HIGH INTENSITY INTERVAL TRAINING FREQUENCY: CARDIOMETABOLIC HEALTH, QUALITY OF LIFE, PERCEPTUAL RESPONSES AND FUTURE EXERCISE ADHERENCE IN INACTIVE ADULTS

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ABSTRACT

Physical inactivity is a critical public health concern and lack of time is reported as the main barrier for not engaging in regular physical activity. High intensity interval training (HIIT) is considered as an effective and time efficient training mode. However, whether HIIT with a reduced frequency is an efficient physical activity strategy is less clear. Furthermore, there is the need of a comprehensive study that would evaluate not only the physiological adaptations to HIIT but also the psychological factors and moreover to determine the utility of HIIT as an exercise strategy for promoting future physical activity participation. Therefore, the aim of this thesis was to investigate and compare the efficacy of HIIT with low and moderate training frequency (2 and 3 times per week) on physiological and metabolic variables, on perceptual and quality of life responses and to examine whether this intervention could influence future exercise participation in healthy inactive adults .

Thirty five healthy inactive adults (age: 31.7±2.6 yrs, VO_2peak: 32.7±7.4 $ml \cdot kg^{-1} \cdot min^{-1}$) were randomly assigned to a control and two training groups, which performed 10 x 60 s cycling at ~83% of peak power, two (HIIT-2) or three times per week (HIIT-3) for 8 weeks. Prior and after the HIIT intervention, cardiorespiratory fitness, body composition, biochemical variables and quality of life were evaluated. Furthermore, following the HIIT intervention, exercise enjoyment and the intention to implement HIIT in the future were evaluated. Eight weeks after cessation of the training stimulus, follow-up evaluations of quality of life and physical activity were performed.

The results demonstrated that following 8 weeks of HIIT 2 or 3 times per week, similar improvements were found in both training groups in peak oxygen uptake, insulin concentration during a 2-hour oral glucose tolerance test, waist circumference, thigh lean cross sectional area and physical health component of quality of life. However, a decrease in total body fat, trunk fat, total and low-density lipoprotein cholesterol and an enhancement of mental health component and total score of quality of life were observed only after HIIT-3. Regarding perceptual responses both training groups displayed manageable ratings of perceived exertion, enjoyment and intentions to implement HIIT in the future. During the follow up period, vigorous and total physical activity as well as total score of quality of life was increased in both training groups compared to baseline. The change in total score of quality of life between baseline and follow up was correlated with the corresponding change in vigorous physical activity.

In conclusion, the current results suggest that 8 weeks of low frequency HIIT (2 times/week) is effective in promoting particular cardiometabolic health indices, quality of life and positive perceptual responses in inactive adults. However, a higher HIIT frequency (3 times/week) is required for body fat reduction, blood lipid profile and on mental well-being. Moreover HIIT, regardless of training frequency, appears to influence future exercise participation.

Keywords: high intensity training, frequency, maximal oxygen uptake, health, perceptual responses

ΠΕΡΙΛΗΨΗ

Η έλλειψη φυσικής δραστηριότητας είναι ένα σημαντικό πρόβλημα για τη δημόσια υγεία και η έλλειψη χρόνου αναφέρεται ως το κύριο εμπόδιο για τη μη συμμετοχή σε τακτική φυσική δραστηριότητα. Η υψηλής έντασης διαλειμματική προπόνηση (HIIT) θεωρείται ως μια αποτελεσματική και αποδοτική σε χρόνο μορφή προπόνησης. Ωστόσο, είναι λιγότερο σαφές εάν η HIIT με μειωμένη συχνότητα είναι μια αποτελεσματική στρατηγική φυσικής δραστηριότητας. Επιπλέον, υπάρχει η ανάγκη μιας διεξοδικής μελέτης που θα αξιολογεί όχι μόνο τις φυσιολογικές προσαρμογές της HIIT αλλά και τους ψυχολογικούς παράγοντες και επιπλέον θα καθορίζει τη χρησιμότητα της HIIT ως στρατηγική άσκησης για την προώθηση της μελλοντικής συμμετοχής στη φυσική δραστηριότητα. Σκοπός αυτής της εργασίας ήταν να διερευνήσει και να συγκρίνει την αποτελεσματικότητα της HIIT με χαμηλή και μέτρια συχνότητα προπόνησης (2 και 3 φορές την εβδομάδα) στις φυσιολογικές και μεταβολικές μεταβλητές, στις αντιληπτικές αποκρίσεις και στην ποιότητα ζωής και να εξετάσει κατά πόσο αυτή η παρέμβαση μπορεί να επηρεάσει τη μελλοντική συμμετοχή στην άσκηση σε υγιείς μη φυσικά δραστήριους ενήλικες.

Τριάντα πέντε υγιείς μη φυσικά δραστήριοι ενήλικες (ηλικία: 31,7 ± 2,6 έτη, VO_2peak: 32.7 ± 7.4 ml·kg^{-1}·min^{-1}) ανατέθηκαν τυχαία σε μία ομάδα ελέγχου και σε δύο ομάδες προπόνησης, οι οποίες πραγματοποίησαν ποδηλάτηση 10 x 60 s στο 83% της μέγιστης ισχύος, δύο (HIIT-2) ή τρεις φορές την εβδομάδα (HIIT-3) για 8 εβδομάδες. Πριν και μετά την παρέμβαση HIIT αξιολογήθηκε η καρδιοαναπνευστική ικανότητα, η σύσταση του σώματος, οι βιοχημικές μεταβλητές και η ποιότητα ζωής. Επιπλέον, μετά την παρέμβαση HIIT αξιολογήθηκε η ευχαρίστηση που προκάλεσε η άσκηση και η πρόθεση να εφαρμοστεί η HIIT στο μέλλον. Οκτώ εβδομάδες μετά το τέλος της προπονητικής περιόδου, πραγματοποιήθηκε αξιολόγηση της ποιότητας ζωής και της φυσικής δραστηριότητας.

Τα αποτελέσματα έδειξαν ότι μετά από 8 εβδομάδες HIIT 2 ή 3 φορές την εβδομάδα, παρατηρήθηκαν παρόμοιες βελτιώσεις και στις δύο ομάδες προπόνησης σε μέγιστη πρόσληψη οξυγόνου, συγκέντρωση ινσουλίνης κατά το τέλος της δοκιμασίας ανοχής γλυκόζης, περιφέρεια μέσης, άλιπη εγκάρσια διατομή μηρού και συνιστώσα σωματικής υγείας της ποιότητας ζωής. Εντούτοις, παρατηρήθηκε μείωση του συνολικού σωματικού λίπους, του λίπους κορμού, της ολικής και της χαμηλής πυκνότητας λιποπρωτεϊνικής χοληστερόλης και αύξηση της συνιστώσας της ψυχικής υγείας και της συνολικής βαθμολογίας της ποιότητας ζωής, μόνο μετά την HIIT-3. Όσον αφορά τις αντιληπτές

αποκρίσεις, και οι δύο ομάδες προπόνησης εξέφρασαν υψηλά επίπεδα ευχαρίστησης και πρόθεση για την εφαρμογή της HIIT στο μέλλον. Δύο μήνες μετά το τέλος της προπόνησης, η έντονη και η συνολική φυσική δραστηριότητα καθώς και η συνολική βαθμολογία της ποιότητας ζωής αυξήθηκαν και στις δύο ομάδες προπόνησης σε σύγκριση με την αρχή, με τις διαφορές στις δύο αυτές παραμέτρους να συσχετίζονται.
Συμπερασματικά, τα αποτελέσματα της παρούσας έρευνας υποδηλώνουν ότι 8 εβδομάδες HIIT χαμηλής συχνότητας (2 φορές / εβδομάδα) είναι αποτελεσματικές στην προώθηση συγκεκριμένων καρδιομεταβολικών δεικτών υγείας, ποιότητας ζωής και θετικών αντιληπτικών αποκρίσεων σε μη φυσικά δραστήριους ενήλικες. Ωστόσο, απαιτείται υψηλότερη συχνότητα HIIT (3 φορές / εβδομάδα) για τη μείωση του σωματικού λίπους, την βελτίωση του λιπιδαιμικού προφίλ στο αίμα και για την ψυχική ευεξία. Επιπλέον, η HIIT, ανεξάρτητα από τη συχνότητα προπόνησης, φαίνεται να επηρεάζει τη μελλοντική ενασχόληση με την άσκηση.

Λέξεις κλειδιά: προπόνηση υψηλής έντασης, συχνότητα, μέγιστη πρόσληψη οξυγόνου, υγεία, αντιληπτικές αποκρίσεις

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AUC	Area under the curve
BMI	Body mass index
CRP	C- reactive protein
CSA	Cross sectional area
$HbA1_C$	Glycosylated haemoglobin
HDL-C	High-density lipoprotein cholesterol
HIIT	High intensity interval training
HOMA-IR	Insulin resistance homeostatic model assessment
HR	Heart rate
HRQOL	Health related quality of life
IPAQ	International physical activity questionnaire
ISI	Insulin sensitivity index
LDL-C	Low-density lipoprotein cholesterol
MET	Metabolic equivalents of task
MICT	Moderate intensity continuous training
OGTT	Oral glucose tolerance test
PA	Physical activity
RPE	Rate of perceived exertion
TC	Total cholesterol
TG	Triglycerides
VLDL-C	Very low-density lipoprotein cholesterol
VO_2max	Maximal oxygen consumption
VO_2peak	Peak oxygen consumption

1 CHAPTER 1. INTRODUCTION

1.1 Rationale of research

It is well documented that physical activity has beneficial effects on physical and mental health. Even though the benefits of physical activity are well known, approximately one third of the adult population remains physically inactive, making physical inactivity one of the leading risk factors for mortality and morbitidy, which is responsible for an estimated 9% of premature deaths worldwide (I.-M. Lee et al., 2012). Besides time spent in physical activity, sedentary behavior is independently associated with several important detrimental health outcomes (Biswas et al., 2015). One consequence of inactivity and sedentary behavior is low cardiorespiratory fitness, which is one of the strongest predictors of mortality risk associated with an increased prevalence of cardiovascular disease risk factors (Carnethon, Gulati, & Greenland, 2005). Several reasons have been reported for not engaging in physical activity; however, the main barrier for physical activity appears to be the lack of time (Brownson, Baker, Housemann, Brennan, & Bacak, 2001). For improving and maintaining physical fitness and health, physical activity guidelines have been recommended (Garber et al., 2011). However, research has been shown that exercise performed at a vigorous intensity appears to promote greater cardio-protective benefits than exercise of a moderate intensity (Swain & Franklin, 2006). In addition, some positive effects on health through exercise may be induced with less commitment time than the available recommendations (D. C. Lee et al., 2014). Consequently, exercise interventions are required with a modest time investment which should be targeting to enhance physical activity engagement, attenuate sedentary behavior and increase the cardiorespiratory fitness level to the optimal health benefits.

An effective, practical and time efficient training mode is high-intensity interval training (HIIT). HIIT is characterized by brief, intermittent bouts of vigorous activity lasting from a 6 s to 4 min, interspersed by periods of rest and/or of low-intensity exercise, with each session lasting around 20 min (Buchheit & Laursen, 2013). HIIT has been found to consistently induce significant improvements in cardiorespiratory fitness parameters in a wide range of populations using different exercise protocols and duration (Milanović, Sporiš, & Weston, 2015; M. Weston, Taylor, Batterham, & Hopkins, 2014). Moreover many studies have shown that HIIT may increase fitness to a greater extent than moderate-intensity continuous training in healthy and clinical population despite the lower training volume and time commitment (Milanović et al., 2015; Nybo et al., 2010; O'Donovan et al., 2005; K. S. Weston, Wisløff, & Coombes, 2014). These improvements may be explained by a combination of cardiovascular (e.g. increased stroke volume and cardiac output) and peripheral (e.g. enhance mitochondrial function and capillary density) adaptations (Cassidy, Thoma, Houghton, & Trenell, 2016).

Furthermore, HIIT appears to be an effective physical activity strategy to improve glucose regulation in healthy adults; particularly in those with impaired glucose metabolic control (Jelleyman et al., 2015). Specifically, most of the studies evaluated the metabolic impact of HIIT found improvements in insulin resistance and/or sensitivity (Gillen et al., 2016; Shepherd et al., 2015), fasting glucose (Madsen, Thorup, Overgaard, & Jeppesen, 2015; Nybo et al., 2010), indices of oral glucose tolerance test (Babraj et al., 2009; Nybo et al., 2010) and reduction in HbA_{1C} (Mitranun, Deerochanawong, Tanaka, & Suksom, 2014). However, there are some inconsistencies among studies for the glucose regulation indicators which may be due to differences in exercise protocol employed, the duration of the intervention and/or the involved population. Several mechanisms have been associated with the improved glucose regulation following HIIT, such as an enhanced skeletal muscle glucose transport capacity by increasing GLUT-4 content, mitochondrial capacity and muscle glycogen depletion (Jelleyman et al., 2015). Interestingly, some studies have shown sex-based differences in the adaptive response to HIIT in glucose regulation. For instance, Metcalfe et al. (2012) reported that insulin sensitivity significantly improved in male but not in female subjects after 6 weeks of a reduced-exertion HIIT (REHIT) and Gillen et al. (2014) showed that average blood glucose concentration, glucose area under the curve and the daily peak glucose concentration for a 24 h period were improved in men but not women following 6 weeks of intense intermittent exercise. However, additional studies are warranted to determine whether female respond less to HIIT.

Regarding the effect of HIIT on blood lipid profile, there is inconsistency among training studies. Some studies reported a positive effect (Shepherd et al., 2015), while others reported no changes on blood lipids (Smith-Ryan, Trexler, Wingfield, & Blue, 2016). Furthermore, HIIT appears to alter body composition (Cassidy, Thoma, Houghton, et al., 2016) and these effects are more apparent in obese/overweight population (Batacan, Duncan, Dalbo, Tucker, & Fenning, 2017). In addition, HIIT has been shown to elicit some other health-related adaptations such as improved antioxidant status (Bogdanis et al., 2013) and endothelial function (Schjerve et al., 2008).

However, beyond the growing evidence regarding the effectiveness of HIIT in inducing physiological adaptations, there is limited evidence concerning its effect on psychological well-being (Shepherd et al., 2015). Health-related quality of life includes aspects of life that affect perceived physical and mental health. Studies have shown that achieving the recommended levels of physical activity is associated with better overall health-related quality of life (Brown et al., 2004). Although, some positive results have been reported, there are limited available data concerning the potential impact of HIIT on health-related quality of life in healthy adults (Knowles, Herbert, Easton, Sculthorpe, & Grace, 2015). It is important therefore to evaluate the perceptual responses during and after HIIT since it was found that perceptual responses are associated with future adherence to physical activity (Williams et al., 2008). Responses like rating of perceived exertion, enjoyment, scheduling and task self-efficacy have been investigated mainly following acute HIIT sessions (Bartlett et al., 2011; Jung, Bourne, & Little, 2014; Kilpatrick et al., 2015). The positive perceptual responses that most studies have reported indicate that HIIT is a feasible, tolerable and enjoyable training intervention for various populations. However, more research is needed to examine the effect of chronic HIIT training on these indices and whether these responses may influence or alter the long-term exercise adherence.

However, some other studies question the safeness and tolerability of HIIT protocols in general population, opposing the notion that HIIT could be viable public health strategy (Biddle & Batterham, 2015; Holloway & Spriet, 2015). Due to the demanding nature of some HIIT protocols that require enormous motivation, it has been suggested that HIIT may not be enjoyable for some individuals (Gibala, Little, MacDonald, & Hawley, 2012) and that a high intensity program could be seen as aversive by the participants contributing to a poor adherence (Ekkekakis, Parfitt, & Petruzzello, 2011).

Some recent studies incorporating HIIT with lower volume suggested that improvements in metabolic health and cardiorespiratory fitness may occur despite the lower exercise volume and time commitment (Gillen et al., 2016; Metcalfe et al., 2012; Vollaard, Metcalfe, & Williams, 2017). Therefore, another possible time efficient strategy could be the reduction of the training frequency, which is less investigated as a training mode. Most of the HIIT studies have been conducted with a frequency of three times per week. However, since the lack of daily time is the main barrier for adherence in physical activity, this frequency could be considered as time consuming one discouraging many people to get involved in effective physical activity programs. Consequently, a reduction in HIIT frequency per week could possibly be particularly attractive to the general population. In clinical and aging populations, some studies have recently used the lower frequency HIIT due to the feasibility of this protocol for the participants (Adamson, Lorimer, Cobley, Lloyd, & Babraj, 2014; Benda et al., 2015; Grace et al., 2015; Knowles et al., 2015). However, there are scarce data regarding the efficacy of low frequency HIIT on healthy adults (Kavaliauskas, Steer, & Babraj, 2017; Nakahara, Ueda, & Miyamoto, 2015). In addition, it is currently unclear, whether a HIIT frequency lower than 3 times per week may affect the magnitude of health-related adaptations and perceptual responses that are achieved using higher HIIT frequencies.

To date, there is no comprehensive study to evaluate the effect of different HIIT frequencies on physiological, metabolic and psychological variables associated with health and quality of life. Moreover, it would be interesting to examine if perceptual responses to HIIT would actually translate to increases in future adherence to physical activity.

1.2 Purpose of the research

Taking into consideration the necessity to find less time-consuming but effective training intervention programs in an attempt to reduce physical inactivity hazards, the present study aimed to investigate and compare the efficacy of HIIT with low and moderate training frequency (2 and 3 times per week) on cardiometabolic health, quality of life and perceptual responses in healthy inactive adults.

The objectives of this research were to:

a) Investigate if a low frequency HIIT program may induce beneficial adaptations on physical fitness, health indices and quality of life and promote positive perceived responses and compare these adaptations and responses with the corresponding ones when training frequency is moderate

b) Examine whether the perceptual responses following the HIIT intervention could influence future physical activity participation
c) Explore potential gender-based differences in the adaptive response to HIIT

The hypotheses of this study were:

a) Two sessions of HIIT per week would elicit similar adaptations in physiological, metabolic and psychological variables, as three sessions of HIIT per week
b) These adaptations would be more apparent in male participants.
c) Both HIIT frequencies will be perceived as enjoyable promoting future exercise participation

1.3 Significance of Thesis

Given the detrimental effects of inactivity in mortality and morbidity, it is emerging to find attractive, effective and practical exercise interventions to battle the growing problem of inactivity. HIIT is a practical and a less time consuming training intervention, which has been shown to elicit many health-related physiological adaptations in various populations (Gillen & Gibala, 2014). However, no HIIT study has simultaneously examined cardiometabolic adaptations, quality of life and perceived responses. Consequently, this is the first study which comprehensively examined the effects of HIIT on multiple aspects of health related parameters (metabolic, physiological, and psychological).

Moreover, recent studies have shown that a physical activity frequency as low as 1 or 2 sessions per week is associated with lower mortality risks (O'Donovan et al., 2017), however, little is known about HIIT interventions with less than 3 training sessions per week. Considering that less frequent bouts of physical activity might be easily attractive and fit into a busy lifestyle schedule, this study may suggest that lower frequency of HIIT would be more convincing physical activity strategy to encourage physically inactive adults to start exercising. It would be important to evaluate whether this intervention is able to promote active lifestyle, reduce sedentary behavior and securing the future engagement with physical activity. The success of such intervention might be vital for inactive individuals particularly following the third decade of their life where a substantial decline in their cardiorespiratory fitness is usually observed.

2 CHAPTER 2. LITERATURE REVIEW

2.1 Physical activity and health

2.1.1 Physical activity

Physical activity is defined as any bodily movement produced by skeletal muscles that result in energy expenditure beyond resting expenditure (Eijsvogels, George, & Thompson, 2016).

Regular physical activity is associated with numerous physical and mental health benefits in human (Garber et al., 2011). The relationships between physical activity and improved quality of life, reduced morbidity and mortality are well documented (Kopperstad, Skogen, Sivertsen, Tell, & Sæther, 2017; Myers et al., 2015; Rehn & Winett, 2013). Increased level of physical activity may reduce prevalence of overweight and obesity, type 2 diabetes, musculoskeletal disease, osteoporosis, cardiovascular disease, cancer, COPD, Alzheimer's disease, depression and anxiety (Rehn & Winett, 2013). Exercise has been found so beneficial for health that it could be considered as a drug (Viña, Sanchis-Gomar, Martinez-Bello, & Gomez-Cabrera, 2012). A recent review suggested that exercise can be prescribed as medicine, since it could be used as a first-line treatment for 26 different chronic diseases such as among others psychiatric, metabolic, cardiovascular and pulmonary diseases, musculoskeletal disorders and cancer (Pedersen & Saltin, 2015).

The favorable effects of physical activity / exercise are presented in Figure 1.

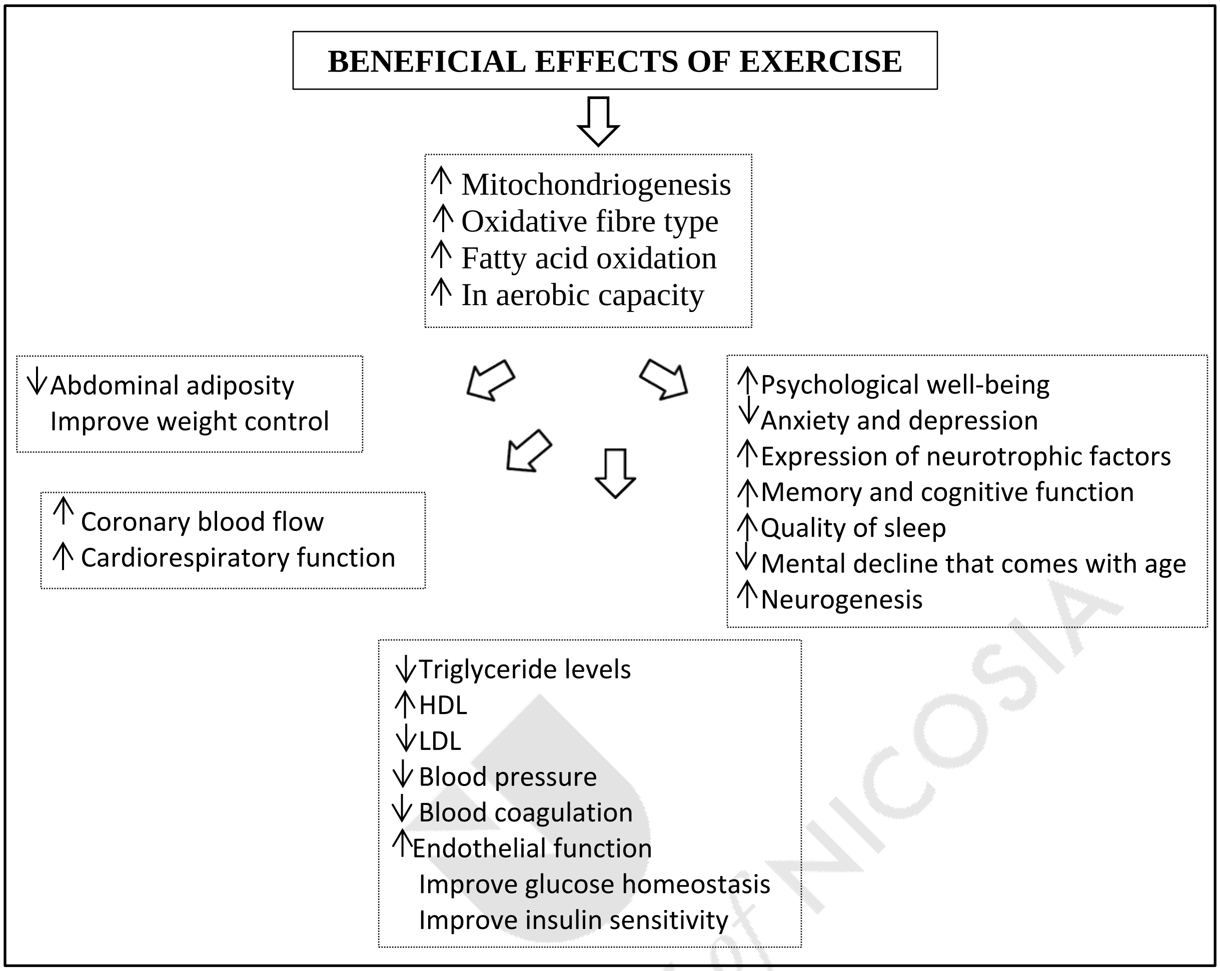

Figure 1 Health benefits of exercise/physical activity in tissues and organs. Redrawn from Viña et al. (2012).

For improving and maintain physical fitness and health, according to the position stand of American College of Sports Medicine (ACSM) (Garber et al., 2011), adults should engage in moderate-intensity cardiorespiratory exercise training for ≥30 min/d on ≥5 d/wk for a total of ≥150 min/wk, vigorous-intensity cardiorespiratory exercise training for ≥20 min/d on ≥3 d/wk (≥75 min/wk), or a combination of moderate- and vigorous-intensity exercise to achieve a total energy expenditure of ≥500–1000 MET min wk^{-1} (Moderate exercise = 64-76% HRmax or 46-63% VO_2max, Vigorous exercise = 77-95% HRmax or 64-90% VO_2max) (MET = metabolic equivalents of task). In previous exercise recommendations, vigorous-intensity physical activity was not recommended (Pate, Pratt, Blair, & Haskell, 1995). Recent guidelines however, suggest that vigorous-intensity exercise is explicitly an integral part of the physical activity recommendation (Garber et al., 2011; Haskell et al., 2007). On the other hand, these guidelines offer no specific recommendations regarding sedentary time or goals for cardiorespiratory fitness levels (Bouchard, Blair, & Katzmarzyk, 2015), although there is strong evidence for their association with health.

2.1.2 Sedentary Behavior

Sedentary behavior has been defined as any waking behavior characterized by an energy expenditure ≤1.5 METs while in a sitting or reclining posture (Sedentary Behaviour Research Network, 2012). Time-spent in sedentary behaviors is frequently referred to as sitting time. According to the recent Eurobarometer, of the citizens of the European Union countries on a usual day, the 17% spend <2.5 hours sitting, 43% spend 2.5-5.5 hours, 26% spend 5.5-8.5 hours and 11% spend more than 8.5 hours sitting down (EU, 2014). Similar are the corresponding percentages in Cyprus. Worldwide, the proportion of adults spending ≥4 hour per day sitting was found to be 41.5% (Hallal et al., 2012).

Sedentary behavior is increasingly recognized as a public health risk that needs to be monitored at the population level (Loyen et al., 2016). Sedentary time is independently associated with increased risk for all-cause mortality, cardiovascular disease incidence or mortality, cancer incidence or mortality (breast, colon, colorectal, endometrial, and epithelial ovarian), and type 2 diabetes in adults (Biddle et al., 2016; Biswas et al., 2015; Eijsvogels, George, et al., 2016). A recent analysis of 54 countries worldwide reported that sitting time was responsible for 3.8% of all-cause mortality, which is estimated at about 433,000 deaths/year (Rezende et al., 2016). Therefore, it has been proposed that decreasing sedentary behavior could be an important perspective for active lifestyle promotion, especially among people with lower physical activity levels (Rezende et al., 2016). In a recent review, the associations between sedentary behavior and various biomarkers in older adults were investigated (Wirth et al., 2016). Their results showed that sedentary behavior was associated in an unfavorable direction, in anthropometric (BMI, waist circumference, neck circumference, fat mass), blood lipid (cholesterol, HDL, LDL), glycaemic (HbA_{1C}, insulin, HOMA-IR, C-peptide) and hormonal (leptin) biomarkers.

Furthermore, an 11 year follow-up of the HUNT study reported that sitting ≥8 h/day was associated with a 17% higher risk of developing diabetes compared with sitting ≤4 h/day, adjusted for age, sex and education. From the same study it was shown that among participants with low leisure-time physical activity, sitting 5–7 h/day and ≥8 h/day were associated with a 26% and 30% higher risk of diabetes, respectively, compared with sitting ≤4 h/day, indicating that prolonged sitting may contribute to an increased diabetes risk among physically inactive individuals (Åsvold, Midthjell, Krokstad, Rangul, & Bauman, 2017). Moreover, it has been proposed that the risk of all-cause mortality increases significantly from about >7 hours per day of sitting (Chau et al., 2013). Therefore, these studies demonstrate the hazards associated with sedentary behavior, and indicate the importance of reducing sedentary behavior for public health.

2.1.3 Physical Inactivity

Physical inactivity is a distinct factor from sedentary behavior. “Inactive” is a term for describing those who are performing insufficient amounts of moderate to vigorous intensity physical activity (MVPA) (i.e., not meeting specified physical activity guidelines) (Sedentary Behaviour Research Network, 2012).

According to the last Special Eurobarometer 412 “Sport and physical activity”, 41% of Europeans exercise or play sport at least once a week, while 59% of Europeans never or seldom do so. Moreover, 48% do some form of other physical activity (such as cycling, dancing or gardening) at least once a week, while 30% never do this kind of activity. This percentage was higher in Cyprus, where 57% of the Cypriots say they never do this kind of physical activity. Similarly worldwide, a report from 122 countries presented that 31.1% of adults are physically inactive, with proportions ranging from 17.0% in southeast Asia to about 43% in the Americas and the eastern Mediterranean (Hallal et al., 2012). Inactivity increases with age since the amount of regular activity that people do tends to decrease with age (EU, 2014; Hallal et al., 2012). Furthermore, women are more inactive (33.9%) than are men (27.9%) (Hallal et al., 2012) with this disparity to be present mainly in young ages (EU, 2014).

Physical activity barriers are related with sedentary and inactive behaviors (Salmon, Owen, Crawford, Bauman, & Sallis, 2003). Therefore, physical activity interventions could be more effective when they are designed to target and alter the variables that influence physical activity (Trost, Owen, Bauman, Sallis, & Brown, 2002). The main reason given for not engaging in physical activity more regularly is lack of time (Brownson et al., 2001; EU, 2014). Some more personal barriers reported were: feeling too tired, obtaining enough physical activity at one’s job and no motivation to be physically active (Brownson et al., 2001). Moreover, enjoyment has been associated with participation in physical activity and sedentary behavior (Salmon et al., 2003) and physical activity self-efficacy has been consistently correlated with physical activity behavior (Trost et al., 2002). According to Eurobarometer (EU, 2014), in Cyprus in the question what is the main reason for not practicing sport more often, 49% of the Cypriots reported that they do not have the time, 20% they lack motivation or are not interested, 18% it is too expensive and 11% they have a disability or illness.

Physical inactivity is concerned as one of the biggest public health problems of 21st century (Blair, 2009) and should be a public health priority (Kohl et al., 2012). Physical inactivity is now identified as the fourth leading risk factor for global mortality (World Health Organization, 2010). Recent epidemiological evidence suggests that physical inactivity worldwide is responsible for 6% of the coronary heart disease, 7% of type 2 diabetes, 10% of breast cancer and 10% of colon cancer (I.-M. Lee et al., 2012). Concerning Cyprus, these numbers are higher, 9.2%, 11.4%, 16.3% and 16.4% respectively. Generally, inactivity appears to be responsible for 9% of premature mortality (14.8% in Cyprus) or >5.3 of the 57 million deaths that occurred worldwide in 2008. If inactivity were not eliminated, but decreased instead by 10% or 25%, >533 000 and >1.3 million deaths, respectively, may be averted each year worldwide. Similar results have been presented for European population (Ekelund et al., 2015). Avoiding all inactivity would theoretically reduce all-cause mortality by 7.4%. From the approximately 9.2 million deaths occurred in European men and women in 2008, 676 000 deaths may be attributable to physical inactivity compared with 337 000 deaths attributable to obesity (BMI >30). These results suggest that the influence of physical inactivity on mortality appears to be greater than that of obesity in European men and women.

Taken together inactivity and sedentary behaviors represent separate and distinct risk factors for all-cause mortality (Biswas et al., 2015; Bouchard et al., 2015). Hence, for optimal health benefits, adults should both be physically active and limit as much as possible their time spent sitting.

2.1.4 Cardiorespiratory fitness

Cardiorespiratory fitness (CRF) is a reliable measure of habitual physical activity (Lee, Artero, Sui, & Blair, 2010). CRF has been considered as a health-related component of physical fitness defined as the ability of the circulatory, respiratory, and muscular systems to supply oxygen during sustained physical activity (Lee et al., 2010). Several studies have shown that low CRF is associated with morbidity and mortality in both men and women independently of other risk factors (Kodama et al., 2009; Lee et al., 2010; Stevens, Cai, Evenson, & Thomas, 2002). Moreover, it has been reported that positive change in physical fitness is associated with lower risk of mortality (Erikssen et al., 1998) and that high fitness attenuates the detrimental effects of obesity on mortality (Stevens et al., 2002).

In another study based on the follow-up of a large population of women and men in the Aerobics Center Longitudinal Study (ACLS), it was reported that low cardiorespiratory fitness accounts for about 16% of all deaths in both women and men, which is substantially more, than other risk factors like obesity, smoking, high blood cholesterol and diabetes (Blair, 2009). From the same study it was shown that the most fit men and women had 43% and 53% lower risk for all-cause mortality and 47% and 70% lower risk of CVD mortality, compared with the least fit men and women, respectively (Lee et al., 2010). Similarly, a meta-analysis from 33 studies and ~100 000 participants showed that individuals with low CRF had a substantially higher risk of all-cause mortality and coronary heart / cardiovascular disease compared with those with intermediate and high CRF (Kodama et al., 2009).

After reaching the maximal value of CRF between age of 20–30 years, a reduction in VO_2max usually begin in the third decade of life (Fleg et al., 2005; Hawkins & Wiswell, 2003; Lee et al., 2010), whereas the age loss rates of approximately 10% per decade were uniformly noted in sedentary and active population (Hawkins & Wiswell, 2003). The proposed mechanisms that could be responsible for this age-associated decline are central and peripheral adaptations to aging such as the reduced maximum heart rate and the alterations in body composition (decreased lean body mass and increased fat mass) (Hawkins & Wiswell, 2003).

2.1.5 Dose-response relationship among physical activity, sedentary behavior, cardiorespiratory fitness and adverse health outcomes

Taken together the above studies some questions are raising:

1. How much exercise is required for an individual to be healthy?
2. Is there an optimal exercise dose or a dose-response relationship between physical activity and adverse health outcomes?
3. Does the CRF level of the individuals influence the risk of mortality?
4. Could PA diminish the detrimental effects of sedentary behavior?
5. What are the outcomes when performing exercise above or below the recommended values of physical activity?

It has been shown that a 1-MET (3.5 mL/min/kg) higher level of maximal aerobic capacity was associated with 13% and 15% reductions in risk of all-cause mortality and coronary heart / cardiovascular disease, respectively (Kodama et al., 2009). The same study suggested that a minimal CRF of 7.9 METs may be important for significant prevention of all-cause mortality and coronary heart / cardiovascular disease. Another study suggested that an increase in 11.25 MET-h/week for an inactive individual was associated with a 23% reduction of risk for cardiovascular mortality and 26% diabetes mellitus incidence, independent of body weight (Wahid et al., 2016).

Furthermore, the deleterious effects of high levels of sedentary time appears to become less pronounced as participation in physical activity increases (Biswas et al., 2015; Chau et al., 2013). Although further work on dose–response relationships is required, Chau et al., (2013) estimated the risk of all-cause mortality for sitting 10 h/day to be 34% and 52% higher than sitting for 1 h/day when physical activity was and was not taken into account, respectively. In addition, a study showed that replacement of 1 hour per day of sitting with an equal amount of physical activity was associated with lower mortality among less active older adults (Matthews et al., 2015). Interestingly, a recent meta-analysis study (n > 1 000 000), indicated that high levels of physical activity, equivalent to 60–75 min of moderate intensity per day (higher than the public physical activity recommendations), seem to eliminate the increased mortality risks associated with high sitting time (Sugawara & Nikaido, 2014).

Therefore, these studies indicate that small changes in sedentary behavior or even replacing some sitting time with physical activity may lower disease risk and improve health.

It is well documented that performing the recommended amount of physical activity has a positive effect on fitness, reducing the development of several clinical diseases including cardiovascular and all-type of cancer incidences mortality risks (Arem et al., 2015; Church, Earnest, Skinner, & Blair, 2007; Garber et al., 2011; Wen et al., 2011). However, increasing the volume of physical activity appears to further decrease the mortality and morbidity risk. A previous study for example suggested that exercise at the 150% of the recommended physical activity amount had a proportionally greater increase in physical fitness when compared with the traditional recommended amount of physical activity (Church et al., 2007). However, although individuals who perform physical activity at the classical recommended levels may achieve most of the mortality benefits, the upper threshold of longevity benefit appears to be approximately 3 to 5 times the recommended physical activity minimum (Arem et al., 2015). A recent document from the American College of Cardiology's Sports and Exercise Cardiology Leadership Council reported that the optimal exercise dose for reducing the risk for cardiovascular incidences was established at 41 MET-h/week that equals 547 min/week of moderate-intensity exercise at 4.5 METs or 289 min/week of vigorous-intensity exercise at 8.5 METs (Eijsvogels, Molossi, Lee, Emery, & Thompson, 2016).

However, it is not well established which is the minimum amount of exercise that could induce reductions in clinical diseases. Studies have shown that even small increases in physical activity of inactive individuals (e.g. even below the recommended 30 min per day exercise volume), may elicit major health benefits (Eijsvogels, Molossi, et al., 2016). Individuals that engaged in physical activity below the minimum daily recommended physical activity (30 min) had significant health benefits compared with inactive individuals. For example, Wen et al. (2011) suggested that if inactive individuals perform 15 min of moderate-intensity daily exercise, one in six all-cause deaths and one in nine deaths from cancer might be prevented. Similarly, it was found that in sedentary individuals, 5 to 10 min/day (<75 min/week) of running is associated with lower risks of all-cause and CVD mortality, compared with no running (Lee et al., 2014). In another study, it was found that all-cause mortality risk was lower in the insufficiently active participants who reported 1 or 2 physical activity sessions per week than in the inactive participants (O'Donovan et al., 2017). Moreover, in the study contacted by Church et al. (2007), it was found that in sedentary, postmenopausal overweight or obese women, even activity at the 4-kcal/kg per week level (approximately 72 min/week, half of the recommended volume) was associated with a significant improvement in fitness compared with women in the non-exercise control group.

Therefore, the above reports emphasize that even low volumes of physical activity can effectively reduce mortality and may suggest that sedentary individuals, who find it difficult to accumulate 150 min of activity per week, may be encouraged to exercise even for lower time or frequency.

2.1.6 Moderate vs vigorous physical activity

Current physical activity guidelines suggest that 150 min of moderate- and/or 75 min of vigorous- intensity physical activity respectively are required of an individual to elicit health benefits (Garber et al., 2011). Consequently, individuals may select their activity patterns according to their preferences and physical abilities (Gebel et al., 2015). However, it has been suggested that if the proportion of total moderate to vigorous physical activity (MVPA) is achieved through vigorous activity may promote more benefits than through moderate activity pattern (Eijsvogels, George, et al., 2016; Gebel et al., 2015; Swain & Franklin, 2006; Wen, Wai, Tsai, & Chen, 2014).

The significant benefits of vigorous activity in reducing mortality were recently indicated. A study showed that among adults who reported their daily physical activity, those who engaged in vigorous activity were found to be associated with risk reductions (9-13%) for mortality (Gebel et al., 2015). Supporting the above results, another study showed that a 5-min run is as good as 15-min walk in terms of mortality reduction, and a 25-min run can generate benefits that would require 4 times longer to accomplish with walking (Wen et al., 2014). In addition, a systematic review demonstrated that if the total energy expenditure of exercise is held constant, vigorous intensity exercise appears to confer greater cardioprotective benefits than moderate intensity one (Swain & Franklin, 2006). This finding may be explained particularly by the greater improvements of cardiorespiratory fitness induced by vigorous- intensity compared to moderate-intensity exercise (Lee et al., 2014; O'Donovan et al., 2005; Swain & Franklin, 2006). Consequently, 2 minutes of moderate activity may not be equivalent to 1 minute of vigorous activity (Gebel et al., 2015) and thus when is feasible, vigorous activity should be preferred as a superior physical activity pattern.

2.1.7 Summary

Epidemiological studies have revealed that time spent in sedentary behaviors, level of physical activity and cardiorespiratory fitness are all (jointly and independently) associated with mortality rates and with several clinical diseases such as obesity, type 2 diabetes, hypertension, cardiovascular disease, aging- associated frailty, and cancer (Bouchard et al., 2015). For successful reduction of mortality risk, public health should focus not only on physical activity but also to less sitting and higher cardiorespiratory fitness. The precise intensity and minimum volume of training that is required to influence health markers is still unclear. As previously mentioned, the lack of time is the main barrier which leads to inactivity. At the same time, the positive effects on health through exercise may be induced with less commitment time than the traditional recommendations. Consequently, exercise intervention with a modest time investment but with high intensity may enhance physical activity engagement, attenuate sedentary behavior and increase the cardiorespiratory fitness level for optimal health benefits.

2.2 High Intensity Interval Training (HIIT)

As it was stated above, although the health benefits of physical activity are well documented, many adults do not exercise at all and lack of time is the most commonly cited barrier to regular exercise participation. To overcome this barrier, high-intensity interval training (HIIT) is identified as a time efficient mode of exercise training with a time commitment of ~ 15-25 min per session.

HIIT refers to repeated bouts of relatively brief intermittent exercise, performed either with an ‘‘all-out’’ effort or at an intensity close to maximum. Depending on the training intensity, a single bout may last from few seconds to few minutes; with multiple efforts separated by 1-4 minutes of rest or low-intensity exercise (Gibala & McGee, 2008). Different HIIT protocols have been proposed the past decade. Examples of protocols employed in interval training studies are shown in Figure 2.

One of the most usual HIIT protocols is the sprint interval training (SIT) which includes 4-6 “all out” or “supramaximal” 30 s sprints (Wingate test), that corresponds to intensities ≥100% VO_2max (Weston et al., 2014a). This protocol, has been found to increase VO_2peak (Whyte, Gill, & Cathcart, 2010), insulin sensitivity (Babraj et al., 2009; Richards et al., 2010; Whyte et al., 2010) and various markers of mitochondrial content (Gibala et al., 2006) in only two weeks of training. However, although SIT has been presented as an effective and time efficient training intervention, it is very demanding training method requiring enormous motivation, and it may not be safe and tolerable appealing some individuals (Gibala et al., 2012). Given the strenuous nature of the SIT, it is possible that cardiovascular or musculoskeletal complications could arise especially in older or less fit individuals (Macpherson, Hazell, Olver, Paterson, & Lemon, 2011).

Another high intensity protocol is the aerobic interval training (AIT) that includes longer submaximal intervals. Specifically, each training session consists 10 minutes of warm-up followed by 4X4 minutes intervals at 90–95% of HRmax, alternating with 3-minute of active recovery at 70% of HRmax, ending with a 5-minute cool- down, giving a total exercise time of 40 minutes (Tjønna et al., 2008). Although, this was reported to be an effective protocol in enhancing aerobic capacity and reducing metabolic syndrome risk factors (Ciolac et al., 2010; Tjønna et al., 2008), is not time efficient.

Recently, studies have employed modified interval training protocols, which are time effective and probably more suitable for individuals with low physical fitness. Low-volume high intensity interval training (HIIT) includes exercise training sessions with ≤30 minutes duration each; this includes warm-up, ≤10 minutes of vigorous exercise, recovery periods between intervals and cool down (Gillen & Gibala, 2014). An example is the reduced-exertion high-intensity interval training (REHIT) which incorporates two 20-s all-out cycle sprints in a 10-min exercise session (Metcalfe et al., 2012). Another example of a low volume HIIT is a protocol that consists of 10 bouts of 60 s of exercise at an intensity that elicits ~90% of maximal heart rate interspersed with 60 s of recovery between intervals (Little et al., 2011). Such protocols involves a total of only ~25 min per session producing lower weekly total work-load and training duration than the traditional recommended public health guidelines (Garber et al., 2011). The health benefits of this HIIT model have been demonstrated in many studies evaluating various populations (Currie, McKelvie, & MacDonald, 2012; Gillen, Percival, Ludzki, Tarnopolsky, & Gibala, 2013; Hood, Little, Tarnopolsky, Myslik, & Gibala, 2011; Jung, Bourne, Beauchamp, Robinson, & Little, 2015; Little et al., 2011; Saint-Maurice, Kim, Welk, & Gaesser, 2015; Smith-Ryan et al., 2016).

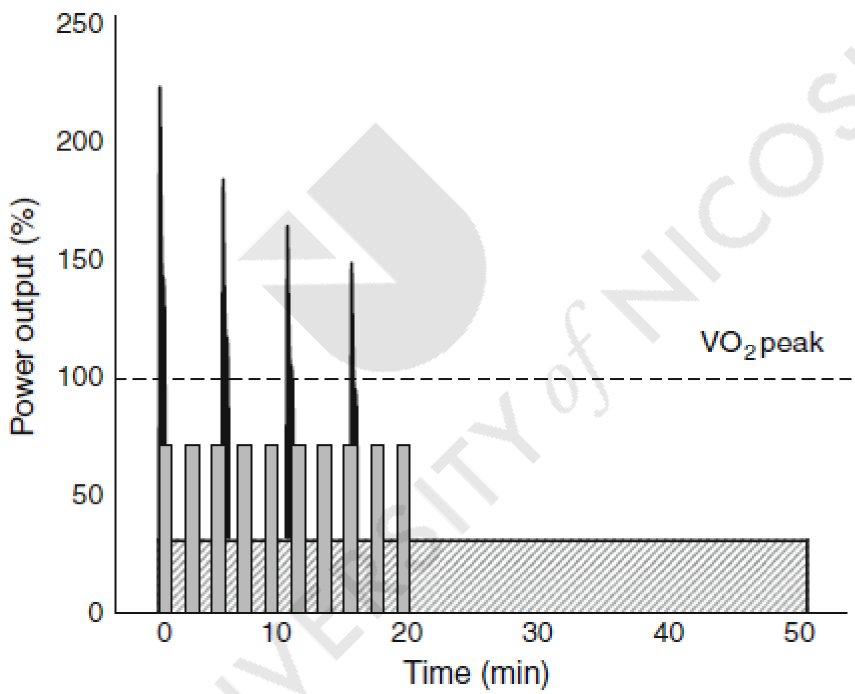

Figure 2 Examples of protocols employed in interval training studies, expressed relative to peak power output (PPO) that is required to elicit VO_2peak. The figure shows typical moderate intensity continuous training, e.g. 50min at ~35% of PPO, which elicits ~70% of HRmax (hatched box); low-volume HIIT, e.g. 10x1min at constant workload corresponding to ~75% of PPO, interspersed with 1min of recovery, which elicits ~85-90% of HRmax during the intervals (grey bars); and low-volume SIT, e.g. 4x30s "all out" effort at a variable power output corresponding to ~175% of PPO, interspersed with 4min of recovery which elicits ~90-95% of HRmax during the intervals (black bars). Reprinted from Gibala, Gillen, & Percival (2014).

2.2.1 Health related benefits of HIIT

2.2.1.1 Cardiorespiratory fitness, cardiovascular and peripheral adaptations

CRF is one of the major predictors of mortality risks, which was found to be improved with HIIT (Cassidy, Thoma, Houghton, et al., 2016; Kessler, Sisson, & Short, 2012) and is usually measured with VO_2max/VO_2peak. A meta-analysis for example, evaluating 28 HIIT studies (lasting ≥ 2 weeks) reported that there was a beneficial effect on VO_2max (5.5 ±1.2 mL/kg/min) in healthy normal-weight young to middle-aged adults, when compared with no-exercise controls (Milanović et al., 2015). In addition, they found enhanced beneficial effects for HIIT with longer repetitions, greater work: rest ratios and longer training interventions. From a recent meta-analysis, it was found that short-term (<12 weeks) HIIT studies improved VO_2max by 3.8 mL/kg/min in normal weight populations and by 4.43 mL/kg/min in overweight/obese populations (Batacan, Duncan, Dalbo, Tucker, & Fenning, 2017). Larger effects were found from long-term (>12 weeks) HIIT studies with an aggregate improvement of 6.04 mL/kg/min in overweight/obese populations. Furthermore, another meta-analysis showed a 0.30 L/min increase in VO_2max with HIIT (Jelleyman et al., 2015), whereas a higher increase (0.51 L/min) was found in the meta-analysis of Bacon, Carter, Ogle, & Joyner (2013) from studies that used interval training alone or in combination with steady-state training. Substantial improvements in the endurance fitness of sedentary and non-athletic participants were also found in the meta-analysis of Weston et al. (2014b) from studies that utilized mainly the SIT protocol. Similarly, twelve studies from the review of Sloth, Sloth, Overgaard, & Dalgas (2013) in which SIT was performed, reported significant increases of VO_2max in the range of 4.2–13.4%.

The adaptive effect of HIIT on VO_2max appears to favor the less fit individuals, since studies have shown greater improvements in VO_2max in adults with typically lower baseline fitness (Astorino, Schubert, Palumbo, Stirling, McMillan, et al., 2013; Milanović et al., 2015; Weston et al., 2014b). In a recent study it was reported that the training response is likely not affected by age but may rather be affected by the initial training status. In that study, different age groups (from 20 to 70+ years) performed an 8-week AIT intervention and exhibited similar (9%–13%) improvements in VO_2max (Støren et al., 2017). In contrast to age, the percentage improvements after HIIT were inversely associated with baseline training status. Furthermore, HIIT seems to elicit rapid improvements in CRF. Several studies have shown significant increment in VO_2max following only 2 weeks of training with a frequency of 3 sessions per week after SIT (Hazell, MacPherson, Gravelle, & Lemon, 2010; Whyte et al., 2010), AIT (Talanian, Galloway, Heigenhauser, Bonen, & Spriet, 2007) or more practical low volume HIIT interventions (Esfandiari, Sasson, & Goodman, 2014; Klonizakis et al., 2014). In addition, the time course of changes in VO_2max in response to prolonged interval training has been presented by Astorino et al. (2013). The results of that study showed that more intense interval training may induce larger and faster changes in VO_2max in untrained individuals compared to lower intensities (but still intense), but similar improvements may be revealed after a period of time.

Moreover, several studies have shown that HIIT may increase CRF to a greater extent than moderate- intensity continuous training (MICT) in healthy and clinical populations despite the lower training volume and time commitment (Milanović et al., 2015; Nybo et al., 2010; O'Donovan et al., 2005; Weston et al., 2014a). A possibly small beneficial effect of HIIT compared with endurance training on VO_2max was found in a recent meta-analysis of healthy adults (1.2 ±0.9 mL/kg/min) (Milanović et al., 2015). Weston et al. (2014a) evaluated 10 studies from patients with lifestyle-induced chronic diseases and reported that HIIT is superior (by almost twice increment - 3.03 mL/kg/min) to MICT in improving CRF in these populations. Similarly, HIIT showed increased ability to enhance CRF compared with MICT in clinical patients (Ramos, Dalleck, Tjonna, Beetham, & Coombes, 2015).

The observed improvements in VO_2max with HIIT can be explained by a combination of central and peripheral factors promoting an enhanced availability, extraction and utilization of oxygen (Weston et al., 2014b). Skeletal muscle and cardiac adaptations that may contribute to the increased gain of VO_2max are shown in Figure 3 (Cassidy, Thoma, Houghton, et al., 2016).

Studies on central adaptations are more limited and equivocal than peripheral effects of HIIT. A single bout of HIIT was shown to acutely increase in brachial artery endothelial-dependent function at rest, in a population with coronary artery as it was assessed using brachial artery flow-mediated dilation (FMD) (Currie et al., 2012). Moreover, improvement of brachial artery FMD has been found after 12 weeks of low volume HIIT in patients with coronary artery disease (Currie, Dubberley, McKelvie, & MacDonald, 2013). In contrast, macrovascular endothelial function did not improve after 2-weeks of HIIT, despite the enhancement observed in VO_2peak (Klonizakis et al., 2014). However, this possibly was due to the short training duration of that study. However, a meta-analysis revealed that HIIT is a more potent stimulus in improving vascular endothelial function than MICT (Ramos et al., 2015).

Interestingly, Wisløff et al. (2007) showed an increase in ejection fraction in patients with heart failure, after 12 weeks of AIT to the same degree as treating with ACE inhibitors and β-blockers. The same study presented augmentation of stroke volume and endothelial function and reversed left ventricular remodeling. In another study, it was reported that four weeks of SIT improved circulatory function during submaximal exercise by increasing stroke volume in sedentary, overweight/obese women (Trilk, Singhal, Bigelman, & Cureton, 2011). Moreover, an improved cardiac output was found after 8 weeks of intermittent training in sedentary adults that was correlated with the increment of VO_2max ($r=0.71$) (Daussin et al., 2008). Furthermore, increased exercise stroke volume and cardiac output were observed, secondary to increases in end-diastolic volume after six sessions of HIIT in previously untrained men, without global changes in systolic performance or cardiac morphology at rest (Esfandiari et al., 2014). In addition, increases in stroke volume and cardiac output were found following 20 sessions of periodized HIIT, suggesting that the observed increases in VO_2max as a result of HIIT are mediated by improvements in central O_2 delivery (Astorino et al., 2017). In a recent study, 12 weeks of HIIT was found to increase end diastolic volume, stroke volume, ejection fraction and cardiac structure and function in type 2 diabetes patients (Cassidy, Thoma, Hallsworth, et al., 2016). In contrast, no improvement in cardiac output was found after 6 weeks of SIT in healthy recreationally active participants, although an improvement in VO_2max was reported, possibly due to insufficient duration of the exercise intervals (Macpherson et al., 2011).

At muscle fibers level, interval training has been found to improve mitochondrial content (MacInnis & Gibala, 2016). Early studies focused on changes in mitochondrial enzymes, such as citrate synthase (CS) activity which is a commonly-used biomarker in exercise training studies, and has been strongly associated with mitochondrial content (Granata, Oliveira, Little, Renner, & Bishop, 2016; Larsen et al., 2012). CS has been found to enhance rapidly after just 2 weeks of HIIT (Little, Safdar, Wilkin, Tarnopolsky, & Gibala, 2010; Talanian et al., 2007) and SIT (Burgomaster, Heigenhauser, & Gibala, 2006) and following 12 weeks of brief SIT in sedentary men (Gillen et al., 2016). In contrast, CS remained unchanged after four weeks of either SIT or HIIT (Granata et al., 2016) and after 12 weeks of intense interval running (Nybo et al., 2010). The reasons for these discrepancies are not readily apparent, but may relate to methodological differences in CS activity assay, the participants' fitness level or training status, and differences in training duration or study design (Granata et al., 2016). Subsequent studies have also considered mitochondrial function as determined by mitochondrial respiration which have showed to increase after SIT (Granata et al., 2016). It has been suggested that training intensity may be an important determinant of improvements in mitochondrial function, but not in mitochondrial content (Bishop, Granata, & Eynon, 2014). However due to methodological differences across studies, further research is warranted to comprehensively justify this assumption.

Furthermore, peroxisome proliferator-activated receptor, gamma, coactivator 1, alpha (PGC-1α) is a critical coordinator for the activation of metabolic genes controlling substrate use and mitochondrial biogenesis (Tjønna et al., 2008). Particularly, PGC-1α coordinates mitochondrial biogenesis by interacting with various nuclear genes encoding for mitochondrial proteins (Burgomaster et al., 2008). Increases in PGC-1α have been reported following SIT (Burgomaster et al., 2008; Granata et al., 2016) and AIT (Schjerve et al., 2008; Tjønna et al., 2008). In addition, Wisløff et al. (2007) found that protein levels of PGC-1 were increased by 47% after 12 weeks of AIT and correlated with improved VO_2peak (r=0.71).

Another peripheral adaptation to HIIT is the increased capillary density which plays a major role in O_2 supply to mitochondria (Daussin et al., 2008). Six weeks of SIT improved all measures of capillarization within the m. vastus lateralis to a similar extent as endurance training in healthy sedentary young men (Cocks et al., 2013). Moreover an 21% increment in muscular capillarization was found after 8 weeks of intermittent training in sedentary adults (Daussin et al., 2008). Furthermore, the maximal rate of Ca^{2+} reuptake into the sarcoplasmic reticulum in skeletal muscles has been found to increase with AIT (Schjerve et al., 2008;

Tjønna et al., 2008) and this reuptake was correlated with the improvement in VO_2peak (r=0.56) (Wisløff et al., 2007). Sarcoplasmic reticulum Ca^{2+} handling plays an important role in muscle fatigue and the observed increases lead to improvement of the work capacity of the muscle (Cassidy, Thoma, Houghton, et al., 2016).

In conclusion, it appears that intensity is a very important stimulus for increasing CRF (Trilk et al., 2011). The interval nature of HIIT that includes rest periods, enables participants to exercise at higher exercise intensities, thereby challenging both skeletal muscles and the cardiovascular system (Cassidy, Thoma, Houghton, et al., 2016). Therefore, HIIT with different protocols has been found to induce significant changes in VO_2max in a wide variety of populations including adolescents (Racil et al., 2016), heart failure patients (Wisløff et al., 2007), overweight/obese adults (Whyte et al., 2010), middle aged adults (Adamson et al., 2014), older adults (Knowles et al., 2015) and type 2 diabetes patients (Madsen et al., 2015).

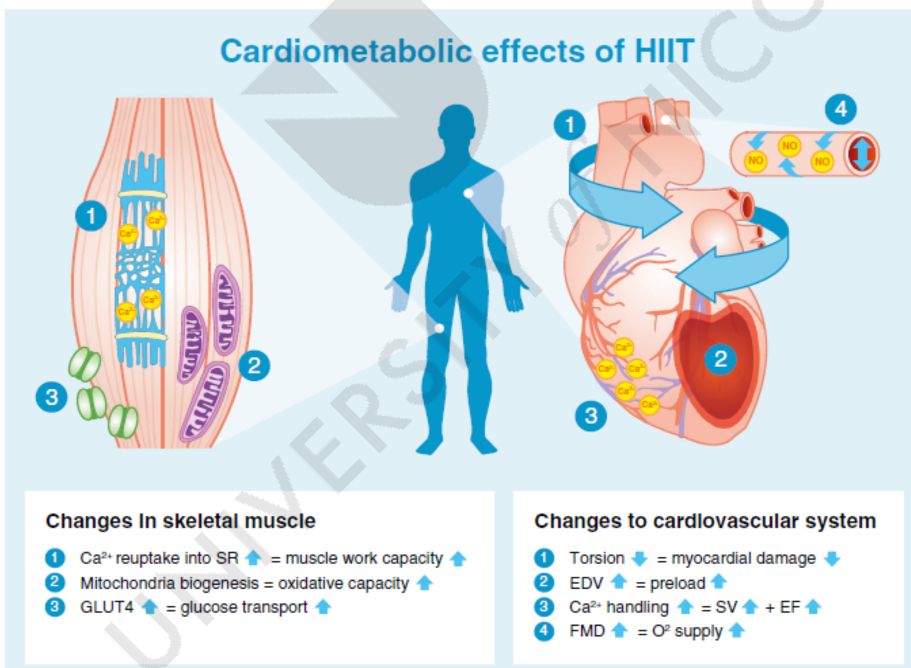

Figure 3 Cardiometabolic effects of HIIT (EDV-end diastolic volume; EF-ejection fraction; FMD-flow mediated dilation; SR-sarcoplasmic reticulum; SV-stroke volume). Reprinted from Cassidy et al. (2016).

2.2.1.2 Glucose regulation

In a healthy person, glucose regulation in the blood is controlled by the regulation of glucose production by the liver, and to a lesser degree by the kidney, as well as uptake by peripheral tissues, primarily skeletal muscle, liver, and adipose tissue (Roberts, Hevener, & Barnard, 2013). Insulin is a central regulatory hormone in the maintenance of glucose homeostasis.

Skeletal muscle is responsible for most of the uptake of glucose, via insulin- and non-insulin-mediated glucose uptake; the latter stimulated by muscular contraction (Adams, 2013; Cassidy, Thoma, Houghton, et al., 2016). The entry of glucose into the cell is achieved primarily via a carrier- mediated process, which includes a family of transporters known as GLUT proteins. Insulin-stimulated transport of glucose into cells is achieved by insulin binding to its cell surface receptor and the initiation of a cascade of signaling events culminating in the redistribution of GLUT-4 (the insulin responsive glucose transporter) to the plasma membrane (Roberts et al., 2013). This translocation of the GLUT-4 isoform may be stimulated by both exercise and insulin. It has been suggested that physical activity and exercise may prevent, control or improve impaired metabolic regulation (Ekelund et al., 2007; Pedersen & Saltin, 2015; Roberts et al., 2013). Following HIIT, improvements in glucose regulation have been reported, often similar or superior to MICT (Racil et al., 2016; Sandvei et al., 2012; Tjønna et al., 2008).

2.2.1.2.1 Fasting glucose and insulin

Fasting glucose is predominantly a marker of hepatic insulin sensitivity (Cassidy, Thoma, Houghton, et al., 2016). There is inconsistency between the HIIT training studies on the effect of HIIT in fasting glucose and insulin levels, where some report reduced values, while others report no change.

Following 2 weeks of SIT no effect was found on fasting glucose or insulin on healthy sedentary or recreationally active adults (Babraj et al., 2009; Richards et al., 2010). In longer training studies, fasting glucose was reduced after 12 weeks of intense interval running and 8 weeks of SIT in untrained healthy participants (Nybo et al., 2010; Sandvei et al., 2012). In the study of Madsen et al. (2015), fasting glucose was reduced only in type 2 diabetes patients but not in healthy matched individuals after 8 weeks of HIIT (10×1 min intervals). In another low volume HIIT study, training reduced fasting insulin, whereas fasting glucose was unchanged (Shepherd et al., 2015). In contrast, no beneficial effect was found in neither fasting glucose nor insulin, in type 2 diabetes patients after 12 weeks of HIIT (Cassidy, Thoma, Hallsworth, et al., 2016). In AIT studies, no change in fasting glucose and insulin C- peptide was found in obese adults after 12 weeks of training (Schjerve et al., 2008), while a significant reduction was observed after 3 months of training in obese adolescents for both measures (Tjønna et al., 2009).

A recent meta-analysis reported no effect on fasting glucose or insulin in normal weight population following short-term (<12 weeks), whereas in overweight participants a reduction in fasting glucose was observed with no effect on fasting insulin (Batacan et al., 2017). In another meta-analysis, HIIT resulted in a decrease in fasting glucose (0.13 mmol/L) compared with baseline, although this reduction was not different compared with the control group. On the other hand, there was a decrease in fasting glucose (0.92 mmol/L) compared to the control group in those with metabolic syndrome or type 2 diabetes (Jelleyman et al., 2015). From the same meta-analysis, a decrease was reported in fasting insulin compared to baseline (0.93 μU/L); however, this effect was not present when HIIT was compared with a control group.

2.2.1.2.2 HbA$_{1C}$

Fewer studies have investigated the effect of HIIT on glycosylated haemoglobin (HbA$_{1C}$), a long-term marker of glycemic control, with controversial results. A significant decrease in HbA$_{1C}$ was reported in type 2 diabetes patients but not in healthy individuals following 8 weeks of low volume HIIT (Madsen et al., 2015). Similarly, a reduction in HbA$_{1C}$ was detected in type 2 diabetic patients after 12 weeks of interval aerobic exercise training (Mitranun et al., 2014). Three months of AIT found to decrease HbA$_{1C}$ in obese adolescents (Tjønna et al., 2009) but not in obese adults (Schjerve et al., 2008). In addition 12 weeks of HIIT also failed to change HbA$_{1C}$ in patients with type 2 diabetes (Cassidy, Thoma, Hallsworth, et al., 2016). Meta-analysis showed that no beneficial effect in HbA$_{1C}$ was found compared to baseline; however, within the metabolic syndrome/type 2 diabetes population, there was a significant reduction of 0.25% (Jelleyman et al., 2015).

2.2.1.2.3 OGTT

Other indicators of glucose regulation are glucose/insulin area under the curve (AUC) and 2h glucose/insulin levels following an oral glucose tolerance test (OGTT). OGTT is a standardized procedure, where after an overnight fast subjects consume a 75-g oral glucose load and blood samples are taken for 120 min. With this test, postprandial hyperglycemia can be assessed and is used clinically for diagnosing of type 2 diabetes (American Diabetes Association, 2010). Like previous indicators of glucose metabolism, these factors are similarly inconsistent across studies.

The glucose and insulin areas under the curve (AUC) were found to be reduced post-training in young healthy males after just six sessions of SIT (Babraj et al., 2009) and after 10 weeks of low volume HIIT based in a gym in inactive adults (Shepherd et al., 2015). In another low volume HIIT study, glucose and insulin AUC did not change in type 2 diabetes patients or in healthy individuals however in type 2 diabetes patients blood glucose concentration 2 h after oral ingestion of 75 g of glucose was reduced (Madsen et al., 2015). Similarly, glucose level 2 h after OGTT was also reported to be reduced in untrained men after they completed 12 weeks of intense interval running (Nybo et al., 2010) and in young healthy adults following 8 weeks of SIT (Sandvei et al., 2012). Moreover, no reductions were found in glucose and insulin AUCs in both males and females after 6 weeks of a reduced-exertion HIIT (REHIT) (Metcalfe et al., 2012).

2.2.1.2.4 Insulin resistance/sensitivity

Insulin resistance (i.e., low insulin sensitivity) has been suggested as the major underpinning link between physical inactivity and metabolic syndrome (Roberts et al., 2013). As presented in Figure 4, an hyperbolic relationship exists between insulin secretion and insulin sensitivity and exercise training/physically activity status could modify this relationship (Roberts et al., 2013).

Different methods exist to assess insulin resistance/sensitivity. The gold standard is the hyperinsulinaemic euglycaemic clamp technique (Richards et al., 2010), however is expensive and not easily applicable in clinical practice. Other methods include homeostasis model assessment of fasting glucose and insulin (HOMA-IR) which is an index of hepatic insulin resistance (D. R. Matthews et al., 1985), the Matsuda insulin sensitivity index from an OGTT (Matsuda & DeFronzo, 1999) and the Cederholm index (Cederholm & Wibell, 1990) which is a peripheral insulin sensitivity index. All of these techniques correlate well with the results of glucose clamp test (Gutch, Kumar, Razi, Gupta, & Gupta, 2015).

Studies assessing the metabolic impact of HIIT on healthy adults have found improvements in insulin resistance or sensitivity (Babraj et al., 2009; Cocks et al., 2013; Gillen et al., 2016; Hood et al., 2011; Richards et al., 2010; Sandvei et al., 2012; Shepherd et al., 2013, 2015), whereas other found no change following HIIT (Madsen et al., 2015). On the other hand, some studies in populations with common metabolic diseases have shown an improvement following HIIT (Fisher et al., 2015; Madsen et al., 2015; Mitranun et al., 2014; Racil et al., 2016), while some others found no change in insulin resistance or sensitivity (Boyd, Simpson, Jung, & Gurd, 2013; Cassidy, Thoma, Hallsworth, et al., 2016; Gillen et al., 2013; Heydari, Freund, & Boutcher, 2012b; Robinson et al., 2015). Furthermore, some studies have reported that HIIT improves insulin sensitivity more effectively compared to MICT (Racil et al., 2016; Sandvei et al., 2012; Tjønna et al., 2008); however, this was not universal (Cocks et al., 2013; Fisher et al., 2015; Gillen et al., 2016; Mitranun et al., 2014; Shepherd et al., 2015).

In one of the few studies that examined gender differences, it was shown that insulin sensitivity significantly improved in male but not in female subjects after 6 weeks of a reduced-exertion HIIT (REHIT) (Metcalfe et al., 2012). Meta-analysis of 29 studies showed that HIIT induced a significant reduction in HOMA- insulin resistance score of 0.33 compared with baseline and HIIT was effective in improving measures of insulin resistance compared with continuous exercise and a non-exercise control groups (Jelleyman et al., 2015). However, the same meta-analysis reported that the largest effects were seen in those with type 2 diabetes or metabolic syndrome, suggesting that HIIT may improve insulin sensitivity only in those who are insulin resistant (Jelleyman et al., 2015).

Several mechanisms have been associated with improved insulin sensitivity following HIIT. An increased skeletal muscle glucose transport capacity by increased GLUT-4 content has been involved. As it was mentioned before, GLUT-4 is a glucose transporter which plays an important role in the insulin-induced glucose uptake by muscle and adipose tissues.

Skeletal muscle GLUT-4 protein content has been found to increase after HIIT in various studies (Gillen et al., 2014; Hood et al., 2011; Little et al., 2011).

Changes in muscle mitochondrial capacity may be another potential factor. Reduced mitochondrial activity has been observed in people with insulin resistance and type 2 diabetes and has been suggested to contribute to insulin resistance (Petersen, Dufour, Befroy, Garcia, & Shulman, 2004). As it was referred earlier, HIIT may increase mitochondrial capacity and therefore HIIT interventions may be effective for the treatment and prevention of type 2 diabetes (Hood et al., 2011; Little et al., 2011)

It has also been suggested that glycogen depletion, especially in SIT, may induce improvements in insulin sensitivity, since its depletion correlates with several aspects of enhanced insulin signaling (Roberts et al., 2013). Repeated Wingate sprints and sprints of shorter duration have been found to reduce skeletal muscle glycogen levels (Bogdanis, Nevill, Boobis, & Lakomy, 1996; Metcalfe et al., 2015). It has been suggested that this glycogen turnover may be sufficient to induce beneficial adaptations to insulin sensitivity (Babraj et al., 2009; Metcalfe et al., 2012; Whyte et al., 2010).

The reported inconsistencies of glucose regulation indicators across studies may be explained by various reasons. Some of them could be the differences in exercise protocol, the duration of the intervention or the involved population. Another plausible explanation could be the variation in time between the last exercise bout and the blood sampling. For example, Whyte et al. (2010) observed an augmentation of insulin sensitivity 24-hour after the last bout, but this change was lost at the 72-hour post-intervention assessment. Therefore, it is important to determine the time of the post intervention test for being able to clarify if the observed changes are due to an acute effect of the last exercise bout or a training adaptation. In addition, one more explanation for the discrepancies between studies may be inter-individual variability as shown by the wide range of the changes in plasma insulin AUC (from -54% to +70%) in response to REHIT (Metcalfe, Tardif, Thompson, & Vollaard, 2016b).

In conclusion, the literature indicates that HIIT could be an effective physical activity strategy to improve glucose regulation in healthy adults, but mostly in those with impaired metabolic control.

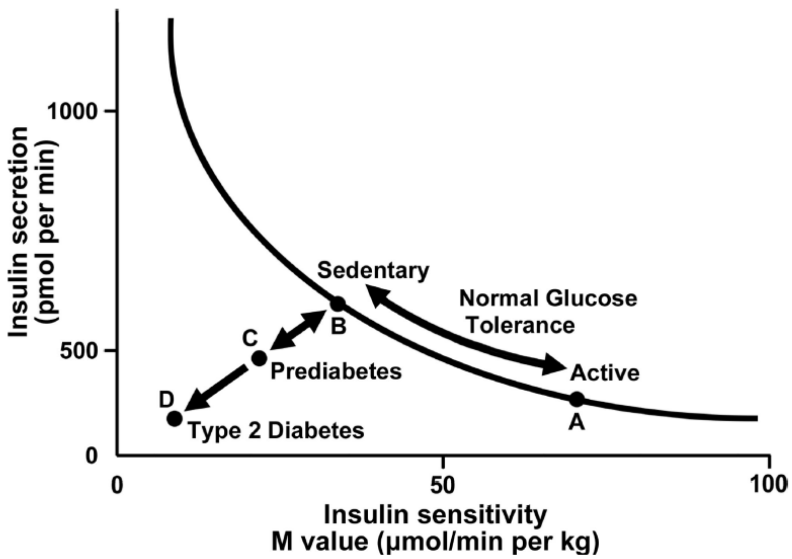

Figure 4 Graph depicting the hyperbolic relation between insulin secretion and insulin sensitivity. Insulin secretion rises as insulin sensitivity falls when an individual goes from a state of exercise training/being physically active (point A) to detraining/sedentary (point B) and vice versa, that is, bidirectionality of the two arrows from B to A when undergoing exercise training/increasing physical activity levels. A failure of insulin secretion to compensate for a fall in insulin sensitivity is noted when both insulin secretion and insulin sensitivity decline from points B to C, leading to elevated fasting glucose and prediabetes (impaired glucose tolerance). A progressive decline in both insulin secretion and insulin sensitivity to point D indicates type 2 diabetes. Reprinted from Roberts, Hevener, & Barnard (2013).

2.2.1.3 Blood Lipids

Plasma cholesterol (TC) and triglycerides (TG) circulate as lipoproteins [e.g. low-density lipoprotein cholesterol (LDL-C) and high-density lipoprotein cholesterol (HDL-C)] (Piepoli et al., 2016). The role of dyslipidemia, especially hypercholesterolemia, in the development of cardiovascular diseases is well documented (Piepoli et al., 2016). A positive influence of physical activity on blood lipids has been suggested from comparisons between sedentary and physically active groups (Durstine et al., 2001). It has been suggested that training volume rather than training intensity is more important for the improvement of the lipid profile (Durstine et al., 2001; Kraus et al., 2002; Swain & Franklin, 2006); although some time efficient HIIT interventions have shown positive changes in lipid profile (O'Donovan et al., 2005; Sandvei et al., 2012; Shepherd et al., 2015).

Previous research has shown that 10 weeks of HIIT, performed in a group-based gym setting, contributed to reductions of TC and LDL-C and increment of HDL-C in healthy inactive adults (Shepherd et al., 2015). In the same study the LDL-C to HDL-C ratio was reduced, whereas a trend for a reduction in fasting TG concentration was observed. Similarly, following 8 weeks of SIT in young lean participants, a reduction in TC and LDL-C was found, although HDL –C and TG remained unchanged (Sandvei et al., 2012). Moreover, the reductions in TC, LDL-C and non-HDL-C that were reported after 24 weeks of high intensity exercise in sedentary men were significantly different than control group, whereas no change was found for HDL –C and TG (O'Donovan et al., 2005).

In contrast, other HIIT studies were unable to stimulate significant positive changes in blood lipids (Heydari et al., 2012b; Kong et al., 2016; Madsen et al., 2015; Nybo et al., 2010; Smith-Ryan et al., 2016). HDL, LDL, TC and the ratio of total and HDL cholesterol remained unchanged following 12-weeks of intense running in untrained men (Nybo et al., 2010) and high intensity intermittent exercise in overweight men (Heydari et al., 2012b). However, a trend for significant difference was found for TG and TC after 8 weeks of HIIT in type 2 diabetes patients (Madsen et al., 2015). The meta-analysis of Batacan et al. (2017) also showed no influence of short or long-term HIIT interventions on blood lipids in normal weight and overweight/obese populations.

2.2.1.4 Body composition

The epidemic of obesity is one of the major health problems and the prevalence of obesity has increased the last decades, mainly due to an unhealthy diet and lack of physical activity. Obesity is linked with mortality, cardiovascular diseases, type 2 diabetes and several types of cancer (Mitchell, Catenacci, Wyatt, & Hill, 2011). Therefore, effective fat loss strategies for prevention and treatment of obesity are required and it appears that HIIT is a time efficient alternative solution.

2.2.1.4.1 Weight loss

Meta-analysis of HIIT interventions with <12 weeks duration revealed no significant effect on body mass in normal weight and overweight/obese populations (Batacan et al., 2017). Indeed, many studies found no change in body mass following different HIIT protocols in various populations (Astorino, Schubert, Palumbo, Stirling, McMillan, et al., 2013; Cassidy, Thoma, Hallsworth, et al., 2016; Fisher et al., 2015; Gillen et al., 2013; Kong et al., 2016; Nybo et al., 2010; Smith-Ryan et al., 2016). However a few studies showed a reduction in healthy population (Madsen et al., 2015; Shepherd et al., 2015; Trapp, Chisholm, Freund, & Boutcher, 2008). In addition, some other studies, mostly larger in duration, showed that HIIT induced moderate weight loss in adults with common metabolic diseases (Heydari et al., 2012b; Madsen et al., 2015; Mitranun et al., 2014; Tjønna et al., 2008). For example, following 16 weeks of AIT, a reduction of 3% in body mass was found in metabolic syndrome patients, a similar change with the continuous moderate exercise group (Tjønna et al., 2008). Moreover, it was shown that body mass reduced after 9 and 12 weeks of high intensity intermittent exercise but not at the first 3 and 6 weeks in young overweight men (Heydari et al., 2012b). In another meta-analysis study, following HIIT a reduction of 0.7 kg in body weight compared with baseline and a reduction of 1.3 kg compared with control conditions was found. A greater effect of 2.3 kg was observed in the metabolic syndrome/ type 2 diabetes subgroup. In contrast, there was no difference in weight loss following HIIT compared with continuous training overall (Jelleyman et al., 2015).

2.2.1.4.2 Total Body fat

Some studies have shown that HIIT may decrease whole body fat mass, even when weight remains stable (Fisher et al., 2015; Gillen et al., 2013; Smith-Ryan et al., 2016). For instance, a reduction of ~2 kg in fat mass was reported in overweight/obese women ffollowing 3 weeks of HIIT (Smith-Ryan et al., 2016), while a smaller decrease (~0.6 kg) was found following 6 weeks of low volume HIIT in overweight women (Gillen et al., 2013). Other studies have shown a reduction in fat mass with a concomitant decrease in body mass (Heydari et al., 2012b; Mitranun et al., 2014; Shepherd et al., 2015; Trapp et al., 2008). From these studies, Shepherd et al. (2015) showed a similar loss (~1 kg) in fat mass between HIIT and MICT after 10 weeks of training, whereas Trapp et al. (2008) reported a larger fat mass loss of ~2.5 kg in young healthy women following 15 weeks of high-intensity intermittent exercise, which was higher than the steady-state exercise group, even though the estimated total energy expenditure over training period was similar between the 2 training programs. Moreover, Mitranun et al. (2014) showed similar loss in body fat percentage between continuous and interval aerobic exercise training matched for energy expenditure/exercise session, in participants with type 2 diabetes after 12 weeks of intervention. However, O’Donovan et al. (2005) showed higher change in body fat percentage in high intensity compared to moderate intensity exercise group after 24 weeks of training with equal energy cost. Consequently, these results may demonstrate that it remains unclear whether HIIT is more effective and efficient way in controlling body composition than MICT.

Some others studies failed to show a reduction in fat mass in healthy (Astorino, Schubert, Palumbo, Stirling, McMillan, et al., 2013; Madsen et al., 2015; Nybo et al., 2010) and obese adults (Kong et al., 2016) and in type 2 diabetes patients (Cassidy, Thoma, Hallsworth, et al., 2016; Madsen et al., 2015) following HIIT. A recent meta-analysis showed no effect of short-term HIIT (<12 weeks) on body fat in normal and overweight/obese population, although a significantly improved % body fat was found in overweight/obese populations after long-term HIIT (≥12 weeks) (Batacan et al., 2017). Furthermore, some studies suggested that greater baseline fat levels may induce a greater fat loss following HIIT training (Boutcher, 2011; Smith-Ryan et al., 2016; Trapp et al., 2008).

2.2.1.4.3 Abdominal, visceral and trunk fat

The distribution of body fat, especially intra-abdominal adipose tissue accumulation has been correlated with a cluster of diabetogenic, atherogenic, prothrombotic and inflammatory metabolic abnormalities increasing the risk of type 2 diabetes and cardiovascular disease (Després, 2006). Moreover, the abdominal obesity has been independently associated with an increased risk of coronary heart disease and type 2 diabetes independently of overall adiposity (Després, 2006). Therefore, an investigation whether HIIT may induce a reduction of abdominal fat and not only of overall fat mass is required.

Using DEXA, Gillen et al. (2013) revealed a reduction in abdominal fat percentage in overweight women after 6 weeks of low volume HIIT and Trapp et al. (2008) reported a decrease in central abdominal (0.15 kg) and trunk fat (1.4 kg) following 15 weeks of high-intensity intermittent exercise in young healthy women, when compared with the steady-state respective exercise groups. Similar changes were found by Heydari, Freund, & Boutcher (2012) who also used DEXA and a similar HIIT protocol and reported a decrease in abdominal fat by 0.14 kg (6.6%) and a reduction of trunk fat by 1.4 kg (8.4%), in overweight young male after 12 weeks of training. Moreover, a smaller reduction of trunk fat (0.4 kg) was reported following 10 weeks of HIIT in inactive participants (Shepherd et al., 2015) and a non-significant 11.3 cm decrease in abdominal fat thickness was demonstrated in overweight/obese women after 3 weeks of HIIT (Smith-Ryan et al., 2016).

In another study (Heydari et al., 2012b), abdominal and visceral fat distribution were measured by computerized tomography scans. It was reported that abdominal fat decreased by 8.5% at L2/L3 and 6.6% at L4/L5 and visceral fat was reduced by 17% at level L2/L3 and 10% at level L4/L5 after 12 weeks of high-intensity intermittent exercise in overweight males. Furthermore, using MRI, Cassidy, Thoma, Hallsworth, et al. (2016) showed a reduction in visceral adipose tissue (from 201 to 181 cm^2) and a 39% relative reduction in liver fat (from 6.9 to 4.2%), following 12 week of HIIT in patients with type 2 diabetes.

Waist circumference is an indicator of abdominal adiposity, since it is associated with total abdominal and visceral fat (Clasey et al., 1999). Several HIIT studies presented reduction in waist circumference in various populations (Heydari et al., 2012b; Madsen et al., 2015; O'Donovan et al., 2005; Tjønna et al., 2008). HIIT induced a change of 2cm and 1.4cm in waist girth in healthy sedentary men (O'Donovan et al., 2005) and women respectively (Astorino, Schubert, Palumbo, Stirling, McMillan, et al., 2013). Moreover, waist circumference changed by 4% in elderly healthy participants and by 5.7% in type 2 diabetes patients following 8 weeks of HIIT (Madsen et al., 2015). In AIT studies, waist circumference was reduced by 5 cm in metabolic syndrome patients after 16 weeks (Tjønna et al., 2008) and by 7.2 cm in overweight adolescents after 12 months of training (Tjønna et al., 2009). In addition, it has been shown that during 12 weeks of high-intensity intermittent exercise in overweight males, waist circumference was significantly reduced by 2.6 cm in week 6 and afterwards a further not significant reduction occurred by 0.9 cm up to week 12 (Heydari et al., 2012b). This reduction also was significantly correlated with the reduction in visceral fat at week six (Heydari et al., 2012b). Furthermore, meta-analysis revealed no evidence for the effect of short- term HIIT on waist circumference in normal weight populations, although a reduction was revealed in overweight/obese populations after short or long- term HIIT (Batacan et al., 2017).

Different possible mechanisms for the induced fat loss by HIIT have been suggested. Firstly, a catecholamine response has been shown to be significantly elevated after HIIT

(Trapp et al., 2008), as it appears that intensity is the main factor able to alter catecholamine responses to exercise (Zouhal, Jacob, Delamarche, & Gratas-Delamarche, 2008). Catecholamines have been shown to induce lipolysis (Zouhal et al., 2008), particularly in the abdominal tissue where an increased concentration of β-adrenergic receptors have been found compared to subcutaneous fat (Rebuffé-Scrive, Andersson, Olbe, & Björntorp, 1989).

Another potential mechanism that could be involved in the reduction of fat mass is an increased fat oxidation following HIIT. In a study by Astorino, Schubert, Palumbo, Stirling, & McMillan (2013), it was reported that HIIT may enhance lipid oxidation during progressive exercise, following either moderate or more strenuous interval training in sedentary women. They presented also that fat oxidation reached its maximum rate approximately at the 6th week of the training intervention period and thereafter it was maintained constant. This may suggest that changes in intensity, greater number of bouts, and/or higher training frequency should be executed to promote continued increments in fat oxidation. Furthermore seven HIIT sessions, over a 2-wk period, increased post-training whole-body and skeletal muscle capacity for fat oxidation during exercise (60 min of cycling at ~60% pre-training VO_2peak) in recreationally active women (Talanian et al., 2007). The enhancement in fat oxidation after HIIT may possibly link with increased mitochondrial biogenesis and function, as it was previously explained (Bishop et al., 2014).

Collectively, due to different experimental HIIT protocols and population employed, conclusions regarding the effect of HIIT on body composition indices might be drawn with caution. However, based on the above observations it appears that HIIT may induce favorable changes in body composition and could be an optimal exercise stimulus to promote fat loss, especially in adults with common metabolic diseases.

2.2.1.5 Health- related quality of life

The World Health Organization defines quality of life as “an individual’s perception of their position in life in the context of culture and value systems in which they live, and in relation to their goals, expectations, standards and concerns. It is a broad ranging concept affected in a complex way by the persons’ physical health, psychological state, level of independence, social relationships and their relationship to salient features of their environment” (WHOQOL Group, 1998). Health-related quality of life (HRQOL) is a multi-dimensional construct which refers to health perceptions and may adopt the definition of health by World Health Organization: "state of complete physical, mental, and social wellbeing and not merely the absence of disease or infirmity" (Knowles et al., 2015; Ware, 1995).

The most widely used measure of HRQOL is the SF-36 questionnaire which is a 36-item short-form survey for measuring health perception, both physical and mental, in clinical and general population (Ware & Sherbourne, 1992). The SF-36 has been translated and widely used in several languages and its reliability and validity has been proved in several reports (Aaronson et al., 1998; Brazier et al., 1992). The Greek SF-36 has been previously validated as well (Pappa, Kontodimopoulos, & Niakas, 2005).

The SF-36 questionnaire measures eight health concepts (dimensions/domains): 1) physical functioning; 2) role limitations because of physical health problems; 3) bodily pain; 4) social functioning; 5) general mental health (psychological distress and psychological well-being); 6) role limitations because of emotional problems; 7) vitality (energy/fatigue); and 8) general health perceptions (Ware & Sherbourne, 1992). These eight concepts are summarized in two summary component measures: a) physical health component and b) mental health component, assessing the impact of health on physical and social/emotional function respectively.

Achieving the recommended levels of physical activity may provide additional benefits beyond gaining physical health and reduced risk of mortality. Findings from 2001 Behavioral Risk Factor Surveillance System survey, using data from 175 850 adults, presented that the recommended levels of physical activity are associated with better overall HRQOL and perceived health status and that these relationships extend across all age, racial/ethnic and sex groups (Brown et al., 2003). Similarly, meeting public health recommendations for physical activity was shown to be associated with higher HRQOL scores in a relatively large sample of French adults (Vuillemin et al., 2005). In the same study, it was reported that higher intensity in leisure time PA was associated with greater HRQOL. Furthermore for both men and women, subjects attaining vigorous PA had better HRQOL than subjects attaining moderate PA in physical functioning, bodily pain, vitality, and general health dimensions and in physical health component score.

Even though previous research has presented that various types of exercise training (e.g. aerobic, resistance, flexibility) may positively affect HRQOL in disease and healthy populations (Gillison, Skevington, Sato, Standage, & Evangelidou, 2009; Segal et al., 2001), studies however, evaluating the impact of HIIT interventions on HRQOL are limited.

An increase in the SF-36 subscale physical function was found in heart failure patients following either 12 weeks of HIIT or continuous training without however observing any change in the SF-36 total score (Benda et al., 2015). In heart transplant recipients, HIIT enhanced physical health component but mental health component was unaffected (Dall et al., 2015). Moreover, in the 8 subscales of the SF-36, there were significant improvements in physical function, energy, pain and general health. In physically inactive middle-aged women at risk for metabolic syndrome, 6 weeks of SIT increased the constructs role-physical and vitality compared with a non-exercise control group (Freese et al., 2014). In patients with coronary artery disease, significant increases in the role-emotional, mental health, and self-reported health status scales as well as the mental health index were observed following HIIT (Jaureguizar et al., 2016). In lifelong sedentary ageing men, improved perceptions of all domains of HRQOL were reported except social functioning and role limitations due to emotional problems, after 13 weeks of preconditioning exercise and low volume HIIT (Knowles et al., 2015). The researchers of that study suggested that HIIT is more effective at improving physical health as opposed to mental health in sedentary ageing men. In another study, where only the item general perceptions of health from SF-36 was used, the results revealed beneficial effects of HIT on health perceptions following low volume HIIT in a gym in physically inactive volunteers (Shepherd et al., 2015). Therefore, in spite of the positive indications, the contribution of HIIT on HRQOL particularly in healthy adults remains relatively under-examined.

2.2.2 Perceptual responses to HIIT

For physiological adaptations points of view, HIIT, as previously mentioned, has been reported as an alternative training method to more time- consuming traditional modes of continuous exercise. However, for exercise training to produce a significant impact on functional capacity and quality of life, an exercise program has to be both adopted and adhered as well (MacDonald & Currie, 2009). Since positive perceptual responses may predict future exercise engagement (Williams et al., 2008), it is important to investigate how participants are receptive to HIIT, whether HIIT will be enjoyable and tolerable to them but most importantly, whether they will be adhering to HIIT.

In some previous studies it has been shown that pleasure is reduced when exercising above the ventilatory or lactate threshold (Ekkekakis et al., 2011). Consequently, this may result in poor adherence to a high intensity program which is seen as aversive by the participants. Moreover, research has mainly described perceptual responses to various types of exercise training (e.g. aerobic, resistance), less is known however regarding how these measures change in response to HIIT. Although studies have presented perceptual responses after acute sessions, the effects of chronic training on these indices are under examined and thus less clear.

2.2.2.1 Rating of perceived exertion (RPE)

The perception of exertion is defined as the subjective intensity of effort, strain, discomfort and/or fatigue that is experienced during physical exercise (Robertson & Noble, 1997). The assessment of perceived exertion is most frequently undertaken utilizing category scales. Such scales are the 15-partition scale (i.e., the RPE scale) or the Borg's 10-partition Category-Ratio (CR-10) scale. RPE increases with increased intensity and/or duration of exercise and has been influenced by cardiorespiratory, metabolic and peripheral factors such as heart rate, oxygen consumption, blood pH levels and lactic acid concentration as well as other non-specific mediators like hormonal responses to exercise stimulus, body core and skin temperature and pain responsiveness (Robertson & Noble, 1997).

The exertional response to HIIT sessions vary between studies, due to the different protocols that have been used. Average peak RPE values for all ten 1-min high-intensity intervals (90% VO_2peak, 1 min recovery) or five 2-min high-intensity intervals (80-100% VO_2peak, 1min recovery) sessions were reported to be 14.1 and 14.9 respectively, in overweight/obese women (Smith-Ryan et al., 2016). Higher mean peak RPE (16) for 3x20 s ‘all-out’ cycling efforts during HIIT intervention was found by Gillen et al. (2016). In the study of Kilpatrick et al. (2015), RPE responses were examined while comparing interval sessions with different duration (30 s, 60 s and 120 s) that utilized 1:1 work-to-recovery ratios and required the same amount of total work. Their results showed that performing more intervals with shorter durations appears to produce lower post-exercise RPE values than fewer intervals of longer duration and equal intensity. This may suggest that shorter HIIT intervals are more palatable than longer intervals in unfit and overweight adults (Kilpatrick et al. 2015). Furthermore, it has been reported that active and insufficiently active participants have the same RPE responses during a HIIT session (Frazão et al., 2016).

Additionally, it has been reported that intense exercise elicits higher RPE than moderate intensity exercise. For instance, in sedentary middle-aged men, RPE increased more during Wingate-based HIIT than moderate-intensity continuous training sessions (Saanijoki et al., 2015). In another study, higher ratings of RPE were recorded after HIIT running (6×3 min at 90% VO_2max) compared to moderate-intensity continuous running in recreationally active men (Bartlett et al., 2011). Furthermore, in a recent study, it was shown that HIIT (8x1 min bouts of cycling at 85% maximal workload) induced higher RPE values by 1.5–2.7 units (RPE 1-10) during the bout compared to MICT (20 min of cycling at 45% maximal workload) in recreationally active men and women (Thum, Parsons, Whittle, & Astorino, 2017). Similarly, HIIT elicited higher RPE values than moderate continuous training in 6 weeks of training, even though the protocols were equal in energy expenditure (Heisz, Tejada, Paolucci, & Muir, 2016). Comparing HIIT (8 s of sprinting and 12 s of passive rest for a maximum of 60 repetitions) to moderate-to-vigorous continuous training, it was revealed that HIIT elicited lower RPE during 5 weeks of intervention (Kong et al., 2016).

Nevertheless, it has been suggested that HIIT- induced exertion, is diminished over-time as the exercise intervention goes on (Saanijoki et al., 2015; Smith-Ryan et al., 2016). For instance, RPE showed to decline over 6 days of Wingate based HIIT (Saanijoki et al., 2015) and after 3 weeks of HIIT, where RPE decreased significantly from the end of the first training session to the end of the last interval session for 2min intervals by 2.1 and for 1min intervals by 2.3 (Smith-Ryan et al., 2016). In contrast, no change in RPE was reported during

6 weeks of HIIT; this result may be due to the increased workload across the intervention (Heisz et al., 2016).

2.2.2.2 Enjoyment

Enjoyment has been found to be a significant predictor of sufficient participation in physical activity (Salmon et al., 2003) and it is a key component for HIIT to be feasible and sustainable (Smith-Ryan, 2017). A recent study showed that post-exercise enjoyment of SIT was predictive of post-exercise attitudes towards SIT, which in turn mediated post-exercise intentions (Stork & Martin Ginis, 2016).

Research suggests that an acute bout of high-intensity interval exercise may be more enjoyable than an acute bout of continuous exercise. Bartlett et al. (2011) demonstrated that recreationally active males perceive high-intensity interval running (6x3 min at 90% VO_2max) to be more enjoyable than moderate-intensity continuous running (50 min at 70% VO_2max) despite higher RPE. Similarly, in a subsequent study, greater enjoyment was found in HIIT (8x1 min at 85% Wmax) compared to MICT (20 min at 45% Wmax), despite the higher metabolic stress in the form of significantly higher RPE, heart rate and blood lactate in recreationally active men and women (Thum et al., 2017). In the same study also it was reported that 92% of participants demonstrated higher enjoyment and preference for HIIT compared to MICT. In the study of Jung, Bourne, & Little (2014), a single bout of HIIT (1 min at 100% Wpeak and 1 min at 20% Wpeak for 20 min) was found to be more enjoyable and a preferable exercise modality compared to continuous vigorous-intensity exercise (80% Wpeak for 20 min) but comparable with continuous moderate-intensity exercise (40% Wpeak for 40 min). In addition, comparing three near-maximal intensity interval trials that varied in duration from 30 s to 120 s in overweight to obese and insufficiently active adults, the results revealed that protocols with 30 s or 60 s high-intensity intervals are rated as more enjoyable than protocols with 120 s high-intensity intervals (Martinez, Kilpatrick, Salomon, Jung, & Little, 2015).

Furthermore, only a few recent studies have examined changes in enjoyment over time with chronic HIIT training (Heisz et al., 2016; Kong et al., 2016). A study investigated the perceived enjoyment at the first six week of a HIIT (10x1 min at ~90–95% peak HR) compared to a MICT (27.5 min at ~70–75% peak HR) program in sedentary young adults (Heisz et al., 2016). The results revealed that similar levels of enjoyment were reported at the beginning of training between the 2 groups, however as training progressed, enjoyment for HIIT increased whereas enjoyment for MICT remained constant and lower. Hence, HIIT was found significantly more enjoyable than MICT after weeks five and six. Another study also showed that a HIIT (20 min of repeated 8 s cycling interspersed with 12 s rest intervals) intervention is more enjoyable than moderate-to-vigorous intensity continuous training (40 min at 60-80% of VO_2peak), in overweight and obese individuals (Kong et al., 2016). However, in that study HIIT group had significantly higher scores on physical activity enjoyment scale (PAES) than the continuous group in any of the 5 weeks during the exercise intervention. One more study found that HIIT may be an enjoyable form of exercise for overweight/obese population in 3 weeks of training (Smith-Ryan, 2017). They reported that enjoyment went up over the training series, with enjoyment on the last day of training to be significantly higher than all other training days, suggesting that such population may become accustomed to HIIT. Moreover, it was shown that gender, higher baseline fitness status or greater lean mass had no influence on enjoyment.

2.2.2.3 Self-efficacy

Physical activity/exercise self-efficacy refers to a person's confidence in his/her ability to be regularly physically active (Trost et al., 2002). In a review paper that examined factors related with adults' participation in physical activity, self-efficacy emerged as the most consistent correlate of physical activity behavior between different psychological, cognitive, and emotional factors (Trost et al., 2002). Furthermore, Rodgers, Wilson, Hall, Fraser, & Murray (2008) suggest the existence of a multidimensional conceptualization of exercise self-efficacy with three behavioral subdomains: task, scheduling, and coping. These exercise self-efficacy domains can be distinguished from each other but are relevant to the exercise experience as they are correlated with exercise intentions and behavior. Considering that increased self-efficacy towards exercise improves adherence, physical activity interventions should be structured to maximize enhancement in self-efficacy in an effort to improve physical and health status (McAuley et al., 2006, 2011).

Very few studies have considered self-efficacy after acute sessions or training interventions with HIIT. In the study of Jung, Bourne, & Little (2014), exercise task-efficacy was examined after a single bout of HIIT (1 min at 100% Wpeak and 1 min at 20% Wpeak for 20 min), a continuous vigorous-intensity exercise (80% Wpeak for 20 min) and a continuous moderate-intensity exercise (40% Wpeak for 40 min). The participants of the study showed the same confidence in their ability to perform HIIT as they did with continuous moderate-intensity; while confidence was substantially lower for completing continuous vigorous-intensity exercise. In the study of Boyd et al. (2013), self-efficacy was examined after the completion of 9 sessions of HIIT over three weeks at either low (70%) or high (100%) peak work-rate in overweight/obese sedentary males. Their results showed that both groups reported equally high scheduling (8.1 vs. 7.9) and task (8.8 vs. 8.4) self-efficacy, utilizing a 10-point Likert scale. These findings suggest that sedentary participants perceived HIIT as tolerable and were confident that they could schedule and compete such high-intensity interval sessions into their weekly routine.

Generally, the reasons for positive perceptual responses of HIIT which may even be superior to MICT, may vary according to exercise and testing protocols and population. It is possible that participants find HIIT more motivating due to the followed varied procedure during training sessions, unlike continuous exercise where maintaining the same pace for long time can be perceived as monotonous (Thum et al., 2017; Tjønna et al., 2008). Moreover, the intermittent nature of the high intensity intervals where it switches from hard bouts to recovery may enable participants to experience a sense of accomplishment, not shown during continuous training. Hence, these multiple successful experiences, may increase self-confidence and therefore self-efficacy beliefs (Jung et al., 2014; Kilpatrick, Greeley, & Ferron, 2016; Thum et al., 2017). For this perhaps reason, the positive perceived responses may particularly be seen in HIIT interventions where the participants are aware of their training progress, getting thus a positive feedback, where change in exercise enjoyment from weeks one to six was predicted by increases in workload (Heisz et al. 2016).

Overall, studies indicate positive perceptual responses after HIIT which makes HIIT a feasible, tolerable and enjoyable training intervention for various populations. However, more research is required to examine if these responses may influence the long-term exercise adherence.

2.2.3 HIIT with reduced volume

Even though public health recommendations are established, the optimal duration, frequency and intensity of an exercise program to elicit health benefits remains to be elucidated. Given that lack of time is the main barrier for adherence in physical activity, interest is emerging to find more practical and less time consuming training interventions, like HIIT. However, it is interesting to investigate if different HIIT protocol parameters (e.g. number of bouts, training frequency) can be modulated, and be effective in achieving health adaptations with an even less time commitment. This is an important area of research, as each of these protocol parameters will impact on the likelihood of sedentary individuals adopting and adhering to an HIIT intervention (Vollaard & Metcalfe, 2017).

Recently some very brief SIT protocols (fewer and/or shorter sprints) have been found to be similarly effective with endurance training. For instance, Gillen et al. (2016) used a cycling protocol involving just 1 minute of intense exercise (3x20 s “all-out” sprints) within a 10-minute training session including warm-up and cool-down in sedentary men for 12 weeks. Their results showed an enhanced in insulin sensitivity, cardiorespiratory fitness, and skeletal muscle mitochondrial content to the same extent as MICT, despite a five-fold lower exercise volume and time commitment. The same protocol has been previously used reporting that following 6 weeks of training in overweight adults, there were improvements in skeletal muscle oxidative capacity and in indices of cardiometabolic health including VO_2peak and blood pressure, with a time commitment of only 30 min per week (Gillen et al., 2014). Furthermore, a similar 10-minute reduced exertion HIIT (REHIT), consisted of one or two “all-out sprints” for 6 weeks, was shown to be a feasible exercise intervention that may improve metabolic health and aerobic capacity in sedentary young men (Metcalfe et al., 2012). Interestingly, in a recent meta-analysis examining whether modifying the number of sprint repetitions in a SIT session may affect VO_2max, it was shown that the improvement in VO_2max with SIT is not attenuated with fewer sprint repetitions (Vollaard et al., 2017).

Another possible time efficient strategy could be the reduction of the training frequency, which is less investigated as a training mode. It is currently unclear whether the use of reduced frequency interventions can induce health benefits even though these interventions are below the recommended levels of physical activity. In most of the previous training studies, HIIT was carried out with a frequency of three times per week, however this frequency is time consuming and perhaps discouraging for some populations, especially if lack of time is considered the main barrier for physical activity.

In clinical and aging populations, some studies have recently used the lower frequency HIIT due to the feasibility of this protocol for the participants (Adamson et al., 2014; Benda et al., 2015; Grace et al., 2015; Knowles et al., 2015). Heart failure patients performed HIIT training twice a week for 12 weeks and reported significant improvements in parameters of physical fitness whilst no major effect of training was found on cardiovascular structure and function and on total quality of life. Grace et al. (2015) also, based on previous studies which indicated that older individuals take longer to recover from strenuous exercise, used a much lower frequency HIIT protocol. The participants of that study were older adults who performed HIIT every 5 days and their results showed increment of cardiorespiratory fitness in both lifelong sedentary and exercising aging men after 6 weeks of training. Moreover, from the same study, HIIT appears to enhance health-related quality of life and exercise motives in ageing males (Knowles et al., 2015). Furthermore, Adamson, Lorimer, Cobley, Lloyd, & Babraj (2014) recently showed that performance of twice-a-week HIIT can improve aerobic and functional capacity and metabolic health in middle aged population. Specifically, using a short duration HIIT, they reported 8% increment in VO_2peak and a 6% reduction in glucose AUC following 8 weeks of training.

However, there is limited data regarding the efficacy of reduced frequency of HIIT on cardiorespiratory fitness, health indices or quality of life in young healthy adults. In one recent study, Nakahara, Ueda, & Miyamoto (2015) used a severe-intensity interval training which was consisted of three bouts of exercises to volitional fatigue at 80% maximum work rate just once a week for three months in young healthy volunteers. They found improvements in cardiorespiratory function and cardiac morphological adaptations involving left ventricular hypertrophy and cardiorespiratory metabolic response during submaximal exercise. Some other studies though, did not find augmentation in VO_2max after 6 weeks of either once or twice HIIT training per week in physically active individuals (Dalleck et al., 2010), or after 4 weeks of twice SIT training per week in untrained females (Kavaliauskas et al., 2017).

Therefore, the results of the above studies indicate that health adaptations and particularly cardiovascular fitness may occur even following lower frequency HIIT programs, although the results are not consistent. Accordingly, there is a need to determine whether reductions in the frequency of HIIT, could still result in the gain of physiological and psychological adaptations. Furthermore, it is unknown whether a low HIIT frequency may affect the magnitude of these adaptations that would be achieved with higher HIIT frequencies.

2.2.4 HIIT for public health

Even though the efficacy of HIIT on various health parameters is well documented, the effectiveness of HIIT as a public health strategy has been questioned (Biddle & Batterham, 2015; Hardcastle, Ray, Beale, & Hagger, 2014).

The controversial findings of the effects of HIIT on psychological responses and the influence in future exercise adherence, have led to discussion and debate as to whether interval exercise should be advocated in public health strategies promoting physical activity (Stork, Banfield, Gibala, & Martin Ginis, 2017). Concerning the psychological responses to interval exercise, it has been questioned whether sedentary population will feel physically capable and sufficiently motivated to take up and maintain a regime of highly intense exercise (Hardcastle et al., 2014). In some previous studies it has been shown that pleasure is reduced when exercising above the ventilatory or lactate threshold (Ekkekakis et al., 2011) and as a result people may avoid participating in a high intensity program. Another study showed that prescribing a higher intensity exercise decreased adherence and resulted in the completion of less exercise over 6 months in healthy sedentary adults (Perri et al., 2002). Therefore it has been suggested that HIIT (and particularly SIT) is unlikely to be taken up by the majority of the sedentary population and that exercise with lower intensities which is generally rated as more pleasant, is more likely to be tolerated by most individuals, increasing therefore the exercise adherence (Hardcastle et al., 2014). In addition, most HIIT/SIT studies have been undertaken in supervised laboratory conditions and according to some researchers whether sedentary individuals will choose a high intensity protocol in a real life setting is doubtful (Biddle & Batterham, 2015; Hardcastle et al., 2014).

On the other hand, supporters have argued that high intensity exercise can be a public health strategy and is a viable exercise modality for sedentary individuals (Astorino & Thum, 2016; Biddle & Batterham, 2015; Jung, Little, & Batterham, 2016). Firstly, the existence of varying HIIT protocols that are more practical and scalable than SIT, makes them suitable and tolerable for different populations (Biddle & Batterham, 2015). Recent research counters the assertion that high intensity exercise is not enjoyed by the participants. A recent review has reported that enjoyment of, and preferences for interval exercise are equal or greater than for continuous exercise, and participants can hold relatively positive social cognitions regarding interval exercise (Stork et al., 2017). In addition some recent studies have focused on real setting HIIT/SIT protocols. For instance, brief, intense stair climbing is a practical, time-efficient strategy which has been shown to improve cardiorespiratory fitness in previously untrained women (Allison et al., 2017). Moreover, the potential utility of HIIT as an alternative exercise strategy that could bolster exercise adherence was shown in a study which demonstrated that individuals with prediabetes can adhere to HIIT independently (as assessed by self-report in free-living conditions) for one month following a very brief supervised laboratory intervention and do so at a level that is greater than traditional moderate-intensity continuous training (Jung et al., 2015).

Apart from the psychological responses, the safety of high intensity exercise, especially for clinical populations, has also been controversial. It is advocated that vigorous activity could acutely and transiently increase the risk of sudden cardiac death and myocardial infarction in susceptible persons (Thompson et al., 2007). The incidence of both acute myocardial infarction and sudden death has been shown to be greatest in the habitually least physically active individuals (Thompson et al., 2007).

In contrast, a study indicated that the risk of a cardiovascular event is low after both high-intensity exercise and moderate-intensity exercise among 4846 patients with coronary heart disease in a cardiovascular rehabilitation setting (Rognmo et al., 2012). Furthermore, many studies have used various HIIT protocols in clinical populations such as heart failure patients (Wisløff et al., 2007), patients with coronary artery disease (Currie et al., 2013) individuals with type 2 diabetes (Madsen et al., 2015), with beneficial effects. Although the safety profile of HIIT has not been fully established, there are increasing data demonstrating that in stable and selected patients it can be performed safely with impressive improvements in physiology, functional capacity and quality of life (Wisløff, Coombes, & Rognmo, 2015)

However caution is needed before such training is advocated to the general public (Hardcastle et al., 2014). Strategies such as health check before engaging in this type of training or the inclusion of a precondition phase of training prior to initiating HIIT appear prudent to make HIIT a safe option for the general population.

3 CHAPTER 3. GENERAL METHODS

3.1 Participants

Healthy inactive participants, men and women, between the ages of 27 and 37 years old, were recruited from posters, social media, and word of mouth. Finally, thirty five of them (n=35), were eligible and volunteered to participate in the current study after being fully informed of the test requirements and provided written informed consent. Flow chart of participants is presented in Figure 5. The participants' characteristics at baseline are presented in Table 1.

Inclusion criteria were: (a) inactive lifestyle for the past year before the study, (b) nonsmokers, (c) without diagnosed metabolic or cardiovascular diseases. Inactive lifestyle was confirmed after the completion of the Greek version of the short International Physical Activity Questionnaire (IPAQ-Gr short) (Craig et al., 2003; Papathanasiou et al., 2009), as all participants were classified into low physical activity category (Total Physical Activity score < 600 MET.min.wk^{-1}) (IPAQ, 2005). In this questionnaire the participants were asked to estimate the amount of time spent in walking, moderate and vigorous intensity physical activity over the preceding 7 day period. The Greek version (IPAQ-Gr) was found to present acceptable reliability properties in Greek adults (Papathanasiou et al., 2009). Subjects also completed a detailed medical history questionnaire for ensuring their health status, before their enrollment to the study. Ethical approval was obtained from the Cyprus national bioethics committee.

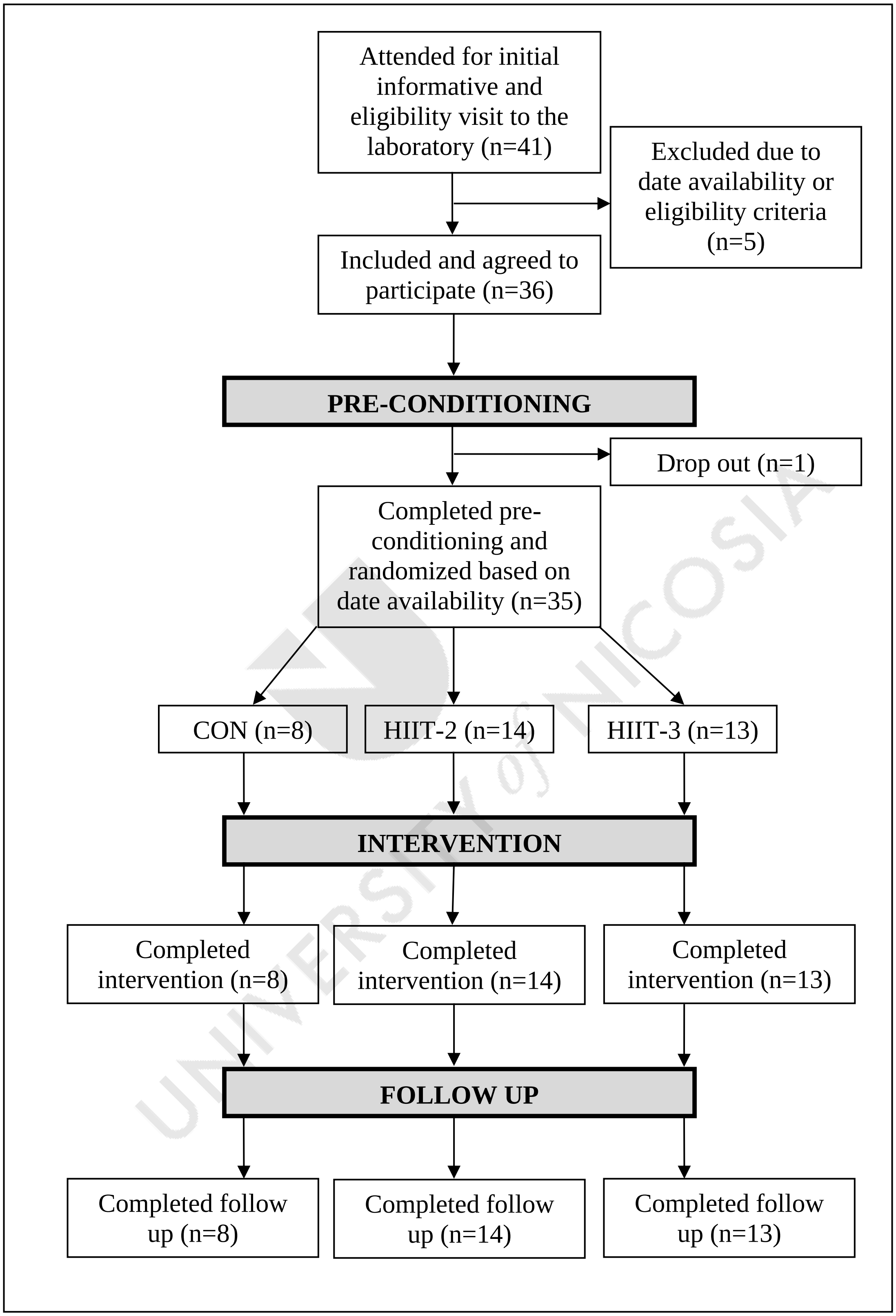

Figure 5 Flow chart of the participants through the study

Table 1 Baseline participants' characteristics for each group

Variable		CON (n=8)	HIIT-2 (n=14)	HIIT-3 (n=13)
Sex	M (male)	n=4	n=6	n=7
	F (female)	n=4	n=8	n=6
Age (years)		31.7±0.8	31.5±3.5	31.9±2.4
Height (m)		1.7±0.1	1.7±0.1	1.7±0.1
Weight (kg)		67.4±12.2	66.5±18.9	69.6±17.6
BMI (kg/m^2)		23.4±3.1	23.6±4.6	24.1±4.2
% Body Fat		16.6±6.7	18.8±5.7	17.0±5.4
VO_2peak (ml/kg/min)		33.0±9.2	32.4±6.5	33.0±7.8

3.2 Study design

Participants were randomly assigned to one of the 2 training groups, who performed high intensity interval training two times per week (HIIT-2: n=14) and three times per week (HIIT-3: n=13) or to a control group (CON: n=8). Initially, all participants of the HIIT-2 and HIIT-3 groups underwent through a 3week pre-conditioning, familiarization and testing period. Afterwards, the HIIT-2 and HIIT-3 intervention groups trained 2 and 3 times per week respectively, over an 8-week period with the same HIIT protocol; whereas the participants in the CON group continued their usual daily activities for the same time period. None of the participants withdrew from the HIIT intervention. A follow up evaluation session was scheduled two months after the completion of the intervention. All participants also completed the follow up evaluations. Training sessions were held in the human performance laboratory in University of Nicosia and were all supervised by the researcher.

All participants completed a series of tests at the beginning and after an 8-week period including measurement of VO_2peak, body composition, biochemical blood variables and evaluation of quality of life (Chapter 4). Body composition, VO_2peak, and blood tests were also performed for HIIT-2 and HIIT-3 after the initial 4 weeks of training. Evaluations of perceptual responses and IPAQ were held for all participants at the end of the HIIT intervention (Chapter 5). Assessments of quality of life, IPAQ and perceptual responses were also examined 2 months following the completion of the 8-week period for all participants (Chapter 5). (See experimental protocol in Figure 6).

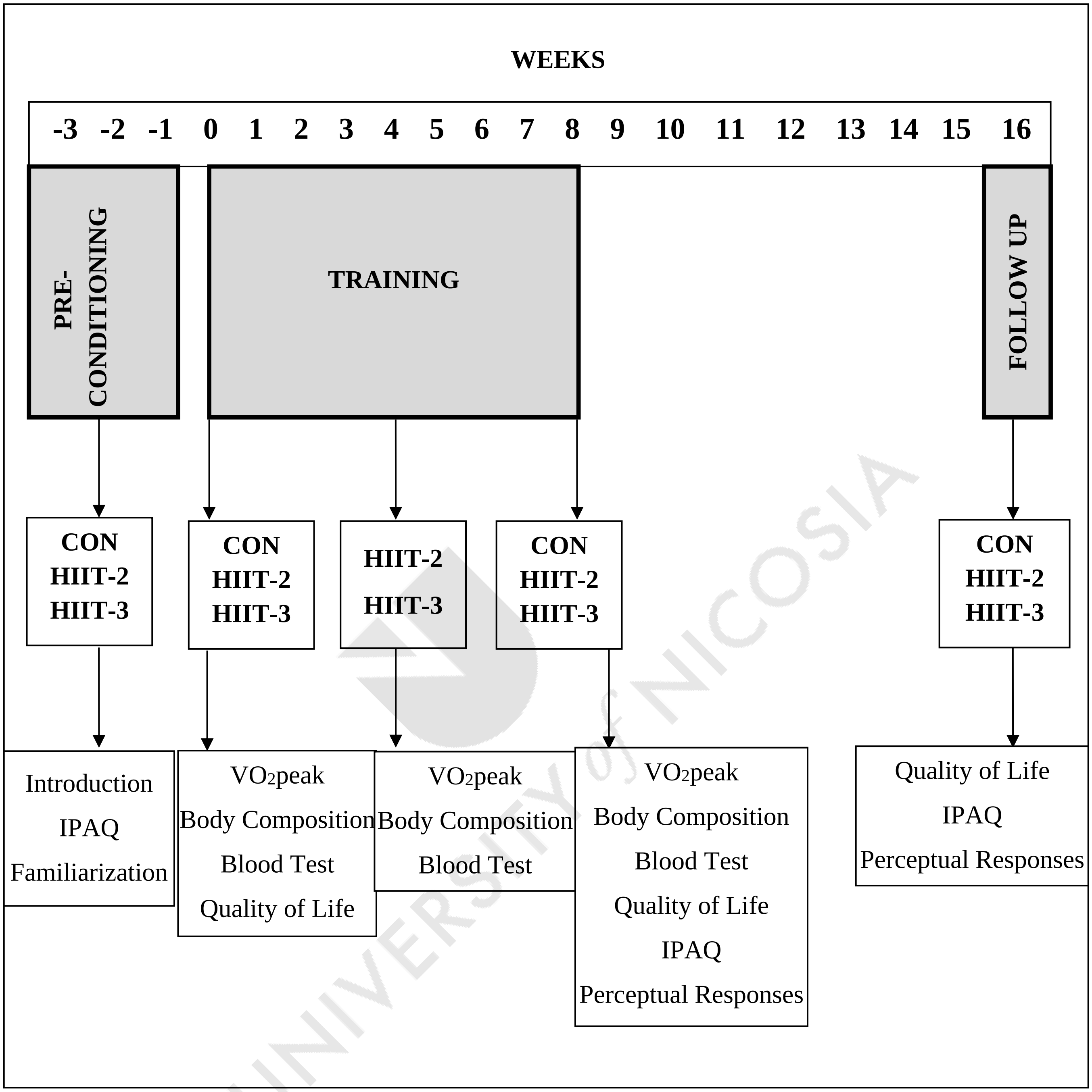

Figure 6 Experimental protocol

3.3 Assessments

Body composition: Percent of body fat was estimated using standard equations after measuring skinfold thickness (Jackson & Pollock, 1978). Moreover, trunk fat percentage and waist circumference were measured using a validated bioelectrical impedance device (Viscan Tanita abdominal fat analyzer AB140, ICC=0.996) (Browning et al., 2010). Thigh circumference was measured at the midpoint of the anterior surface of the right thigh, midway between patella and inguinal fold. Thigh lean cross-sectional area (CSA) was estimated from the thigh circumference and the thigh skinfold thickness, using the multiple regression equation provided by Housh et al. (Housh et al., 1995).

Cardiorespiratory fitness: Peak oxygen uptake (VO_2peak) was determined using a progressive test (15-20 $W \cdot min^{-1}$) to exhaustion on a cycle ergometer (Monark LC6 NOVO, Sweden). VO_2peak was defined as the highest 30 s average for VO_2 if at least three of the following criteria were met: a plateau in VO_2 despite increasing intensity, RER > 1.15, heart rate within 10 beats of age-predicted maximum, and a rating of perceived exertion (RPE) of 18 or greater. Peak power output (Wpeak) and peak heart rate (HRpeak) were also recorded.

Quality of life: Quality of life was assessed by the Short-form 36 Health survey (SF-36) (Ware et al., 1995). The SF-36 is a self-administrated 36 item survey that produces scores on eight constructs, which are summarized in two components: the physical health and the mental health component. Moreover, these scores are summed to give a total SF-36 score. The validity of the Greek version have been previously demonstrated (Pappa et al., 2005).

4 CHAPTER 4. HIGH INTENSITY INTERVAL TRAINING FREQUENCY: CARDIOMETABOLIC EFFECTS AND QUALITY OF LIFE

4.1 Abstract

This study examined the effects of high intensity interval training (HIIT) frequency on cardiometabolic health and quality of life. Thirty five healthy inactive adults (age: 31.7±2.6 yrs, VO_2peak: 32.7±7.4 $ml \cdot kg^{-1} \cdot min^{-1}$) were randomly assigned to a control and two training groups, which performed 10 x 60 s cycling at ~83% of peak power, two (HIIT-2) or three times per week (HIIT-3) for 8 weeks. Similar improvements were found in both training groups in peak oxygen uptake (HIIT-2: 10.8%, p= 0.017, HIIT-3: 13.6%, p=0.002), insulin concentration at the end of a 2-hour oral glucose tolerance test (HIIT-2: 36±19 to 24±12 $mU \cdot L^{-1}$, p=0.008; HIIT-3: 39±25 to 28±27 $mU \cdot L^{-1}$, p=0.024) and in the physical health component of quality of life (HIIT-2: 75±14 to 83±4, p=0.015; HIIT-3: 73±17 to 86±7, p=0.012). However, HIIT-3 conferred additional health-related benefits by reducing total body and trunk fat percentage (p=0.018 and 0.002, respectively), total cholesterol and low-density lipoprotein-cholesterol (p=0.01 and 0.02, respectively) and by improving the mental component of quality of life (p=0.028). In conclusion, performing HIIT only twice per week is effective in promoting cardiometabolic health-related adaptations and quality of life in inactive adults. However, a higher HIIT frequency is required for an effect on fat deposits, cholesterol and mental component of well-being.

Key Words: abdominal adiposity; glucose tolerance; cholesterol; maximal oxygen uptake

4.2 Introduction

Physical inactivity is one of the leading risk factors for mortality and shortage of time is one of the main reasons given for not exercising (Brownson et al., 2001). Low-volume high intensity interval training (HIIT) is considered as a time efficient training intervention and a viable alternative to traditional exercise. Such protocol require lower weekly total work and training duration than the recommended public health guidelines (Garber et al., 2011), but elicit health-related adaptations such as improved cardiorespiratory fitness (Nybo et al., 2010), insulin sensitivity (Madsen et al., 2015) and antioxidant status (Bogdanis et al., 2013), which are similar or even greater compared with continuous moderate-intensity training (Weston et al., 2014b). Despite the growing volume of evidence regarding the physiological adaptations to HIIT, there is limited information regarding its effect on quality of life.

In most of the previous training studies, HIIT was carried out with a frequency of three times per week. However, this frequency may not be attained by individuals who find lack of time as the main barrier for adherence in physical activity programs, and it is very interesting to know if reducing the frequency of exercise still offers some health benefits. In clinical and aging populations, some studies have recently used lower frequency HIIT due to the inability of the participants to follow or tolerate 3 sessions per week (Adamson et al., 2014; Knowles et al., 2015). However, there are limited and conflicting results regarding the efficacy of low frequency of HIIT on various health indices in healthy adults. Furthermore, it is unknown whether a low HIIT frequency may cause comparable physiological and health-related adaptations, as those achieved with higher HIIT frequencies. To date, there is no comprehensive study to evaluate the effect of different HIIT frequencies on physiological, metabolic and psychological variables associated with health and quality of life. Thus, the aim of the present study was to examine and compare the efficacy of HIIT with low and moderate training frequency (2 and 3 times per week) on physiological, metabolic and psychological variables in healthy inactive adults. It was hypothesized that 2 sessions of HIIT each week may be equally effective as 3 sessions per week in improving VO_2peak, body composition, biochemical blood variables and quality of life, in unaccustomed individuals.

4.3 Materials and Methods

4.3.1 Study Design

Thirty five healthy inactive adults (n=35, age: 31.7±2.6yr, BMI: 23.7±4 kg·m^{-2}), were eligible to participate in the study as described in Chapter 3. Participants were randomly assigned to one of the 2 training groups, who performed HIIT two times per week (HIIT-2: n=14, 8 females / 6 males) and three times per week (HIIT-3: n=13, 6 females / 7 males) or to a control group (CON: n=8, 4 females / 4 males). Initially, all participants of the HIIT-2 and HIIT-3 groups went through a 3week pre-conditioning, familiarization and testing period (as described below), to avoid an abrupt increase in physical activity and exercise intensity. Afterwards, the HIIT-2 and HIIT-3 intervention groups trained 2 and 3 times per week respectively, over an 8-week period with the same HIIT protocol; whereas the participants in the CON group continued their usual daily activities for the same time period. All participants completed a series of tests at the beginning and after an 8-week period including measurement of VO_2peak, body composition, biochemical blood variables and evaluation of quality of life (as described in Chapter 3). Body composition, VO_2peak, and blood tests were also performed for HIIT-2 and HIIT-3 after 4 weeks of training.

Participants were asked to maintain their habitual lifestyle and diet habits during the intervention period. They recorded a 72-hour food diary before the baseline blood testing and replicated this before subsequent tests. They were also asked to refrain from alcohol and vigorous physical activities for 48 hours before the testing days. No participant withdrew from the study and no adverse events or musculoskeletal injuries were reported throughout the intervention.

4.3.2 Preconditioning and training

Preconditioning: A preconditioning phase, consisting of three training sessions that included continuous incremental cycling and 5 – 7 x 60-s moderate to high intensity bouts interspersed with 60 s of low intensity exercise, served as a preparation for training and as familiarization with the testing and training procedures.

High Intensity Interval Training (HIIT): Training was performed on a cycle ergometer (Monark LC6 Novo), set to constant watt mode at a pedal cadence of 70–80 rpm. Each HIIT session consisted of 10 x 60 s cycling intervals at an intensity of ~83% of the Wpeak obtained during VO_2peak test, interspersed with 60 s of low intensity exercise (~30% Wpeak at 50 rpm). Each training session included a 3-minute warm-up and 2-minute cool-down at 50 W. Power output was readjusted after four weeks of training according to each participant's new VO2peak test for the remaining period, in order to maintain the target relative intensity. Training sessions were held on non-consecutive days throughout each week, and were all supervised by one of the authors.

4.3.3 Assessments

Blood analyses: Participants visited the laboratory after overnight fasting and venous blood samples (~ 10 mL) were taken from an antecubital vein, to obtain concentrations of glucose, insulin, glycosylated haemoglobin ($HbA1_C$), C- reactive protein (CRP), total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C) and triglycerides (TG). An amount of ~ 7 mL was collected in plain tubes and allowed to clot for 30 minutes. Then the samples were centrifuged at 4000rpm for 8 minutes and the serum was decanted. Insulin concentration was determined using chemiluminescent microparticle immunoassay (CMIA) technology (Abbott Architect Plus analyzer). Glucose was analyzed using the enzymatic UV test (hexokinase method) (Beckman Coulter AU 680 analyzer). TC, HDL-C and TG were determined using the enzymatic colour test (Beckman Coulter AU 680 analyzer). CRP was analyzed using the immuno-turbidimetric test (Beckman Coulter AU 680 analyzer). Furthermore, ~3 mL was drawn into EDTA tubes and $HbA1_C$ was measured using the immuno-inhibition test (Beckman Coulter AU 480 analyzer). Low-density lipoprotein cholesterol (LDL-C) and very low-density lipoprotein cholesterol (VLDL-C) were calculated using the Friedwald's equations (Friedewald, Levy, & Fredrickson, 1972). Atherogenic index was calculated as TC/HDL.

Oral glucose tolerance test (OGTT): After ingestion of 75 g of glucose, 2-3 mL of blood was collected at 60 and 120 minutes later, for glucose and insulin determination. Insulin sensitivity was calculated using the insulin sensitivity index (ISI), as described by Matsuda and DeFronzo (Matsuda & DeFronzo, 1999). In addition, insulin resistance was calculated using the insulin resistance homeostatic model assessment (HOMA-IR) (Matthews et al., 1985). Glucose and insulin area under the curve (AUC) values were calculated using the trapezoidal rule. All participants abstained from exercise and followed a pre-recorded diet for 72h prior to OGTTs to avoid the effects of acute exercise.

4.3.4 Statistical analysis

A mixed factor two-way ANOVA (time x group) with Tukey post hoc tests was used to compare changes in the dependent variables over time between and within the groups. Gender effect was explored within each group separately, using two-way repeated measures ANOVA. For pairwise comparisons, the magnitude of effect sizes were determined by calculating Cohen's d (small effect = 0.20–0.49, medium effect = 0.50–0.79 and large effect ≥0.80). All statistical procedures were performed using SPSS version 20. Statistical significance was accepted at $p \leq 0.05$ and variables are presented as mean ± SD.

4.4 Results

There were no baseline differences between groups in any variable ($p > 0.05$) and no significant change in any variable was observed in the CON group. Adherence was the same in both training groups (97.8%). Mean work per session (including intervals and recovery) was similar between the 2 training groups (HIIT-2: 107 ± 31 kJ, HIIT-3: 117 ± 27 kJ, $p = 0.388$), and total work was significantly higher in HIIT-3 compared to HIIT-2 (2815 ± 61 vs 1719 ± 497 kJ, $p < 0.001$). Fidelity of exercise training was calculated according to Taylor, Weston, & Batterham (2015), using a cut-point of 80% of maximal heart rate that was used as the criterion for satisfactory compliance to high-intensity exercise for all bouts. Thus fidelity was similar in both groups, with participants in the HIIT-2 group attaining the criterion in 145 of 160 bouts (90.6%) and participants in the HIIT-3 group attaining it in 215 of the 240 bouts (89.6%).

4.4.1 Body composition

Body composition: No significant changes in body weight and BMI were observed for any group. After 8 weeks of intervention waist circumference was significantly reduced in HIIT-2 ($p = 0.047$) and in HIIT-3 ($p = 0.003$), compared with their respective baseline values.

The reductions in waist circumference for HIIT-2 and HIIT-3 were significantly different from that of the control group ($p = 0.044$ and $p = 0.033$, $d = 0.56$ and $d = 1.0$, respectively) with no difference between the two HIIT groups (Table 2). Thigh lean CSA was significantly and similarly increased in both training groups at the end of the 8-week training period ($p < 0.01$), and this increase was greater compared with that of the CON group ($p < 0.01$, $d = 1.3$ and 2.0, respectively). Body fat and trunk fat percentage were significantly reduced only in HIIT-3, compared with baseline ($p = 0.018$ and $p = 0.002$, respectively) and compared with the CON and the HIIT-2 condition ($p = 0.025$ and 0.047, $d = 1.31$ and 0.84, respectively, see Table 2). A significant interaction effect for time x gender was observed for trunk fat percentage in HIIT-3 ($p = 0.03$), with a significant reduction only in female subjects ($p = 0.004$) and for thigh lean CSA in HIIT-2 ($p = 0.014$), with greater improvement in male compared with female participants ($p = 0.002$).

Table 2. Body composition measurements at baseline and after 8 weeks of intervention

Variable	**CON**		**HIIT-2**		**HIIT-3**	
	Baseline	**8 weeks**	**Baseline**	**8 weeks**	**Baseline**	**8 weeks**
Weight (kg)	67.4±12.2	67.4±13.1	66.5±18.9	66.1±18.5	69.6±17.6	69.2±17.3
BMI ($kg \cdot m^{-2}$)	23.4±3.1	23.4±3.4	23.6±4.6	23.4±4.4	24.1±4.2	24.0±4.1
% Body Fat	16.6±6.7	17.1±6.9	18.8±5.7	19.0±6.2	17.0±5.4	16.3±5.0*†#
Waist circumference(cm)	88.8±8.7	88.5±8.9	89.9±12.6	88.4±12.6*†	90.2±12.3	87.9±12.0**†
%Trunk fat	25.5±7.3	25.4±7.6	28.3±7.2	27.0±7.9	26.1±8.9	24.2±8.8**†#
Thigh lean CSA(cm^2)	135.6±20.3	133.9±21.4	122.2±30.5	133.7±34.3**‡	133.4±21.2	142.7±22.2**‡

* and **: $p < 0.05$ and $p < 0.01$ from the corresponding baseline value; † and ‡: $p < 0.05$ and $p < 0.01$from CON; #: $p < 0.05$ from HIIT-2

4.4.2 Cardiorespiratory fitness

After 4 weeks of training, VO_2peak significantly increased only in HIIT-3 (HIIT-2: 2.2 %, $p > 0.05$, Cohen's $d = 0.11$, HIIT-3: 11.6 %, $p = 0.002$, Cohen's $d = 0.47$). After 8 weeks, VO_2peak significantly and similarly increased in HIIT-2 by 3.5 ± 2.8 $ml \cdot kg^{-1} \cdot min^{-1}$ (10.8 %, $p = 0.017$, Cohen's $d = 0.56$) and in HIIT-3 by 4.5 ± 4.9 $ml \cdot kg^{-1} \cdot min^{-1}$ (13.6 %, $p = 0.002$, Cohen's $d = 0.55$). Both increases were greater compared with the CON group ($p < 0.05$) (Figure 7).

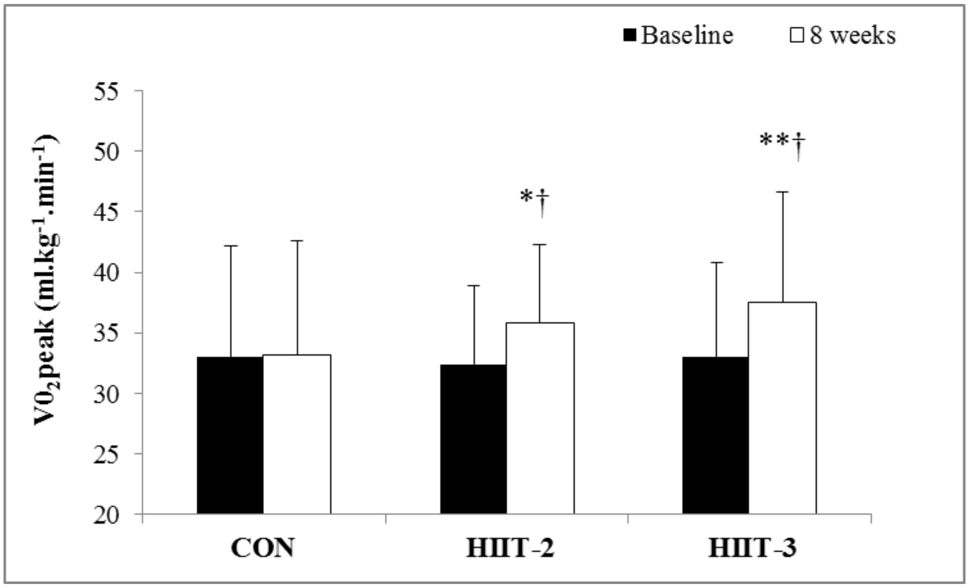

Figure 7 Cardiorespiratory fitness at baseline and after 8 weeks of intervention for each group
* and **: p<0.02 and < 0.01 from baseline; †: p < 0.05 from CON

4.4.3 Blood biochemical parameters

Fasting blood glucose and insulin were not significantly changed in any of the three groups after the intervention (Table 3). Similarly, glucose AUC and insulin AUC values were not altered significantly. Blood insulin concentration at the end of OGTT was significantly reduced in both HIIT-2 and HIIT-3 ($p = 0.008$ and $p = 0.024$, Cohen's d = 0.77 and 0.42, respectively, Table 3). Insulin sensitivity (ISI), HOMA-IR scores, HbA1c and CRP did not change significantly after the intervention (Table 3). When male and female participants were analyzed separately, it was observed that improvements in glucose and insulin AUC were found only in male participants (time x gender interaction, $p < 0.05$).

TC and LDL-C were significantly reduced only in HIIT-3 group ($p = 0.01$ and $p = 0.02$, Cohen's d = 0.58 and 0.49, respectively), while HDL-C, TG, VLDL-C and atherogenic index remained unchanged (Table 3).

Table 3 Blood biochemical parameters at baseline and after 8 weeks of intervention

Variable	CON		HIIT-2		HIIT-3	
	Baseline	8 weeks	Baseline	8 weeks	Baseline	8 weeks
Fasting Glucose (mmol·L^{-1})	5.0±0.2	5.0±0.3	5.0±0.3	4.9±0.3	4.9±0.5	4.8±0.5
Fasting Insulin (mU·L^{-1})	6.2±1.1	6.3±1.6	6.0±3.1	5.8±1.7	6.3±2.3	5.7±2.3
Glucose at end of OGTT (mmol·L^{-1})	4.5±0.3	4.4±0.8	4.6±0.9	4.5±1.3	4.8±1.2	4.1±1.1
Insulin at end of OGTT	27.3±13.2	21.9±10.2	35.5±19.1	23.7±11.9**	38.8±24.9	28.4±27.3*
Glucose AUC (mmol·min·L^{-1})	602±77	592±86	619±108	595±103	623±178	604±129
Insulin AUC (mU·min·L^{-1})	4258±2480	3795±1869	4926±2823	3792±1281	5063±3185	4370±2365
ISI	8.6±2.9	9.0 ±3.2	8.5±3.4	9.2±3.1	9.3±5.5	10.0±4.8
HOMA-IR	1.4±0.2	1.4±0.4	1.3±0.8	1.3±0.4	1.4±0.6	1.3±0.6
HbA1c (%)	5.2±0.3	5.2±0.2	5.3±0.3	5.1±0.3	5.0±0.2	5.1±0.2
CRP (mg·L^{-1})	0.9±0.4	1.1±0.6	1.6±1.1	1.1±0.7	1.0±0.6	0.9±0.5
TC (mmol·L^{-1})	4.9±0.5	4.8±0.8	4.8±0.8	4.8±0.7	5.0±0.6	4.7±0.6**
HDL-C (mmol·L^{-1})	1.4±0.2	1.4±0.2	1.4±0.3	1.4±0.3	1.5±0.3	1.4±0.3
TG (mmol·L^{-1})	0.±0.2	0.7±0.2	0.8±0.3	0.8±0.3	0.8±0.3	0.7±0.2
LDL-C (mmol·L^{-1})	3.1±0.5	3.1±0.8	3.0±0.9	3.0±0.8	3.2±0.5	3.0±0.6*
VLDL-C (mmol·L^{-1})	0.3±0.1	0.3±0.1	0.4±0.1	0.4±0.1	0.3±0.2	0.3±0.1
Atherogenic Index	3.5±0.7	3.6±0.9	3.5±1	3.6±1	3.6±0.8	3.5±0.8

** $p < 0.01$ and * $p < 0.05$ different from corresponding baseline value

4.4.4 Quality of life

Both HIIT-2 and HIIT-3 improved similarly the physical health component after training (p = 0.015 and p = 0.012, Cohen's d = 0.86 and 0.97, respectively, Figure 8). Both groups improved significantly compared with CON (p = 0.048 and p = 0.013 for HIIT-2 and HIIT-3, respectively). However, the mental health component was significantly elevated only in HIIT-3 compared with the baseline value (p = 0.028, Cohen's d = 0.69) and the CON group (p = 0.045, Cohen's d = 1.2).

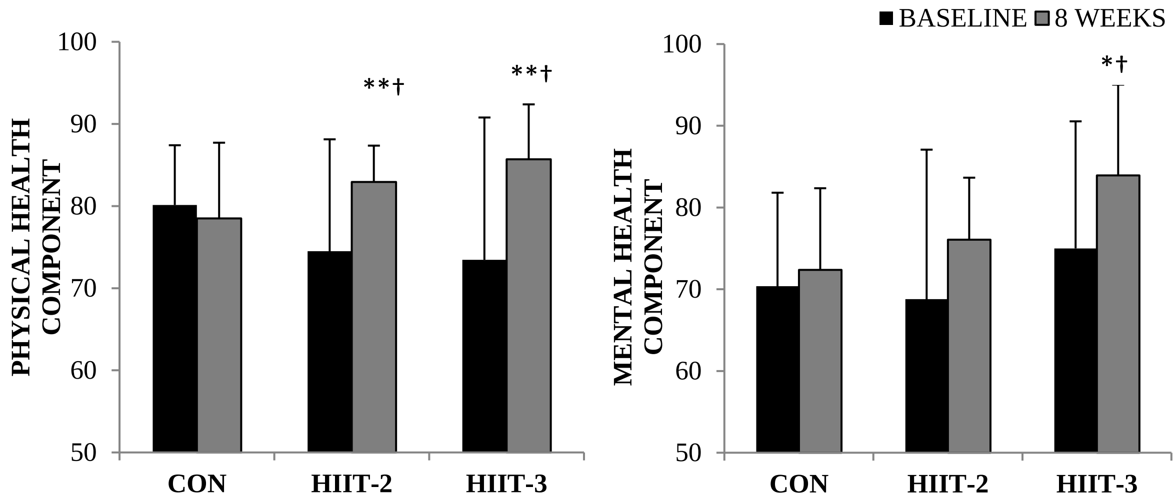

Figure 8 Quality of life (SF-36) physical (left panel) and mental (right panel) health component at baseline and after 8 weeks of intervention for each group. * and **: $p < 0.05$ and < 0.02 from baseline †: $p < 0.05$ from CON

4.5 Discussion

The present study demonstrated that HIIT performed either two or three times per week, leads to significant improvements in VO_2peak, waist circumference, thigh lean CSA, insulin concentration at the end of the OGTT and physical health component of quality of life. Most importantly, the magnitude of these training-induced adaptations was unaffected by training frequency, as it was similar in the two training groups. However, there were additional health-related benefits in the group that trained 3 times per week, i.e. reduction of body fat and trunk fat percentage, decrease of total cholesterol and LDL-C, and improvement of the mental health component of quality of life.

Some studies that used HIIT or sprint training with a frequency of 1-2 sessions per week for 4-6 weeks, reported no effect on VO_2max (Dalleck et al., 2010; Kavaliauskas et al., 2017). This finding is in agreement with our result that after the initial 4 weeks of training, there was no improvement of cardiorespiratory fitness in HIIT-2. However, at the end of the 8 week training period, VO_2peak improved in HIIT-2 as much as in HIIT-3 group, with the latter group showing no further improvement from 4 to 8 weeks of training. This may suggest that 8 sessions of HIIT, as performed by the HIIT-2 group in the first 4 weeks, are not adequate for VO_{2max} improvement, and a larger number of sessions (≥12) is required to elicit cardiorespiratory adaptations during HIIT. Therefore, the total training volume may also be important when the frequency of training is low, in order to induce cardiorespiratory adaptations. In support of this notion, Adamson et al. (2014) reported an 8% improvement in VO_2peak after 8 weeks of short duration HIIT performed twice per week in middle aged untrained population. Furthermore, Nakahara et al. (2015) presented an 11% improvement in VO_2max after severe-intensity interval training which consisted of three bouts of exercises to volitional fatigue just once a week for three months. The magnitude of VO_2peak improvement found in the present study (3.5 - 4.5 $ml \cdot kg^{-1} \cdot min^{-1}$) is consistent with meta-analysis data reporting increases of 3.8 $ml \cdot kg^{-1} \cdot min^{-1}$ after HIIT (Batacan et al., 2017).

Recent meta-analyses have reported the positive impact of HIIT on body composition indices like fat mass and waist circumference (Keating, Johnson, Mielke, & Coombes, 2017; Wewege, van den Berg, Ward, & Keech, 2017). In the present study even though body weight remained unchanged, the percentage of total body and trunk fat, was decreased in HIIT-3. Moreover, waist circumference was reduced in both training groups (Table 2). Similarly in the recent meta-analysis of Wewege et al. (2017), it was shown that HIIT can reduce whole-body fat mass and waist circumference in the absence of body mass changes. A decrease in these indirect indices of abdominal adiposity (Clasey et al., 1999) may reduce the risk of cardiovascular diseases and type 2 diabetes (Després, 2006). A possible mechanism that may promote fat loss during HIIT is the significant catecholamine response to high intensity exercise, that enhances lipolysis (Zouhal et al., 2008). The reduction in trunk fat may be explained by the increased concentration of β-adrenergic receptors in abdominal tissue compared to subcutaneous fat (Rebuffé-Scrive et al., 1989). Another potential mechanism that could be involved in the reduction of fat mass is an increased fat oxidation following HIIT (Astorino, Schubert, Palumbo, Stirling, McMillan, et al., 2013), that is possibly linked with increased mitochondrial biogenesis and function (Bishop et al., 2014). Additionally, post-exercise oxygen consumption (EPOC) and appetite suppression following high-intensity exercise could also be involved (Hazell, Olver, Hamilton, & Lemon, 2012; Sim, Wallman, Fairchild, & Guelfi, 2014). Furthermore, in the present study, both training groups increased thigh lean CSA, indicating a gain in leg muscle mass. Increased muscle mass may elevate basal metabolic rate (Speakman & Selman, 2003), and thus increased fat oxidation during rest, and may also improve insulin sensitivity (Srikanthan & Karlamangla, 2011).

Recently, emphasis has been placed on the effectiveness of HIIT on blood glucose regulation (Batacan et al., 2017; Jelleyman et al., 2015). Controversial results have been reported for healthy normal weight adults, while data from populations with impaired metabolic control show positive effects (Batacan et al., 2017; Jelleyman et al., 2015). Moreover a recent study suggested that the exercise HIIT volume matters in promoting pancreatic beta cell function improvement (Ramos et al., 2016). In the present study, insulin at the end of the OGTT was significantly lowered in both training groups (Table 3). No other significant changes were observed in other OGTT parameters, whereas HbA1c was also unaltered, possibly due to the fact that baseline values were within the normal range, indicating a healthy population (Jelleyman et al., 2015) (Table 3). Insulin sensitivity failed to show significant improvements in both training groups. However, when male and female participants were analyzed separately, improved insulin sensitivity was found in the male participants of both training groups. This finding is consistent with other studies which reported that changes in insulin sensitivity in response to sprint-type high intensity training are gender-specific (Gillen et al., 2014; Metcalfe et al., 2012). Although the mechanisms that may explain differences in insulin sensitivity between males and females following HIIT should be further investigated, it may be speculated that the hormonal changes during the menstrual cycle may affect insulin sensitivity (Valdes & Elkind-Hirsch, 1991). Due to practical issues, the phase of menstrual cycle was not taken into account in the present study, and this may be considered as a limitation. A possible explanation for the improved insulin sensitivity in males may include the greater increase in muscle mass accompanied by an increased glucose uptake (Marcus et al., 2013; Srikanthan & Karlamangla, 2011), a larger degree of glycogen depletion, due to higher glycolytic rate during high intensity exercise (Esbjornsson-Liljedahl, Sundberg, Norman, & Jansson, 1999).

In the present study, only HIIT-3 resulted in significant changes in total cholesterol and LDL-C (Table 3).This is in agreement with some studies showing reductions in TC and LDL-C, after HIIT in inactive individuals (O'Donovan et al., 2005; Shepherd et al., 2015). However, other studies failed to show improvements in blood lipids profile (Madsen et al., 2015; Nybo et al., 2010). Decreases in TC and LDL-C are important as this decreases the risk of cardiovascular diseases (Piepoli et al., 2016). The fact that HIIT-2 failed to induce any influence in lipid profile may be explained by the possibility of training volume threshold which should be surpassed to induce favorable blood lipid changes (Nybo et al., 2010) and thus a longer training period of low frequency HIIT may be needed to elicit positive changes in cholesterol.

Cross sectional studies have shown that persons attaining the recommended levels of physical activity are more likely to have better quality of life levels (Brown et al., 2003; Vuillemin et al., 2005). In the present study, despite the low weekly training time commitment compared with public health guidelines, HIIT-3 improved both physical and mental health component, while HIIT-2 improved only the physical health component. Therefore, the beneficial health-related effects of HIIT on general population also include an improvement of quality of life of the participants. In the present study, the lack of an effect of HIIT-2 on the mental aspect may suggest that an increased training frequency of HIIT or a longer duration of training may be necessary to elicit positive psychological effects on quality of life in inactive adults.

In conclusion, the present study showed that HIIT-2 may improve particular cardiometabolic health indices and the physical component of quality of life following 8 weeks of training in inactive men and women. However, HIIT-3 conferred additional health-related benefits by reducing total body and abdominal fat, TC and LDL-C and by improving the mental component of quality of life. Importantly, the present study adds to the existing knowledge of positive effects of HIIT and shows that despite a low training frequency (i.e. 2 times per week), HIIT can still promote specific health-related adaptations in inactive population in a time efficient way.

5 CHAPTER 5. THE EFFECT OF HIGH INTENSITY INTERVAL TRAINING ON PERCEPTUAL RESPONSES, QUALITY OF LIFE AND FUTURE EXERCISE PARTICIPATION

5.1 Abstract

The effectiveness of high intensity interval training (HIIT) in inducing positive physiological adaptations is well documented. However, its effect on well-being and on participants' future interest in constantly getting involved in exercise programs are less evaluated. The present study examined the effects of HIIT on perceptual responses and quality of life and its influence in future exercise participation, following the termination of an 8-week of training intervention. Thirty five healthy inactive adults were randomly assigned to a control (CON) and to two training groups which performed HIIT (10 x 60 s cycling at ~83% of Wpeak), two (HIIT-2) or three times per week (HIIT-3) for 8 weeks. Following the HIIT intervention, exercise enjoyment, quality of life and the intention to implement HIIT in the future were evaluated. Eight weeks after cessation of the training stimulus, follow-up evaluations of quality of life and physical activity were performed. High levels of enjoyment were observed in both training groups following the intervention. Only HIIT-3 improved quality of life ($p<0.05$). All HIIT-3 participants reported intention to implement HIIT in the future at least once a week as compared to 92.9% of HIIT-2 and 37.5% of CON participants [$x^2(2)=15\ 262$, $p<0.001$]. At follow-up, both training groups improved quality of life and increased vigorous and total physical activity participation levels ($p<0.05$). The positive change in quality of life was correlated with the change in vigorous physical activity from pre-intervention to follow-up ($r=0.406$, $p<0.05$). During the 8-week post-intervention period, 84.6%, 35.7% and none of the HIIT-3, HIIT-2 and CON participants, respectively, reported that they completed HIIT at least once a week [$x^2(2)=15\ 228$, $p<0.001$] and 84.6%, 85.7% and 37.5%, respectively, reported that they completed other types of exercise [$x^2(2)=7\ 351$, $p=0.025$]. At follow-up, 64% and 77% of participants of HIIT-2 and HIIT-3 respectively, were classified in the moderate or high physical activity category, compared to inactive classification at baseline. This study showed that HIIT is an enjoyable exercise method, promoting future exercise participation and improving quality of life in inactive individuals. These positive results seem to continue for at least 8 weeks following cessation of the HIIT intervention.

Keywords: enjoyment, intervals, exercise adherence, quality of life, physical activity

5.2 Introduction

Physical inactivity is considered as one of the biggest public health problem of the 21st century (Blair, 2009). High-intensity interval training (HIIT) may serve as an effective alternative to the problem of lack of time for improving fitness and health. Despite the growing evidence regarding the effectiveness of HIIT in inducing physiological adaptations, little is known about its effect on psychological variables and well-being (Shepherd et al., 2015) while there is currently a debate about the conflicting psychological consequences of engaging in interval exercise training (Biddle & Batterham, 2015; Stork et al., 2017). A single HIIT session has been shown to induce higher self-confidence (exercise self-efficacy) and intention to engage in HIIT compared with continuous vigorous-intensity exercise (Jung et al., 2014). Studies suggested that the psychological aspects of HIIT should be carefully considered since they may be related with physical activity (PA) behavior and may predict future intentions to engage in this type of activities as well as future exercise adherence (Salmon et al., 2003; Stork & Martin Ginis, 2016; Trost et al., 2002; Williams, Dunsiger, Jennings, & Marcus, 2012). However, the long-term effects of HIIT on perceptions such as enjoyment and intention to participate in future physical activities remain largely unknown.

There is limited evidence that HIIT also improves aspects of health-related quality of life (HRQOL) (Knowles et al., 2015). Previous studies have shown that inactive people have lower scores of HRQOL than insufficiently active or people who meet the recommended levels of moderate or vigorous PA (Brown et al., 2004; Vuillemin et al., 2005). Given the lack of available time for PA, it is of importance to determine the minimum exercise duration and frequency required to induce favorable physiological and psychological adaptations. A recent study (Metcalfe, Tardif, Thompson, & Vollaard, 2016a) reported an increase in maximal oxygen uptake following 6 weeks of “reduced exertion HIIT”, including two 10-20 s sprints performed 3 times per week. However, data on psychological variables and perceptual responses to HIIT are sparse and it is currently unknown whether a reduced training frequency may be effective in that respect. Thus, the aims of the present study were to compare enjoyment, quality of life and intention to implement PA to a low-volume HIIT performed 2 or 3 times per week, in sedentary adults, and to evaluate if HIIT may influence future physical activity participation as evaluated two months after cessation of the training period. It was hypothesized that both HIIT frequencies would be perceived equally enjoyable, improve quality of life and would promote and long-term exercise adherence.

5.3 Methods

5.3.1 Study Design

Thirty five healthy inactive adults (n=35, age: 31.7±2.6yr, BMI: 23.7±4 kg·m^{-2}), were eligible to participate in the study as described in Chapter 3. The participants were randomly assigned to a control group (CON) that continued their daily life activities and to two training groups that performed HIIT two (HIIT-2) or three (HIIT-3) times per week for 8 weeks. All participants went firstly through a 3 week pre-conditioning, familiarization and testing period, which included assessments of body composition, VO_2peak, IPAQ and quality of life (as described in Chapter 3). Afterwards, the HIIT-2 and HIIT-3 intervention groups trained 2 and 3 times per week respectively, over an 8-week period with the same HIIT protocol as described in Chapter 4. Throughout the intervention, participant's perceived exertion was evaluated with the Borg rating of perceived exertion (RPE 6-20) before, during and after each training session. In addition, heart rate (HR) was recorded continuously during exercise (Polar H6 Bluetooth smart). Following the completion of the 8-week period, perceptual responses and HRQOL were evaluated. A follow up session was scheduled two months after the completion of the intervention where all participants completed the following questionnaires: IPAQ, HRQOL and perceptual responses. During that period, no prescription was given to the participants relevant to physical activity.

5.3.2 Assessments

IPAQ: For the IPAQ questionnaire the participants were asked to estimate the amount of time spent in walking, moderate and vigorous intensity PA over the preceding 7 day period. The outcome was calculated and expressed in METs (units of metabolic equivalence) per week. Also, the participants were classified in one of the following categories (Papathanasiou et al., 2009):

Low PA profile: Total PA score < 600 MET.min.wk^{-1}

Moderate PA profile: Vigorous PA score ≥ 480 $MET.min.wk^{-1}$ or Total PA score ≥ 600 $MET.min.wk^{-1}$

High PA profile: Vigorous PA score ≥ 1500 $MET.min.wk^{-1}$ or Total PA score ≥ 3000 $MET.min.wk^{-1}$

In addition, the time spend sitting was recorded in the questionnaire to serve as an additional indicator variable of time spent in sedentary activity. Furthermore in the following up session, the IPAQ-Gr questionnaire was completed again to estimate the amount of time and intensity of PA over this period and to compare it with the one given before the intervention. The Greek version (IPAQ-Gr) was found to present acceptable reliability properties in Greek adults (Papathanasiou et al., 2009).

Perceptual responses: Moreover, a questionnaire was completed by all participants after the training period to evaluate enjoyment of training and intentions to implement high intensity exercise in the future, according to Boyd, Simpson, Jung, & Gurd, (2013). The questionnaire utilized a 7-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree). Control group answered only about the intentions. Two months after the intervention, at the following up session, a new questionnaire was administered to all participants to evaluate the completion of HIIT or other types of exercise during that period.

5.3.3 Statistical analysis

Differences in baseline values were tested with one-way Analysis of Variance (ANOVA) for the scale variables and chi square test for equal representation of the gender in the three groups. A mixed factor two-way ANOVA (time x group) with Tukey post hoc tests was used to compare changes in the dependent variables over time between the groups. Pearson's correlation coefficient was used to assess bivariate correlations. All statistical procedures were performed using SPSS version 20. Statistical significance was accepted at $p \leq 0.05$ and variables are presented as mean ± SD.

5.4 Results

5.4.1 HR and RPE

In the HIIT-2 group, the average maximum heart rate across all 16 training sessions for all participants increased from 145 ± 2 b/min (77.6% ± 1 of peak HR) at the 1st bout to 174 ± 2 b/min (93.3% ± 1 of peak HR) at the 10^{th} bout. In the HIIT-3 group, the average maximum heart rate across all 24 training sessions for all participants increased from 139 ± 4 b/min (77.0 % ± 1.6 of peak HR) at the 1^{st} bout to 169 ± 2 b/min (93.3% ± 1.1 of peak HR) at the 10thbout.

A significant time effect ($p < 0.001$) was found for the RPE scores at the 10^{th} bout between the first training session of weeks 1, 2, 4, 6 and 8 (Figure 9). Moreover, RPE measured following the end of 10^{th} bout was reduced between the 1^{st} and last training session for HIIT-2 (from 17.7 ± 1.7 to 15.6 ± 2.1, $p = 0.010$) and for HIIT-3 (from 17.8 ± 2.2 to 14.5 ± 2.0, $p <0.001$). Mean RPE for the whole session was also decreased between the1^{st} and last training session for HIIT-2 (from 14.8 ± 1.7to 12.6 ± 1.0, $p = 0.002$) and for HIIT-3 (from 14.6±1.9 to 11.4 ± 1.4, $p < 0.001$).

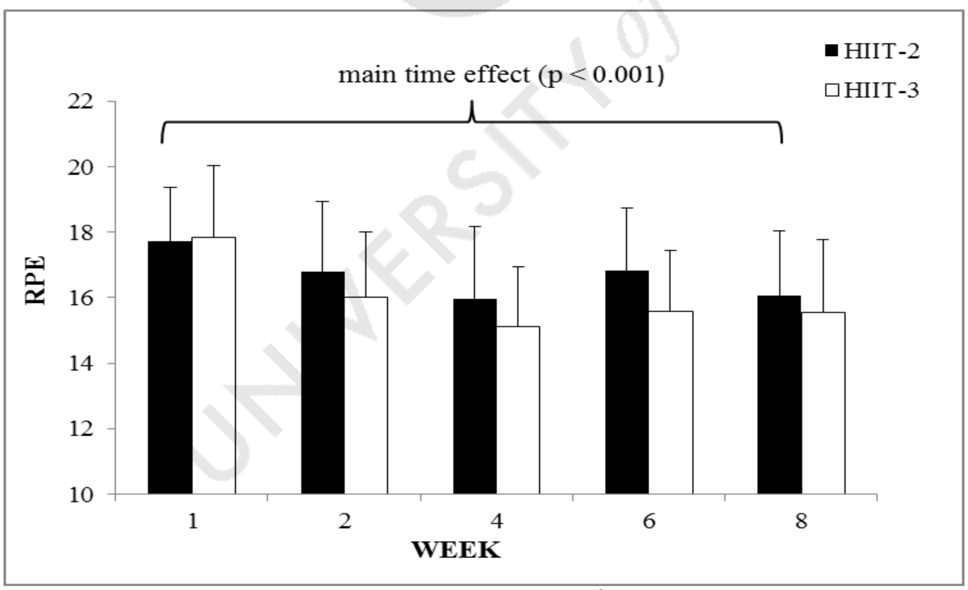

Figure 9 Rate of perceived exertion (RPE) at the end of the 10^{th} interval at the first training of weeks 1, 2, 4, 6 and 8 for each group

5.4.2 HRQOL

All HRQOL (SF-36) scores are presented in Table 4.

Training effect. HRQOL (SF-36) scores for PHC, MHC and total SF-36 score are presented in Table 2. The two-way mixed-model ANOVA revealed a significant main effect of time in PHC (p = 0.009), MHC (p = 0.013) and total SF-36 score (p = 0.008) and a significant interaction for group x time in PHC (p = 0.022). Compared with baseline, in the HIIT-2 group, there was a significant increase post intervention in PHC (p = 0.015) and a trend for significant increment in total SF-36 score (p = 0.064), while a significant augmentation was observed for both components (PHC: p= 0.012, MHC: p = 0.028) and total SF-36 score (p = 0.024) in HIIT-3. The change of PHC for HIIT-3 group was significantly different from CON (p = 0.034).

Follow up. However, at the follow up, both components and total SF-36 score were elevated for the HIIT-2 group compared to baseline (p = 0.044, p = 0.026, p = 0.018 respectively), where they remained significantly increased in HIIT-3 (p = 0.025, p = 0.042, p = 0.027 respectively). The change of PHC and total SF-36 score from pre intervention to follow-up was significantly higher than CON (p = 0.14 and p = 0.038 respectively) only for HIIT-3. No significant changes were observed between post intervention and follow-up in any of these variables.

Table 4 Health-related quality of life (SF-36) scores at pre- and post- intervention and after follow up in each group

Variable	**CON**			**HIIT-2**			**HIIT-3**		
	Pre	Post	Follow up	Pre	Post	Follow up	Pre	Post	Follow up
Physical Health Component	80.1±7.3	78.5±9.2	74.9±4.7	74.5±13.6	82.9±4.4*	80.7±5.8*	73.5±17.3	85.7±6.7*†	84.5±8.7*†
Mental Health Component	70.4±11.4	72.4±10	68.4±12.1	68.8±18.3	76.1±7.6	77.3±10.3*	75±15.5	83.9±11.1*	83.8±9.1*
Total SF36 Score	76.1±9.5	76.8±9.2	72.8±8.1	74.1±15.3	81.8±5.5	82.1±6.8*	76.9±16.4	87.4±7.4*	86.7±8.1†*

* p<0.05 different from baseline
† p < 0.05 change from baseline is significantly different than CON

5.4.3 Perceptual responses

Training effect. Following 8 weeks of training, perceived enjoyment of HIIT was rated similarly high by participants of both training groups (HIIT-2: 6.0 ± 1.1, HIIT-3: 6.0 ± 1.1, scale 1-7). All HIIT-3 participants reported intention to implement high intensity exercise in the future at least once per week (84.6% 3 times/week, 15.4% 5 times/week) as compared to 92.9% of HIIT-2 participants (28.6% 2 times/week, 57.1% 3 times/week, 7.1% 5 times/week) and 37.5% of CON participants (12.5% 1 time/week, 12.5% 3 times/week and 12.5% 5 times/week) [x^2 (2) = 15 262, $p < 0.001$].

Follow up. At the follow up session, 84.6% of the HIIT-3 participants reported that they completed HIIT least once per week during the 8-week post intervention period (7.7% 1 time/week, 30.8% 2 times/week, 38.5% 3 times/week and 7.1% 5 times/week) as compared to only 35.7% of HIIT-2 participants (14.3% 2 times/week, 21.4% 3 times/week) and none of the CON participants [x^2 (2) = 15 228, $p < 0.001$]. Moreover, 84.6%, 85.7% and 37.5% of the HIIT-3, HIIT-2 and CON participants respectively reported that they completed other types of exercise at least once per week [x^2 (2) = 7 351, $p = 0.025$].

5.4.4 Self-reported PA

Self-reported PA of the participants of each group (according to IPAQ) at pre intervention and at follow-up are presented in Table 5. Vigorous PA was significantly increased in both training groups (HIIT-2: $p = 0.027$, HIIT-3: $p < 0.001$), whereas the difference between HIIT-3 and CON was statistically significant ($p = 0.005$) and a trend for significant difference was observed between HIIT-2 and HIIT-3 ($p = 0.075$). Similarly, both training groups significantly augmented total PA ($p < 0.001$). This increment was significantly different between HIIT-3 and CON ($p = 0.004$), while atendency for significant difference was found between HIIT-2 and CON ($p = 0.057$). Moderate PA increased significantly only in HIIT-2 ($p = 0.029$). Sitting time remained unchanged in all groups (HIIT-2: $p = 0.245$, HIIT-3: $p = 0.105$). At pre intervention, the participants of all three groups were classified as inactive (low PA in the IPAQ). At follow-up, 12.5% of the participants of CON, 64.3% of HIIT-2 and 76.9% of HIIT-3 were classified in the moderate or high PA category [$x^2(4) = 10.275$, $p = 0.036$)] (Table 5).

Table 5 Self-reported physical activity (IPAQ) for each group at pre- intervention and follow up

Variable		**CON**		**HIIT-2**		**HIIT-3**	
		Pre	Follow up	Pre	Follow up	Pre	Follow up
Vigorous PA (MET-min/wk)		0±0	0±0	0±0	371±559*	0±0	862±709**†
Moderate PA (MET-min/wk)		125±173	120±143	194±156	399±309*	225±204	251±318
Walking (MET-min/wk)		124±235	186±353	154±146	242±136	123±110	194±163
Total PA (MET-min/wk)		249±223	306±358	349±165	1012±505**	348±219	1307±871**†
Sitting time (minutes/day)		360±203	368±196	444±270	411±251	402±179	318±177
	Low	100%	87.5%	100%	35.7%	100%	23.1%
PA Category	**Moderate**	0%	12.5%	0%	57.1%	0%	53.8%
	High	0%	0%	0%	7.1%	0%	23.1%

*   p<0.05 different from pre intervention
** p<0.001 different from pre intervention
†   p < 0.05 change from pre intervention is significantly different than CON

The change in total SF-36 score before the intervention and after the follow-up period was significantly correlated with the corresponding change in vigorous PA ($r = 0.406$, $p = 0.016$) in all participants (Figure 10). A tendency for significant correlation was found between change in total SF-36 score and change in total PA for the same time points ($r = 0.318$, $p = 0.063$). The change in sitting time was not significantly correlated with change in total SF-36 score ($r = -0.221$, $p = 0.202$).

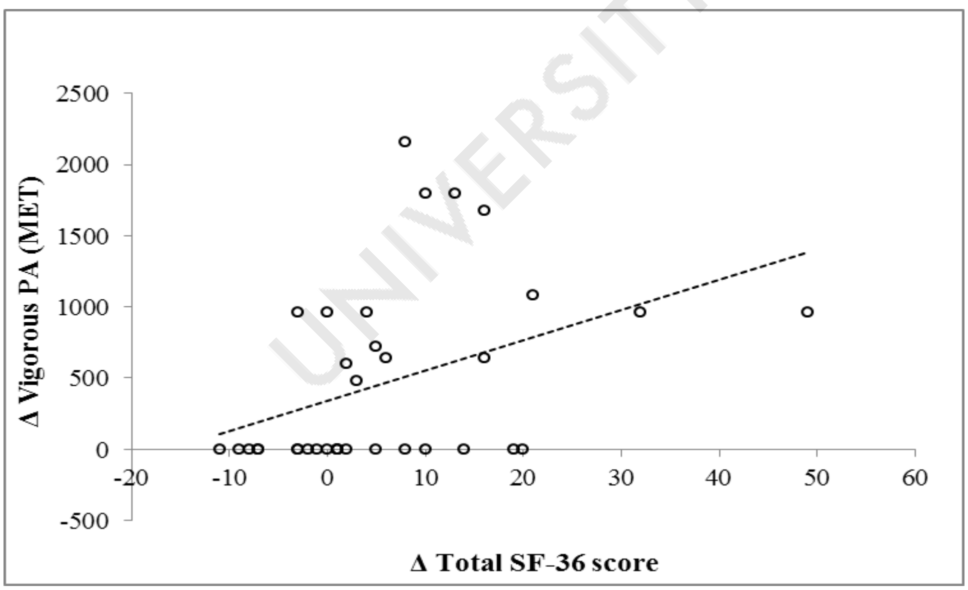

Figure 10 Correlations of changes in vigorous PA in MET compared to changes in total SF-36 score between pre-intervention and follow-up (Δ=follow-up – pre intervention)

5.5 Discussion

This study demonstrated that 8-weeks of HIIT in inactive population performed either two or three times per week, induced high levels of perceived enjoyment, and intention to implement high intensity exercise in the future. Higher HIIT frequency was associated with enhanced total quality of life. Furthermore, this study showed that HIIT may stimulate enhanced future engagement in vigorous and total PA alongside improved health related quality of life.

In the present study, the level of enjoyment was assessed following 8-week of training, in contrast with most studies that reported enjoyment after acute sessions. The results revealed high levels of enjoyment from both training groups following the training intervention, supporting previous reports from acute studies which suggested that this protocol effectively enhances enjoyment and other perceptual responses to exercise (Jung et al., 2014; Martinez et al., 2015; Thum et al., 2017). In one of the few studies which evaluated enjoyment following a HIIT program, similar high levels of enjoyment with the present study were found after three weeks of low or high intensity/volume interval training protocol (Boyd et al., 2013). In the present study, the participants of the two training groups rated similarly the level of enjoyment. Consequently, the two HIIT frequencies examined do not seem to affect enjoyment of the training program. The observed high levels of enjoyment could be of special importance, since it has been suggested that enjoyment is a key component that may make HIIT both feasible and sustainable (Smith-Ryan, 2017). Furthermore, a recent study showed that enjoyment may predict attitudes towards interval exercise which in turn could mediate future intentions to participate in interval exercise (Stork & Martin Ginis, 2016).

It has been suggested that chronic training may lead to increased enjoyment through the weeks for HIIT protocols in sedentary young adults (Heisz et al., 2016). This may be related with reduced effort perception during the intervention period. In the present study, it was found that mean session RPE and RPE at 10th bout were reduced from the first training session to the last interval session in both training groups, despite the readjustment of power output after four weeks of the HIIT training. A decreased RPE has also been observed in other HIIT studies (Saanijoki et al., 2015; Smith-Ryan et al., 2016). These manageable ratings of perceived exertion, along with the moderate-to-high cardiovascular loading (77-93% of peak

HR) may suggest an augmented exercise tolerance (Marcora & Staiano, 2010) and imply that previously inactive population can get accustomed to this practical mode of HIIT.

Most of the HIIT participants reported intention to implement high intensity exercise in the future, contrary to the CON participants. It has been suggested that the intermittent nature of the high intensity intervals where hard efforts are alternated with low intensity work, may promote a sense of accomplishment that is not experienced during continuous training (Jung et al., 2014; Kilpatrick et al., 2016). Hence, HIIT could serve to increase self-confidence and therefore self-efficacy beliefs (Jung et al., 2014; Kilpatrick et al., 2016). Thus, the improved exercise tolerance and the reported feelings of enjoyment may be related with the reported intentions to implement high intensity exercise at least once a week in the future.

The potential effect of HIIT interventions on future participation in HIIT or other forms of PA has rarely been examined. In the present study, during the 8-week post-intervention period, most of the HIIT-3 participants (84.6%) reported that they completed at least one session of HIIT per week, while most of the participants of both HIIT groups stated that they completed other types of exercise at least once a week. The positive influence of both HIIT programs on physical activity are further supported by the results of the IPAQ. Both training groups increased vigorous PA at follow-up compared with pre-intervention. Studies that evaluated adherence to HIIT outside of supervised laboratory conditions are rare. One recent study (Shepherd et al., 2015) reported that the increments in vigorous intensity PA after a HIIT intervention, assessed by IPAQ, were sustained for the 3-month follow-up period. Similarly in another study it was found that participants with pre-diabetes can adhere to HIIT independently for one month (thrice-weekly) following a brief training intervention similar to the present study (Jung et al., 2015). In that study it was shown that during the one-month follow-up, the participants engaged in vigorous PA for 24 minutes per week, as assessed by accelerometers (Jung et al. 2015). In the present study, HIIT-2 and HIIT-3 participants engaged in vigorous PA for 21 and 41 minutes per week respectively, although this different was not statistically significant. Total PA was also enhanced compared to pre-intervention for both training groups, as shown by the 64% and 77% of participants of HIIT-2 and HIIT-3 respectively, who were classified in the moderate or high PA category, instead of being inactive at baseline. These results show the prevalence of vigorous PA and the change of the habitual PA patterns of the participants following the HIIT program.

Following the training intervention, the total HRQOL score increased significantly only in HIIT-3 due to improvement in both physical and mental health component. The increment in MHC shows that HIIT may also augment mental health besides the expected improvement in physical health. Possibly, the non-significant improvement found in total SF-36 score of HIIT-2 could be attributed to the inadequate duration of the intervention period when the training frequency is low. Interestingly, at the follow-up session, total HRQOL score of HIIT-2 significantly improved compared to pre- intervention, while the significant increment in the HIIT-3 group was sustained. The increased vigorous physical activity recorded at the follow-up session in both training groups maybe related with these findings, as suggested by the positive correlation between change in total SF-36 score and change in vigorous PA from pre-intervention to follow-up. This is not surprising, since higher intensity in leisure time PA has been shown to be associated with greater HRQOL (Vuillemin et al., 2005). Moreover, it appears that vigorous intensity has a larger impact on HRQOL than total PA, since, no association was found between change in total PA and HRQOL.

In conclusion, both HIIT frequencies were shown to be enjoyable, inducing intention to implement high intensity exercise in the future. After a two month follow-up period an improvement in quality of life and a change of the habitual PA patterns of the participants were observed. The results of the present study highlight the positive influence of HIIT on promoting sustainable exercise adherence. As one of the main objectives of a training intervention is adoption and maintenance of enhanced PA habits, this study suggests that both low and medium frequency HIIT is an exercise strategy which may promote PA adherence in inactive individuals.

6 CHAPTER 6. GENERAL DISCUSSION

6.1 Discussion of major findings

The combination of inactivity, sedentary behavior and low cardiorespiratory fitness may induce detrimental health effects (Bouchard et al., 2015). Research has shown that health benefits can be achieved even with attaining less than the recommended physical activity guidelines. The last decade, many studies have been published showing that HIIT is a time efficient training program providing promising results regarding the physiological adaptations occurring following training (i.e. improved cardiorespiratory fitness, insulin sensitivity, body fat levels etc.), which can be even greater than continuous training besides the lower time commitment and training volume (Cassidy, Thoma, Houghton, et al., 2016; Jelleyman et al., 2015; Milanović et al., 2015). However, the optimal structure of a HIIT intervention in terms of duration, intensity and frequency remains unclear. Similarly still unclear is to what extent HIIT may promote maximum health benefits and whether is suitable, enjoyable and tolerable for the general population. In addition, the ability of a HIIT intervention to promote future PA adherence and contribute in maintaining the training adaptations has rarely been investigated. To our knowledge only few studies have employed lower HIIT frequency and particularly in healthy inactive population. Consequently, the aim of the current first experiment (Chapter 4) was to examine and compare the efficacy of HIIT with low and moderate training frequency (2 and 3 times per week respectively) on physiological, metabolic and psychological variables in healthy inactive adults.

The effect of a HIIT intervention with a 3-times frequency per week on VO_2max has been reported in several previous studies (Astorino, Schubert, Palumbo, Stirling, McMillan, et al., 2013; Jacobs et al., 2013; Nybo et al., 2010). The results of the current study support the previous relevant reports. Particularly, VO_2peak for this group (HIIT-3) augmented by 4.5 $ml·kg^{-1}·min^{-1}$ (0.28 $L·min^{-1}$), which corresponds to a percentage of 13.6% compared to baseline. Meta-analyses presented an improvement of 5.5 $ml·kg^{-1}·min^{-1}$ on VO_2max in healthy normal-weight aged 18–45 years old adults who incorporated HIIT in >2 weeks when compared with no-exercise controls (Milanović et al., 2015) and an augmentation by 3.8 $ml·kg^{-1}·min^{-1}$ in short-term (<12 weeks) HIIT studies in normal weight populations (Batacan et al., 2017). Similar with the current investigation, the meta-analysis report presented by Jelleyman et al. (2015), reported an increase of 0.30 $L·min^{-1}$ compared with baseline. In a recent study that investigated the training response to HIIT in different age groups, in the age group 30-39 years (the participants of HIIT-3 had a mean age of 31.9 years), it was reported an increment of 8.8% (3.3 ml·kg^{-1}·min^{-1}, 0.28 L·min^{-1}) after 8 weeks of aerobic interval training (Støren et al., 2017). In addition, it is important to note that in the present study the greater increment in VO_2peak occurred rapidly, as it was shown from the augmentation after 4 weeks by 11.6% in HIIT-3. However, the further improvement from the fourth to eighth week was not statistically significant. Possibly, the large rapid effect on VO_2peak in the early weeks may induce slower adaptations in the last weeks. The importance of total training volume, resulting from the higher training frequency was more evident in the present study by the positive changes found for other parameters, such as body and trunk fat, total cholesterol and LDL-C and mental health in quality of life.

The novel finding of this study regarding VO_2peak is the observed improvement in the group that trained twice per week. HIIT-2 increased VO_2peak by 3.5 ml·kg^{-1}·min^{-1} (10.8 %) which is similar with some of the above mentioned meta-analyses (Batacan et al., 2017; Støren et al., 2017) that incorporated studies with different training frequencies. However, there is limited comparative data regarding the efficacy of HIIT with low frequency on cardiorespiratory fitness, especially in healthy young populations. Lower improvements were found in the study of Adamson, Lorimer, Cobley, Lloyd, & Babraj (2014) which used HIIT twice a week for 8 weeks and reported an 8% increment (2.7 ml·kg^{-1}·min^{-1}) in middle aged untrained population and in the study of Grace et al. (2015) where HIIT was executed once every 5 days and showed increases of 7.4% and 8.3% in lifelong exercisers and lifelong sedentary aging men respectively. Similar improvement (11%) in VO_2max was reported by Nakahara, Ueda, & Miyamoto (2015) in healthy males following training once a week for 3 months, although their protocol was consisted of 3 bouts until volitional fatigue. In contrast, some other studies failed to find significant improvements in VO_2peak following reduced frequency of HIIT (Dalleck et al., 2010; Kavaliauskas et al., 2017). The reason for this lack of improvement might be the short duration of their training program. Similarly, in the present study no improvement in VO_2peak was found after the first 4 weeks of training. Therefore, it is suggested that performing HIIT twice a week, may require more than 4 weeks of training for eliciting fitness benefits; in contrast to the rapid improvements seen in 4 weeks of training following HIIT with higher training frequencies.

Some previous studies have reported improvements in VO_2max in just 6-9 sessions using a frequency of 3 times/week, while in the present study no improvement was found after 8 sessions with a low training frequency (Astorino, Schubert, Palumbo, Stirling, McMillan, et al., 2013; Cochran, Little, Tarnopolsky, & Gibala, 2010; Hood et al., 2011). Therefore it can be assumed that not only the number of sessions accounts for change in VO_2max but also the frequency of these sessions, at least in the first weeks of training. In the study of Astorino et al. (2013), it was shown that more intense interval training may induce larger and faster changes in VO_2max in untrained individuals compared to lower intensities, but similar improvements may revealed after a longer period of time, illustrating a potential advantage of more intense interval training versus moderate exercise intensity early on in training. Possibly an early advantage of the higher versus lower training frequency may explain the findings of the present study resulting in faster adaptations. Interestingly it appears that high frequency results in faster cardiorespiratory adaptations, but similar longer-term improvements are reached when frequency is lower. Thus it may be speculated that more time, and thus more sessions, are necessary to attain similar adaptations with low training frequency. Similarly, another study showed that both moderate and high frequency of high-intensity aerobic interval training improved VO_2max, however a different progression of the adaptation was found since the highest VO_2max-values occurred at different time points (Hatle et al., 2014).

Overall, this study showed that after 8 weeks of training, regardless of frequency, cardiorespiratory fitness may improve; and the importance of this result lays in the fact that CRF is a strong predictor of mortality (Lee et al., 2010). This finding is noteworthy given that 1 MET increase (3.5 $ml \cdot kg^{-1} \cdot min^{-1}$) in VO_2max is associated with 13% and 15% decrements in risk of all-cause mortality and coronary heart/cardiovascular disease, respectively (Kodama et al., 2009). Therefore, HIIT just twice per week is enough stimulator to lower the risk of mortality. This augmentation of VO_2peak could be linked to peripheral adaptations as mitochondria biogenesis and to central adaptations like increased stroke volume and cardiac output (Cassidy, Thoma, Houghton, & Trenell, 2016; MacInnis & Gibala, 2016). However, these are only speculations since none of these parameters was measured.

Regarding glucose regulation, the results of the current study presented that only blood insulin concentration 2 h after OGTT showed statistically significant improvement after the HIIT intervention in both training groups. The finding that both training frequencies improved insulin concentration at that time point indicates that even low training frequency may improve this parameter of glucose regulation. Furthermore, despite the lack of significance in the improvement on the other parameters, these findings are in line with previous data that showed no improvement in insulin sensitivity in healthy adults following HIIT (Madsen et al., 2015) nor in AUCs (Madsen et al., 2015; Metcalfe et al., 2012). The lack of significant changes in these variables (insulin sensitivity, glucose and insulin AUCs, HbA_{1C}) may be due to various parameters.

Firstly, the blood samples were taken 72 h after the last training bout for avoiding an acute effect of recent exercise bout. However in another HIIT study, an increment of insulin sensitivity 24-hour was found after the last bout, but this change was lost at the 72-hour post-intervention assessment (Whyte et al., 2010). In support of this finding, a meta-analysis showed that the improvement in insulin sensitivity diminishes progressively as the time following exercise increases (Jelleyman et al., 2015).

Secondly, a large inter-individual variability observed in the current study. From the 27 participants that followed training, only 15 of them (56%) numerically improved insulin sensitivity, indicating that some participants did not get this benefit. Similarly, Metcalfe et al., (2016) presented large inter-individual variability in response to REHIT, e.g. the plasma insulin AUC in individual change scores ranged from -54% to +70% and 38% of participants failed to numerically improve plasma glucose AUC or insulin sensitivity. The existence of individual patterns of response may reflect different causes like genetic factors, insufficient training stimulus, day-to-day biological variation or technical error (Bonafiglia et al., 2016; Metcalfe et al., 2016b). Thirdly, the participants taken part in the current study were healthy. Largest effects however, of HIIT on glucose regulation, have been found in adults with type 2 diabetes or metabolic syndrome (Jelleyman et al., 2015) and a greater improvement has been shown in those individuals with poorer insulin sensitivity pre-training (Metcalfe et al., 2016b). Moreover, a meta-regression suggests that for achieving a reduction in HOMA-IR of 0.5 units, baseline HOMA needs to be at least 3.18 (Jelleyman et al., 2015), a value that was not observed in any of our participants, since in the present study all participants had normal baseline values.

It is interesting to note that when insulin sensitivity and glucose and insulin AUCs were analyzed separately for each gender, improvements in these parameters were observed only in male participants. These findings are in agreement with previous studies investigating the gender-specific response to HIIT (Gillen et al., 2014; Metcalfe et al., 2012). The reasons for these discrepancies are not well understood and more research in this area is needed. It has been suggested that HIIT may enhance insulin sensitivity via glycogen depletion response to very high (Wingate-based) intensity exercise (Bogdanis et al., 1996; Esbjornsson-Liljedahl et al., 1999) and correlates with several aspects of enhanced insulin signaling (Babraj et al., 2009; Roberts et al., 2013; Whyte et al., 2010). However, studies have been shown that female break down less muscle glycogen in type I fibers than male during a single Wingate sprint (Esbjornsson-Liljedahl et al., 1999).

Another possible related mechanism for increasing insulin sensitivity following HIIT, is increased glucose skeletal muscle uptake via increased translocation of GLUT4, the insulin responsive glucose transporter (Roberts et al., 2013), that has been found to be elevated after HIIT (Gillen et al., 2014; Hood et al., 2011). Furthermore, Gillen et al., (2014) reported that total GLUT4 protein content increased by training 6-fold more in men compared to women. In addition, it may be speculated that hormonal changes during the menstrual cycle may also affect insulin sensitivity (Valdes & Elkind-Hirsch, 1991), a parameter that was not evaluated in the present study. Consequently, the phase of menstrual cycle should be taken into account when examining training-induced responses to HIIT in females. Overall, the above could be some explanations for the potential gender differences. However, the mechanisms that may explain the differences between males and females following HIIT should be further investigated.

In the present study, the HIIT response to blood lipid profile was also examined. The results showed improvement of TC and LDL-C, without altering HDL-C and TG, only in the HIIT-3 group. This is in line with other HIIT studies that found similar reductions in inactive and sedentary adults (O’Donovan et al., 2005; Shepherd et al., 2015). This finding has clinical importance, particularly in such population, given that an improved blood lipid profile favors a reduction in cardiovascular disease risk (Piepoli et al., 2016). However, it has been suggested that training volume, rather than training intensity, has the greatest influence on favorable blood lipid changes (Durstine et al., 2001; Nybo et al., 2010). This is perhaps the reason for the non-improvement of HIIT-2 observed in the current study. Thus, benefits for blood lipids in low frequency group may require additional weeks of training.

Another blood biomarker evaluated in this study was C-reactive protein (CRP). CRP is a marker of inflammation and has been identified as a potential biomarker related to future cardiovascular disease risk (Loprinzi et al., 2013). Reductions in CRP may contribute to the beneficial effects of habitual physical activity on preventing cardiovascular diseases. A systematic review concluded that both cross-sectional comparisons and longitudinal exercise training studies demonstrate a long-term "anti-inflammatory" effect of physical activity (Kasapis & Thompson, 2005). Similarly, another study showed that objectively-measured physical activity using accelerometers was significantly inversely associated with CRP in adults (Loprinzi et al., 2013). Chronic physical activity reduces resting CRP levels by multiple mechanisms, including a decrease in cytokine production by adipose tissue, skeletal muscles, endothelial and blood mononuclear cells, improved endothelial function and insulin sensitivity, and possibly an antioxidant effect (Kasapis & Thompson, 2005). However, only few studies so far examined the effect of long-term HIIT interventions on CRP. In the present study, no significant improvement was found in any of the training groups. This is in accordance with a recent meta-analysis that showed no effect of HIIT on CRP in overweight/obese populations (Batacan et al., 2017). Possible reasons for the non-significant change could be the normal baseline values and the pre-participation healthy status of the current participants. In general, all biochemical parameters were unaltered after the first 4 weeks of training, suggesting that beneficial alteration in blood variables required more time to occur than cardiorespiratory fitness.

This study has also examined the effect of HIIT on body composition. Body weight was unchanged in both groups after the intervention. Meta-analysis of HIIT programs with duration <12 weeks also revealed no significant effect on body mass in normal weight and overweight/obese populations (Batacan et al., 2017). It could be speculated that weight-may remained unchanged because the reduction in adiposity was balanced by a gain in fat free mass. From the results in the present study, it was shown that both training groups increased the estimated thigh muscle CSA, indicating a gain in muscle mass. Although the effect of HIIT on fat free mass has not been extensively examined, the contribution of HIIT to increase fat free mass was previously confirmed (Heydari, Freund, & Boutcher, 2012a). In this study, high intensity cycling (8 s sprint, 12 s recovery for 20-min session) three times per week, for 12 weeks, resulted in increased total, leg, and trunk fat free mass (using DEXA analysis) in the exercise group compared with the control one.

Some studies have shown that HIIT may decrease whole body fat mass, even when weight remains stable (Fisher et al., 2015; Gillen et al., 2013; Smith-Ryan et al., 2016). Similarly, in the HIIT-3 group total body fat was reduced, unlike in the HIIT-2 group that remained unchanged. However, given that HIIT results in a greater fat reduction effect on overweight/obese subjects (Batacan et al., 2017; Boutcher, 2011), it would be interesting to investigate whether performing HIIT 2 times per week will be adequate to elicit favorable changes in body composition in such populations. Concerning trunk fat, similarly, a reduction was found only in the HIIT-3 group. Nevertheless a reduction in waist circumference was found in both training groups. Both waist circumference and trunk fat may be considered as indirect measures of abdominal adiposity (Clasey et al., 1999). The importance of the decrease in abdominal fat is illustrated by the association between abdominal fat with the risk of cardiovascular diseases and type 2 diabetes (Després, 2006), and the improvement of these indices has been suggested to confer improvements in metabolic syndrome risk factors (Batacan et al., 2017).

This thesis also offers new and supporting knowledge concerning the effect of HIIT on quality of life. Even though previous studies have shown the positive effect of physical activity on quality of life (Brown et al., 2003; Vuillemin et al., 2005), little data were available for the impact of HIIT on HRQOL and particularly on healthy adults. Following 8 weeks of training, both training groups increased their physical health component. This result was somewhat expected, at least for the moderate training frequency, given the effectiveness of interval training in producing physiological benefits. However, the finding in the low frequency group, besides the physiological benefits, suggests that HIIT may also contribute to a higher physical component of HRQOL on healthy inactive adults. In another study where lifelong sedentary ageing men participated, it was observed that 13 weeks of preconditioning exercise and low volume HIIT were more effective in improving physical health as opposed to mental health (Knowles et al., 2015). In heart failure patients that utilized similar protocol with the present study and a frequency of 2 times per week, an improved subscale for physical functioning was found, without improvements in physical or mental health component (Benda et al., 2015). In the present study, for the group training 3 times per week, mental health component was also increased, unlike low frequency group where non-significant improvement was observed. These results indicate that HIIT may also augment mental health component of HRQOL. However higher training frequency or longer training duration might be needed to elicit positive psychological effects in healthy inactive adults.

In addition, in the current study, HRQOL was evaluated at the follow up session, two months after the termination of the HIIT intervention (Chapter 5). Interestingly, total SF-36 score was significantly increased compared to baseline in both training groups since both physical and mental health components were elevated. These findings could be explained by the enhanced physical activity during the follow up period from all the participants, as it was evaluated using the self-reported IPAQ. However, the nature of the performed exercise appears to influence the association with the positive change in total SF-36 score. A correlation was found between change in total SF-36 score and change in vigorous PA from pre- intervention to follow up, however no significant correlation was found between change in total SF-36 score and change in total PA. Therefore, it is important to maintain vigorous intensity PA to have enhanced HRQOL.

Self-reported vigorous and total PA of both training groups increased at follow up compared to pre- intervention. This resulted in change of the PA categories distribution across the groups compared to baseline. At baseline all participants belonged to the low PA category, instead of only 36% and 23% of the HIIT-2 and HIIT-3 participants respectively that remained to low PA category at follow up. The fact that both training HIIT frequencies were able to promote active lifestyle changing the habitual PA patterns of the participants might be considered as an important finding of the current investigation (Chapter 5). However, the small reduction of daily sitting time that was observed was not adequate to promote statistically significant reduction in sedentary behavior.

From the available published research, it appears that there is growing debate and conflicting theoretical viewpoints about how people psychologically respond to interval exercise (Stork et al., 2017). Consequently, one of the aims of the current research (Chapter 5) was to evaluate the perceptual responses during and following the HIIT intervention. Manageable ratings of perceived exertion were displayed by the participants through intervention. The highest RPE at the last interval of a session was seen in the first training for both HIIT-2 and HIIT-3 (17.7 and 17.8 respectively) and significantly reduced through the weeks, reduced by 2.1 and 3.3 units in each group at the last training session (15.6 and 14.5 respectively). Similar reduction (2.3 units) was found after 3 weeks of HIIT using the same protocol with a frequency of 3 times per week in overweight/obese women (Smith-Ryan et al., 2016). These modest RPE values show that the particular protocol is tolerable by inactive population and it may lead to more positive feelings towards HIIT. Moreover, they may provide a separate benefit for novice exercisers who may enter into an exercise program with relatively low levels of self-efficacy (Kilpatrick et al., 2016).

More psychological outcome measures such as enjoyment, tasking and intentions have been recently started to be rapidly examined. This was presented in a very recent review, where it was shown that from the 42 articles that reported on psychological outcomes associated with interval exercise, nearly 40% of them were published in 2016 (Stork et al., 2017). From the same review, it was reported that less than one third of these studies have been conducted after a period of a training program, while the rest of them reported on investigations of acute responses to interval exercise protocols. Therefore, the current study (Chapter 5) was aimed to explore the psychological responses following the HIIT intervention and whether different training frequencies might influence differently these responses.

Enjoyment was assessed via single item administered following the end of the HIIT intervention. It appears that training frequency does not affect enjoyment of the training program, since perceived enjoyment of HIIT was rated similarly high by participants of both training groups. The importance of the observed high levels of enjoyment is illustrated by the association between enjoyment and participation in interval exercise (Stork & Martin Ginis, 2016) or generally in physical activity (Salmon et al., 2003). Furthermore, similar enjoyment scores were displayed by the participants that continued HIIT during the follow up period.

Moreover, the confidence of the participants for their engagement to HIIT was shown by their reported intention to implement high intensity exercise in the future. The result that most of the HIIT participants stated intention to implement high intensity exercise at least once a week in the future was very encouraging. This shows that a HIIT intervention could lead to positive feelings towards high intensity exercise and intention to continue getting involved in this type of PA.

The potential of HIIT interventions with different frequencies on future adherence in HIIT or in general in PA has rarely been examined. The results in the current study showed that more participants of the HIIT-3 group reported that they completed at least one session of HIIT per week, during the two month follow up period, indicating that training frequency during the intervention influenced their real engagement to HIIT. Moreover, the results presented that almost all HIIT participants reported engagement to other forms of exercise during this period. Taken all together, it can be concluded that a HIIT intervention may lead to future adherence in PA or HIIT

6.2 Limitations and strengths of thesis

This thesis faced several limitations. Firstly, the small sample size of each gender in each group may limit the comparisons between males and females. Larger studies are warranted to confirm and expand the present findings for gender effect on HIIT.

In the Chapter 4, the effects of HIIT were examined in an 8-week training intervention. Possibly, intervention of longer duration could alter the effects of HIIT on physiological and psychological responses and/or future adherence rates of the participants, particularly in the low frequency training group. Some parameters like insulin sensitivity or mental health component of quality of life showed non-significant improvements in HIIT-2 group, therefore perhaps an intervention with longer duration could lead to statistical differences. Moreover, another limitation was that OGTT was conducted with blood samples taken at 3 time points (0, 60, 120 min). The original calculation of the insulin sensitivity index (Matsuda index), is based on five plasma glucose and insulin measurements (0, 30, 60, 90 and 120 min). However, it has been shown that calculation of this index using fewer time points agrees well with the original calculation (DeFronzo & Matsuda, 2010). For evaluating the relevant parameters of body composition, the bioelectrical impedance analysis and skinfolds measurement were used. Even though, their reliability has been reported, yet, more accurate techniques exist like DEXA or MRI and should be used in future studies.

Furthermore, the dietary intake of the participants throughout the intervention period was not controlled, thus it is possible that alterations in their diet may have affected the results, particularly the body composition and blood biochemical parameters. However, a 72-h control of diet prior to OGTT was conducted, to avoid/minimize this affect. In addition, the menstrual cycle was not considered at the tests of the training intervention in females which could have affected the training-induced responses of some parameters, like insulin sensitivity.

In the Chapter 5, at the follow up session, the measures of exercise adherence were derived from the completion of self-recorded IPAQ and self-efficacy questionnaires. Thus, PA and intensity were not actually counted and therefore it is unknown whether the participants that stated doing PA, truly engaged in it and in which intensity. A possible solution for future investigations could be the use of accelerometers or completion of training logbooks during the follow up period.

On the other hand, several aspects of the present thesis represent significant methodological strengths. Importantly, this thesis was comprehensive, in evaluating various aspects of physiological and psychological health following HIIT. Moreover, the addition of a follow up session, to examine the future adherence to PA after a HIIT intervention is rare and contributes to the existent knowledge of the positive adaptations to HIIT. Overall, this thesis was also strengthened by the inclusion of a mixed gender population, which broadens our findings to a more diverse population. Moreover, the present thesis included a control group that received no exercise intervention, to make sure the results were only due to the factors under investigation. In addition, all exercise sessions were supervised with high compliance rate as well as no dropouts or adverse effects, indicating that this intervention was efficacious and tolerable by the inactive population engaged.

The inclusion of a precondition phase of training prior to initiating HIIT was important as may reduce the risk associated with exercise-induced ischemic events, particularly in low fitness level populations as our participants (Gillen & Gibala, 2014; Holloway & Spriet, 2015). Preconditioning phase served also as familiarization, to ensure that the participants' improvements were due to training adaptations. Moreover, a follow up VO_2peak tests were conducted following 4 weeks of training to readjust the power output of the training bouts for the remaining period in order to maintain the target relative intensity.

Furthermore, the determination of the timing of the post-training samples after the last exercise bout is critical when interpreting results like insulin sensitivity to ensure that the observed changes are due to a training adaptation and not an acute effect of a recent exercise bout. For instance, Whyte et al. (2010) observed an augmentation of insulin sensitivity 24-hour after the last bout, but this change was lost at the 72-hour post-intervention assessment. In the study of Chapter 4, all blood samples were consistently taken 72h after the last training bout, in order to assess the chronic adaptations following HIIT.

6.3 Practical applications and future research directions

This thesis showed that HIIT may be together an effective and enjoyable exercise intervention for inactive adults. The exercise bouts were held with intensity which was below maximum, and as a consequence mean exertion was perceived as "somewhat hard", showing that HIIT is not necessary to be exhaustive and intolerable to induce adaptations. Therefore, this thesis suggests that HIIT should be used as an alternative exercise strategy for those who have limited available time and that this protocol is suitable, applicable and sustainable for inactive adults.

Moreover, a primary aim of the present thesis was to investigate if lower frequency of HIIT can produce beneficial adaptations on fitness, health and quality of life. The results suggest that even though training three times per week can confer more beneficial adaptations, like improved fat mass, lipid profile and mental functioning, yet training twice a week is enough to provide sufficient training stimulus to increase particular health indices. Consequently, we should encourage people that are unable to follow or tolerate more frequent training sessions, to train twice per week since they can still benefit from this low frequency PA. Furthermore, HIIT with low frequency could be an effective PA strategy for less motivated subjects, especially persons with low fitness level and/or with sedentary behavior, since it could more easily fit in a busy program and may be easier for participants to accomplish given that "lack of time" represents a common barrier to exercise completion.

Based on the findings of Chapter 5, HIIT could change the habitual PA patterns of the participants following training. Therefore, for inactive people, community or organizations could provide supervised HIIT training interventions in order to increase the participants' self-efficacy and thus future adherence to PA.

On the basis of the promising and encouraging results of the present thesis for the efficacy of HIIT on cardiometabolic health, quality of life and future adherence to PA, more research is needed to verify and expand these findings. Future studies should include larger sample sizes from both genders. Particularly, well- controlled studies are warranted to determine whether potential sex-based differences influence the adaptive response to HIIT. However, the phase of menstrual cycle should be taken into account when examining training-induced responses to HIIT in females.

In addition, future studies should compare low and medium training frequencies in programs with longer duration. In order to induce particular physiological and psychological adaptations, the total training volume may be extremely important when the frequency of training is low. Possibly in longer interventions, using the low frequency HIIT, the adaptations might be potentially the same for all cardiometabolic and quality of life parameters as the higher HIIT frequencies; but this is only speculations. Nonetheless, the effects of training frequency and total volume remain to be further investigated in longer-term studies.

Moreover, future research may replicate this study in obese/overweight adults as well as in patients or older adults and investigate the effects of low frequency HIIT on these populations. Taken into account that greater improvements in metabolic control were found on individuals with metabolic syndrome or type 2 diabetes (Cassidy, Thoma, Houghton, et al., 2016; Jelleyman et al., 2015) and greater fat reduction effect was found on overweight/obese subjects (Batacan et al., 2017; Boutcher, 2011), it is plausible that for such populations performing HIIT 2 times per week may elicit important favorable changes in glucose regulation and body composition, although this requires further research to confirm.

Even though this thesis was well comprehensive comparing with other HIIT studies, more tests could be added in future studies. For instance, it would be interesting to examine the effect of low frequency training on muscle level and particularly on mitochondria since limited data are available to ascertain whether weekly training frequency influences mitochondrial adaptations in humans (MacInnis & Gibala, 2016). In addition, it has been suggested that HIIT sessions can cause post-exercise suppressed appetite (Boutcher, 2011), but the effect of chronic HIIT training on appetite is less investigated. Thus, in future HIIT studies, the effect of HIIT on appetite i.e. using appetite questionnaires or evaluating appetite hormones should be examines during and after the intervention.

Lastly, in this thesis, follow up session was scheduled only two months after the end of the intervention. More research is needed to determine whether individuals can adhere to PA over longer term after a HIIT program and whether the duration or frequency of the HIIT intervention could influence the future adherence.

Overall, it is hoped that the insights provided from this thesis will prompt future research to further explore the physiological and psychological benefits from the low frequency HIIT program, as this could have important implications from the perspective of enhancing physical activity adherence especially in inactive or clinical populations.

6.4 Conclusions

This thesis provides novel findings on a range of issues concerning the effect of HIIT on various aspects of health of inactive adults. Firstly, this thesis presented that low frequency HIIT (e.g. 2 times per week) may promote specific health-related adaptations, similar with higher training frequency, such as significant improvements in VO_2peak, waist circumference, thigh lean CSA, insulin concentration at the end of the OGTT and physical health component of quality of life, despite the lower time commitment. However, moderate frequency HIIT (e.g. 3 times per week) may confer additional health-related benefits by reducing total body and abdominal fat, TC and LDL-C and by improving the mental component of quality of life. Moreover, HIIT was perceived as enjoyable, promoting high levels of self-efficacy and intentions for future engagement in HIIT, regardless of training frequency. Besides these physiological and psychological adaptations and responses, another important finding of this thesis is that HIIT may influence future interval training or general physical activity participation, as it was shown 2 months after the cessation of the structured HIIT intervention. From the results of this thesis it can be concluded that HIIT is a viable health-enhancing exercise strategy that may greatly contribute against the battle of inactivity, one of the main public health problems of the modern societies worldwide.

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8 APPENDICES

8.1 Consent form

ΕΝΤΥΠΑ ΣΥΓΚΑΤΑΘΕΣΗΣ για συμμετοχή σε πρόγραμμα έρευνας (Τα έντυπα αποτελούνται συνολικά από 4 σελίδες)

Καλείστε να συμμετάσχετε σε ένα ερευνητικό πρόγραμμα. Πιο κάτω (βλ. **«Πληροφορίες για Ασθενείς ή/και Εθελοντές»**) θα σας δοθούν εξηγήσεις σε απλή γλώσσα σχετικά με το τι θα ζητηθεί από εσάς ή/και τι θα σας συμβεί σε εσάς, εάν συμφωνήσετε να συμμετάσχετε στο πρόγραμμα. Θα σας περιγραφούν οποιοιδήποτε κίνδυνοι μπορεί να υπάρξουν ή ταλαιπωρία που τυχόν θα υποστείτε από την συμμετοχή σας στο πρόγραμμα. Θα σας επεξηγηθεί με κάθε λεπτομέρεια τι θα ζητηθεί από εσάς και ποιος ή ποιοι θα έχουν πρόσβαση στις πληροφορίες ή/και άλλο υλικό που εθελοντικά θα δώσετε για το πρόγραμμα. Θα σας δοθεί η χρονική περίοδος για την οποία οι υπεύθυνοι του προγράμματος θα έχουν πρόσβαση στις πληροφορίες ή/και υλικό που θα δώσετε. Θα σας επεξηγηθεί τι ελπίζουμε να μάθουμε από το πρόγραμμα σαν αποτέλεσμα και της δικής σας συμμετοχής. Επίσης, θα σας δοθεί μία εκτίμηση για το όφελος που μπορεί να υπάρξει για τους ερευνητές ή/και χρηματοδότες αυτού του προγράμματος. **Δεν πρέπει να συμμετάσχετε, εάν δεν επιθυμείτε ή εάν έχετε οποιουσδήποτε ενδοιασμούς που αφορούν την συμμετοχή σας στο πρόγραμμα.** Εάν αποφασίσετε να συμμετάσχετε, πρέπει να αναφέρετε εάν είχατε συμμετάσχει σε οποιοδήποτε άλλο πρόγραμμα έρευνας μέσα στους τελευταίους 12 μήνες. **Είστε ελεύθεροι να αποσύρετε οποιαδήποτε στιγμή εσείς επιθυμείτε την συγκατάθεση για την συμμετοχή σας στο πρόγραμμα.** Έχετε το δικαίωμα να υποβάλετε τυχόν παράπονα ή καταγγελίες, που αφορούν το πρόγραμμα στο οποίο συμμετέχετε, προς την Επιτροπή Βιοηθικής που ενέκρινε το πρόγραμμα ή ακόμη και στην Εθνική Επιτροπή Βιοηθικής Κύπρου.

Πρέπει όλες οι σελίδες των εντύπων συγκατάθεσης να φέρουν το ονοματεπώνυμο και την υπογραφή σας.

Σύντομος Τίτλος του Προγράμματος στο οποίο καλείστε να συμμετάσχετε
Η ΕΠΙΔΡΑΣΗ ΤΗΣ ΔΙΑΛΕΙΜΜΑΤΙΚΗΣ ΠΡΟΠΟΝΗΣΗΣ ΥΨΗΛΗΣ ΕΝΤΑΣΗΣ ΣΤΗΝ ΦΥΣΙΚΗ ΚΑΤΑΣΤΑΣΗ ΚΑΙ ΣΤΗΝ ΥΓΕΙΑ
Υπεύθυνος του Προγράμματος στο οποίο καλείστε να συμμετάσχετε
ΜΑΡΙΟΣ ΧΑΤΖΗΧΑΡΑΛΑΜΠΟΥΣ

Επίθετο Δοκιμαζόμενου:	…………………………………	Όνομα Δοκιμαζόμενου:	………………… …
Ημερομηνία:		Υπογραφή Δοκιμαζόμενου	

ΕΝΤΥΠΑ ΣΥΓΚΑΤΑΘΕΣΗΣ για συμμετοχή σε πρόγραμμα έρευνας (Τα έντυπα αποτελούνται συνολικά από 4 σελίδες)	
Σύντομος Τίτλος του Προγράμματος στο οποίο καλείστε να συμμετάσχετε	
Η ΕΠΙΔΡΑΣΗ ΤΗΣ ΔΙΑΛΕΙΜΜΑΤΙΚΗΣ ΠΡΟΠΟΝΗΣΗΣ ΥΨΗΛΗΣ ΕΝΤΑΣΗΣ ΣΤΗΝ ΦΥΣΙΚΗ ΚΑΤΑΣΤΑΣΗ ΚΑΙ ΣΤΗΝ ΥΓΕΙΑ	
Δίδετε συγκατάθεση για τον εαυτό σας ή για κάποιο άλλο άτομο;	
Εάν πιο πάνω απαντήσατε για κάποιον άλλο, τότε δώσετε λεπτομέρειες και το όνομα του.	

Ερώτηση	ΝΑΙ ή ΟΧΙ
Συμπληρώσατε τα έντυπα συγκατάθεσης εσείς προσωπικά;	
Τους τελευταίους 12 μήνες έχετε συμμετάσχει σε οποιοδήποτε άλλο ερευνητικό πρόγραμμα;	
Διαβάσατε και καταλάβατε τις πληροφορίες για ασθενείς ή/και εθελοντές;	
Είχατε την ευκαιρία να ρωτήσετε ερωτήσεις και να συζητήσετε το Πρόγραμμα;	
Δόθηκαν ικανοποιητικές απαντήσεις και εξηγήσεις στα τυχόν ερωτήματά σας;	
Καταλαβαίνετε ότι μπορείτε να αποσυρθείτε από το πρόγραμμα, όποτε θέλετε;	
Καταλαβαίνετε ότι, εάν αποσυρθείτε, δεν είναι αναγκαίο να δώσετε οποιεσδήποτε εξηγήσεις για την απόφαση που πήρατε;	
(Για ασθενείς) καταλαβαίνετε ότι, εάν αποσυρθείτε, δεν θα υπάρξουν επιπτώσεις στην τυχόν θεραπεία που παίρνετε ή που μπορεί να πάρετε μελλοντικά;	
Συμφωνείτε να συμμετάσχετε στο πρόγραμμα;	
Με ποιόν υπεύθυνο μιλήσατε;	

Επίθετο Δοκιμαζόμενου:	…………………………………	Όνομα Δοκιμαζόμενου:	………………… …
Ημερομηνία:		Υπογραφή Δοκιμαζόμενου	

ΕΝΤΥΠΑ ΣΥΓΚΑΤΑΘΕΣΗΣ για συμμετοχή σε πρόγραμμα έρευνας (Τα έντυπα αποτελούνται συνολικά από 4 σελίδες)
Σύντομος Τίτλος του Προγράμματος στο οποίο καλείστε να συμμετάσχετε
Η ΕΠΙΔΡΑΣΗ ΤΗΣ ΔΙΑΛΕΙΜΜΑΤΙΚΗΣ ΠΡΟΠΟΝΗΣΗΣ ΥΨΗΛΗΣ ΕΝΤΑΣΗΣ ΣΤΗΝ ΦΥΣΙΚΗ ΚΑΤΑΣΤΑΣΗ ΚΑΙ ΣΤΗΝ ΥΓΕΙΑ

ΠΛΗΡΟΦΟΡΙΕΣ ΓΙΑ ΑΣΘΕΝΕΙΣ ή/και ΕΘΕΛΟΝΤΕΣ

Σας έχει ζητηθεί να δώσετε την συγκατάθεση σας για την συμμετοχή σας στην παρούσα έρευνα. Η έρευνα αυτή διεξάγεται στα πλαίσια του Διδακτορικού προγράμματος σπουδών Επιστήμη της Άσκησης και της Φυσικής Αγωγής του Πανεπιστημίου Λευκωσίας και είναι μέρος της διδακτορικής έρευνας από την υποψήφια διδάκτωρ Πηνελόπη Σταυρινού. Πριν δώσετε την συγκατάθεση σας, θα ήθελα να διαβάσετε το περιεχόμενο αυτό πολύ προσεκτικά.

Ο σκοπός αυτής της έρευνας είναι να εξετάσει την επίδραση του προγράμματος άσκησης υψηλής έντασης που έχει την ελάχιστη δυνατή διάρκεια στην υγεία και στην φυσική κατάσταση για να μπορεί να εφαρμοστεί από άτομα με ελάχιστο ελεύθερο χρόνο.

Αφού δώσετε την γραπτή συγκατάθεση σας και το ιατρικό σας ιστορικό, θα γίνει αιμοληψία για καθορισμό διάφορων βιοχημικών παραγόντων (τριγλυκερίδια, γλυκόζη, χοληστερόλη). Έπετα θα γίνουν οι ακόλουθες δοκιμασίες: σωματομετρήσεις για προσδιορισμό της σωματικής σύστασης (μετρήσεις ύψους και σωματικού βάρους καθώς και μέτρηση δερματοπτυχών), αξιολόγηση φυσικής κατάστασης (μέτρηση της μέγιστης πρόσληψης οξυγόνου και αναερόβιου κατωφλιού) και μετρήσεις της αρτηριακής πίεσης και καρδιακής συχνότητας σε ηρεμία. Αυτές οι αξιολογήσεις θα γίνουν τρεις φορές συνολικά: πριν ξεκινήσει το πρόγραμμα προπόνησης, τέσσερις και οκτώ εβδομάδες αργότερα.

Η προπονητική περίοδος θα διαρκέσει οκτώ εβδομάδες και οι προπονήσεις ποικίλουν ανάλογα με την ομάδα στην οποία θα ανήκετε. Η ομάδα ελέγχου θα συνεχίσει τις καθημερινές της συνήθειες και δεν θα προπονηθεί καθόλου, παρά μόνο θα αξιολογηθεί. Η πρώτη και δεύτερη ομάδα προπόνησης θα εκτελεί το προπονητικό πρωτόκολλο τρεις και δύο φορές την εβδομάδα αντίστοιχα για όλο το διάστημα των οκτώ εβδομάδων. Η ανάθεση σας σε κάποια ομάδα θα γίνει με τυχαία δειγματοληψία.

Επίθετο Δοκιμαζόμενου:	…………………………………	Όνομα Δοκιμαζόμενου:	……… ……………
Ημερομηνία:		Υπογραφή Δοκιμαζόμενου	

ΕΝΤΥΠΑ ΣΥΓΚΑΤΑΘΕΣΗΣ

για συμμετοχή σε πρόγραμμα έρευνας
(Τα έντυπα αποτελούνται συνολικά από 4 σελίδες)

Σύντομος Τίτλος του Προγράμματος στο οποίο καλείστε να συμμετάσχετε
Η ΕΠΙΔΡΑΣΗ ΤΗΣ ΔΙΑΛΕΙΜΜΑΤΙΚΗΣ ΠΡΟΠΟΝΗΣΗΣ ΥΨΗΛΗΣ ΕΝΤΑΣΗΣ ΣΤΗΝ ΦΥΣΙΚΗ ΚΑΤΑΣΤΑΣΗ ΚΑΙ ΣΤΗΝ ΥΓΕΙΑ

ΠΛΗΡΟΦΟΡΙΕΣ ΓΙΑ ΑΣΘΕΝΕΙΣ ή/και ΕΘΕΛΟΝΤΕΣ, συνέχεια:

Το προπονητικό πρωτόκολλο περιλαμβάνει 10 ποδηλατήσεις διάρκειας ενός λεπτού με ενδοιάμεση ξεκούραση επίσης ενός λεπτού. Η ένταση της ποδηλάτησης θα κυμαίνεται στο ~80% του μέγιστου σας παραγόμενου έργου. Η όλη διάρκεια της προπόνησης θα είναι περίπου εικοσιπέντε λεπτά.

Όλα τα δεδομένα που θα συλλεκτούν θα είναι εμπιστευτικά και πρόσβαση σε αυτά θα έχει μόνο η ερευνήτρια (Πηνελόπη Σταυρινού), καθώς και ο κάθε συμμετέχων που θα μπορεί να γνωρίζει τα δικά του αποτελέσματα για αξιοποίηση τους στην προπονητική διαδικασία. Πρέπει να τονισθεί ότι θα είστε ελεύθεροι να αρνηθείτε την συμμετοχής σας και να αποχωρήσετε από την έρευνα οποιαδήποτε στιγμή.

Αν έχετε οποιαδήποτε απορία ή ανησυχία για την έρευνα ή χρειάζεστε κάποιες επιπλέον πληροφορίες μπορείτε να καλέσετε την Πηνελόπη Σταυρινού στο 99939808 ή τον υπεύθυνο καθηγητή Dr. Μάριο Χατζηχαραλάμπους στο 22461566. Σε περίπτωση που για οποιοδήποτε λόγο επιθυμείτε να διαμαρτυρηθείτε για οποιοδήποτε λόγο σχετικό με την ερευνητική διαδικασία ή να ζητήσετε την ανεξάρτητη γνώμη κάποιου λειτουργού του Πανεπιστημίου μας σε σχέση με την έρευνα που λαμβάνετε μέρος, σας παρακαλούμε να μην διστάσετε να επικοινωνήσετε με την Επιτροπή Βιοηθικής του Πανεπιστημίου Λευκωσίας και συγκεκριμένα με τον Δρ. Κωνσταντίνο Αδαμίδη, τηλ: 22841675.

Ευχαριστούμε για την εθελοντική σας συγκατάθεση για συμμετοχή σε αυτή την έρευνα.

Διάβασα το παραπάνω κείμενο και κατανόησα πλήρως τις διαδικασίες στις οποίες θα υποβληθώ. Δέχομαι να συμμετάσχω στην έρευνα διατηρώντας το δικαίωμα να σταματήσω ή να αποσυρθώ οποιαδήποτε στιγμή, σύμφωνα με την προσωπική μου κρίση.

Επίθετο Δοκιμαζόμενου:	…………………………………	Όνομα Δοκιμαζόμενου:	………………… …
Ημερομηνία:		Υπογραφή Δοκιμαζόμενου	

8.2 General health and screening questionnaire

ΙΑΤΡΙΚΟ ΙΣΤΟΡΙΚΟ ΔΟΚΙΜΑΖΟΜΕΝΟΥ

Επώνυμο:___________________________ Όνομα : ________________________________

Ημερομηνία Γεννήσεως :______________________

Διεύθυνση:____

Τηλ. ______________________ Κιν. ____________________ Τηλ. Εργασίας:___________

Οικογενειακός Γιατρός :____

ΜΕΡΟΣ Α

Πότε ήταν η τελευταία φορά που έκανες πλήρη ιατρικό έλεγχο/ εξετάσεις;

____

Έχεις εξεταστεί ξανά σε εργομετρικό εργαστήριο; Αν ναι πότε;

____

Είσαι αλλεργικός σε τροφές, φάρμακα ή άλλες ουσίες. Α ναι σε ποιες;

____

Σου έχει αναφερθεί ότι πάσχεις από κάποια χρόνια ή σοβαρή ασθένεια. Αν ναι από ποια/ ποιες:____

Αναφέρετε τις τρεις τελευταίες φορές που νοσηλευτήκατε:

Χειρουργεία:

Έτος	Αιτία	Νοσοκομείο

Νοσηλεία άλλου είδους:

Έτος	Αιτία	Νοσοκομείο

Κάνατε ποτέ μετάγγιση αίματος; Αν ναι, πότε;

____

____

ΜΕΡΟΣ Β

Κατά την διάρκεια των τελευταίων 12 μηνών :

1. Σου χορηγήθηκε από γιατρό κάποιο φάρμακο;	ΝΑΙ	ΟΧΙ
2. Έχεις αισθανθεί τάση για λιποθυμία ή ζάλη;	ΝΑΙ	ΟΧΙ
3. Αντιμετωπίζεις συχνά προβλήματα διαταραχής ύπνου;	ΝΑΙ	ΟΧΙ
4. Έχεις αισθανθεί το οπτικό σου πεδίο θολό;	ΝΑΙ	ΟΧΙ
5. Έχεις έντονους πονοκεφάλους;	ΝΑΙ	ΟΧΙ
6. Έχεις συνήθως το πρωί βήχα;	ΝΑΙ	ΟΧΙ
7. Σου συμβαίνει να δυσκολεύεσαι να μιλήσεις ή ψευδίζεις;	ΝΑΙ	ΟΧΙ
8. Αισθάνεσαι νευρικός ή αγχώδης χωρίς ιδιαίτερη αιτία;	ΝΑΙ	ΟΧΙ
9. Έχεις αισθανθεί την καρδιά σου να χτυπά ασυνήθιστα (σαν να 'φτερουγίζει');	ΝΑΙ	ΟΧΙ
10. Υπάρχουν φορές που η καρδιά σου χτυπά πολύ γρήγορα χωρίς ιδιαίτερο λόγο (ταχυκαρδίες);	ΝΑΙ	ΟΧΙ
11. Καπνίζεις συστηματικά; Αν ναι πόσα τσιγάρα την ημέρα; ______	ΝΑΙ	ΟΧΙ
12. Καταναλώνεις αλκοόλ συστηματικά (κάθε 1-2 μέρες); Αν ναι πόσο; ______	ΝΑΙ	ΟΧΙ

Πρόσφατα:

1. Έχεις αισθανθεί 'να σου κόβεται η αναπνοή' ή να μη μπορείς να αναπνεύσεις όταν περπατάς ή όταν κάθεσαι; ΝΑΙ ΟΧΙ
2. Έχεις αισθανθεί υπερβολική δύσπνοια ή υπέρμετρη κόπωση κατά την άσκηση; ΝΑΙ ΟΧΙ
3. Έχεις αισθανθεί ξαφνικά 'τσιμπήματα'/ μουδιάσματα στα χέρια, πόδια ή πρόσωπο ή να μην 'αισθάνεσαι' αυτά τα μέρη του σώματος; ΝΑΙ ΟΧΙ
4. Έχεις ποτέ παρατηρήσει ότι τα πόδια ή τα χέρια σου είναι πιο κρύα από το υπόλοιπο μέρος του σώματός σου; ΝΑΙ ΟΧΙ
5. Έχεις πρηξίματα στα πόδια ή αστραγάλους; ΝΑΙ ΟΧΙ
6. Έχεις αισθανθεί πίεση, βάρος, πόνο ή 'πλάκωμα' στο στήθος; ΝΑΙ ΟΧΙ
7. Σου έχουν αναφέρει ποτέ ότι η πίεση του αίματός σου δεν είναι φυσιολογική; ΝΑΙ ΟΧΙ

8. Σου έχουν αναφέρει ποτέ ότι τα επίπεδα των τριγλυκεριδίων ή της χοληστερόλης στο αίμα σου δεν είναι φυσιολογικά; ΝΑΙ ΟΧΙ
9. Υποφέρεις από διαβήτη; ΝΑΙ ΟΧΙ
   Αν ναι, πώς τον ελέγχεις; ______________________________________
10. Πώς θα αξιολογούσες τη γενική σου υγεία;
    α) Άριστη β) Πολύ καλή γ) Καλή δ) Μέτρια ε) Κακή
11. Πόσο συχνά γυμνάζεσαι;
    α) καθόλου β) ελαφρά (π.χ. περπάτημα)
    γ) συστηματικά με χαμηλή ένταση (λιγότερο από 4 φορές την εβδομάδα, για 30 λεπτά)
    δ) συστηματικά με υψηλή ένταση (περισσότερες από 4 φορές την εβδομάδα)
12. Πώς θα αξιολογούσες τη διατροφή σου;
    α) ισορροπημένη β) μέτρια γ) φτωχή
13. Πόση καφεΐνη καταναλώνεις ημερησίως;
    α) καθόλου β) καφέ:__________/ημέρα
    γ) τσάι:____________/ημέρα δ) αναψυκτικά τύπου Cola:____________/ημέρα
14. Πίνεις αλκοόλ; ΝΑΙ ΟΧΙ
    Αν ναι, τι είδους;____
    Πόσα ποτά την εβδομάδα;____
15. Καπνίζεις; ΝΑΙ ΟΧΙ
    Αν ναι, πόσα τσιγάρα ημερησίως; ______________________________________
16. Πόσο συχνά θα χαρακτήριζες ότι το επίπεδο άγχους σου είναι υψηλό;
    α) σχεδόν πάντα β) πολύ συχνά γ) συχνά δ) μερικές φορές
    ε) σπάνια
17. Σου έχουν αναφέρει ότι πάσχεις ή στο παρελθόν έπασχες από μία ή περισσότερες από τις ακόλουθες ασθένειες;

Έμφραγμα μυοκαρδίου	Θρόμβωση Στεφανιαίων Αρτηριών	Θυρεοειδή
Αρτηριοσκλήρωση	Ανεύρυσμα	Υπέρταση - Υπόταση
Καρδιακή Μαρμαρυγή	Καρδιακό Αποκλεισμό	Στηθάγχη
Καρδιακή Ανεπάρκεια	Περιφερειακή Θρόμβωση	Άσθμα
Καρδιακές αρρυθμίες	Ηπατίτιδα	Εμφύσημα
Οστεοπόρωση	Αναιμία	Άγχος ή κατάθλιψη
Κήλη	Φλεβίτιδα	Επιληψία
Ανορεξία/ βουλιμία	Έλκος	Αμηνόρροια

Ορθοπεδικά **ή άλλα** προβλήματα (πχ. μέση, γόνατο, ώμος, κλπ):

____

____

ΜΕΡΟΣ Γ

ΟΙΚΟΓΕΝΕΙΑΚΟ ΙΣΤΟΡΙΚΟ

	Ηλικία		Σοβαρά προβλήματα υγείας ή αιτία θανάτου
Πατέρας			
Μητέρα			
Αδέρφια	Α Θ		
	Α Θ		
	Α Θ		

	Ηλικία	Σοβαρά προβλήματα υγείας ή αιτία θανάτου
Από πατέρα		
Παππούς		
Γιαγιά		
Από μητέρα		
Παππούς		
Γιαγιά		

Ημερομηνία: _______________

Ονοματεπώνυμο: ________________________________

Υπογραφή:________________

8.3 Health related quality of life (SF-36)

SF 36 (ΕΡΩΤΗΜΑΤΟΛΟΓΙΟ ΓΙΑ ΤΗΝ ΠΟΙΟΤΗΤΑ ΖΩΗΣ)

Το ερωτηματολόγιο αυτό αναφέρεται στην προσωπική σας άποψη σχετικά με την υγεία σας και την φυσική σας κατάσταση. Δεν υπάρχουν σωστές και λάθος απαντήσεις. Απατήστε στις ερωτήσεις, σημειώνοντας με Χ τον κύκλο που περιγράφει καλύτερα την απάντησή σας. Αν δεν είστε απόλυτα βέβαιος/ βέβαιη για την απάντηση σας, παρακαλούμε δώστε την απάντηση που νομίζετε ότι ταιριάζει καλύτερα στην περίπτωσή σας.

Ονοματεπώνυμο:____

1. Γενικά, θα λέγατε ότι η υγεία σας είναι:

Άριστη	Πολύ καλή	Καλή	Μέτρια	Κακή
O	O	O	O	O

2. Συγκριτικά με ένα χρόνο πριν, πώς θα εκτιμούσατε την υγεία σας σε γενικές γραμμές τώρα;

Πολύ καλύτερα τώρα από ένα χρόνο πριν	Κάπως καλύτερα τώρα	Σχεδόν ίδιο όπως ένα χρόνο πριν	Κάπως χειρότερα τώρα	Πολύ χειρότερα τώρα
O	O	O	O	O

3. Οι παρακάτω προτάσεις περιέχουν δραστηριότητες που πιθανώς να κάνετε κατά τη διάρκεια μιας συνηθισμένης ημέρας. Η τωρινή κατάσταση της υγείας σας, σας περιορίζει σε αυτές τις δραστηριότητες; Εάν ναι, πόσο;

	Ναι, με περιορίζει Πολύ	**Ναι, με περιορίζει Λίγο**	**Όχι, δε με περιορίζει καθόλου**
Α. Σε κουραστικές δραστηριότητες, όπως το τρέξιμο, το σήκωμα βαριών αντικειμένων, η συμμετοχή σε δυναμικά σπορ	O	O	O
Β. Σε μέτριας έντασης δραστηριότητες, όπως η μετακίνηση ενός τραπεζιού, το σπρώξιμο μιας ηλεκτρικής σκούπας, ο περίπατος στην εξοχή ή	O	O	O

όταν παίζετε ρακέτες στην παραλία			
Γ. Όταν σηκώνετε ή μεταφέρετε ψώνια από την αγορά	O	O	O
Δ. Στο ανέβασμα ενός ορόφου σκαλοπάτια	O	O	O
Ε. Στο ανέβασμα αρκετών (2-3) ορόφων σκαλοπάτια	O	O	O
Στ. Στο λύγισμα, γονάτισμα, σκύψιμο	O	O	O
Ζ. Στο περπάτημα πάνω από ένα χιλιόμετρο	O	O	O
Η. Στο περπάτημα μερικών εκατοντάδων μέτρων	O	O	O
Θ. Στο περπάτημα εκατό μέτρων	O	O	O
Ι. Όταν ντύνεστε ή όταν κάνετε μπάνιο	O	O	O

4. Κατά τη διάρκεια των 4 προηγούμενων εβδομάδων, είχατε οποιαδήποτε από τα ακόλουθα προβλήματα με τη δουλειά σας ή με άλλες καθημερινές δραστηριότητες ως αποτέλεσμα της σωματικής σας υγείας;

	ΝΑΙ	**ΟΧΙ**
Α. Μειώσατε το συνολικό χρόνο που συνήθως ξοδεύετε στη δουλειά ή σε άλλες δραστηριότητες	O	O
Β. Καταφέρατε λιγότερα πράγματα από ότι θα θέλατε	O	O
Γ. Περιορίσατε τα είδη της δουλειάς ή των άλλων δραστηριοτήτων σας	O	O
Δ. Δυσκολευτήκατε να κάνετε τη δουλειά ή άλλες δραστηριότητές σας (π.χ. χρειαστήκατε να καταβάλετε περισσότερη προσπάθεια)	O	O

5. Κατά τη διάρκεια των 4 προηγούμενων εβδομάδων, είχατε οποιαδήποτε από τα ακόλουθα προβλήματα με τη δουλειά σας ή με άλλες καθημερινές δραστηριότητες ως αποτέλεσμα συναισθηματικών προβλημάτων (π.χ. κατάθλιψη, άγχος);

	ΝΑΙ	**ΟΧΙ**

Α. Μειώσατε <u>το συνολικό χρόνο</u> στο διάβασμα σας ή κάνατε άλλες δραστηριότητες	O	O
Β. Καταφέρατε <u>λιγότερα πράγματα</u> από ότι θα θέλατε	O	O
Γ. Διαβάσατε ή κάνατε δραστηριότητες <u>λιγότερο προσεκτικά</u> από ότι συνήθως	O	O

6. Κατά τη διάρκεια των 4 προηγούμενων εβδομάδων σε τι βαθμό η φυσική σας κατάσταση ή τα συναισθηματικά σας προβλήματα παρεμπόδισαν τις κανονικές κοινωνικές δραστηριότητες σας με την οικογένεια, και τους φίλους;

Καθόλου	Λίγο	Μέτρια	Αρκετά	Πάρα πολύ
O	O	O	O	O

7. Πόσο <u>σωματικό</u> πόνο είχατε κατά τη <u>διάρκεια των προηγούμενων 4 εβδομάδων;</u>

Καθόλου	Πολύ ήπιο	Ήπιο	Μέτριο	Έντονο	Πολύ έντονο
O	O	O	O	O	O

8. **Τις <u>τελευταίες 4 εβδομάδες</u>, πόσο επηρέασε ο πόνος τη συνηθισμένη εργασία σας (τόσο την εργασία έξω από το σπίτι όσο και μέσα σε αυτό);**

Καθόλου	Λίγο	Μέτρια	Αρκετά	Πάρα πολύ
O	O	O	O	O

9. Αυτές οι ερωτήσεις είναι σχετικές με το πώς αισθανθήκατε κατά τη <u>διάρκεια των 4 προηγούμενων εβδομάδων</u>. Για κάθε ερώτηση παρακαλώ δώστε την απάντηση που πλησιάζει περισσότερο στο πώς είχατε αισθανθεί.

Για πόσο χρόνο κατά τη διάρκεια των 4 προηγούμενων εβδομάδων….

	Συνεχώς	Το μεγαλύτεροο διάστημα	Σημαντικό διάστημα	Μερικές φορές	Μικρό διά-στημα	Καθόλου
Αισθανθήκατε γεμάτος ενέργεια;	O	O	O	O	O	O
Ήσασταν πολύ νευρικός;	O	O	O	O	O	O

Αισθανθήκατε τόσο πεσμένος ώστε τίποτα δεν μπορούσε να σας ανεβάσει τη διάθεση;	O	O	O	O	O	O
Αισθανθήκατε ήρεμος και χαλαρός;	O	O	O	O	O	O
Είχατε πολλή ενέργεια;	O	O	O	O	O	O
Αισθανόσαστε απελπισία και μελαγχολία;	O	O	O	O	O	O
Αισθανθήκατε εξάντληση;	O	O	O	O	O	O
Ήσασταν ευτυχής;	O	O	O	O	O	O
Αισθανθήκατε κούραση;	O	O	O	O	O	O

10. Τις τελευταίες <u>4 εβδομάδες</u>, για πόσο χρονικό διάστημα η σωματική σας υγεία ή τα συναισθηματικά σας προβλήματα επηρέασαν τις κοινωνικές σας δραστηριότητες (π.χ. επισκέψεις σε φίλους, συγγενείς, κλπ.);

Συνεχώς	Το μεγαλύτεροο διάστημα	Μερικές φορές	Μικρό διάστημα	Καθόλου
O	O	O	O	O

11. Σε τι βαθμό ισχύουν για σας <u>κάθε μία</u> από τις ακόλουθες δηλώσεις;

	Σίγουρα ΝΑΙ	**Μάλλον ΝΑΙ**	**Δεν ξέρω**	**Μάλλον ΟΧΙ**	**Σίγουρα ΟΧΙ**
Νομίζω ότι αρρωσταίνω λίγο πιο εύκολα απ' ότι οι άλλοι	O	O	O	O	O
Είμαι τόσο υγιής όσο όλοι οι γνωστοί μου	O	O	O	O	O
Περιμένω η υγεία μου να χειροτερέψει	O	O	O	O	O
Η υγεία μου είναι εξαιρετική	O	O	O	O	O

Ευχαριστούμε για την συμμετοχή σας!

8.4 Perceptual responses after intervention

<u>Ερωτηματολόγιο</u>

Όνομα: Ημερομηνία:

Έχετε συμπληρώσει το πρόγραμμα προπόνησης υψηλής έντασης. Το ερωτηματολόγιο αυτό αφορά το κατά πόσο απολαύσατε αυτό το πρόγραμμα και την πρόθεση σας να το συνεχίσετε.

Παρακαλώ διαβάστε πρώτα όλες τις ερωτήσεις και έπειτα κυκλώστε τον αριθμό που αντιπροσωπεύει καλύτερα την κάθε απάντηση σας.

1. Πόσο ευχάριστο ήταν για εσάς να συμμετέχετε σε υψηλής έντασης διαλειμματική προπόνηση 2 φορές την εβδομάδα ;

1 2 3 4 5 6 7

Καθόλου ευχάριστο — Εξαιρετικά ευχάριστο

2. Πόσο πεπεισμένοι είστε πως θα μπορούσατε μελλοντικά να προγραμματίσετε προπονήσεις υψηλής έντασης 2 φορές την εβδομάδα ;

1 2 3 4 5 6 7 8 9 10

Καθόλου πεπεισμένος — Εντελώς πεπεισμένος

3. Πόσο πεπεισμένοι είστε πως θα ολοκληρώνετε μελλοντικά προπονήσεις υψηλής έντασης 2 φορές την εβδομάδα ;

1 2 3 4 5 6 7 8 9 10

Καθόλου πεπεισμένος — Εντελώς πεπεισμένος

4. Μετά την ολοκλήρωση αυτής της έρευνας, σκοπεύετε να προσθέσετε έντονη ή πολύ έντονη άσκηση τουλάχιστον τριάντα λεπτών στον ελεύθερο σας χρόνο ;

a) *Μία φορά την εβδομάδα*

1 2 3 4 5 6 7

Διαφωνώ εντελώς — Συμφωνώ εντελώς

b) *Δύο φορές την εβδομάδα*

1 2 3 4 5 6 7

Διαφωνώ εντελώς — Συμφωνώ εντελώς

c) *Τρεις φορές την εβδομάδα*

1 2 3 4 5 6 7

Διαφωνώ εντελώς — Συμφωνώ εντελώς

d) *Πέντε φορές την εβδομάδα*

1 2 3 4 5 6 7

Διαφωνώ εντελώς — Συμφωνώ εντελώς

Ευχαριστούμε πολύ για τον χρόνο σας!

8.5 Perceptual responses after follow up period

<u>Ερωτηματολόγιο</u>

Όνομα: Ημερομηνία:

Έχετε συμπληρώσει 2 μήνες από τότε που ολοκληρώσατε το πρόγραμμα προπόνησης υψηλής έντασης. Το ερωτηματολόγιο αυτό αφορά το κατά πόσο το διάστημα αυτό έχετε γυμναστεί. Παρακαλώ διαβάστε πρώτα όλες τις ερωτήσεις και έπειτα κυκλώστε τον αριθμό που αντιπροσωπεύει καλύτερα την κάθε απάντηση σας.

5. Προγραμματίσατε προπονήσεις υψηλής έντασης αυτό το διάστημα ;

a) *Μία φορά την εβδομάδα*

1 2 3 4 5 6 7

Διαφωνώ εντελώς — Συμφωνώ εντελώς

b) *Δύο φορές την εβδομάδα*

1 2 3 4 5 6 7

Διαφωνώ εντελώς — Συμφωνώ εντελώς

c) *Τρεις φορές την εβδομάδα*

1 2 3 4 5 6 7

Διαφωνώ εντελώς — Συμφωνώ εντελώς

d) *Πέντε φορές την εβδομάδα*

1 2 3 4 5 6 7

Διαφωνώ εντελώς — Συμφωνώ εντελώς

6. Ολοκληρώσατε τις προπονήσεις υψηλής έντασης αυτό το διάστημα ;

a) *Μία φορά την εβδομάδα*

1 2 3 4 5 6 7

Διαφωνώ εντελώς — Συμφωνώ εντελώς

b) *Δύο φορές την εβδομάδα*

1 2 3 4 5 6 7

Διαφωνώ εντελώς — Συμφωνώ εντελώς

c) *Τρεις φορές την εβδομάδα*

1 2 3 4 5 6 7

Διαφωνώ εντελώς — Συμφωνώ εντελώς

d) *Πέντε φορές την εβδομάδα*

1	2	3	4	5	6	7

Διαφωνώ εντελώς — Συμφωνώ εντελώς

e) Πόσο ευχάριστο ήταν για εσάς να εκτελείτε υψηλής έντασης διαλειμματική προπόνηση αυτό το διάστημα ;

1	2	3	4	5	6	7

Καθόλου ευχάριστο — Εξαιρετικά ευχάριστο

f) Πραγματοποιήσατε αυτό το διάστημα άλλης μορφής άσκηση ;

1	2	3	4	5	6	7	8	9	10

Διαφωνώ εντελώς — Συμφωνώ εντελώς

Αν ναι, πόσες φορές την εβδομάδα ολοκληρώσατε προπόνηση:

- Συνεχόμενης άσκησης με χαμηλή/μέτρια ένταση

a) *Μία φορά την εβδομάδα*

1	2	3	4	5	6	7

Διαφωνώ εντελώς — Συμφωνώ εντελώς

b) *Δύο φορές την εβδομάδα*

1 2 3 4 5 6 7

Διαφωνώ εντελώς — Συμφωνώ εντελώς

c) *Τρεις φορές την εβδομάδα*

1 2 3 4 5 6 7

Διαφωνώ εντελώς — Συμφωνώ εντελώς

d) *Πέντε φορές την εβδομάδα*

1 2 3 4 5 6 7

Διαφωνώ εντελώς — Συμφωνώ εντελώς

- Άσκησης με αντιστάσεις (π.χ. βάρη)

a) *Μία φορά την εβδομάδα*

1 2 3 4 5 6 7

Διαφωνώ εντελώς — Συμφωνώ εντελώς

b) *Δύο φορές την εβδομάδα*

1 2 3 4 5 6 7

Διαφωνώ εντελώς — Συμφωνώ εντελώς

c) *Τρεις φορές την εβδομάδα*

1 2 3 4 5 6 7

Διαφωνώ εντελώς | Συμφωνώ εντελώς

d) *Πέντε φορές την εβδομάδα*

1 2 3 4 5 6 7

Διαφωνώ εντελώς | Συμφωνώ εντελώς

- Άλλης μορφής άσκηση (ορίστε το είδος άσκησης ………………………..)

a) *Μία φορά την εβδομάδα*

1 2 3 4 5 6 7

Διαφωνώ εντελώς | Συμφωνώ εντελώς

b) *Δύο φορές την εβδομάδα*

1 2 3 4 5 6 7

Διαφωνώ εντελώς | Συμφωνώ εντελώς

c) *Τρεις φορές την εβδομάδα*

1	2	3	4	5	6	7
Διαφωνώ εντελώς						Συμφωνώ εντελώς

d) *Πέντε φορές την εβδομάδα*

1	2	3	4	5	6	7
Διαφωνώ εντελώς						Συμφωνώ εντελώς

Ευχαριστούμε πολύ για τον χρόνο σας!

8.6 International Physical Activity Questionnaire

International Physical Activity Questionnaire*

Short - self answered - 7 items

Greek Version**

Οι παρακάτω ερωτήσεις αφορούν στο χρόνο που έχετε αφιερώσει για κάποια σωματική δραστηριότητα τις **<u>τελευταίες 7 ημέρες</u>**. Περιλαμβάνουν ερωτήσεις σχετικά με δραστηριότητες που κάνετε κατά την εργασία σας, στις μετακινήσεις σας, στις δουλειές του σπιτιού, του κήπου και στον ελεύθερο χρόνο σας για ψυχαγωγία, άσκηση ή άθληση. Σας παρακαλώ να απαντήσετε όλες τις ερωτήσεις, ακόμα και εάν πιστεύετε ότι δεν είστε ένα ιδιαίτερα σωματικά δραστήριο άτομο.

Πριν απαντήσετε τις ερωτήσεις 1 και 2, σκεφτείτε όλες τις **<u>έντονες</u>** σωματικές δραστηριότητες που κάνατε κατά τις **<u>τελευταίες 7 ημέρες</u>**. Μια έντονη σωματική δραστηριότητα αναφέρεται σε δραστηριότητες που απαιτούν έντονη σωματική προσπάθεια και σας κάνουν να αναπνέετε σημαντικά δυσκολότερα από ότι συνήθως. Σκεφθείτε μόνο τις **<u>έντονες</u>** σωματικές δραστηριότητες που κάνατε και είχαν διάρκεια **<u>μεγαλύτερη από 10 λεπτά</u>** κάθε φορά.

1. **Κατά τις τελευταίες 7 ημέρες, πόσες ημέρες κάνατε κάποια έντονη σωματική δραστηριότητα, όπως σκάψιμο, έντονη άσκηση με βάρη, τρέξιμο σε διάδρομο με κλίση, γρήγορο τρέξιμο, aerobics, γρήγορη ποδηλασία, γρήγορη κολύμβηση, τένις μονό, αγώνας σε γήπεδο (ποδόσφαιρο, basketball-μπάσκετ, volleyball-βόλεϊ, κλπ);**

_____ ημέρες ανά εβδομάδα

☐ εάν δεν κάνατε έντονες σωματικές δραστηριότητες, τότε προχωρήστε στην ερώτηση 3

2. **Τις ημέρες που κάνατε κάποια έντονη σωματική δραστηριότητα, πόσο χρόνο αφιερώνατε συνήθως;**

_____ λεπτά ανά ημέρα δεν γνωρίζω/δεν είμαι βέβαιος ☐

* The IPAQ group: https://sites.google.com/site/theipaq/home
** Papathanasiou G, et al. *Hellenic J Cardiol*. 2009; 50: 283-294.

Πριν απαντήσετε τις ερωτήσεις 3 και 4, σκεφτείτε όλες τις **μέτριας έντασης** σωματικές δραστηριότητες που κάνατε κατά τις **τελευταίες 7 ημέρες**. Μια μέτριας έντασης σωματική δραστηριότητα αναφέρεται σε δραστηριότητες που απαιτούν μέτρια σωματική προσπάθεια και σας κάνουν να αναπνέετε κάπως δυσκολότερα από ότι συνήθως. Σκεφθείτε μόνο τις **μέτριας έντασης** σωματικές δραστηριότητές που κάνατε και είχαν διάρκεια **μεγαλύτερη από 10 λεπτά** κάθε φορά.

3. **Κατά τις τελευταίες 7 ημέρες, πόσες ημέρες κάνατε κάποια μέτρια σωματική δραστηριότητα, όπως το να σηκώσετε και να μεταφέρετε ελαφρά βάρη (λιγότερο από 10 κιλά), συνολική καθαριότητα του σπιτιού, ήπιες ρυθμικές ασκήσεις σώματος, ποδηλασία αναψυχής με χαμηλή ταχύτητα, χαλαρή κολύμβηση; Σας παρακαλώ να μη συμπεριλάβετε το περπάτημα.**

_____ ημέρες ανά εβδομάδα

☐ εάν δεν κάνατε μέτριας έντασης σωματικές δραστηριότητες,

τότε προχωρήστε στην ερώτηση 5

4. **Τις ημέρες που κάνατε κάποια μέτρια σωματική δραστηριότητα, πόσο χρόνο αφιερώνατε συνήθως;**

_____ λεπτά ανά ημέρα δεν γνωρίζω/δεν είμαι βέβαιος ☐

Πριν απαντήσετε στις ερωτήσεις 5 και 6, σκεφτείτε το χρόνο που περπατήσατε κατά τις **τελευταίες 7 ημέρες**. Να συμπεριλάβετε το περπάτημα στο χώρο της εργασίας σας, στο σπίτι, στις μετακινήσεις σας και στον ελεύθερο χρόνο σας για ψυχαγωγία, άσκηση ή άθληση.

5. **Κατά τις τελευταίες 7 ημέρες, πόσες ημέρες περπατήσατε για περισσότερο από 10 συνεχόμενα λεπτά;**

_____ ημέρες ανά εβδομάδα

☐ εάν δεν περπατήσατε καμία φορά περισσότερο από 10 συνεχόμενα λεπτά, τότε προχωρήστε στην ερώτηση 7

6. Τις ημέρες που περπατήσατε, για περισσότερο από 10 συνεχόμενα λεπτά, πόσο χρόνο περάσατε περπατώντας;

_____ λεπτά ανά ημέρα δεν γνωρίζω/δεν είμαι βέβαιος ☐

7. Κατά τις τελευταίες 7 ημέρες, πόσο χρόνο περάσατε καθισμένος/η σε μια συνηθισμένη μέρα; Ο χρόνος αυτός μπορεί να περιλαμβάνει το χρόνο που περνάτε καθισμένος/η στο σπίτι, στο γραφείο, στο αυτοκίνητο, όταν διαβάζετε, όταν είστε με φίλους, ξεκουράζεστε σε πολυθρόνα ή βλέπετε τηλεόραση, <u>αλλά δεν περιλαμβάνει τον ύπνο.</u>

_____ ώρες ανά ημέρα δεν γνωρίζω/δεν είμαι βέβαιος ☐

Τέλος του ερωτηματολογίου. Σας ευχαριστούμε για τη συμμετοχή σας.