EFFECTS OF DIFFERENT TYPES OF EXERCISE INTENSITIES ON IMMUNE RESPONSES, BONE METABOLISM MARKERS, ANTIOXIDANT STATUS AND SELECTED PHYSIOLOGICAL PARAMETERS IN PHYSICALLY INACTIVE ADULTS

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2025

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by

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Thesis submitted in fulfilment of the requirements
for the degree of
Doctor of Philosophy

August 2025

ACKNOWLEDGEMENT

I would like to express my heartfelt gratitude my main supervisor, Dr Ayu Suzailiana Muhamad, for her invaluable guidance and unwavering support throughout my academic journey. I also extend my sincere thanks to my co-supervisors, Prof. Dr Chen Chee Keong, Assoc. Prof. Dr Ooi Foong Kiew and Dr Marilyn Ong Li Yin. Their steadfast support and insightful guidance were instrumental in shaping this research. I am truly fortunate to have such knowledge, committed, and understanding mentors.

My gratitude extends to the laboratory staff of Exercise and Sports Science laboratory for their assistance during my research. Special thanks go to Madam Norlida and Madam Nurfadhillah Ain for sharing their expertise in sample analysis and for being excellent listeners and advisors during this challenging journey. Additionally, I would like to thank Universiti Malaysia Terengganu (UMT) for the financial support provided through the TAPE-RG grant (UMT/TAPE-RG/55277).

Finally, I dedicate this thesis to my beloved parents; Mr Suhaimi and Madam Nur Hidayah, whose endlessly love, prayers, and encouragement have been my foundation. I am especially grateful to my lovely wife for her unwavering support and for taking care our children during my data collection phase. To my kids, you are motivation and inspiration in completing this study. Thank you to everyone who has contributed directly or indirectly; your friendship and support have made these years memorable.

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LIST OF SYMBOLS

α	Greek small letter alpha
β	Greek small letter beta
γ	Greek small gamma
µ	Micro sign
®	Registered sign
±	Plus-minus sign

LIST OF ABBREVIATIONS

1CTP	Carboxy-terminal telopeptide of type 1 collagen
AC	Anaerobic capacity
ADCC	Antibody-dependent cellular cytotoxic
AP	Anaerobic power
BALP	Bone alkaline phosphatase
BLCs	Bone lining cells
BMD	Bone mineral density
BMI	Body mass index
BMU	Basic multicellular unit
CBUA	Calcaneus broadband ultrasound attenuation
CAT	Catalase
CRF	Cardiorespiratory fitness
CSI	Stiffness index
CT	Computed tomography
DAMPs	Damage-associated molecular patterns
DEXA	Dual-energy x-ray absorptiometry
DM	Diabetes mellitus
DPD	Deoxypyridinoline
ELISA	Enzyme-linked immunosorbent assay
EPO	Eosinophil peroxidase
FI	Fatigue index
GHO	Global health observatory
GPX	Glutathione peroxidase
HCL	Hydrochloric acid
HIIT	High-intensity interval training
HR_{max}	Maximum heart rate
HRP	Horseradish
IFCC	International Federation of Clinical Chemistry
IFN-γ	Interferon-gamma
IgE	Immunoglobulin E
IL-2	Interleukin-2

IL-4	Interleukin-4
IL-6	Interleukin-6
IL-10	Interleukin-10
IOF	International Osteoporosis Foundation
IPAQ-SF	International physical activity questionnaire-short form
LSD	Long slow distance
MBP	Major basic protein
MDA	Malondialdehyde
MHC	Major histocompatibility complex
MVC	Maximal voluntary contraction
MICT	Moderate-intensity continuous training
MMPs	Matrix metalloproteinases
MP	Mean power
MRI	Magnetic resonance imaging
NAM	N-acetylmuramic acid
NAG	N-acetylglucosamine
NCDs	Non-communicable disease
NCRs	Natural cytotoxic receptors
NTX-1	N-terminal cross-linking telopeptide of type collagen
OC	Osteocalcin
PAMPs	Pathogen-associated molecular patterns
PARQ	Physical activity readiness questionnaire
PICP	C-terminal propeptide of type 1 procollagen
PINP	N-terminal propeptide of type 1 procollagen
PPi	Inorganic pyrophosphate
PPRs	Pattern recognition receptors
PTH	Parathyroid hormone
Qmax	Maximum stroke volume
RANKL	Receptor activator of nuclear factor kappa-β ligand
ROS	Reactive oxygen species
SD	Standard deviation
SOD	Superoxidase
TAC	Total antioxidant capacity

TAS	Total antioxidant status
TBARS	Thiobarbituric acid reactive substances
TGF-β	Transforming growth factor-beta
TLRs	Toll-like receptors
TNF-α	Tumour necrosis factor-alpha
TRAP	Tartrate-resistance acid phosphate
VO_{2max}	Maximum oxygen consumption
WAC	Wingate anaerobic capacity
WBC	White blood cell
WHO	World Health Organisation

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KESAN INTENSITI SENAMAN YANG BERBEZA TERHADAP TINDAK BALAS IMUN, PENANDA METABOLISME TULANG, STATUS ANTIOKSIDAN DAN PARAMETER FISIOLOGI TERPILIH DALAM KALANGAN DEWASA TIDAK AKTIF SECARA FIZIKAL

ABSTRAK

Latihan berselang berintensiti tinggi (HIIT) dan latihan berterusan berintensiti sederhana (MICT) telah terbukti dapat meningkatkan kecergasan dan kesihatan umum individu yang sihat. Walau bagaimanapun, setakat ini, kajian mengenai kesan HIIT dan MICT terhadap tindak balas imun, penanda metabolisme tulang, dan status antioksidan dalam kalangan dewasa yang tidak aktif secara fizikal masih terhad. Oleh itu, kajian ini dijalankan. Tiga puluh enam orang lelaki dan perempuan dewasa yang tidak aktif secara fizikal, berumur 18-35 tahun telah direkrut dan dibahagikan secara rawak kepada kumpulan HIIT, MICT atau kawalan dengan 12 peserta dalam setiap kumpulan (n=12). Peserta dalam kumpulan HIIT melakukan 2 set larian 6-8 ulangan pada 85-95% HR_{max} di atas treadmill bermotor selama 30 saat, 3 kali seminggu selama 8 minggu. Peserta dalam kumpulan MICT melakukan larian selama 30 minit di atas treadmill bermotor pada 55-70% HR_{max} 3 kali seminggu selama 8 minggu. Peserta dalam kumpulan kawalan tidak melakukan sebarang latihan senaman sepanjang tempoh intervensi. Ukuran antropometrik, penggunaan oksigen maksimum (VO_{2max}), kapasiti anaerobik Wingate, kekuatan dan kuasa otot isokinetik, sampel darah (untuk analisis kiraan darah keseluruhan, kalsium, fosfatase alkali, osteokalsin, telopeptida terminal karboksil kolagen jenis-1 dan status total antioksidan) dan sampel air liur (untuk analisis kadar aliran air liur dan kepekatan serta kadar rembesan lysozyme air liur) diambil sebelum dan selepas 8 minggu intervensi latihan. Keputusan

menunjukkan bahawa kedua-dua HIIT dan MICT meningkatkan kepekatan lysozyme air liur dan kuasa purata extensi lutut dominan ada $300^{o}.s^{-1}$ berbanding pengukuran awal secara signifikan ($p<0.05$), walaupun tiada perbezaan signifikan diperhatikan antara kumpulan ($p>0.05$). VO_{2max} meningkat dengan ketara dalam kumpulan HIIT ($p<0.05$), manakala jumlah kiraan monosit dan kepekatan ALP serum adalah lebih tinggi dalam kumpulan MICT berbanding dengan kawalan selepas intervasi ($p<0.05$). Pengurangan yang signifikan dalam kuasa anaerobik dan puncak diperhatikan dalam kedua-dua kumpulan pada ujian pasca berbanding dengan pengukuran awal ($p<0.05$). Tiada perbezaan signifikan di antara kumpulan dan masa ditemui dalam parameter pengukuran yang lain. Kesimpulannya, kedua-dua HIIT dan MICT meningkatkan penanda tindak balas imun tertentu dan kuasa otot isokinetik dalam kalangan dewasa yang tidak aktif secara fizikal. Walau bagaimanapun, HIIT menunjukkan peningkatan yang unggul dalam kecergasan kardiovaskular dan MICT lebih baik dalam meningkatkan penanda metabolism tulang. Penemuan ini mencadangkan bahawa pengamal harus mempertimbangkan untuk memasukkan HIIT ke dalam rejimen senaman sebagai alternatif yang menjimatkan masa yang boleh menarik mereka yang mempunyai kekangan masa untuk bersenam sambil memberikan manfaat kesihatan yang berkesan.

EFFECTS OF DIFFERENT TYPES OF EXERCISE INTENSITIES ON IMMUNE RESPONSES, BONE METABOLISM MARKERS, ANTIOXIDANT STATUS AND SELECTED PHYSIOLOGICAL PARAMETERS IN PHYSICALLY INACTIVE ADULTS

ABSTRACT

High-intensity interval training (HIIT) and moderate-intensity continuous training (MICT) was proven to enhance general fitness and health in healthy individuals. However, to date, studies on the effects of HIIT and MICT on immune responses, bone metabolism markers and antioxidant status in physically inactive adults are still limited. Therefore, the study was carried out. Thirty-six physically inactive male and female adults, aged 18-35 years were recruited and randomly assigned to HIIT, MICT or control groups with 12 participants per group (n=12). Participants in the HIIT group performed 2 sets of 6-8 repetitions of running at 85-95% of HR_{max} on a motorised treadmill for 30 seconds, 3 times per week for 8 weeks. Participants in the MICT group performed 30 min of running on a motorised treadmill at 55-70% of HR_{max}, 3 times per week for 8 weeks. Participants in the control group did not engage in any exercise training throughout the intervention period. Anthropometric measurements, maximum oxygen consumption (VO_{2max}), Wingate anaerobic capacity, isokinetic muscular strength and power, blood (for the analysis of whole blood count, calcium, alkaline phosphatase, osteocalcin, carboxy-terminal telopeptide of type-1 collagen and total antioxidant status) and saliva samples (for analysis of saliva flow rate and salivary lysozyme concentration and secretion rate) were taken prior to and following 8 weeks of training intervention. Results indicated that both HIIT and MICT significantly increased salivary lysozyme concentration and dominant knee extension average power at $300^{o}.s^{-1}$ compared to pre-test measurement ($p<0.05$), though no significant differences were observed between groups ($p>0.05$). VO_{2max} improved significantly in the HIIT group ($p<0.05$), whereas total monocyte count and serum ALP concentration were significantly higher in the MICT group compared to controls post-intervention ($p<0.05$). A significant reduction in anaerobic and peak power were noted in both groups at post-test compared to pre-test measurements ($p<0.05$). No significant differences across groups and time were found in the other measure parameters. In conclusion, both HIIT and MICT enhance specific immune response markers and isokinetic muscular power in physically inactive adults. However, HIIT demonstrated superior improvements in cardiovascular fitness and MICT was better at enhancing bone metabolism marker. These findings suggest that practitioners should consider incorporating HIIT into exercise regimens as a time-efficient alternative that may appeal to those with perceived time constrains for exercise while providing effective health benefits.

CHAPTER 1

INTRODUCTION

1.1 Background

Physical inactivity, defined as a state that does not meet the minimum physical activity guidelines (Thivel et al., 2018). It is a significant global health concern with detrimental effects on individual well-being and public health. Research has consistently linked physical inactivity to obesity, non-communicable diseases, and increased mortality rates (Amine et al., 2003; Katzmarzyk et al., 2022).

According to the World Health Organisation (WHO), non-communicable diseases (NCDs) are responsible for a staggering 38 million deaths annually, and physical inactivity is a primary risk factor. In 2019, WHO ranked physical inactivity as the fourth leading risk factor for global mortality (World Health Organization, 2020). Data from the "Global levels of physical inactivity in adults: off track to 2030" revealed that a concerning 31.0% of adults were insufficiently physically active (World Health Organization, 2024). More recent data from the National Institute of Health (NIH)/ Ministry of Health Malaysia, (2024) in Malaysia paints a similarly alarming picture, showing that 1 in 3 adults in Malaysia are physically inactive. These statistics underscore the urgent need to address physical inactivity as a pressing health issue in Malaysia and globally.

Regular participation in physical activity offers a myriad of health benefits, ranging from improved physical fitness to reduced risk of chronic diseases. Research has consistently demonstrated the positive impact of physical activity on overall health and well-being. Studies have shown that physical activity is associated with a lower risk of chronic diseases, including cardiovascular disease, hypertension, type 2 diabetes, allergies, and obesity (Anderson & Durstine, 2019; Winzer et al., 2018). The WHO recommends that adults aged 18-64 engage at least 150-300 minutes of moderate-intensity aerobic physical activity per week or 75-150 minutes of vigorous-intensity aerobic physical activity per week, or an equivalent combination of both, to reap substantial health benefits (World Health Organization, 2020).

Maintaining physical fitness and overall health is paramount, and various exercise programmes have been proposed to achieve this goal. Traditionally, aerobic or endurance training, often referred to as moderate-intensity continuous training (MICT), has been the cornerstone of exercise recommendations from health (Riebe et al., 2018). MICT typically involves 30-60 minutes of sustained activity at moderate intensity (64-76% of peak heart rate) and has demonstrated numerous health benefits, including improved cardiorespiratory fitness, immune function, bone health, antioxidant status and other health related markers (Abd El-Kader & Al-Shreef, 2018; Khammassi et al., 2020; McClean et al., 2011; Quaney et al., 2009; Wilmore, 2003). In recent years, high-intensity interval training (HIIT) has gained significant popularity as a potential alternative to MICT for fitness and health improvement (Cassidy et al., 2017; Dolci et al., 2020; Garciá-Pinillos et al., 2017; Martin-Smith et al., 2020b; Viana et al., 2019). HIIT involves alternating short bursts of intense activity and brief recovery periods, typically lasting less than 30 minutes in total (Buchheit & Laursen, 2013b).

HIIT has rapidly popularity due to its efficiency and effectiveness in improving overall health and fitness. Initially conceived as a training method for athletes, HIIT has since expanded its reach to diverse population, including individual with chronic conditions and sedentary older adults. Research has consistently demonstrated the benefits of HIIT in improving health outcomes for those with chronic diseases. For instance, Sawyer et al. (2020) found that HIIT significantly enhance cardiorespiratory fitness and exercise capacity in patients with Chronic Obstructive Pulmonary Disease (COPD), rivalling traditional continuous exercise. Similarly, Wormgoor et al. (2017) proposed HIIT as a therapeutic approach for individuals with Type 2 Diabetes, highlighting its potential to improve metabolic health. Grace et al. (2018) further emphasised the safety and effectiveness of HIIT as an exercise prescription for sedentary older adults, promoting cardiovascular function and metabolic capacity. This is particularly significant as sedentary aging increases the risk of various chronic diseases.

Beyond its general health benefits, HIIT has also emerged as a valuable tool for athletes seeking to enhance their performance. Several studies consistently shown that HIIT can significantly boost endurance and power output in athletes (Dolci et al., 2020; Garciá-Pinillos et al., 2017; Mallol et al., 2019; Rafael et al., 2020). Mallol et al. (2019) demonstrated its effectiveness in improving endurance performance of triathletes, while Rafeal et al. (2020) found that HIIT led to improvements in both aerobic and anaerobic performances in amateur athletes. In a comparative study by Ní Chéilleachair et al. (2017), HIIT was found to be superior to traditional long slow distance (LSD) training in trained rowers. The study revealed that HIIT produced greater gains in aerobic power and endurance performance, suggesting its potential as a superior training method for athlete seeking to optimise their efficiency and power output.

While numerous studies have explored the individual benefits of MICT and HIIT on health status, limited research has directly compared their effects on immune responses, bone metabolism markers, antioxidant status and selected physiological parameters between HIIT and MICT in physically inactive adults. Therefore, further research was conducted to investigate the effects of these two training methods on these aspects to determine their effectiveness in improving health outcomes among physically inactive adults.

The anticipated findings from this study could provide valuable insights for practitioners and individuals seeking effective exercise routines. It is hypothesized that HIIT may yield comparable improvements to MICT in immune responses, bone metabolism markers, antioxidant status, and selected physiological parameters among physically inactive adults. This research aims to contribute valuable information that could support the adoption of HIIT as a feasible and time-efficient exercise option for individuals facing prolonged endurance exercise contrains.

1.2 Problem statement

Despite the established benefits of both MICT and HIIT for improving physical fitness and health outcomes, there is a notable gap in research directly comparing their effects on immune responses, bone metabolism markers, antioxidant status, and selected physiological parameters in physically inactive adults. This lack of comparative analysis limits the understanding of which training method may be more effective for enhancing overall health in this demographic, particularly as both methods have shown promise in various populations, including those with chronic conditions and athletes. Consequently, further investigation is necessary to elucidate the relative advantages of HIIT versus MICT in promoting health outcomes among physically inactive adults.

1.3 Research questions

1. What are the comparative effects of MICT and HIIT on immune responses in physically inactive adults?

2. How do MICT and HIIT influence bone metabolism markers in physically inactive adults?

3. What impact do MICT and HIIT have on antioxidant status among physically inactive adults?

4. How do MICT and HIIT affect selected physiological parameters in physically inactive adults?

1.4 Objective of the study

1.4.1 General objective

To investigate the effects of different types of exercise intensities on immune responses, bone metabolism markers, antioxidant status and selected physiological parameters in physically inactive adult following 8 weeks of the intervention period.

1.4.2 Specific objectives

1. To compare the effects of HIIT and MICT on immune responses (Total white blood cell (WBC) count, T lymphocytes ($CD3^+$, $CD4^+$, $CD8^+$) counts, B lymphocyte count, natural killer (NK) cells count, saliva flow rate,

salivary lysozyme concentration and salivary lysozyme secretion rate) in physically inactive adults following 8 weeks of the intervention period.

2. To compare the effects of HIIT and MICT on bone metabolism markers (serum total calcium, osteocalcin, alkaline phosphatase, carboxy-terminal telopeptide of type 1 collagen (1CTP)) in physically inactive adults following 8 weeks of the intervention period.
3. To compare the effects of HIIT and MICT on antioxidant status (serum total antioxidant status (TAS)) in physically inactive adults following 8 weeks of the intervention period.
4. To compare the effects of HIIT and MICT on selected physiological parameters (Maximum oxygen consumption (VO_{2max}), Wingate anaerobic capacity, isokinetic muscular strength and power) in physically inactive adults following 8 weeks of the intervention period.

1.5 Hypotheses

HA1a: There are significant interactions between group and time on immune response after 8 weeks of training intervention in physically inactive adults.

HA1b: There are significant differences between HIIT and MICT on immune responses after 8 weeks of training intervention in physically inactive adults.

HA2a: There are significant interactions between group and time on bone metabolism markers after 8 weeks of training intervention in physically inactive adults.

HA2b: There are significant differences between HIIT and MICT on bone metabolism markers after 8 weeks of training intervention in physically inactive adults.

HA3a: There are significant interactions between group and time on antioxidant status after 8 weeks of training intervention in physically inactive adults.

HA3b: There are significant differences between HIIT and MICT on antioxidant status after 8 weeks of training interventions in physically inactive adults.

HA4a: There are significant interactions between group and time on selected physiological parameters after 8 weeks of training intervention in physically inactive adults.

HA4b: There are significant differences between HIIT and MICT on selected physiological parameters after 8 weeks of training interventions in physically inactive adults.

1.6 Significance of the study

The current study investigates the impact of HIIT and MICT on immune responses, bone metabolism markers, antioxidant status, and selected physiological parameters in physically inactive adult males. This research holds great significance due to several reasons.

Firstly, physical inactivity is a growing problem worldwide, contributing to various health concerns such as obesity, cardiovascular diseases, and premature death. Understanding how different forms of exercise affect key health metrics will help develop strategies to combat these issues effectively. By comparing HIIT and MICT, researchers aim to identify the most beneficial form of exercise for promoting better health outcomes.

Secondly, while both HIIT and MICT have proven health benefits, little is known about their comparative impacts on immune responses, bone metabolism markers, antioxidant status, and physiological parameters. This knowledge gap hinders the development of optimal exercise regimens tailored to individual needs. Filling this void through rigorous scientific investigation will enable healthcare providers to make informed decisions regarding patient care.

Thirdly, HIIT has recently garnered attention due to its potential advantages over traditional exercise modalities. Its shorter duration makes it appealing to those with busy schedules, yet its effectiveness remains uncertain when compared to MICT. Conducting a controlled experiment will shed light on whether HIIT indeed delivers equal or superior health benefits relative to MICT. Such information will guide future public health initiatives aimed at increasing physical activity levels.

Overall, the significance of this study lies in its potential to advance our understanding of the relationship between exercise modality and health outcomes. By providing clear guidance on what constitutes an ideal workout regime, this research stands to benefit society at large by encouraging greater physical activity and thereby improving overall health.

1.7 Operational definitions

Table 1.1 Operational definitions

Term	Definition
High-intensity interval training (HIIT)	HIIT is a fitness regimen characterised by alternating short bursts of intense activity and brief recovery periods, typically lasting less than 30 minutes in total. In the present study, HIIT intervention consists of 2 sets of 6-8 repetitions 30 seconds of running at 85-95% of estimated maximum heart rate (HR_{max}) on motorised treadmill, 3 times per week for 8 weeks (Coates et al., 2023).

Table 1.1 Continued

Term	Definition
Moderate-intensity continuous training (MICT)	MICT is a form of aerobic exercise characterised by maintaining a steady, moderate effort over an extended period. This training method typically involves exercising at 64-76% of an individual's peak heart rate for durations ranging from 30 to 60 minutes. In the present study, MICT intervention consists of 1 set of 30 minutes of running at 55-70% of estimated HR_{max} on motorized treadmill, 3 times per week for 8 weeks (Riebe et al., 2018).
Immune response	Immune response is the body's defense mechanism against harmful pathogens which involves a complex network of cells, tissues, and organs working together to recognize and eliminate these threats. The immune response is typically divided into innate and adaptive immune response. In this study, immune responses were measured by total white blood cell (WBC) count, T lymphocytes ($CD3^+$, $CD4^+$, $CD8^+$) counts, B lymphocyte count, natural killer (NK) cells count, saliva flow rate, salivary lysozyme concentration and secretion rate (Nicholson, 2016).
Bone metabolism markers	Bone metabolism markers also known as bone turnover markers, are biochemical indicators used to assess the dynamic processes of bone formation and resorption. These markers provide insights into the activity of osteoblasts (cells responsible for bone formation) and osteoclast (cells responsible for bone resorption), reflecting the overall metabolic status of bone tissue. In the present study, bone metabolism markers were measured by bone formation (serum total calcium, serum osteocalcin, serum alkaline phosphatase) and bone resorption markers (serum carboxy-terminal telopeptide of type 1 collagen (1CTP)) (Ooi & Sahrir, 2018).
Antioxidant status	Antioxidant status refers to the balance between antioxidants and reactive species, primarily reactive oxygen species (ROS) and reactive nitrogen species (RNS). Marker of antioxidant status which is measured in the present study was the serum total antioxidant status (TAS) (Gulcin, 2020).
Physiological capacities	Physiological capacities refer to the ability of body to perform physical tasks and functions effectively. Physiological parameters which are measured in the present study were the maximum oxygen consumption (VO_{2max}), Wingate anaerobic capacity, isokinetic muscular strength and power (Wells & Norris, 2009).
Physically inactive	Adults who are categorised as category 1 (<600 MET-min/week) assessed through International physical activity questionnaire-short form (IPAQ-SF) (Thivel et al., 2018).

CHAPTER 2

LITERATURE REVIEW

2.1 High-intensity interval training

High-intensity interval training (HIIT), also referred to as high-intensity interval exercise (HIIE), has gained significant attention in the fitness community and academic research for its effectiveness in improving various health and fitness outcomes. This training method is characterised by short burst of high-intensity activity, typically performed at 77-90% of maximal heart rate (HR_{max}), interspersed with short duration of active or passive rest interval (Coates et al., 2023). HIIT can be categorised into two primary types: “aerobic HIIT” and “body weight/resistance HIIT” or “resistance HIIT”. Each type utilizes high-intensity activities but differs in exercise modality.

Aerobic HIIT typically incorporates activities like running or cycling. This form workouts may include structured sessions such as track-based running or spin classes, where participants alternate between high-intensity sprints and recovery periods. In contrast, resistance/body weight HIIT makes use of calisthenics, plyometrics and loaded lifts in training programmes such as Cross-Fit, Tabata, boot camp training, or other similar classes. Although both types of HIIT programmed are widely used and research indicates the effectiveness of body weight-type HIIT programming (McRae et al., 2012), most research has focused on HIIT that primarily is aerobic because cycling and treadmill running enable more accurate assessment of work to describe the training stimulus.

One of the most compelling advantages of HIIT is its time efficiency. Traditional exercise regimens often require longer durations to achieve similar health benefits (Corte de Araujo et al., 2012). In contrast, HIIT can deliver comparable results in approximately half the time. This aspect is particularly appealing in today's fast-paced society where time constraints often hinder regular exercise participation.

2.1.1 The safety of high-intensity interval training in physically inactive individuals

The application of HIIT has garnered significant attention due to its effectiveness in improving various health outcomes across diverse populations. However, the intensity of HIIT raises questions about its safety, especially for those who are physically inactive.

One of the primary concerns regarding HIIT in inactive individuals is the potential for cardiovascular events. Studies indicate that individuals with sedentary lifestyle may have underlying cardiovascular issues that could be exacerbated by high-intensity exercise. For example, a study by Ramírez-Vélez et al. (2016) highlights that while HIIT can improve cardiovascular health, it also poses risks for those with pre-existing conditions, such as hypertension or coronary artery disease. Therefore, proper screening and assessment are crucial before initiating HIIT programmes.

In addition to cardiovascular risk, musculoskeletal injuries are a significant concern when implementing HIIT in physically inactive individuals. The abrupt transition from a sedentary lifestyle to high-intensity exercise can lead to injuries such as strains and sprains. For instance, a systematic review by Knapik, (2022) found that injury incidences during high-intensity activities are comparable to those in similar sports and exercise programmes, with shoulders, backs, and knees being the most frequently injured areas. Gradual progression and tailored exercise prescriptions are essential to mitigate these risks.

Despite these concerns, evidence suggests that with appropriate modifications and supervision, HIIT can be safely implemented in physically inactive individuals. A study by Gibala et al. (2014) demonstrated that even short bouts of HIIT could be beneficial without compromising safety when participants were gradually acclimatised to higher intensities. Furthermore, a randomised controlled trial by Farland, (2014) indicated that supervised HIIT sessions led to significant improvements in fitness levels without an increase in diverse events among previously sedentary adults.

To ensure the safe implementation of HIIT among physically inactive individuals, several recommendations can be made. Firstly, conducting thorough pre-exercise screening is essential to identify any underlying health issues that may pose risks during HIIT sessions. This process typically includes assessing medical history, current health conditions, and any previous injuries. For individuals with existing health concerns, such as cardiovascular disease or diabetes, it may be necessary to obtain medical clearance before beginning an exercise programme. Research has indicated that high-intensity exercise can increase the risk of acute cardiovascular events, particularly in those who have been sedentary for extended periods (Francois & Little, 2015; Wewege et al., 2018). Therefore, implementing a comprehensive screening protocol helps ensure that participants are fit to engage in vigorous exercise.

Secondly, starting with lower intensity and gradually increasing both the intensity and duration of intervals is crucial for safety introducing HIIT to inactive individuals. This approach allows participants to build a foundational level of fitness before progressing to more challenging workouts. Gradual progressing helps prevent injury and reduces the likelihood of overwhelming participants, which can lead to dropout from the programme (Hough, 2021). By allowing individuals to adapt physically and phychologically, they are more likely to sustain their engagement with HIIT over time.

Thirdly, implementing supervised sessions led by qualified professionals is vital for ensuring safety during HIIT workouts. Trained instructors can provide guidance on proper techniques, monitor participants' responses to exercise, and modify exercises as needed based on individual capabilities. Research shows that supervised training environments not only enhance safety but also improve adherence to exercise programme among previously inactive individuals (Coates et al., 2023; Dunston & Taylor, 2023).

In conclusion, the safety of HIIT in physically inactive individuals is a multifaceted issue that requires careful consideration and planning. While there are inherent risks associated with high-intensity exercise, evidence supports the notion that HIIT can be safely integrated into the routines of inactive individuals when appropriate precautions are taken. By focusing on individualised assessments, gradual progression, and professional supervision, the benefits of HIIT can be harnessed while minimising potential risks.

Table 2.1 Summary of high-intensity interval training, including its types and safety considerations for physically inactive individuals

Aspect	**Details**
Definition	• Short bursts of high-intensity activity (77-90% HR_{max}) interspersed with rest (active/passive).
Types of HIIT	• **Aerobic HIIT:** Running, cycling, track sprints, spin classes. • **Resistance/Bodyweight HIIT:** Calisthenics, plyometrics, loaded lifts (e.g., CrossFit, Tabata). Most research focuses on aerobic HIIT due to easier workload measurement.
Key advantage	• Time-efficient: comparable health benefits to traditional exercise but in roughly half the time.

Table 2.1 Continued

Aspect	Details
Safety in physically inactive individuals	
Risks	• Cardiovascular events risk especially in those with pre-existing conditions; musculoskeletal injuries (strains, sprains). Common injury sites—shoulders, back, knees.
Screening recommendations	• Thorough pre-exercise screening and medical clearance essential before starting HIIT.
Progression guidelines	• Start with low intensity/duration; gradually increase workload to build fitness and prevent injury.
Supervision importance	• Qualified professional-led sessions improve technique, safety, adherence, and individualized adjustments.
Summary	• HIIT offers efficient improvements in cardiovascular, metabolic, and muscular health. With proper screening, gradual progression, and supervision, HIIT can be safely implemented even in physically inactive individuals, maximizing benefits while minimizing risks.

2.2 Moderate-intensity continuous training

Moderate-intensity continuous training (MICT) is a form of exercise characterised by sustained periods of aerobic activity performed at a consistent moderate intensity. This type of training is widely recognised for its health benefits and is often compared to HIIT in terms of effectiveness and participant adherence.

MICT typically involves activities such as jogging, cycling, swimming, or rowing, performed at intensities that are moderate relative to an individual's maximum capacity. For instance, moderate intensity is often defined as 60-65% of an individual's VO_{2max} or 70-75% of their HR_{max} for durations of 30 to 50 minutes (Maturana et al., 2021). This level intensity is sufficient to elevate heart rate and breathing rate, yet still allows for conversation, albeit with some difficulty.

While HIIT is known for its time efficiency and higher enjoyment levels due to its varied and intense nature (Thum et al., 2017a), MICT offers a more consistent and potentially less strenuous alternative. Studies have shown that both HIIT and MICT can lead to similar improvements in body composition and cardiorespiratory fitness, although HIIT may elicit greater enjoyment among participants (Guo et al., 2023b; Thum et al., 2017a). However, a systematic review found no significant differences in quality of life or mental health outcomes between HIIT and MICT for patients with cardiovascular diseases (Yu et al., 2023a).

Adherence to exercise programmes is influenced by factors such as enjoyment, perceived exertion, and time efficiency. While HIIT is often preferred for its novelty and efficiency, MICT can offer a more sustainable ann comfortable option for those who prefer a consistent pace (Thum et al., 2017b; Vella et al., 2017). In overweight and obese adults, both HIIT and MICT have been found to elicit similar levels of enjoyment and adherence, suggesting that individual preferences play a significant role in choosing between these training methods (Vella et al., 2017).

In conclusion, MICT is a valuable form of exercise that offers substantial health benefits and can be tailored to suit various fitness levels and preferences. Its consistent nature makes it an attractive option for those seeking a more predictable and sustainable exercise routine. While it may not offer the same level of enjoyment as HIIT for some, MICT remains a critical component of a balanced exercise regimen.

2.2.1 The beneficial effects of moderate-intensity continuous training on health indicators

MICT is a widely recognised form of exercise that offers numerous health benefits, particularly in improving body composition, enhancing metabolic health, and boosting cardiovascular fitness. MICT has been shown to effectively reduce body mass

(BM) and fat mass (FM) in individuals with obesity. A study involving adolescents with obesity found that both MICT and combined training significantly reduced BM and FM, although MICT was more effective in reducing BM (D'Alleva et al., 2023). Similarly, a systematic review highlighted that MICT, alongside HIIT, can improve body composition by reducing fat mass and body mass index (BMI) (Guo et al., 2023a).

In addition, MICT contributes to improved metabolic health by enhancing insulin sensitivity and reducing blood pressure. For instance, a study on moderate-intensity exercise demonstrated a decline in body fat and improved glycemic response, which are crucial for metabolic health (Syeda et al., 2023). Additionally, regular physical activity, including MICT, has been linked to a reduced risk of developing type 2 DM and other metabolic disorders (DiPietro et al., 2019). MICT is beneficial for improving cardiovascular fitness and autonomic function. A study involving sedentary middle-aged men showed that MICT increased oxygen uptake and improved flow-mediated dilation (FMD), a marker of endothelial function (Collins et al., 2023).

Furthermore, MICT has been associated with impairments in heart rate variability, indicating enhanced autonomic modulation (Collins et al., 2023). Beyond physical fitness, MICT also offers psychological and cognitive advantages. Regular engagement in moderate-intensity exercise can reduce symptoms of anxiety and improve cognitive function (DiPietro et al., 2019). These benefits contribute to an overall improvement in quality of life and perceived well-being.

In conclusion, MICT offers a comprehensive array of health benefits, from improving body composition and metabolic health to enhancing cardiovascular fitness and psychological well-being. Its accessibility and adaptability make it an ideal choice for individuals seeking to incorporate regular activity into their lifestyle. As supported by the literature, MICT is a valuable component of a healthy lifestyle, contributing to both immediate and long-term health improvements (D'Alleva et al., 2023; DiPietro et al., 2019; Guo et al., 2023b; Syeda et al., 2023).

Table 2.2 Summary of moderate-intensity continuous training's characteristics, benefits, comparisons with HIIT, and practical implications

Aspect	MICT
Definition & characteristics	• Sustained aerobic activity at moderate intensity (60-65% VO_{2max} or 70-75% HR_{max}), lasting 30-50 minutes; activities include jogging, cycling, swimming, rowing.
Comparison with HIIT	• Similar improvements in body composition and cardiorespiratory fitness; MICT offers a consistent, less strenuous exercise alternative with comparable adherence; HIIT may offer higher enjoyment for some.
Exercise adherence & enjoyment	• MICT provides a more sustainable and comfortable pace preferred by some; both HIIT and MICT show similar adherence levels in overweight/obese adults, influenced by individual preferences.
Body composition effects	• Effectively reduces body mass (BM) and fat mass (FM), especially in individuals with obesity; may be more effective than combined training at reducing BM in adolescents.
Metabolic health benefits	• Enhances insulin sensitivity, improves glycemic response, reduces blood pressure; linked to decreased risk of type 2 diabetes and metabolic disorders.
Cardiovascular fitness	• Improves oxygen uptake, endothelial function (flow-mediated dilation), and autonomic modulation (heart rate variability).
Psychological & cognitive benefits	• Reduces symptoms of anxiety and enhances cognitive function; contributes to improved quality of life and well-being.
Practical considerations	• Adaptable to various fitness levels and preferences; supports predictable and sustainable exercise routines.

2.3 Immune response

The immune response is a highly intricate and coordinated defense mechanism that can be broadly categorised into two primary systems: the innate immune system and the adaptive (specific) immune system. Each of these systems plays a crucial role in protecting the body from pathogens, employing distinct strategies and components to achieve their respective functions.

2.3.1 Innate immune response

The innate immune system serves as the body's first line of defense against invading pathogens. It comprises physical barriers, such as the skin and mucosa membranes, as well as chemical barriers like gastric acid and antimicrobial peptides. These components work together to prevent pathogen entry and establish an immediate response upon infection (Kaur & Secord, 2021). For instance, the skin acts as a formidable barrier, while mucosal surfaces in the respiratory and gastrointestinal tracts provide additional protection through mucus secretion and ciliary action (Chaplin, 2010).

Once a pathogen breaches these barriers, the innate immune system activates through various mechanisms (Iwasaki & Medzhitov, 2015). Phagocytic cells, such as macrophages and neutrophils, play a pivotal role in recognising and engulfing pathogens. They identify pathogens by recognising specific molecular patterns known as pathogen-associated molecular patterns (PAMPs) using receptors like Toll-like receptors (TLRs). Upon recognition, macrophages initiate phagocytosis, encapsulating the pathogen in a phagosome that subsequently fuses with lysosomes to degrade the pathogen (Chaplin, 2010; Janeway et al., 2001).

In addition to direct phagocytosis, the innate immune response involves the release of cytokines, which are signalling molecules that orchestrate inflammation and recruit additional immune cells to the site of infection (Iwasaki & Medzhitov, 2015). This inflammatory response is characterised by redness, heat, swelling, and pain, facilitating increased blood flow and permeability to allow immune cells to exit the bloodstream and enter affected tissues (Carrillo et al., 2017).

2.3.1(a) Monocytes and macrophages

Macrophages are essential components of the innate immune system, playing a pivotal role in immune response and tissue homeostasis (Gordon & Martinez-Pomares, 2017). They originate from monocyte, a type of white blood cell that circulates in the bloodstream. Upon encountering signals indicative of infection or tissue damage, monocyte migrate from the bloodstream into tissues, where they undergo a transformation into macrophages. This process is crucial for effective immune surveillance and response.

Monocytes are recruited to tissues primarily in response to inflammatory signals, such as cytokines and chemokines released during infection or injury. The migration is facilitated by the CCR2-CCL2 axis, which directs monocytes from the bone marrow to sites of inflammation (Dash et al., 2024). Once they arrive at the tissue, monocytes undergone significant morphological and functional changes over approximately eight hours. They enlarge considerably and begin to produce granules filled with enzymes and other substances essential for their phagocytic functions (Italiani & Boraschi, 2014). This transformation is not merely a physical change; it involves the acquisition of a unique functional phenotype influenced by the local microenvironment, leading to the classification of macrophages into distinct functional types, primarily M1 (pro-inflammatory) and M2 (anti-inflammatory) (Herb et al., 2024; Italiani & Boraschi, 2014).

One of the hallmark functions of macrophages is phagocytosis, the process by which they ingest pathogen, dead cells, and debris. This process is critical for initiating an immune response and involves several steps: recognition of pathogens, engulfment, and degradation within specialised compartments called phagosomes (Wu & Hirschi, 2021). The enzymes contained within the granules play a vital role in breaking down these foreign entities, thus contributing to pathogen clearance.

In addition to their phagocytic capabilities, macrophages secrete various signalling molecules that attract other immune cells to sites of infection. This recruitment amplifies the immune response and facilitates coordination among different cell types involved in combating infection (Mosser et al., 2021). Moreover, macrophages interact with T cells by presenting antigens, thereby bridging innate and adaptive immunity (Dash et al., 2024).

2.3.1(b) Neutrophils

Neutrophils constituting 60-70% of circulating leukocytes, are pivotal players in the immune response, acting as the first line defense against infections. These cells are characterised by their ability to phagocytose pathogens and release granules containing enzymes that facilitate the destruction of engulfed microorganisms (Rosales et al., 2016). The traditional view of neutrophil as mere effector cells has evolved significantly, revealing their multifaceted roles in both innate and adaptive immunity (Li et al., 2019).

Neutrophils are primarily recognised for their phagocytic capabilities, which involve the ingestion and degradation of bacteria and fungi. This process is complemented by degranulation, where neutrophils release antimicrobial substances from their granules, enhancing their ability to combat infections (Malech et al., 2020; Rosales, 2018). Furthermore, neutrophils can form neutrophil extracellular traps (NETs), web-like structures composed of DNA and antimicrobial proteins that ensnare and neutralise pathogens, thereby preventing their spread (Mantovani et al., 2011; Shafqat et al., 2023).

The recruitment of neutrophils to sites of infection is a highly regulated process known as chemotaxis. This process is initiated by signals from pathogens, damaged tissues, or complement proteins that attract neutrophils to the affected area (Li et al., 2019). Upon arrival, neutrophils engage in complex interactions with other immune cells, such as macrophages and dendritic cells, which not only enhances their antimicrobial functions but also helps in orchestrating the overall immune response (Mantovani et al., 2011; Rosales, 2018).

Recent studies have highlighted that neutrophils do not merely act as passive responders; they actively participate in shaping the immune landscape. They produce a variety of cytokines and chemokines, which modulate the activity of other immune cells and influence inflammation (Malech et al., 2020; Rosales, 2018). For instance, neutrophils can enhance T cell activation and promote antibody production by B cells, thereby bridging innate and adaptive immunity (Mantovani et al., 2011; Shafqat et al., 2023). This regulatory capacity positions neutrophils as critical modulators in both homeostatic conditions and pathological states, including chronic inflammation and cancer (Mantovani et al., 2011; Rosales, 2018).

Moreover, neutrophils can adopt different functional states depending on the microenvironment they encounter. This versatility allows them to respond effectively to various types of infections and inflammatory conditions (Malech et al., 2020;

Rosales, 2018). Their ability to adapt also raises interesting therapeutic possibilities, targeting specific neutrophil functions could provide new strategies for treating diseases characterised by dysregulated inflammation or immune responses.

2.3.1(c) Eosinophils

Eosinophils are a specialised subset of granulocytes that play multifaceted roles in the immune system, particularly in the defense against parasites and in modulating inflammatory responses (Ramirez et al., 2018; Wen & Rothenberg, 2016). While they can ingest bacteria, their primary functions extend beyond this capability, particularly concerning larger foreign entities such as parasites and cancer cells (Berek, 2016).

Eosinophils possess the ability to phagocytose bacteria, however their efficiency is notably lower than that of neutrophils and macrophages. Research indicates that eosinophils can ingest approximately 50% less Staphylococcus aureus than neutrophils, highlighting their reduced bactericidal capacity (Linch & Gold, 2011; Ondari et al., 2021). Although eosinophils can engage in phagocytosis, they primarily utilize alternative mechanisms to combat larger pathogens, such as helminths. This include the release of cytotoxic granules containing enzyme and proteins that can damage target cells by perforating their membranes, thereby facilitating the destruction of larger invaders (Huang & Appleton, 2016).

Upon encountering foreign cells, eosinophils degranulate, releasing a variety of toxic substances. These granules contain cationic proteins, including major basic protein (MBP) and eosinophil peroxidase (EPO), which are crucial for their cytotoxic effects against parasites (Gazzinelli-Guimaraes et al., 2024; Ondari et al., 2021). The mechanism involves not only direct lysis through membrane disruption but also the formation of extracellular traps, which consist of DNA and granule proteins that ensnare and kill pathogens (Gazzinelli-Guimaraes et al., 2024; Ondari et al., 2021). This dual approach (phagocytosis and degranulation) enables eosinophils to effectively target a range of pathogens, albeit with varying degrees of efficacy.

Eosinophils are particularly adept at combating parasitic infections. They have been shown to be effective against various helminths through mechanisms such as antibody-dependent cellular cytotoxic (ADCC) and the release of reactive oxygen species (ROS) during degranulation (Gazzinelli-Guimaraes et al., 2024; Huang & Appleton, 2016). Interestingly, while eosinophils are less efficient against bacteria compared to neutrophils, they still exhibit some bactericidal activity through the release of granule proteins that can bind to bacterial surfaces and induce cell death (Linch & Gold, 2011; Ondari et al., 2021).

Moreover, there is emerging evidence suggesting that eosinophils may also play a role in tumour surveillance and the destruction of cancer cells. Their presence has been correlated with better outcomes in certain cancers, possibly due to their ability to release cytotoxic factors that target malignant cells. This aspect underscores the evolving understanding of eosinophil functionality beyond traditional roles associated with allergies and parasitic infections.

2.3.1(d) Basophils

Basophils is a type of granulocyte, play a critical role in the immune response, particularly in allergic reactions and inflammation. Although they represent only a small fraction of circulating leukocytes, typically accounting for 0.5% to 1% of the total white blood cell count. They are essential mediators of the immune system’s response to allergens and other inflammatory stimuli (Shah et al., 2021).

Basophils contain large granules filled with histamine, a potent vasoactive amine that significantly influences vascular permeability and blood flow. Upon encountering allergens, basophils undergo a process known as degranulation, wherein they release histamine into the surrounding tissues. This release results in vasodilation, which increases blood flow to the affected area and contributes to the hallmark symptoms of allergic reactions, such as swelling and inflammation (Shah et al., 2021; Siracusa et al., 2013). Histamine acts on various tissues, leading to symptoms like itching, redness, and increased mucus production in respiratory pathways. These are the common manifestations during allergic responses.

The mechanism of histamine release is primarily mediated through high-affinity Immunoglobulin (IgE) receptors on the surface of basophils. When allergens cross-link these receptors by binding to IgE antibodies already attached to basophils, its triggers rapid degranulation and subsequent histamine release (Shah et al., 2021; Siracusa et al., 2013). This process is crucial not only for immediate hypersensitivity reactions but also for orchestrating more extensive immune responses by recruiting other immune cells to the site of inflammation.

In addition to histamine, basophils secrete various cytokines and chemokines that attract other leukocytes, such as eosinophils and neutrophils, to sites of inflammation (Shah et al., 2021). For instance, basophils are known to produce interleukin-4 (IL-4), a cytokine that enhances the differentiation of T lymphocyte (T cells) into T helper 2 (Th2) cells, which are pivotal in orchestrating allergic responses and promoting eosinophil recruitment (Shah et al., 2021; Siracusa et al., 2013). This interaction highlights the role of basophils not only as effector cells but also as regulatory cells within the immune system.