass (g), fat mass (g), BMC, and BMD by using DEXA, while muscle architecture was assessed on three regions of the studied muscle using an ultrasound scan. All measurements such as fibre length, pennation angle, and muscle thickness were measured at three regions of vastus lateralis and body compositions were taken before and after the training intervention. Moreover, to our best knowledge, this was the first study that analyzes the effects of three distinct protocols of "concurrent" training on structural adaptation following such conditions.

Hence, following body composition results there were significant interaction effects between the time and training groups on BMC $F(1, 31) = 6.394$, $P < 0.05$ and BMD $F(1, 31) = 4.721$, $P < 0.05$. Further, there was a significant simple main effect within group on lean mass $F(1, 31) = 25.860$ $P < 0.001$ and BMD F (1,

31) = 4.278, $P < 0.05$ were detected but none of the between groups. Subsequently, significant differences ($P < 0.05$) between two-time points (Pre-Post) were detected through Bonferroni post hoc pairwise comparison on lean mass, BMC, and BMD variables following SIT, while lean mass and BMC following TCT ($P < 0.05$) but none of them were detected following between groups.

On the other hand, the main results of muscle architecture show that there was a significant interaction between the time of measurement and the groups of training methods on proximal fibre length F (2, 26) = 4.184 $P < 0.05$. While a significant simple main effect of the within-subject factor was detected only on proximal fibre length F (1, 26) = 4.481, $p = 0.044$, and following pairwise comparison between two times points only proximal fibre length following HRC training induced significant difference. Furthermore, only on proximal fibre length F (2, 26) = 4.685, $p = 0.018$ was found a significant main effect across the between groups, and non-significant differences were detected following post hoc pairwise comparison between groups for all variables.

7.4.2. HRC induced structural adaptation

7.4.2.1. Body composition:

In the present investigation, following HRC training induced body composition parameters, such as Total Fat %, Lean Mass, Fat Mass, BMC, and BMD were examined. The results depicted that 8 weeks of HRC training improves body composition but it was not statistically significant.

Generally, resistance training is a common mode of increasing Lean mass, Fat-Free Mass, and decreasing Fat Mass (396). HRC training as contemporary announces concurrent training method with resistance exercise-induced increases in all measured parameters such as Lean Mass (1.21 Δ%), Fat Mass (1.11 Δ%), BMC (0.41 Δ%), and BMD (0.94 Δ%) except Total Fat % (– 0.55 Δ%), but none of them were statistically significant. Following the present results, it was clearly indicated that HRC training by itself could provoke body composition adaptations, with reference to young recreationally trained subjects.

Interestingly, the present investigation results were also related to the previous findings which already exist in the literature. Significant decreases were observed by Shaw et al. (397) in Body Fat, total skinfold, and BMI following 16 weeks, 3 times per week of resistance training intervention. Ferreira et al. (396) suggested through their results that Circuit resistance training (CRT) increased Fat-Free Mass and decreased Fat Mass and Body Fat percentage.

Furthermore, after 10 weeks, 2 days per week of resistance exercise induced decreased Fat Mass (10%) for males, and body weight was not change (398) but following 22 weeks of resistance training at 3 days per week, Hanson et al. (399) observed no difference in Body Fat percentage with an increase in Fat-Free Mass in both the males and females of a healthy volunteer. Besides, the study conducted by Harber et al. (229), revealed no differences in body weight, Fat-Free Mass, Fat Mass, or Body Fat % following 10 weeks at 3 times per week circuit resistance training intervention in young adult men, but Almstedt et al. (400) and Ryan et al. (401) revealed that following resistance training increase the bone mineral density.

However, it is clear that resistance training improves muscle strength, endurance, and flexibility. Circuit weight training has been shown to improve body composition by increasing fat-free body mass, muscular strength, and bone mineral status. As well as most studies observed significant decreases in fat mass following 2-3 training sessions per week, and decreased body fat (9.2%) was observed by Chtara et al. (33) following only 2 sessions per week in active people. In addition, a greater reduction in body fat was found by Paoli et al. (92) following high-intensity circuit groups.

However, the results of the present study observed increased Fat Mass (1.11 Δ%) following HRC training which was not in line with the previous results. Perhaps it is due to the training characteristics used during the various CT training protocols, such as the load intensity (i.e., high vs. low loads), number of rounds, number of sets, number of repetitions, and number of exercises or rests between exercises, which must be manipulated in the CT training protocol; these characteristics establish a different dosage of training, and as a result, they impact on the interference effect and promote different and strength adaptations.

Nevertheless, the present results depicted how 2 sessions per week, conducted at moderate intensities (i.e. 6 RM) with a higher volume training (6 repetitions) and shorter rest time (i.e. 35 seconds) may enhance the body composition with small changes in the body weight. These results observed increases in lean mass (1.21 Δ%) and a decrease in Total Fat % (-0.55%) while body weight (0.96 Δ%) had a small increment. One possible explanation for this can be related to Exercise-Induced Muscle Damage (EIMD). Replacement of damaged muscle fibres occurred due to the cellular process where it forms new muscle protein strands (myofibrils) together with fused muscle fibres. Thus it provokes to increase in the thickness and as well as numbers to create muscle growth which is important in the process of satellite cells in the muscle, when they are activated it helps to add more nuclei to the muscle, therefore increasing the muscle cells (myofibrils). On the other hand, another responsible component for muscle growth and repair is the Insulin Growth Factor (IGF)-1 hormone, which is help to regulate the satellite cell function. Specially, both testosterone and Mecho-Growth Factor (MGF) are having vital mechanisms to enhance muscle growth.

Moreover, following the HRC training protocol subjects observed increases in BMC and BMD. When increase the physical activity may lead to decreased loss of bone and therefore decreases the incidents of osteoporotic fractures. Different exercises have been described to stimulate bone growth and preserve bone mass; thus, one possible explanation for exercise-induced increases in BMC and BMD is that the optimal interventions favour a mechanical stimulus on bone both through antigravity loading and the stress exerted on muscles through the training exercise (402).

Hence, taking into consideration of all the above explanations and the own characteristics of the particular training protocol we can conclude that somehow HRC led to an improved body composition but none of the mean differences of any measured variable were not enough to say significant.

7.4.2.2. Muscle architecture:

As previously expected, the following strength-related training-induced decrement in fibre length is more related to the results reported in previous studies (reference). Generally, High-intensity stimulus to circuit-based resistance training alters muscle volume and hence muscular mass. It occurs mostly as a result of a rise in the volume of individual muscle fibres, rather than an increase in the number of fibres. It can increase in volume in two ways, as such by increasing the fibre length, and diameter. Length increases happen due to the addition of new sarcomeres in series, whereas increases in diameter happen through the addition of myofibrils in parallel. Changes in the form and structure of the muscle accommodate these increases in size, requiring no changes to the origin and insertion of the entire muscle.

However, according the present investigation results depicted that following HRC training increases pennation angle and Muscle thickness but fibre length has been decreased in all regions (Proximal, medial and distal) of the vastus lateralis. Thus, according to the given results we assume that it happened due to the inability of muscle fibres to add serial sarcomeres in response to the growth of the vastus lateralis muscle fibre.

However, the mechanism behind the increase in diameter or length is vitally important. The stimulus for getting muscle hypertrophy is mechanical tension, which is generated by the fibre itself. It can happen through active contraction or passive stretch resistance. When the mechanical strain experienced by the muscle fibre is increased by the active components (the actin-myosin cross-bridges), the fibre seems to expand in volume primarily by increasing in diameter, which is accomplished by adding myofibrils in parallel. This impact might be triggered by the outward bulging of muscle fibres caused by the formation of actin-myosin cross bridges, which transversely deforms the muscle fibre. In contrast, when the mechanical strain experienced by the muscle fibre is created more by the passive components (which include the large molecule titin), the fibre seems to expand in volume primarily by increasing in length, by adding sarcomeres in series. This phenomenon might be triggered by titin detecting the stretch exerted on it when the fibre deforms longitudinally.

Moreover, the length of the muscle, the mode of contraction, and the lengthening velocity are all important elements in determining the contribution of passive and active force to the overall mechanical tension generated by the various training regimens. Thus, according to the major findings following the high-intensity circuit-based training, pennation angle, and muscle thickness increased whereas fascicle length decreased, in vastus lateralis. Thus, there were small but consistent increases in muscle fascicle angle and muscle thickness except for the pennation angle of the distal region in vastus lateralis with decreases in fascicle length. It is likely then that these changes are related to the force and/or velocity characteristics or the movement patterns of the high-intensity circuit training exercises, which could be the inability of muscle fibres to add serial sarcomeres in response to growth, which means decrement of fibre length of all three regions or through the addition of myofibrils in parallel by means of increases in diameter on the pennation angle and muscle thickness in all three regions measured.

The size of a muscle has a direct impact on its ability to generate force. In the current study, there was an overall increase in vastus lateralis muscle size as measured by changes in muscle thickness and muscle pennation angle throughout the HRC and TCT training regimens. However, there was a significant simple main effect was detected across the within-subject factor only on proximal fibre length $F(1, 26) = 4.481$, $p = 0.044$ with -19.22 Δ% among all other variables of muscle architecture measurements.

In the absence of fascicle length increases, increases in muscle size occurred in parallel with minor increases in pennation angle (Proximal, Medial, and Distal) and muscle thickness (Proximal, Medial, and Distal). It is also plausible that fibre hypertrophy, which was previously predicted to occur during high-intensity circuit-based training, has occurred. Thus, long-term training adjustments may have resulted in muscle growth increases due to changes in muscle architecture or fibre hypertrophy. Surprisingly, the biggest increases in muscle thickness occurred in the proximal, medial, and distal muscle locations. As a result, the findings support the idea that muscle growth in response to exercise may not be constant over a muscle's length. Selective hypertrophy has been previously reported by other authors (403) and is important to our understanding of muscle adaptations. Moreover, to guarantee that muscle growth improvements are not overlooked, evaluations were done at three places on the muscle following a period of training during the current study, as proposed by Blazevich et al. (320).

7.4.3. SIT induced structural adaptation

7.4.3.1. Body composition:

The information regarding the SIT-induced body composition is narrow. Among the studies, some of them observed non-significant differences in body mass following six weeks of SIT intervention (404, 405), but there was no possibility of recognizing the differences in fat mass, fat-free mass, and BMC due to the lack of measurement. Conversely, some studies reported increases in fat-free mass (405), and decreases in fat mass (266), to the same extent as endurance training, despite no significant change in body mass. On the other hand, Six weeks of sprint interval running which was conducted by Macpherson et al. (266), reported decreased fat mass by 12.4% and increased fat-free mass by 1%. According to our understanding of the current literature, the information on SIT-induced total bone mass comes exclusively from a sprint interval running research done by Nybo et al. (174), where no change was recorded after 12 weeks.

The majority of SIT studies have found improved performance on either the track or the treadmill in a variety of athletes, including runners, soccer players, tennis players, wrestlers, judoka, and handball players, among others. The present investigation was conducted by using recreationally training young men, following SIT observed body composition variables such as Lean Mass (2.14 Δ%*), BMC (1.06 Δ%*), and BMD (1.82 Δ%*) were increases except for Body Weight (-0.35 Δ%), Total Fat Δ% (-1.92 Δ%) and Fat Mass (-0.31%). Interestingly, all increased variables were found statistically significant ($P < 0.05$) differences after 8 weeks of training intervention. To obtain the above-reported results following SIT-induced body composition, one possible explanation could be the capability of the training protocol itself to increase post-exercise oxygen consumption (EPOC).

Basically after intense exercise, each individual burns more energy with the purpose of recovering the muscle cell and glycogen replacement (EPOC). It appears to be strongest when exercise intensity is high (541). EPOC, for example, is greater after HIIT than after longer duration lower intensity exercises (542), because it significantly disrupts the working muscle cells' homeostasis, resulting in a greater energy need after exercise to restore the contracting muscle cells to pre-exercise levels. Many studies also demonstrate that fat oxidation rates increase during EPOC (283, 543). When compared to moderate-intensity endurance training, fatty acid usage during high-intensity bouts of exercise such as SIT (especially the current SIT protocol) may be greater; but, high-intensity exercise may compensate for this shortfall by enhanced fatty acid oxidation via EPOC.

A single SIT session consisted of six repetitions of 20 m running at a maximum pace separated by 15 seconds of rest and an undulated number of blocks per week. Previous research, which is consistent with the current study, found higher EPOC in the 180 minutes after the protocol, which consisted of seven bouts of 30-second cycling at 120% VO_2 max separated by 15-second rest in a single training session. As a result of the provided findings, we may postulate that higher EPOC after SIT session may explain changes in fat mass following this type of exercise. Moreover, All individuals who followed the SIT protocol reported increases in BMC and BMD Increased physical activity may result in less bone loss, which in turn reduces the risk of osteoporotic fractures.

A possible explanation for the exercise-induced increases in BMC and BMD is that different exercises have been shown to promote bone growth and preserve bone mass. The best interventions are those that favor a mechanical stimulus on bone through antigravity loading and the stress placed on muscles during the training exercise (402).

On the other hand, the possible explanation for these findings could be the endothelial cells' function. Due to the particular exercise training might induce endothelial cell growth which promotes angiogenesis Cocks et al. (406) by promoting the proliferation of endothelial cells that directly form blood vessels (407), which requires vascular expansion to grow adipose tissue. Thus, following exercise, triacylglycerol an energy reservoir in adipose tissue is hydrolyzed and released to the circulation as free fatty acids, providing fuel for working muscles. Thus, systematic physical activity leads to a decrease in adipose tissue mass and improves metabolism, which provokes to decrease the fat mass and an increase the lean mass. The reason, lean body mass is related to the Basal Metabolic Rate (BMR), interpreted as the number of calories burn at rest. Thus, a greater amount of Lean Mass indicates a greater BMR. It means that with greater amounts of Lean Mass will have greater energy expenditure during the rest period, helping to avoid calorie imbalances. Interestingly this greater energy expenditure during the rest period is inversely associated with basal metabolic rate, independently of body composition.

In summary, sprint interval training-induced statistically significant decreases in some measured body composition variables such as Body Weight, Total Fat %, and Fat Mass, while others reported no significant increases in Lean Mass, BMC, and BMD. It means that 8 weeks, 2 sessions per week SIT protocol induced considerable body composition adaptations, which required at least 20 – 30 minutes to complete the training session. Moreover, it has been able to elicit the EPOC, angiogenesis, and basal metabolic rate to regulate the aforementioned body composition adaptations.

7.4.3.2. Muscle architecture:

Following SIT training, no significant time and group interaction was reported, but there was a significant time main effect detected only on proximal fibre length $F(1, 26) = 4.481$, $p = 0.044$ among all other variables of muscle architecture measurements. However, after 8 weeks of intervention, each measured variable was adapted differently. Such as fibre length (-4.05 Δ%), pennation angle (-1.51 Δ%), and muscle thickness (-0.74 Δ%) from the proximal region decreased, while fibre length (-12.27 Δ%) and pennation angle (-1.64 Δ%) from the distal region, and pennation angle (-8.12 Δ%), muscle thickness (-0.74

Δ%) from medial region decreased as well as. Interestingly, medial fibre length (1.88 Δ%) and distal muscle thickness (5.29 Δ%) of the vastus lateralis increased. Therefore, it is clear that muscles may adjust to many forms of persistent training. However, in this section, we will discuss the skeletal muscle adaptations caused by short-distance maximal velocity running (i.e. SIT) related training.

The effects of run training on skeletal muscle architecture are not yet known. The leg muscles of sprinters and distance runners, however, have different anatomical structures. When compared to endurance runners, sprinters' vastus lateralis and lateral gastrocnemius are thicker, more finely pennated (with a lower angle relative to the aponeuroses), and have longer fascicles (316). These findings suggest a connection between architectural adaptability and running specialization. The greatest sprinters also showed the most severe architectural traits when grouped based on ability, suggesting that fascicle lengthening allows better muscle-shortening velocity and running speed. The structure of this data, however, prevents it from addressing whether these architectural variations are due to a genetic propensity or a training adaptation.

Moreover, numerous studies have examined how muscles adapt to different training regimes in terms of size, but there is little additional information on how muscles change in terms of architecture after SIT. Additionally, sprint performance and muscle architecture have been examined, but not the adaptation of muscle architecture after sprint interval training (408). It has been noted that a muscle's architecture affects how it contracts. In general, muscles that are used during fast, light contractions have shorter fibres and smaller pennations. Indeed, when kids with cerebral palsy received velocity training, (409) showed an increase in muscular fascicle length. Significant increases in muscle thickness can arise from both muscle hypertrophy and increases in pennation angle and fascicle length, as well as vice versa, according to the research on the link between these variables.

In this sense, it would seem to reason that individuals who regularly engage in high-velocity, low-force contractions during sprint interval training would have muscles with longer fibres, resulting in a greater pennation angle and greater muscle thickness. These findings, however, are at odds with the findings of the current study; SIT demonstrated higher reductions in pennation angle in all three locations, whereas medial fascicle length increased after training while proximal and distal fascicle length decreased. Similar reductions in muscle thickness would most likely follow from these modifications. The peculiarities of the sprint interval training program may have contributed to it.

A comparable increase in muscle shortening velocity is one of the functional implications of an increase in fascicle length. Additionally, a high pennation angle will cause more fibres to be packed, increasing the force required to create (410) while lowering the shortening velocity. In contrast, if the pennation angle decreases, there is less fibre to pack, which results in less force produced but a rise in the shortening velocity. On the other hand, when the angle between the fascicles and tendon is larger, tendon excursion is likewise greater for a given length of fibre shortening (411). This is because, during muscular shortening, fibres in pennate muscles both shorten and rotate. Muscles with more pennation would have less fibre shortening both in length and velocity. As a result, the fibres could exert more force in accordance with their length-tension and force-velocity characteristics. Accordingly, the reductions in pennation seen after the SIT training participants may have, theoretically, had a detrimental impact on their growth of strength and a good impact on their development of speed.

Fascicle length has also been connected to the characteristics of muscular contraction, resulting in the recruitment of longer muscles during rapid contractions (408). Longer fibre lengths may allow muscles to adapt to high-velocity contractions as longer fibres have faster shortening velocities (412). Human muscles with high-force contractions often have shorter fibres (410). However, in our opinion, pinnate fibre properties are also a significant factor in the improvement of fibre properties. Fast twitch muscle fibres are primarily activated by brief sprint running, which has unique properties. Unfortunately, the fibre type of an individual has not been discovered during the current experiment. As a result, it could provide results that are inconsistent with information from earlier publications.

In conclusion, it has been stated whether the unique qualities of the specific training procedure induced muscle architectural alterations, such as increased medial fibre length and vastus lateralis distal muscle thickness, the rest of all other variables were found to decrease after the 8-week intervention. Mean SIT training protocol was not much friendly training method to increase muscle hypertrophy due to the decreases in muscle thickness and pennation angle specially in the medial section, however as we explained previously it has been developed according to the nature of the exercise training by increasing the fibre length of subjects which is critical to improving the sprint timing.

7.4.4. Traditional concurrent training (TCT) induced structural adaptation

7.4.4.1. Body composition

Concurrent strength and endurance training (CT), which commonly identify as Traditional Concurrent Training has differed from contemporary concurrent training, thus it (TCT) is used to enhance athletic performance in different types of sports, as well as the health-promoting strategy for the general population. The TCT (combining strength and endurance exercise modes) stimulate stresses in both the neuromuscular and the cardiovascular systems, and it can also influence the regulation of body composition. Therefore, this section will discuss the effects of TCT on body composition parameters obtained through the dual-energy X-ray absorptiometry test.

Hence, the present investigation was conducted by using recreationally training young men, following TCT (Endurance following strength training) observed body composition variables such as Body Weight (-0.06%), Total Fat % (-6.23%), BMC (-1.01 Δ%*), BMD (-0.92 Δ%) except Lean Mass (4.22 Δ%*). Among all variables, only Lean Mass and BMC detected a statistically significant difference ($P < 0.05$) following the TCT protocol. Hence, the present data depicted that TCT training also could be able to produce decreases in the total body fat % and fat mass by directly reducing adipocyte mass, thus increasing fat-free mass or a combination of both, which was directly in line with the reported data. Hence, the proportion of fat stored in the body is relative to the total body mass; therefore the skeletal muscle mass and Total Body fat % were inversely related.

Thus, according to Willis et al. (285) reported that long-term TCT induced increases in muscle mass with decreases in Fat Mass, thus it has been considered the training mode used for the intervention was an ideal alternative method to decrease the Total body fat %.

Interestingly, TCT could be a premeditated alternative training method that can increase energy expenditure by facilitating to merge of additional amounts and more diverse exercises in a single training session or by increasing training frequency. Some studies reported a positive effect on energy expenditure and body composition following strength and aerobic (TCT) in the same training prescription (413, 167). Dolezal and Potteiger (28) reported following TCT (Strength training with aerobic training) induced increases in absolute RMR. As well as in the same study they observed a significant increase in lean body mass following TCT. Therefore, it was made known the significance of the increase in lean body mass to have reported an absolute increase in RMR. It is also closely relevant in terms of body composition adaptation because respectively the active individual RMR represents about 50% of daily energy expenditure and 70% in sedentary (249).

Hence, the possible explanation for that is could be the energy expenditure. When energy expenditure exceeds the energy intake, a negative energy balance is occurred, which normally leads to weight loss. The reason behind that is the body needs to produce energy to maintain the body functions, therefore producing energy by using the glucose, fat, or protein which is available already in the body. It means depends on the training protocol exercises, duration, intensity and rest …etc. start to decrease the fat mass and total body fat%.

On the other hand, another possible justification for these findings could be related to the lipolysis process due to the convenient intensity and volume of the training protocol (283). Further, it has been reported increases in muscle mass and no changes in body mass. Thus, probably TCT protocol was affected by weight and it could be influenced to increase muscle mass and decrease body fat, encouraging to keep body mass at a normal level. Perhaps, key factors for getting this muscle growth could be due to the intramuscular anabolic signaling, metabolic stress, and response of muscle fibre recruitment which is induced by resistance training (284).

Following the present investigation TCT protocol was performed subjects reported decreases in BMC and BMD. The mechanical stimulus on bone both through antigravity loading and the stress exerted on muscles are vital factors and they induced increases and decreases in bone mass. Not only that, the period of training time and calcium consumption also is remarkably effective in the increases in BMC and BMD. Interestingly following TCT-induced decreases in BMC and BMD were not in line with the previous results. Therefore, it needs more investigations on this matter with that kind of measurement and controls to get a conclusion.

Hence, according to the own characteristics of the training protocol, the changes can differ, specially since the intensity of the training is a vital factor. Because it's already been observed training prescriptions with small intensity provokes greater weight loss. Conversely greater intensity help maintain fat-free mass unchanged, but both low and high-intensity training could be able to produce a remarkable and significant loss of fat tissue. Therefore, according to the present results, it could be able to conclude that due to the convenient intensity and volume of TCT-induced reduction of Fat Mass, Total Body % with BMC and BMD, while increases in lean mass by activating the lipolysis and RMR.

7.4.4.2. Muscle architecture

Many athletes, especially those who play team sports, need to concurrently enhance their strength, power, and endurance adaptations. Therefore, it is standard practice in both athletic and clinical populations to incorporate both resistance- and endurance-based exercise into one training program, known as concurrent training, for the benefit of the specific training regimen (414). Although it is not a novel topic, the effect of skeletal muscle structure on modern concurrent training but traditional concurrent training still needs to be investigated. Strength training changes every aspect of muscle architecture in a way that is likely to enhance overall muscular performance (317, 416).

According to the notion of training specificity, responses to long-term training must be tailored to the type of exercise done in order to produce distinctive and divergent skeletal muscle phenotypes (415). For instance, in response to endurance run training, the pennation angle rises, more closely matching the architectural traits of distance runners (317). On the other hand, strength training increases fascicle length (416), and pennation angle (317, 416, 320) their fore increases muscle thickness, hence literally increasing maximal force-generating capacity and skeletal muscle hypertrophy. The simultaneous development of muscle endurance and strength/power with concurrent training poses a significant degree of complication in exercise prescription due to these drastically different responses (417). Indeed, results from previous research showed "interference" in the rate of gain in hypertrophy, strength, and power when resistance training is done concurrently rather than separately (19, 418), though these data are not conclusive (18). However, in this section we just only consider the traditional concurrent training-induced muscle architecture without comparing it with other training methods; therefore even though there is an interference effect here we are not able to consider it due to the comparison of pre and post-test data following the aforementioned training protocol.

Nonetheless, according to the researcher’s understanding, there is plenty of research regarding concurrent training (contemporary concurrent training methods such as high-intensity circuit training or interval training) induced muscle architecture (e.g. fascicle length, muscle thickness, pennation angle, etc.) in the literature, but least information regarding the traditional concurrent training (endurance training before strength training) induced muscle architecture. Hence, the current investigation is the first to examine muscle architecture adaptation following traditional concurrent strength and endurance training for recreationally trained subjects. This research will be the first to investigate skeletal muscle architecture changes brought on by traditional concurrent training under such circumstances. The information will also add to the limited body of knowledge about skeletal muscle architecture adaptations to concurrent (strength and endurance) training and might perhaps provide further insights into these adaptations.

As previous data explained it has not been able to identify the interference effect following traditional concurrent training, because only considers the training effect on pre to post-assessments. Hence, the major findings of the investigation were increases in fibre length, pennation angle, and muscle thickness following all regions except medial and distal pennation angle and distal muscle thickness. Following the above results, it seems like increasing muscle hypertrophy and muscle volume (419, 420) and consequently in bulk in the vastus lateralis's proximal area. Instead of an increase in the number of fibres, it mostly results from an increase in the volume of each muscle fibre. On the other hand, getting muscle hypertrophy is about the mechanical tension, is generated by the fibre itself, the increment of length and adding sarcomeres in series are the mechanism behind muscle hypertrophy, which is already explained in the section on HRC-induced structural adaptation. Thus it seems like; attenuating of muscle hypertrophy due to endurance training has not happened following the present investigation when we discuss traditional concurrent training alone.

Interestingly, medial (-11.19%) and distal (-1.64%) regions showed decreases in pennation angle and increases in fibre length (medial 37%, Distal 185%), which is similar to the findings of Abe et al. (316). They have found that thicker and longer fascicles in trained sprinters and lesser pennation angles in the vastus lateralis compared to trained distance runners. However, these results have not given a clear idea of whether these adaptations were induced by concurrent resistance or endurance training.

Fascicle length, pennation angle, and muscle thickness may respond differently depending on the training methods and their unique properties. Muscle size changes frequently coincide with changes in fascicle length and pennation angle. These facts more or less agree with the proposals made by Vieira et al. (421). Eccentric and concentric contraction happening during strength training may result in a particular adaptation of the fascicle organization, as well as endurance training. As a result, there is no agreement on what influences plasticity. Even though there isn't enough information to draw a firm conclusion, traditional concurrent training has been shown to cause muscular hypertrophy, particularly in the vastus lateralis muscle's medial and distal regions.

7.4.5. Comparison between three different training protocols induced structural adaptation.

7.4.5.1. Body composition

The major finding observed from the present study was, respective to each training protocol's intensity, volume, and nature of the exercise-induced various body composition adaptations on particular subjects. Interestingly, significant interaction (time*group) was reported on BMC F (1, 31) = 6.394, P < 0.05, and BMD F (1, 31) = 4.721, P < 0.05. However, a non-significant main effect between groups was detected for all variables. Moreover, significant main effects were detected within group on lean mass F (1, 31) = 25.860 P < 0.001 and BMD F (1, 31) = 4.278, P < 0.05, while SIT and TCT have shown significant mean differences among pre-post measurement on Lean Mass and BMD, as well as BMC following SIT. Therefore, these results demonstrate that no training method was better than the other training protocol, but some variables such as Lean mass, BMC, and BMD have better improvement following SIT and TCT respectively.

Excitingly, SIT subjects who performed only high-velocity training (i.e. sprint running with maximum effort) and TCT subjects who performed low-intensity training both induced decreases in Fat Mass and Total Fat %. Therefore, the main reason for the reduction of both body composition variables (Fat Mass and Total Fat %) could be high and low-intensity exercise. Thus, to get more fat loss it seems like the most convenient way to conduct high and low-intensity exercise, as well as to create a training program that combines high and low-intensity exercise. This is due to the unique and complimentary ways that each form of exercise stimulates fat reduction. Furthermore, on a minute-by-minute basis, high-intensity exercise is superior to low-intensity exercise for fat removal. However, because it can be done considerably more frequently, low-intensity exercise has another goal, which is to have a bigger overall impact on weight loss. Therefore, combining high-intensity and low-intensity exercise would be the greatest option since they work so much better as a team than they do separately.

However, following the present investigation results, it seems like SIT and TCT has been provoked more effect on energy expenditure and body composition

(413, 167), therefore seems like both training methods have induced increases in absolute resting metabolic rate (RMR) rather than HRC training subjects. As well as, it seems like SIT and TCT has been provoke more effect on energy expenditure than HRC, inducing to produce more energy by using the glucose, fat, or protein which is available already in the body, guiding to some changes in the body composition (413, 167). Therefore seems like both training methods have induced increases in RMR rather than HRC training subjects. Moreover, another possible justification for these findings could be related to the lipolysis process following the three different training protocols, which is more associated with the convenient intensity and volume of the training protocol to induce body composition adaptation, even though none of them were statistically significant.

Prior research has found both no changes in body composition (83, 422) and changes in body composition following high-intensity interval training (92, 423, 424). High-intensity interval training has been linked to both large changes in body composition (92, 423, 424) and no changes at all in prior research (83, 422). This study's findings about changes in body composition are mostly consistent with those of other investigations, which found that there were no appreciable changes. In this study, the HRC group had the propensity to grow fat mass, but the SIT and TCT groups had a tendency to reduce fat mass. However, even high-intensity-based resistance circuit training-induced increases in Fat Mass are questionable. Perhaps it could be happened due to confounding errors. Even though the researcher controls the food intake it should be violated by participating subjects. Therefore, in light of these findings, further research is required to identify the mechanism of how Fat Mass increased after High-intensity resistance circuit-based training.

The HRC seems to have the strongest effect on body weight rather than the other two training methods even though it is not statistically significant. Because the greater difference in body weight was shown in increases in HRC (0.96 Δ%) subjects rather than decreases in SIT (-0.35 Δ%) and TCT (-0.06 Δ%) subjects. However, the decreases in Body weight following SIT and TCT are very small compared with the increases in body weight following HRC, while decreases in fat mass, Total fat % and increases in lean mass following SIT and

TCT are large when compare with the HRC. Therefore, this may suggest that individuals in the high-intensity and low-intensity training groups were better able to retain their lean body mass than those in the HRC group.

Following the present investigation TCT protocol was performed subjects reported decreases in BMC and BMD. The mechanical stimulation on bone, which is caused by both antigravity loading and the force placed on muscles, is a crucial element that causes changes in bone mass. Not only that, the period of training time and calcium consumption also is remarkably effective in the increases in BMC and BMD. Interestingly following TCT-induced decreases in BMC and BMD were not in line with the previous results. Therefore, it needs more investigations on this matter with that kind of measurement and controls to get a conclusion.

Finally, It is possible to draw the conclusion that HRC, SIT, and TCT offered distinct benefits following the 8-week training period when taking into account significant and none significant increases as well as higher mean differences% changes of all measured variables, but SIT and TCT instead provided significant adaptation (within a group) on Lean Mass, BMC, and BMD, though the differences were not significant enough to presume it was exceptional to other training groups. As a consequence, no program was greater than another, but the length of the training sessions varied. Therefore they may choose the training method for their training plan based on the subjects' needs.

7.4.5.2. Muscle architecture:

Interestingly, HRC was showing significant differences ($P < 0.05$) in morphological adaptations on proximal VL compared with SIT and TCT. Apart from that, these observations imply that each training protocol can be induced morphological adaptations which are identical to their own training protocols after 8 weeks of HRC, TCT, and SIT training under different time duration of training sessions.

The main conclusion of the current study was that the training regimens given to the athletes caused fast changes in muscle architecture. For HRC subjects, who performed only high-intensity resistance circuit-based training, fascicle length decreased whereas pennation angle and muscle thickness increased, particularly in all regions (Proximal, medial and distal) in the vastus lateralis muscle. In subjects who performed sprint interval training, there were small but consistent decreases in muscle fascicle angle in VL in all regions, but muscle thickness and fibre length have been changed oppositely to the fibre length in medial and distal regions.

A statistically significant difference was detected only in HRC following proximal fibre length apart from that there was no significant difference existed among groups following any variables. However, there were some differences that could observe according to the percentage of differences between pre and post-measurement of SIT and TCT groups although these pre-post difference percentages of groups changed differently to the HRC group. The features of one's training program's force and/or velocity, as well as the type of resistance and running exercises, are therefore likely to be responsible for these modifications. Hence, these interpretations are in line with the observations published by Blazevich et al. (320).

Even though some disorganized adaptation was observed following SIT and TCT compared to the HRC, the nature of the exercise of training was vastly different. However they have affected the architectural adaptation, but the movement pattern of resistance exercises of the TCT was almost equal to the HRC training, only changing the rest times. However, given these divergent adaptations among these three distinct training protocols, particularly among HRC vs TCT adaptations, could be consistent with the prior findings from numerous studies demonstrate "interference" in the magnitude of increase in hypertrophy, and strength with concurrent training compared to resistance training performed in isolation (19, 24), although these observations are not conclusive (425) because the concurrent development of muscular strength and endurance with concurrent training presents a high degree of complexity in exercise prescription (417).

Less than previously documented pennation angle alterations were observed in patients who underwent HRC. Pennation angle for the vastus lateralis increased by 34% after 14 weeks of RT, although Blazevich et al. (320) reported a 15% rise for the vastus lateralis after five weeks of training. The beginning training status of the individuals, the concurrent training they undertook, and/or the briefness of the training intervention may all be responsible for the study's less dramatic shift.

Less consistency was seen in the vastus lateralis muscle architecture modifications after various areas. In comparison to HRC, the pennation angle in SIT and TCT subjects decreased from the proximal section of the muscle toward the distal end. The medial and distal sites, however, did not see any noticeable alterations. There were significant variations among the groups ($P < 0.05$) in fiber length following HRC subjects, although the increase in fiber length across the TCT groups subjects in all areas was not significant. The complicated functionality of this pennate muscle may be the cause of the uneven results following these three concurrent training sessions. According to the unique features of the exercise nature of training programs, hip and knee extension occur concurrently throughout the majority of multi-joint lower limb motions (such as pushing movements).

The force-generating capacity is always influenced by muscle size. Following the muscle thickness changes of the present data depicted that, there was a general increase in muscle size of VL across the HRC and TCT subjects, even though there were some differences among the group these differences were not consistent and even they are not statistically significant except proximal fibre length. The various changes in pennation angle and length amongst the groups may be to blame for this disparity. In the HRC group, increases in muscle size occurred as a result of modest increases in pennation angle and without changes in fiber length, but in the TCT group, muscle size grew in line with changes in fiber length. Pennation angle and fiber length changes in the muscle architecture will increase muscle thickness collectively. It is also probable that fiber hypertrophy and sarcomere series increases that were probably expected to occur after the HRC and TCT groups did not occur after the SIT group, which was in contrast to the published results from Liljedahl, et al. (544) from 1996.

As a consequence, the long-term adaptations following three different training protocols even though statistically not significant have led to increases and decreases the muscle size in different regions either by alterations in muscle architecture or fibre hypertrophy. It's interesting to note that after HRC, all areas showed the biggest percentage improvements in muscle thickness. Increases were seen in the TCT data, particularly in the proximal end medial, although SIT was in opposition to both other training procedures. These findings, therefore, lend credence to the idea that muscle hypertrophy is not uniformly distributed over the length of the muscle and is inconsistent along the muscle as well as between training regimens. To guarantee muscle size adaptation after exercise, it is essential to obtain an assessment of muscle architecture at many points. While statistically not significant, the most plausible explanation for these results is that each training program in some way caused muscle architectural changes. Resistant-type training, in particular, is more likely to encourage increasing muscle growth than the sprinting form of exercise. As a result, it is also shown that throughout the course of the 8-week training period, each training program (HRC, SIT, and TCT) provided a variety of advantages; however, no one program was superior to another; instead, it depended on the individual needs of the participants.

However, given the variations in training amount across the groups, the absence of observed changes between them raises some concerns. Although it can be challenging to link strength training, sprint runs, and continuous run training, the HRC and TCT groups were constructed with nearly equivalent training volumes. Both groups' architectural alterations were also quite similar. As a result, it is doubtful that the volume differences would have been significant enough to explain the lack of between-group adaption variations. The analysis of the available data revealed no notable variations in the responses to the training protocols; thus, it is possible that the addition of other exercise patterns would have a substantial impact on the training group.

In conclusion, HRC and TCT training-induced long-term adaptations in muscle size and architecture; especially in proximal fibre length detected significant differences statistically. On the other hand, following SIT has not detected muscle hypertrophy except for medial fibre length and distal muscle thickness. It means, with reference to the muscle hypertrophy adaptations in the monoarticular VL of HRC subjects appeared to be greater than the other two training subjects with respect to fibre length and pennation angle but those increases did not occur equally throughout the entire length of the muscle. An interesting finding of the data was that even increase or decrease in the pennation angle fibre length has been increased following TCT, and as well as following SIT subjects observed even though a decrease pennation angle decreases muscle thickness and fibre length. Hence, this suggests that the force and velocity characteristics of the exercises and the nature of the exercise most likely influenced muscle architecture. However, it revealed that HRC, SIT, and TCT offered different benefits after the 8 weeks training period but no single program was better than another, but the time spent on the training sessions differed. Hence, depending on the necessity of the subjects they can select the training method for their training schedule.

7.5. SECTION 05:

7.5.1. Muscle force, power and 6 Repetition Maximum (Mechanical) adaptation following different training protocols

Generally, muscle mechanics define as the elementary functional properties of muscles that allow them to execute movement with the characteristics of force, velocity, and power. The process of optimizing human performance always required an understanding of these properties and as well how they adapt to programs of regular exercise. It probably delays the decline of human performance associated with the different issues. However, recent years have been shown considerable progress in this particular context, and well-known physiological information had been published as well. However, the main intention of this section is to compare the mechanical force and power behaviour following three different training protocols (HRC, SIT, and TCT) to determine which protocol allows for better adaptations. Furthermore, it will discuss the individual training protocol-induced mechanical adaptation as well.

7.5.2. HRC induced mechanical adaptation

The purpose of this section was to explain the effect of HRC training protocols over 08 weeks on mechanical adaptation in young recreationally trained male athletes aged between 18 to 35 years. The study compares the pre and post-data within the same training protocols for being able to define whether training intervention has induced any mechanical changes and explain the mechanism behind the changes.

As previously expected, following high-intensity resistance circuit-based related training-induced increases of CMJ Height (0.58 Δ%), Pmax CMJ (W/Kg) (0.75 Δ%), Fmax- upper body (N) (5.85 Δ%), and all measured variables in 6 repetitions maximum (RM): Bench Press (27.03 Δ%), Leg Extension (32.77 Δ%), Lat pull down (18.15 Δ%), Deadlift (19.10 Δ%), Biceps Curl (26.92 Δ%) and Ankle Extension (36.80 Δ%), which is in line with the previous results reported (9,10, 546). The appropriate recruitment of motor units that allow for the required force at a particular velocity of movement is the fundamental premise of power. The neuromuscular system that supports these various power output outcomes is reliant on a number of physiological factors, as such muscle fiber types and mechanisms (e.g., size principle).

In general, Strength improvements (i.e. 6RM outcomes) vary according to the important parameters that determine force generation, such as muscle length, muscular contraction velocity, external load on the muscle, level of metabolic stress, or necessity to balance. Strength gains are thus specific to whether we lift or lower weight, move quickly or slowly, lift heavy or light weights, move through full or partial ranges of motion, lift in stable or unstable environments, use "weight" or elastic resistance, direct force vertically or horizontally relative to the body, and train which muscle groups. Moreover, following high-intensity resistance circuit-based training strength-related training-induced decrement of fibre length is more related to the results reported in previous studies (reference).

Subsequently, high-intensity stimulus involved circuit-based resistance training modulates to increase the muscles volume, and therefore also in mass. It happens largely because of an increase in the volume of individual muscle fibers, rather than by an increase in the number of fibers. It can increase in volume in two ways, as such by increasing the fibre length, and diameter. Length increases happen due to the addition of new sarcomeres in series, whereas increases in diameter happen through the addition of myofibrils in parallel. Changes in the shape and structure of the muscle accommodate these size increases, such that the origin and insertion of the whole muscle do not need to be altered.

According to the present results, the special characteristics of the HRC training protocol enhance the force production and velocity as well; therefore increasing the lower body power output and probably maximal force output, but unfortunately, we have not measured the lower body maximal force output. As well as, increased upper body maximal force was detected, it is evident that all measured parameters of 6RM exercises also been increased significantly ($p < 0.05$), specially related to the upper body maximal force biceps curl, bench press lat pull-down were detected increased 6RM (9, 10, 545, 546).

On the other hand, it seems like HRC training-induced increases in the frequency of signaling from the central nervous system to the motor unit or Rate coding to increase the maximum power output of CMJ. As a consequence, it has been increased the CMJ height, which was even explained by Gajewski et al. (426). Increasing signal frequency can result in greater power production because of an increase in the firing rate of motor units and a continual increase in a stepwise fashion of force (427). According to that, it is possible even increases in maximum force output of the upper body (Fmax: 5.85 Δ%) as well. Besides, it is possible that following training induced some muscle fibre transition but unfortunately during this investigation, it has not been measured.

Perhaps, due to the special characteristics of the training protocol itself, it might enhance the ATP-PCR system, which was crucial to increase the power and force output. To produce powerful muscle action within a minimal time frame, a high quantity of ATP needs to be produced and replenished immediately. As a result, ATP is provided using the PCr stores within the muscle fiber itself through the ATP-PCr system. Therefore, possibly it would be helped to increase the maximum force and the maximum power output, and CMJ height.

On the other hand, the volume and intensity of the particular training with a systematic process of resistance training have induced hypertrophy or the enlargement of cells, and neural adaptations that enhance nerve-muscle interaction. There for following HRC induced increases of all 6RM following all exercises.

7.5.3. SIT induced mechanical adaptation

Sprint interval training or repeated maximal-intensity short-duration running or cycling exercise would be able to produce muscle adaptation similar to endurance training. However, most of the research conducted cycling exercises and it was measured through the Wingate test, but there was a significant theoretical gap about the short distance running SIT protocol induces mechanical force and power output. Therefore, according to the best of our knowledge, this is the first study which was measured CMJ height, maximum power output, and maximum force output following short-distance running SIT protocol.

Based on the current study results depicted that non-significant main effect within a group and all measured variables were detected to decrease. In our specialized study with recreationally trained young athletes trained on an indoor track, maximal 20 meters of sprint exercises with 15 seconds micro rest caused significant decreases in the values measured (Upper and lower body) in the force plate -2.39 Δ% for maximum power output and -7.21 Δ% for maximum force (upper body – Push-ups) for the work done. It possibly explains repeated maximal-intensity short-duration running training (SIT) negatively affects the upper body and lower body power and force production, therefore CMJ height as well. However, in contrast to these observation studies conducted through the cycling (428, 429) exercise and they have enhanced the power and force output, thus it seems like specific movement characteristics of short distance high velocity running (SIT) were negatively affected by the physiological mechanism to be produced less power and force output.

Generally, researchers have found that association between fibre length and muscle contraction properties. They depicted that high-velocity actions recruited longer fibre (430, 408) to complete the muscle action. Thus, those who trained consistently in high-velocity contractions like high-velocity short-distance running exercises may adapt to longer fibre lengths because longer fibres encourage higher shortening velocities (412). Conversely, to produce higher force contraction athletes need shorter fibre lengths (410). Therefore, seems like following the present investigation results of short-distance high-velocity SIT protocol induced larger fibre length to enhance the velocity rather than shorter fibre length for force production.

Interestingly, the results observed from the present investigation following SIT decreased maximal power and force capacity, even though it is possible to explain through the inverse relationship between force and velocity curve. Usually, power (force* velocity) has been measured during the concentric muscle action. Thus, if athletes increase the velocity probably the force will be decreased at the moment of the particular action, in contrast to the higher force production decreasing the velocity produced at the particular movement. Hence, to produce more power athletes need to find moderate to minimal force at an intermediate velocity, whereas they can produce peak power. Nevertheless, seems like short distance running SIT protocol induced higher velocity, therefore, decreasing the maximal force and power output, hence CMJ height as well.

Interestingly, even though maximal force and power output decreased, 6RM of each exercise measured: Bench press (2.20 Δ%), Leg Extension (13.20 Δ%), Deadlift (16.89 Δ%), Lat Pull-down (9.82 Δ%) and Ankle Extension (13.83 Δ%) were increased following SIT except Biceps Curl (-0.76.20 Δ%). Interestingly, Leg Extension and Deadlift even detected significant differences ($p < 0.05$) after the training intervention. The question is if increased the 6RM level then why still the maximum force (upper body) and maximum power (lower body) decrease following SIT protocol? The possible physiological explanations for this mainly could be the neural adaptation even though there is a possibility to affect other factors too. Seems like it was not enough impulse to increase MVC and RFD according to its characteristics of training does not favour to increase in MU recruitment and discharge rate. Moreover, Muscle length, muscle contraction velocity, external load on the muscle, and amount of metabolic stress, are even possible factors which crucial for strength development which we can see occurred due to the training protocol, but for the process of power, conversion was not much enough force produced to enhance the maximal power and force.

The training protocol itself is about short sprint running whereas recruiting larger fibre length or due to the training itself enhances larger fibre length which is very important to improve the velocity rather than force.

Conversely, if athletes need to increase the force itself muscle contraction needs to recruit shorter fibre length but following SIT protocol we can't observe that much movement pattern. However, the training volume and intensity would have been positively and negatively affected to increase the strength even though some of them were not much enough to detect a significant difference. Of note, a significant difference was detected between Leg Extension and Dead Lift which is more associated with sprinting running movements, whereas sprinters develop their gluteus and hamstrings muscles which are directly related to the Leg Extension and Dead Lift, therefore it is possible to get the significant difference for both Leg Extension and Dead Lift following SIT protocol.

7.5.4. Traditional concurrent training (TCT) induced mechanical adaptation

Generally, concurrent training (i.e. Strength and endurance training) is used to encourage precise neuromuscular and cardiovascular adaptations. The alterations persuaded by strength training consist of muscle hypertrophy (27), an increase in the motor unit firing rate, and motor unit recruitment capacity (153, 142). These neuromuscular adaptations result in enhanced force (i.e. strength) and power development (431). Conversely, Wilson, et al. (21) observed through their meta-analyses, in many investigations significantly lowered power during CT whereas strength and muscle cross-sectional area were maintained. Hence, it suggested that concurrent endurance training may be affected to a more significant degree for the force at high velocities (i.e. vertical jump) than the force at lower velocities (i.e. heavy squat). The present investigation results are also in line with Wilson et al. (432) suggested lower body maximal power output decreased but lower body related all measured 6RM exercises: Leg extension (20.55 Δ%), Dead Lift (27.15 Δ%), and Ankle Extension (28.51 Δ%) were reported significant difference ($P < 0.05$) between pre and post. It means TCT induced increases of force but maximal power has been decreased due to the effectiveness of concurrent endurance for the force at high velocities (Interference effect).

Moreover, the physiological mechanism behind this may be related to the motor unit and specific muscle type innervation. In the course of the traditional long period of endurance exercises, muscle function, and force production always occurred from a low threshold and through the fatigue-resistant type I muscle fibres. It could be due to the conversion of type IIx fibers to type IIa fibers or type IIa to type I fibers to adapt to the oxygen-demanding endurance exercise following Concurrent training. Hence, it probably aerobic exercise could be detrimental for the subjects who conduct the CT to improve the high rate of force and power development. On the other hand, this could be the interference effect of lower body exercise on present traditional concurrent training.

However, following present investigation results depicted that high-intensity resistance and endurance (i.e. TCT) based related training-induced decrement of CMJ Height (-0.35 Δ%), Pmax CMJ (W/Kg) (-1.87 Δ%) (34, and 27). Interestingly upper body maximum force output (14.32 Δ%) has increased significantly when compared to the pre-post data ($P < 0.05$), which is in line with the previous results reported (123). The appropriate recruitment of motor units that allow for the required force at a particular velocity of movement is the fundamental premise of power. The neuromuscular system that supports these various power output outcomes is reliant on a number of physiological factors (for example, muscle fiber types) and methods (e.g., size principle). Then it is evident that 6RM measured related to upper body exercise: Bench press (16.37 Δ%), Lat Pull-down (14.3 7Δ%), and Biceps Curl (23.42 Δ%) have significant differences ($P < 0.05$) between pre and post. Unfortunately, we are not in a position to predict the upper body interference effect due to the lack of information on the power output.

Interestingly, best of our knowledge to date there is no research investigating upper and lower body concurrent training-induced force and power adaptations in recreationally trained young athletes. Thus these data depicted new information about the concurrent training-induced adaptations. Thus, according to the present data, lower body power output has been decreased and upper body maximal force output has been increased. A possible explanation for this type of adaptation could be due to the intensity and volume of induced different levels of muscle fatigue. Thus, it is evident that muscle force and power outcomes have been affected by the intensity and volume of the concurrent endurance for the force at high velocities. In line with that, depending on the production of muscle fatigue in the upper and lower body mechanical power and force production could be varied. Additionally, because of neurological changes improve nerve-muscle connection and cell hypertrophy. As a result, TCT caused increases in all 6RM after every workout.

7.5.5. Comparison between three different training protocols (HRC, SIT and TCT) induced mechanical adaptation.

The results of the present study suggest young recreationally-trained individuals can improve their upper body maximal force and lower body maximal power output at different levels following unique concurrent training protocols such as high-intensity resistance circuit-based training (HRC), sprint interval training, and combined resistance and endurance (traditional concurrent) training. Furthermore, the volume and/or intensity of the training, as well as movement patterns have appeared to influence the magnitude of the maximal force and power output alterations because dissimilar gains were observed for the HRC, SIT, and TCT groups.

Statistically, the major finding observed from the present study was, respective to each training protocol's intensity, volume, and nature of the exercise-induced various mechanical power and force adaptations on particular subjects. Interestingly, significant interaction (time*group) was reported on upper body maximum force output (Push-up) $F (2, 29) = 4.675$ $P = 0.017$. Moreover, non-significant main effects between groups and within a group were detected for all variables. However, through the post hoc test (within a group) significant difference was detected only on maximum force output - Push-up ($P < 0.05$) following TCT. Furthermore, following the 6 RM test: bench press $F (2, 29) = 9.163$ $p < 0.001$, leg extension $F (2, 29) = 6.700$ $p < 0.001$, and biceps curl $F (2, 25) = 10.739$ $p = 0.001$ were shown significant interaction between the time and groups, and significant main effect were identified for all measured variables but non-significant main effect were detected for any variable across between groups. Nevertheless, these results depicted that no training method was better than the other training protocol due to the existence of the non-significant between-group differences, but comparatively other training protocols HRC took less time and produced a better mechanical force and power output, specially upper body maximal force following TCT than SIT protocol.

In literature, different concurrent training protocols have been tested, but almost all are related to variations of traditional concurrent training, such as strength and endurance performed on the same and different days, in different or within the same training session, sequences of strength and endurance training, but in the present study just compare the mechanical power, force output, and 6 RM following three different types of concurrent training whereas using different time periods for each training protocol.

The present investigation results are also in line with the Wilson et al. (21) suggested lower body maximal power output decreased but like Alcaraz et al. (9) observed in the present investigation also observed increased lower body related all measured 6RM exercises: Leg extension (20.55 Δ%), Dead Lift (27.15 Δ%) and Ankle Extension (28.51 Δ%) were reported significant difference ($P < 0.05$) between pre and post. It means TCT induced increases of force but maximal power has been decreased due to the effectiveness of concurrent endurance for the force at high velocities. Therefore, decreased CMJ height (-0.35 Δ%) was found following TCT as well.

Explosive force is crucial because maximum strength is often required for many sports. It is affected by several neuromuscular factors, as such muscle fibre composition, fascicle length, cross-sectional muscle area, pennation angle, and tendon compliance. However, it is very clear resistance training-induced muscle strength as well as it improves vertical jump performance (433, 434), but high-intensity training is more effective than low-intensity training. In addition, not only intensity but also the speed of the movement was a significant factor that influences the maximal power output. During the exercise, nerve conduction and muscle excitability are not only responsible for muscle strength, but muscle contraction dynamics also have a major role (435). Power is the product of muscle force and speed. To obtain optimal performance, muscle strength or speed should be enhanced to improve explosive power (436). The training method which can induce those changes in neural activation by giving the specific stimulus applied during the training would be able to enhance the power output. According to that, even the performance of a countermovement jump depends on the maximum strength, speed of strength development, muscle coordination, and stretch-shortening cycle, whereas all of those factors can effectively increase maximum power.

A negative effect on strength was observed from different concurrent studies when endurance training was performed before strength training (53, 34, 437, and 19). Thus they suggested strength training following endurance might interfere with force production (438). Furthermore, Wilson et al. (21) suggested that concurrent endurance training may be affected to a more significant degree by the force at high velocities (i.e. vertical jump) than the force at lower velocities (i.e. heavy squat). In line with this notion, the present investigation TCT was designed for strength training before endurance training but even seems like an interference effect was observed due to the reduction of lower body power production. However, TCT induced increases in lower body force but maximal power has been decreased due to the effectiveness of concurrent endurance for the force at high velocities. Therefore could be decreasing the power output, which means power gains were compromised when endurance training was added to the resistance training program (439, 437). Conversely, upper body maximal force output was increased significantly meaning endurance training has not been affected by the production of maximal force. It is evident that when we analyze the 6RM data, all measured 6 RM variables following three different concurrent training have been increased except a few variables following SIT protocol. However, due to the non-significant difference for any 6 RM measured between groups variables depicted that among three training protocols, none of them was better than the other, but the consumed time for each training method was different.

Furthermore, high-intensity circuit-based training elicits similar and even much better increases in maximum power and force as traditional concurrent training, but compare with SIT both HRC and TCT were much better when comparing the mean differences, as measured using a 6RM test. Given that high-intensity circuit training is usually accompanying greater muscle fatigue and therefore positive adaptations in muscular endurance (33). On the other hand, how Alcaraz et al. (10) explained the increased power could be happened due to two significant factors: such as high-load with low-repetition training caused by comparable strength enhancement to the TCT and SIT protocols, and the intention of lifted loads was moving fast during the action. According to this point of view, the increases in both muscle-shortening speed and force-generating capacity could be predictable; therefore it could elicit power increases. Thus, the probability of having this sort of movement constraint is crucial for the enhancement of muscle power for any type of training protocol.

In conclusion, the present findings it possible to say no training method is better than the other. However, it is suggested that recreationally trained individuals can improve their upper body maximal force and lower body maximal power output by unique concurrent training protocol: high-intensity resistance circuit-based training (HRC) than other concurrent training: SIT and TCT (Strength and Endurance). However, since HRC is very time efficient, and both maximal force and power improved only in the HRC group within very less time, we recommend that HRC be incorporated into their training programs who have less time to prepare, while the other two training methods also is recommended for their training sessions according to the athlete or coaches wishes.

VIII - LIMITATIONS

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There were some limitations in the presented studies, which may affect the interpretation of the reported results.

In the present investigation, even though we started with enough sample size per each training protocol due to the dropped of participants in the experimental study may limit the generalizability of the present study findings and may have prevented the identification of potentially significant changes between different concurrent training protocols. Because it will be difficult to find significant between groups from the small sample size, as statistical tests usually require a larger sample size to ensure a representative distribution of the population.

Furthermore, due to the tight academic scheduled of some individuals, student mobility program under ERASMUS scholarships program, summer vacations were considerably affect to the training intervention therefore some of participant were dropped from the study sample.

Moreover, it is uncertain whether performance and subjective markers accurately reflect changes in the athlete's performance status. Because participants' intrinsic motivation level and mentality may affect the accuracy of the markers. Therefore, results may under or overestimate performance levels. However, when conducting the testing of performance markers, we verbally encouraged the participants during every attempt to improve their motivation level.

On the other hand, due to the busy schedule of the laboratory and some technical issues with the DXA machine had to post pond some training session starting dates. While due to the full of activity of the UCAM gym, we had to adjust the training time which was considerably affected to the investigation time.

In addition, even though we informed and controlled the nutrient intake of the recreationally trained athletes during 8 weeks they were not observed 24 hours under the supervision of the investigators, thus there could be some disadvantages for the present data and their interpretation.

IX - CONCLUSIONS

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The conclusions about the neuromuscular, metabolic, cardiorespiratory, structural, and mechanical long-term adaptations between the three distinct concurrent training protocols (HRC vs. SIT vs. TCT) are drawn below in accordance with the results and goals suggested by the present doctoral thesis.

i. Specific to the training demands, each training regimen elicited a variety of neuronal changes linked to the spinal reflex. The finding revealed that each training procedure had a unique neuronal adaptation that was most particular to its training character. Whereas SIT and TCT procedures demonstrated spinal adaptation throughout the intervention, HRC demonstrated supraspinal and spinal adaptation. It follows that while theoretically all of these adaptations exhibit both quantitatively positive and negative changes, both changes are crucial to improving athletic performance.

ii. Although no training approach is superior to the others, following three distinct concurrent training regimens caused different metabolic improvements in blood lipid profiles. Particularly, the TCT protocol was an ideal training method to lower total cholesterol levels and increase HDL-C, but SIT protocol is a time-effective method for performance-based programs that induced a decrease in cholesterol, triglycerides, and LDL-C, whereas HRC also induced positive and negative alterations. Thus, each user could be able to select any training protocol in accordance with their needs.

iii. TCT protocol is much better than the other two concurrent training methods (HRC and SIT); in terms of enhancing the cardiorespiratory variables (VO_2 max, VO_2 max R, Maximum heart rate, Maximum velocity, and Maximum time) in recreationally trained individuals. However, following HRC and SIT also induced an increase in VO_2 max and RMR, but the time consumed by the training sessions is lesser than TCT. Since HRC and SIT are very time efficient and contribute to enhancing cardiorespiratory adaptations, it would be advantageous to use a single mode of an exercise training protocol to improve cardiorespiratory variables. Hence, it is depending on the needs and desires of each individual in terms of their available time for exercising as well as the training plans.

iv. Body composition and Muscle architecture results revealed that HRC, SIT, and TCT offered different benefits after the 8 weeks training period but no single program was better than another, but the time spent on the training sessions differed. Hence, depending on the necessity of the subjects they can select the training method for their training schedule.

v. HRC training program is better than other concurrent training protocols (SIT and TCT) for enhancing force and power in young recreational athletes. Although HRC is recommended since it is so time-effective, the athlete's or coach's preferences may also call for the use of the other two training methods throughout their training sessions.

X - PRACTICAL APPLICATIONS

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Based on the results of the studies presented in this doctoral thesis, the following recommendations may be helpful to coaches, sports scientists and athletes.

The present data showed that HRC, SIT and TCT can produce improvements in neuromuscular, metabolic, cardiorespiratory, structural and mechanical adaptations different way during the 8-week intervention period in recreationally trained male athletes. HRC and SIT training modalities were found to be more demanding than TCT in the perspective of time consuming for the training session. Both, HRC and SIT induced similar or much better adaptations than TCT protocol respective to some physical components.

Moreover, HRC and TCT were more related with the resistance training whereas enhance muscle strength siginificantly while even induced cardiorespiratory adaptation than SIT protocol.

Muscular strength parameters, specifically the 6 RM, are sensitive to the training stress produced by different training modalities (strength and power) and training loads. Moreover, 6 RM is comfortable, affordable, and field user-friendly testing method. Hence, its use is ideal to monitor the training load in performance and clinical purpose as well.

XI - FUTURE RESEARCH LINES

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The scientific literature on comparing different concurrent training in sports is relatively undeveloped area compared to other extents in Sports Science, and almost no scientific literature has been found on three different concurrent training protocols and the cmparison of their adaptations. Furthermore, more in-depth studies on the comparison of different concurrent training protocols are needed. Based on the results obtained in the present thesis, the following research lines can provide more understanding of different concurrent training:

To investigate the chronic effect of different concurrent training loads on spinal reflex adaptation and established the load-spinal reflex adaptation relationship.

Blood rheology and body composition change after different protocols of "concurrent" training in recreationally trained men.

To investigate the dose-response relationship between baseline VO_2 max and the rise in VO_2 max following different concurrent training protocols.

Fatigue Indices and Perceived Exertion Highlight VO_2 max for different concurrent training

To investigate the Sprint Interval Training and Traditional Concurrent Training-specific long-term muscle architecture adaptations.

To compare the endurance and concurrent training protocol-induced specific long-term muscle architecture adaptations.

To investigate the long term adaptations and mechanisms following different type protocols of "concurernt" training in men and women.

XII - REFERENCES

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XIII - APPENDIXES

XIII - APPENDIXES

This chapter provides supplementary information and documents related to this PhD study.

13.1. Training protocol schedule

			CONCURRENT TRAINING METHOD SCHEDULE							
				1st Group						
			09.00h	09.30h	10.00h	10.30h	11.00h	11.30h	12.00h	12.30h
16/10/2017	Week 01	Monday								
		Tuesday								
		Wednesday								
		Thursday								
		Friday								
23/10/2017	Week 02	Monday								
		Tuesday								
		Wednesday								
		Thursday								
		Friday								
30/10/2017	Week 03	Monday								
		Tuesday								
		Wednesday								
		Thursday								
		Friday								

		CONCURRENT TRAINING METHOD SCHEDULE								
			2nd Group							
			09.00h	09.30h	10.00h	10.30h	11.00h	11.30h	12.00h	12.30h
23/10/2017	Week 01	Monday								
		Tuesday								
		Wednesday								
		Thursday								

13.2. Informed consent form

CONSENTIMIENTO INFORMADO / INFORMED CONSENT

Yo,..., con DNI/NIE................................

DECLARO:

Haber sido informado/a del estudio y procedimiento de la investigación de la investigación del Proyecto titulado: Long term adaptations and mechanisms of different type protocols of "concuremt" training in young athletes. (Adaptaciones a largo plazo y mecanismos de diferentes tipos de protocolos de entrenamiento "concurrente" en jóvenes deportistas)

Los investigadores que van a acceder a mis datos personales y a los resultados de las pruebas son: Othalawe gedara Sanajaya Othalawa, Dr. Pedro Alcaraz Ramon, Dr. Jacobo Rubio Arias, Dra. Linda Chung, Dra. Elena Marin Cascales, Dr. Cristian Marín Pagán, Francisco Javier Martinez Noguera, Jorge Carlos Vivas, Tomás Trindade de Freitas, Laura Campoy de Haro.

Asimismo, he podido hacer preguntas del estudio, comprendiendo que me presto de forma voluntaria al mismo y que en cualquier momento puedo abandonarlo sin que me suponga perjuicio de ningún tipo.

CONSIENTO:

1.-) Someterme a las siguientes pruebas exploratorias (en su caso) : Anexo V

2.-) El uso de los datos obtenidos según lo indicado en el párrafo siguiente:

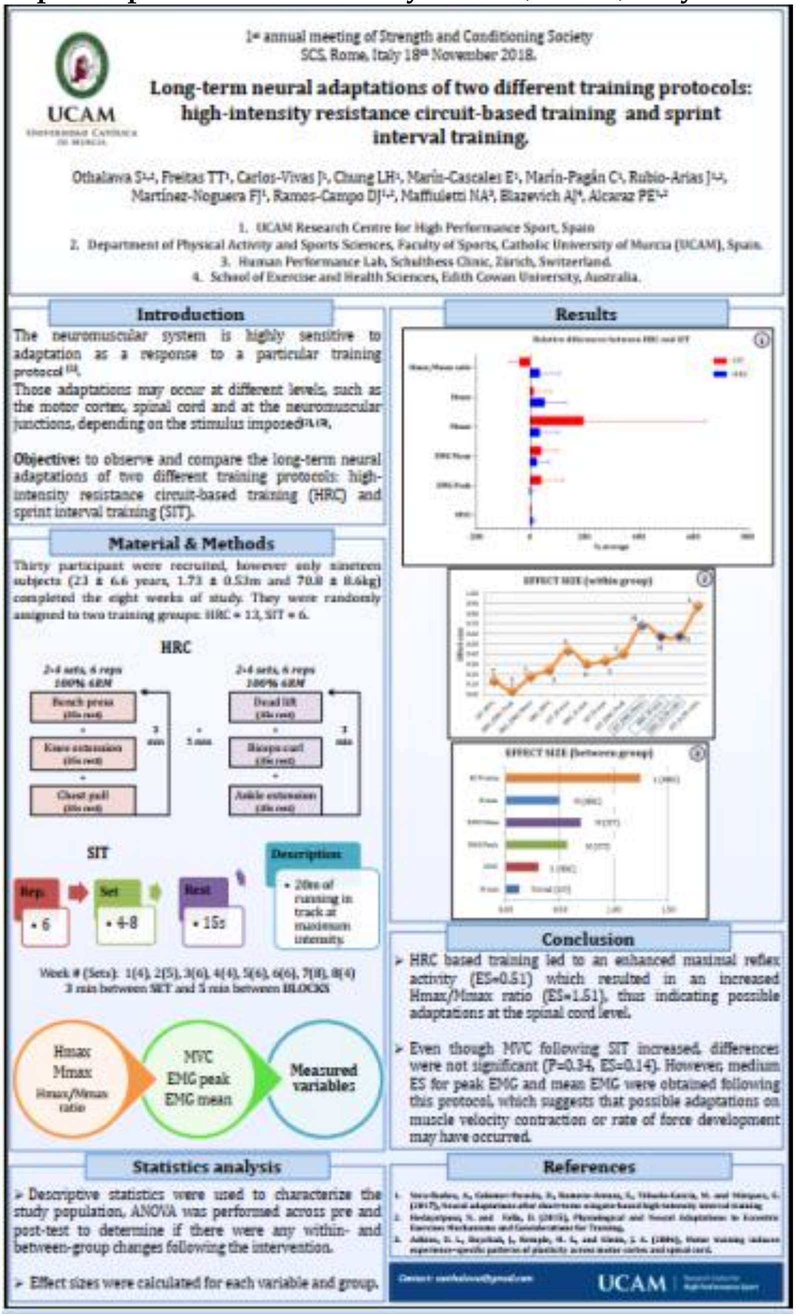
En cumplimiento del Reglamento (UE) 2016/679 del Parlamento Europeo y del Consejo, de 27 de 2016, Real Decreto-:Ley 5/2018, de 27 de julio y ley Organica 15/1999, de 13 de Diciembre, de Protección de Datos de Cáracter Personal, le comunicamos que la información que ha facilitado y la obtenida como consecuencia de las exploraciones a las que las que se va a someter pasará a formar parte del fichero automatizado INVESOCIAL, cuyo titular es la FUNDACIÓN UNIVERSITARIA SAN ANTONI, con la finalidad de INVESTIGACIÓN Y DOCENCIA EN LAS ÁREAS DE CONOCIMIENTO CIENCIAS SOCIALES, JURÍDICAS, DE LA EMPRESA Y DE LA COMUNICACIÓN. Tiene derecho a acceder a esta información y cancelarla o rectificarla, dirigiéndose al domicilio de la entidad, en Avda, de los Jerónimos de Guadalupe 30107 (Murcia). Esta entidad le garantiza la adopción de las medidas oportunas para asegurar el tratamiento confidencial de dichos datos.

En Guadalupe (Murcia) a .... de .... de 20

El investigador,

Fdo:.. Fdo:..

13.3. International Sport Forum of the Strength & Conditioning Society (SCS) and the European Sport Nutrition Society (ESNS), Rome, Italy (Poster)



13.4. Laboratory visit schedule

	Grupo 01 Visita I		Grupo 02 Familiarizacion	Grupo 01 Visita II Vo2 MAX Pre Test	Grupo 02 Visita I	
TIME	MONDAY #######		TUESDAY 10/10/2017	WEDNESDAY 10/11/2017	FRIDAY 13/10/2017	Monday
9.00h	CC31 CC33 CC37	CC31	CC39 CC41	CC37	CC39	
9.30h	CC32 CC34 CC38		CC45	CC32	CC41	
10.00h		CC35		CC34	CC35 CC42	
10.30h	CC36			CC33	CC46	
11.00h				CC31	CC45	
11.30h			CC35	CC36	CC40 ?	
12.00h			CC40 CC44	CC38		CC45 (DXA) 12:30
12.30h			CC42			CC45 (VO2 max) 12:30

13.5. Completion of Pre-test list

PRE TEST LIST

CODE	6RM	CI	RECONOCIMIENTO	BMI	DIETA	ISAK	DXA	ECOGRAFÍA	ESTIMULACIÓN	CMJ+PUSH-UP	RSA
CC31	x		x	x	x			x	x	x	x
CC32	x		x	x	x			x	x	x	x
CC33	x		x	x	x			x	x	x	x
CC34	x		x	x	x			x	x	x	x
CC35	x		x	x	x			x	x		x
CC36	x		x	x	x			x	x	x	x
CC37	x		x	x	x			x	x	x	x
CC38	x		x	x	x			x	x	x	x
CC39	x		x	x	x			x	x	x	x
CC40	x		x	x	x			x	x	x	x
CC41	x		x	x	x			x	x	x	x
CC42	x		x	x	x			x	x	x	x
CC43	x		x	x	x			x	x	x	x
CC44	x		x	x	x			x	x	x	x
CC45	x		x	x	x			x	x	x	x
CC46	x		x	x	x			x	x	x	x

13.6. Check list for familiarization

PRE TEST
Date: ………/……… / 2017
CIARD

CODIGO:

1.	6RM	
2.	RECONOCIMIENTO	
3.	BMI	
4.	ISAK	
5.	DXA	
6.	EC	
7.	ESTIMULACIÓN	
8.	CMJ+PUSH-UP	
9.	RSA	
10.	RMR	
11.	ANALÍTICA	
12.	VO2máx	
13.	Analítica pre informe	

13.7. Check list for familiarization

Concurrent training project

CIARD

	NOMBRE:			
	CODIGO:		**FECHA DE NACIMIENTO:**	
	NUMERO DE TELÉFONO:			
	ALTURA (CM):			
	PESO (KG):			
	IMC:			
		PRE	**POST**	
	CITA PARA RECONOCIMIENTO MÉDICO (Pre):	**V 1**	**V 1**	
		V 2	**V 2**	
	CITA PARA LA TEST DE FUERZA (Pre):	**V 1**	**V 1**	
		V 2	**V 2**	
	CITA PARA RECONOCIMIENTO MÉDICO (Post):			
	CITA PARA LA TEST DE FUERZA (Post):			

13.8. MVC recording sheet

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Código: ______________

Isocinético: Silla: ________ Aparato: ________

Entrenamiento: _____**HIIT** _____**HRC** _____**CT** _____**HRC_Hyp**

EMG/Estimulación eléctrica:

PRE

MVC1: _____ MVC2: _____ MVC3: _____ MVC4: _____

100Hz Tetanus:

mA	N

EMG/Estimulación eléctrica:

POST

MVC1: _____ MVC2: _____ MVC3: _____ MVC4: _____

100Hz Tetanus:

mA	N

13.9. Check list for pre and post

Check list for pre and post test

NOMBRE	
CÓDIGO	
Nº CONTACTO	
TIPO DE ENTRENAMIENTO	
HORARIO ENTRENAMIENTO	
RESPONSABLE	

PRE-TEST				
CI				
IMC				
DIETA				
DXA o ANTROPOMETRÍA				
ECOGRAFÍA	Long. total	1/3	Mitad	2/3
ESTIMULACIÓN				
CMJ+PUSHUP				
ESTIMACIÓN CARGA EJERCICIOS				
RSA				
TMR+RV				
ANALÍTICA				
$VO_{2MÁX}$				
RECONOCIMIENTO MÉDICO				
1RM				

13.10. Data sheet for 6RM

Datasheet for 6 RM

Semana:			**Series:**		**%:**			**HRC**
Codigo:			**Session 1**			**Session 2**		
Bloque	**Nu.**	**Ejercicios**	**Carga**		**6 RM**			**6 RM**
			Antes	**Presente**		**Antes**	**Presente**	
01	I.	Press Pectoral						
	II.	Leg extension						
	III.	Jalon de pecho						
02	IV.	Soleo						
	V.	Bicep curl						
	VI.	Peso muerto						