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Physiological and psychological responses to six weeks of high-intensity interval and moderate-intensity continuous training in physically inactive young adults

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PHYSIOLOGICAL AND PSYCHOLOGICAL RESPONSES TO SIX WEEKS OF HIGH-INTENSITY INTERVAL AND MODERATE-INTENSITY CONTINUOUS TRAINING IN PHYSICALLY INACTIVE YOUNG ADULTS

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Abstract

High-intensity interval training (HIIT) has been proposed as a public health strategy to promote physical activity; yet, there is limited evidence examining factors related to adherence to HIIT. **PURPOSE:** To determine the effect of six weeks of HIIT and moderate-intensity continuous training (MICT) on physiological and psychological responses to training. **METHODS:** Physically inactive young adults (n = 20; age = 21.4 ± 2.2 years) were randomized to the HIIT or MICT group. Assessments of body composition, cardiorespiratory fitness (CRF), moderate-to-vigorous physical activity (MVPA) and sedentary behavior levels were completed prior to and following the intervention. Participants completed 18 training sessions overall, with the first half of the intervention supervised and the latter half unsupervised. Within-session psychological variables were measured pre-, mid-, and post-training at each session. Across-session psychological variables were measured at the end of the first, ninth, and eighteenth training sessions. Differences were analyzed using 2 (group) x 2 (time) ANCOVAs for physiological variables, 2 (group) x 6 (time) ANCOVAs for within-session psychological variables, and 2 (group) x 3 (time) ANOVAs for across-session psychological variables. **RESULTS:** CRF ($\Delta = 2.8$ ml·kg^{-1}·min^{-1}; $p = 0.03$) and peak power output ($\Delta = 20.2$ watts; $p = 0.01$) improved across the intervention with no between group differences ($p > 0.05$). There were no main effects of time, group, or interaction for body composition, affect, in-task enjoyment, self-efficacy, MVPA, or sedentary behavior levels ($p > 0.05$ for all). Perceived competence increased from weeks one (4.7 ± 0.2) to three (5.4 ± 0.1; $p = 0.01$) with no differences at week six (5.2 ± 0.2; $p > 0.05$). There was no difference in post-exercise enjoyment from weeks one to three ($p = 0.07$), but it declined from weeks three to six (p = 0.003) with a significant time by group interaction (p = 0.02).

CONCLUSIONS: Over six weeks of training CRF improved comparably for HIIT and MICT; however, the overall time commitment for HIIT was substantially shorter. Further, the increase observed in perceived competence across supervised training suggests it may be important to provide individualized support at the beginning of a training program to promote adherence. Overall, there is no one-size fits all exercise modality; however, HIIT may be an enjoyable, time-efficient alternative to MICT.

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Chapter 1: Introduction

Engaging in physical activity has been shown to have a variety of benefits for physical and mental health (Penedo & Dahn, 2005; Warburton, Nicol, & Bredin, 2006). Specifically, physical activity has been associated with a decreased risk of cardiovascular disease (Paffenbarger, Blair, & Lee, 2001), obesity (Jakicic & Otto, 2005), and all-cause mortality (Löllgen, Bockenhoff, & Knapp, 2009). Yet, despite the extensive benefits of engaging in adequate amounts of physical activity, almost half of all U.S. adults are currently insufficiently active and do not meet physical activity guidelines of 150 minutes of moderate physical activity each week (Physical Activity Guidelines Advisory Committee, 2018). Therefore, it is important to develop public health strategies to increase adults' engagement in physical activity in the United States. High-intensity interval training (HIIT), which is defined as repeated bouts of vigorous intensity exercise seperated by periods of rest or active recovery (Weston, Wisløff, & Coombes, 2014), has been suggested as a public health strategy to increase physical activity levels due to the decreased time commitment (Biddle & Batterham, 2015; Gillen & Gibala, 2018). However, there is still debate in the literature about whether HIIT would be an effective public health strategy for increasing participation in physical activity in adults (Biddle & Batterham, 2015; Hardcastle, Ray, Beale, & Hagger, 2014).

Work by Gibala and colleagues has demonstrated that HIIT induces similar physiological adaptations to exercise when compared to traditional moderate-intensity continuous training (MICT), but with a smaller time commitment (Gibala, Little, MacDonald, & Hawley, 2012). Equal or greater improvements in cardiorespiratory fitness and cardiometabolic health have been demonstrated for HIIT when compared to

MICT (Burgomaster et al., 2008; Weston et al., 2014). Additionally, HIIT protocols can require as little as 20 minutes to complete (Gibala, Gillen, & Percival, 2014; Little et al., 2011), which is substantially shorter than traditional MICT, commonly 45 minutes or more in duration (Bartlett et al., 2011; Stork, Gibala & Martin Ginis, 2018). The time commitment of physical activity is an important consideration with regards to strategies to increase physical activity levels, particularly as the most common barrier to engaging in physical activity is a perceived lack of time (Trost, Owen, Bauman, Sallis, & Brown, 2002). Proponents of HIIT argue that a lower time commitment may help individuals overcome this often-cited barrier to physical activity, while still achieving similar physiological benefits and adaptations (Biddle & Batterham, 2015; Gillen & Gibala, 2018). Further, the intermittent nature of HIIT allows individuals to work at a higher intensity than would be sustainable during traditional continuous physical activity (Kessler, Sisson, & Short, 2012). Achieving higher intensities, even for short durations, may promote greater adaptations to exercise than would be attained at lower intensities (Gibala et al., 2012; Janssen & Ross, 2012; Kessler et al., 2012). Further, enjoyment tends to be equivalent or greater when participating in HIIT compared to MICT (Bartlett et al., 2011; Kilpatrick, Greeley, & Collins, 2015; Thum, Parsons, Whittle, & Astorino, 2017; Vella, Taylor, & Drummer, 2017). This is an important consideration as enjoyment has previously been positively associated with exercise behavior outcomes such as physical activity engagement and adherence (Dishman et al., 2005). Despite the smaller time commitment, physiological benefits, and greater enjoyment of HIIT, there is still concern that a negative emotional response (i.e., affect) and the challenging nature of

HIIT may result in low adoption and adherence in previously inactive individuals (Biddle & Batterham, 2015; Hardcastle et al., 2014).

Affect, an emotional response of pleasure/displeasure that occurs without much thought (Ekkekakis, Parfitt, & Petruzzello, 2011), tends to be lower during HIIT when compared to MICT (Decker & Ekkekakis, 2017; Jung, Bourne, & Little, 2014; Malik, Williams, Weston, & Barker, 2018). Opponents of HIIT argue that the negative visceral feeling individuals experience during the work intervals of HIIT may lead to low adherence, making it an ineffective public health strategy for increasing physical activity levels (Decker & Ekkekakis, 2017; Hardcastle et al., 2014). However, previous research by Jung et al. (2014) has shown that physically inactive adults tend to prefer HIIT despite a negative affective response. Further, no significant differences in adherence have been demonstrated between HIIT and MICT (Reljic, Wittmann, & Fischer, 2018; Vella et al., 2017) suggesting a negative affective response may not have a detrimental impact on exercise behavior with regards to HIIT.

Additionally, some researchers have argued that HIIT may be too strenuous and challenging for some populations (Hardcastle et al., 2014). However, it is important to consider the wide range of HIIT protocols that have been utilized at varying intensities in an array of different cohorts. One of the original HIIT protocols, developed by Rodas, Ventura, Cadefau, Cusso, and Parra (2000), involved repeated bouts of all-out cycling against a high resistance. This protocol was further developed into the Wingate HIIT model utilized by Burgomaster, Hughes and Heigenhauser (2005), which includes four to six repeated Wingate tests seperated by four minutes of passive rest. Recently, more practical modes of HIIT have been developed such as the 10x1 protocol utilized by Little et al. (2011), involving repeated bouts of cycling for one minute at approximately 90% of maximum heart rate interspersed with rest. These practical HIIT protocols are lower in intensity than the supramaximal Wingate model HIIT protocols and may be more suitable for the general population (Gibala et al., 2012). Moreover, Coquart et al. (2008) found ratings of perceived exertion were lower for interval training than MICT in obese women despite no differences in heart rate. This suggests interval training may feel less strenuous when compared to MICT even though HIIT is of equal or greater intensity (Coquart et al., 2008).

As more practical HIIT protocols are developed, it is important to investigate the physiological and psychological responses to HIIT in free-living conditions. The majority of HIIT research has been laboratory-based (Bartlett et al., 2011; Niven, Thow, Holroyd, Turner, & Phillips, 2018; Oliveria, Slama, Deslandes, Furtado, & Santos, 2013); however, recent research has started to investigate the physiological and psychological responses to HIIT in free-living conditions (Locke et al., 2018; Lunt et al., 2014; Roy et al., 2018; Stork et al., 2018). Research conducted in a laboratory setting allows for control of more confounding variables, but limits the ecological validity of the findings. Further, previous research indicates that adherence to physical activity increases in laboratory settings when supervised (Nugent et al., 2018), but that may not be the case in free-living conditions (Roy et al., 2018). To date, little research has been conducted on the effect of HIIT on physical activity behaviors (i.e., adherence to and engagement in physical activity in free-living situations; Locke et al., 2018; Roy et al., 2018; Stork et al., 2018). Further, the majority of research with regards to psychological responses to HIIT has investigated acute affect and enjoyment responses (Bartlett et al., 2011; Decker &

Ekkekakis, 2017; Jung et al., 2014; Kilpatrick et al., 2015; Thum et al., 2017), which is not generalizable over a prolonged period of training. Vella et al. (2017) looked at enjoyment of HIIT and MICT across eight weeks of training, which included five weeks of unsupervised training in free-living conditions. However, methodological limitations of this study limit the ability to make inferences about psychological responses to HIIT in both laboratory and free-living settings. Foster et al. (2015) and Heisz, Tejada, Paolucci, and Muir (2016) investigated psychological responses to HIIT over six and eight weeks of training in a supervised laboratory setting; however, their findings differ. Foster et al. (2015) found that enjoyment of HIIT and MICT decreased over eight weeks of training, while Heisz et al. (2016) found enjoyment of HIIT increased over six weeks of training compared to enjoyment of MICT, which remained relatively constant. Therefore, future research would be beneficial to understand the psychological responses to HIIT compared to MICT across a period of training in laboratory and free-living settings.

In addition, other psychological constructs such as perceived competence and self-efficacy may influence an individual's psychological response to HIIT as they have been associated with physical activity outcomes (Haslem, Wilkinson, Prusak, Christensen, & Pennington, 2016; Markland & Tobin, 2010). Further, perceived competence and self-efficacy are hypothesized to positively contribute to enjoyment of physical activity (Heisz et al., 2016), which may in turn increase adherence. Although, perceived competence has been positively associated with physical activity levels in adults (Fortier, Sweet, O'Sullivan, & Williams, 2007; Markland & Tobin, 2010), little research has investigated the role of perceived competence with regards to HIIT. In contrast, self-efficacy has been recently investigated with regards to HIIT. Findings from recent studies suggest that self-efficacy may increase over the duration of a HIIT training intervention (Locke et al., 2018) and play a role in adherence to HIIT interventions (Roy et al., 2018). Additionally, self-efficacy has been positively associated with enjoyment (Hu, Motl, McAuley, & Konopack, 2007) and positive affect (Kwan & Bryan, 2010). However, little research has investigated affect, enjoyment, perceived competence, and self-efficacy concurrently with regards to HIIT in comparison to MICT. Further, to date no research has extended this to HIIT and MICT in free-living conditions.

Problem Statement

The primary purpose of this study is to determine the effects of a six-week HIIT and MICT training intervention, that is comprised of three weeks of supervised training followed by three weeks of free-living training, on psychological constructs including affect, enjoyment, perceived competence, and self-efficacy in healthy, physically inactive young adults. Additionally, a secondary purpose is to explore the differences in physiological responses such as cardiorespiratory fitness, body composition, physical activity levels and sedentary behavior levels due to six weeks of HIIT and MICT training in healthy, physically inactive young adults.

Research Questions and Null Hypotheses

Psychological outcomes within a training session.

1. What is the effect of a six-week HIIT or MICT training intervention on affect across a training session in healthy, physically inactive young adults?
    a. There will be no significant difference in the change in affect scores within a training session over six weeks of training.

b. There will be no significant difference in the change in affect scores within a training session between HIIT and MICT.

c. There will be no significant interaction between time and condition on the change in affect scores within a training session between HIIT and MICT.

2. What is the effect of a six-week HIIT or MICT training intervention on enjoyment during exercise (i.e., in-task enjoyment) across a training session in healthy, physically inactive young adults?

   a. There will be no significant difference in the change in in-task enjoyment scores within a training session over six weeks of training.

   b. There will be no significant difference in the change in in-task enjoyment scores within a training session between HIIT and MICT.

   c. There will be no significant interaction between time and condition on the change in in-task enjoyment scores within a training session between HIIT and MICT.

Psychological outcomes across the training intervention.

3. What is the effect of a six-week HIIT or MICT training intervention on perceived competence in healthy, physically inactive young adults?

   a. There will be no significant difference in perceived competence before, during, or after six weeks of training.

   b. There will be no significant difference in perceived competence between HIIT and MICT.

   c. There will be no significant interaction between time and condition on perceived competence.

4. What is the effect of a six-week HIIT or MICT training intervention on self-efficacy in healthy, physically inactive young adults?
    a. There will be no significant difference in self-efficacy before, during, or after six weeks of training.
    b. There will be no significant difference in self-efficacy between HIIT and MICT.
    c. There will be no significant interaction between time and condition on self-efficacy.
5. What is the effect of a six-week HIIT or MICT training intervention on post-exercise enjoyment in healthy, physically inactive young adults?
    a. There will be no significant difference in post-exercise enjoyment before, during, or after six weeks of training.
    b. There will be no significant difference in post-exercise enjoyment between HIIT and MICT.
    c. There will be no significant interaction between time and training group on post-exercise enjoyment.

Physiological outcomes across the training intervention.

6. What is the effect of a six-week HIIT or MICT training intervention on peak oxygen consumption (VO_2peak) in healthy, physically inactive young adults?
    a. There will be no significant difference in VO_2peak following six weeks of training.
    b. There will be no significant difference in VO_2peak between HIIT and MICT.

c. There will be no significant interaction between time and condition on VO_2peak.

7. What is the effect of a six-week HIIT or MICT training intervention on body fat percentage in healthy, physically inactive young adults?
    a. There will be no significant difference in body fat percentage following six weeks of training.
    b. There will be no significant difference in body fat percentage between HIIT and MICT.
    c. There will be no significant interaction between time and condition on body fat percentage.
8. What is the effect of a six-week HIIT or MICT training intervention on moderate-to-vigorous physical activity levels in healthy, physically inactive young adults?
    a. There will be no significant difference in moderate-to-vigorous physical activity levels following six weeks of training.
    b. There will be no significant difference in moderate-to-vigorous physical activity levels between HIIT and MICT.
    c. There will be no significant interaction between time and condition on moderate-to-vigorous physical activity levels.
9. What is the effect of a six-week HIIT or MICT training intervention on sedentary behavior levels in healthy, physically inactive young adults?
    a. There will be no significant difference in sedentary behavior levels following six weeks of training.

b. There will be no significant difference in sedentary behavior levels between HIIT and MICT.

c. There will be no significant interaction between time and condition on sedentary behavior levels.

Independent and Dependent Variables

The independent variables in this study are condition (HIIT vs. MICT), and time across the training intervention (weeks 1-6). The physiological dependent variables include VO_2peak, body fat percentage, moderate-to-vigorous physical activity levels and sedentary behavior levels. The psychological dependent variables are affect, in-task enjoyment, post-exercise enjoyment, perceived competence, and self-efficacy.

Definitions

- Affect – Defined as a visceral response relating to pleasure and displeasure, affect is an emotional response that occurs instinctively without much thought. For the purposes of this study, affect will be operationally defined as the bipolar scale rating obtained from the Feeling Scale (Hardy & Rejeski, 1989).
- In-task enjoyment – A positive emotion, enjoyment, indicates satisfaction in engaging in a task, such as a bout of exercise. Participants will rate their enjoyment on a seven-point Likert scale during exercise using the single-item Exercise Enjoyment Scale (Stanley & Cumming, 2010).
- Post-exercise enjoyment– Enjoyment is an emotion which requires substantial cognition to sum one's feelings of an entire experience. The Physical Activity Enjoyment Scale (PACES) will be administered to participants following exercise

and will be scored by summing the Likert scale rating for all 18-items (Kendzierski & DeCarlo, 1991).

- Perceived competence – An individual's belief in their ability to be able to interact effectively with their environment to successfully complete a personally meaningful task is known as perceived competence. Participants will be asked to complete the 18-item Psychological Need Satisfaction in Exercise Scale following exercise. The score from the competence subscale will be utilized as a measure of perceived competence (Wilson, Rogers, Rodgers, & Wild, 2006).
- Self-efficacy – Defined as an individual's belief in the ability to perform a specific behavior, self-efficacy will be measured using a 5-item task self-efficacy scale adapted from Jung et al. (2014).
- Physically inactive – Individuals not meeting the American College of Sports Medicine's physical activity guidelines, which recommend engaging in at least 150 minutes of moderate or 75 minutes of vigorous physical activity per week (Physical Activity Guidelines Advisory Committee, 2018) are considered to be physically inactive. Participants will self-report their current activity level and will be considered physically inactive if they report less than 150 minutes of moderate physical activity per week over the previous three months.
- Physical activity – Physical activity is defined as any bodily movement produced by skeletal muscles that requires increased energy expenditure (Caspersen, Powell, & Christenson, 1985).

- Sedentary behavior – Any waking activity in a sitting or reclining posture which requires an energy expenditure of less than or equal to one and a half metabolic equivalents is considered to be a sedentary behavior (Tremblay et al., 2017).
- VO_2peak – VO_2peak is defined as the maximum volume of oxygen that an individual can take in and utilize effectively during high intensity exercise. This measurement is obtained from a maximal cardiorespiratory fitness test using a metabolic cart to measure expired gases.
- High-intensity interval training – An exercise bout involving short periods of vigorous intensity exercise to elicit a heart rate of about 90% of age-predicted maximum heart rate interspersed with active rest is considered to be HIIT. Participants in the HIIT group will be asked to cycle at 80% of peak power output for ten, 1-minute intervals interspersed with 1-minute of active rest intervals of cycling at 20% peak power output.
- Moderate-intensity continuous training – Traditional MICT involves exercising at a continuous intensity for a given duration. Participants randomly assigned to the MICT group will be asked to cycle at an intensity equivalent to 40% of their peak power output for 40 minutes.
- Free-living – In contrast to laboratory conditions, free-living conditions involve an unsupervised research setting in which participants continue to go about their usual day-to-day activities while data are being collected.

Assumptions

Although not inclusion criteria for the study, it is assumed participants do not have extensive (i.e., greater than six months) experience with HIIT. It is also assumed participants will honestly and accurately report pre-intervention physical activity. Additionally, it is assumed participants will respond to all surveys honestly and follow pre-test instructions prior to testing. Participants are expected to give their best effort during all testing and complete the free-living testing sessions in accordance with the instructions provided by the researchers. During the training intervention, it is assumed that participants will maintain their current habitual diet and sleep schedule.

Limitations and Delimitations

The results of this study will be limited in their generalizability to inactive, apparently healthy, young adults due to the specific sample used in this study. Additionally, the lack of a non-exercise control group is a limitation of this study; however, the benefits of physical activity have been well-documented (Löllgen et al., 2009; Penedo & Dahn, 2005; Warburton et al., 2006) and the purpose of this study is to investigate the differences between HIIT and traditional MICT. A delimitation of this study is the inclusion of free-living training for half of the training intervention, which limits the control over external sources of error but increases the ecological validity of this study. One such external source of error is the equipment participants utilize during free-living training. Although, it will be suggested that participants train on a spin bike to most closely replicate laboratory training we are unable to control which equipment they use. Further, if individuals utilize different pieces of equipment on different training days this may be a source of error due to resistance and calibration differences.

Chapter 2: Literature Review

Physical activity, defined as any bodily movement produced by skeletal muscles resulting in increased energy expenditure (Physical Activity Guidelines Advisory Committee, 2018), has been well-established to be beneficial for both physical and mental health in the general population and individuals with chronic disease (Penedo & Dahn, 2005; Warburton et al., 2006). In terms of physical health, regularly participating in physical activity has been shown to reduce the risk of cardiovascular disease (Paffenbarger et al., 2001), metabolic disease (Sigal, Kenny, Wasserman, Castaneda-Sceppa, & White, 2006), certain cancers (Lee, 2003), obesity (Jakicic & Otto, 2005) and all-cause mortality (Löllgen et al., 2009). Engaging in vigorous physical activity has been shown to decrease the risk of developing coronary artery disease by up to 40% (Morris, Everitt, Pollard, Chave, & Semmence, 1980). Further, regular moderate-to-vigorous physical activity has shown to reduce the risk of developing colon cancer by nearly 40% and risk of breast cancer by 20-30% (Lee, 2003). Additionally, engaging in adequate amounts of moderate physical activity reduces the risk of developing type 2 diabetes mellitus by 47% in individuals with impaired glucose tolerance (Pan et al., 1997). In terms of mental health, physical activity has been negatively associated with depression and anxiety symptoms (Azevedo Da Silva et al., 2012; Goodwin, 2003). According to the latest physical activity guidelines for health, adults should participate in at least 150 minutes of moderate physical activity, 75 minutes of vigorous physical activity, or a combination of these each week (Physical Activity Guidelines Advisory Committee, 2018). It is important to note that vigorous intensity physical activity may induce greater health benefits than moderate intensity physical activity, specifically with regards to metabolic syndrome (Hu et al., 1999) and type 2 diabetes mellitus (Janssen & Ross, 2012).

Despite the numerous benefits of physical activity, over half of adults in the United States do not currently meet physical activity guidelines (Physical Activity Guidelines Advisory Committee, 2018). Many barriers exist that may prevent individuals from regularly participating in physical activity, such as lack of access to fitness facilities, social support, and knowledge; however, one of the most common barriers to exercise is a perceived lack of time (Daskapan, Tuzun & Eker, 2006; Herazo-Beltran et al., 2017; Trost et al., 2002). Due to its vigorous intensity, HIIT can achieve similar physiological outcomes (i.e., increased skeletal muscle oxidative capacity and increased maximal oxygen uptake) as MICT but in substantially less time (Gibala et al., 2012). Therefore, HIIT may be a time-efficient alternative to MICT with the potential to be an effective strategy to increase physical activity.

High-Intensity Interval Training

HIIT is defined as alternating bouts of vigorous intensity exercise interspersed with rest or low-intensity active recovery (Weston et al., 2014). Exercise bouts during HIIT are ‘near maximal’, eliciting between 80% and 100% of maximal heart rate (Gibala et al., 2014), while rest periods, involve lower intensity exercise or complete rest (Gibala et al., 2014). This is differentiated from sprint interval training which involves supramaximal ‘all-out’ efforts that elicit over 100% of maximal oxygen uptake (Gibala et al., 2014). Both HIIT and sprint interval training are typically shorter in duration than MICT, yet still achieve similar physiological adaptations as MICT including improved cardiorespiratory fitness, endothelial function, and increased insulin sensitivity, despite the overall shorter time commitment (Cuddy, Ramos, & Dalleck, 2019; Gibala et al., 2012; Weston et al., 2014). However, the shorter overall time commitment of HIIT is compensated by a greater exercise intensity (Gibala et al., 2014). Individuals may therefore perceive HIIT as more challenging when compared to MICT (Decker & Ekkekakis, 2017).

HIIT is most often completed on a cycle ergometer; however, it can be completed using any mode of exercise. Recently, more practical modes of HIIT have been developed such as those involving stair climbing (Allison et al., 2017; Jenkins, Nairn, Skelly, Little, & Gibala, 2019) and a combination of aerobic and resistance training (Heinrich, Patel, O'Neal, & Heinrich, 2014). Interval training which combines both aerobic and resistance exercises, specifically multi-joint exercises, has been labeled as high-intensity functional training (Heinrich et al., 2014). High-intensity functional training is thought to be a practical alternative to HIIT or sprint interval training because training intensity is self-selected by the participant, which may result in a greater exercise tolerance (Ekkekakis et al., 2011; Parfitt, Rose, & Burgess, 2006). As more protocols are developed, HIIT becomes a more widely accessible form of training for the general population.

Although HIIT was originally developed for use in the military (Kappagoda, Linden, & Newell, 1979) and athletes (Lindsay et al., 1996), more practical protocols have made HIIT accessible to a wide range of populations including adolescents and individuals with chronic diseases (Little et al., 2011; Martinez, Kilpatrick, Salomon, Jung, & Little, 2015; Racil et al., 2016; Wisløff et al., 2007). HIIT has been shown to significantly improve cardiorespiratory fitness (Racil et al., 2013), body composition

(Racil et al., 2016), and cardiometabolic health outcomes in young obese females (Racil et al., 2016; Racil et al., 2013). Additionally, adolescents have demonstrated favorable perceptual responses, such as affect, enjoyment, and ratings of perceived exertion, to HIIT when compared to MICT (Malik et al., 2018). It is important to note that most HIIT research in adolescents has utilized HIIT protocols with a 1:1 work-to-rest ratio and short intervals ranging from ten seconds (Baquet, Berthoin, Gerbeaux, & Van Praagh, 2001) to one minute (Malik et al., 2018), although longer intervals have also been used (Ingul, Tjonna, Stolen, Stoylen, & Wisløff, 2010). HIIT has also been shown to have favorable outcomes, such as improvements in cardiorespiratory fitness and muscular strength, in a variety of clinical populations including individuals with multiple sclerosis (Zaenker et al., 2018), Parkinson’s disease (Harvey et al., 2019), type 2 diabetes (Little et al., 2011), cardiovascular disease (Wisløff et al., 2007), and obesity (Lunt et al., 2014; Martinez et al., 2015; Su et al., 2019). The majority of HIIT research in clinical populations has utilized variations of the popular 10x1 protocol with a 1:1 work-to-rest ratio (Little et al., 2011; Martinez et al., 2015; Tew et al., 2019) though other protocols have also shown to be well tolerated (Harvey et al., 2019; Rognmo, Hetland, Helgerud, Hoff, & Slordahl, 2004). The favorable physiological and psychological outcomes from HIIT, in a variety of populations, demonstrates that HIIT may be suitable for a wide range of individuals.

Recently, HIIT has become a popular alternative to traditional MICT. HIIT was ranked in the top three American College of Sports Medicine Fitness Trends for 2019 and has been ranked in the top five trends since 2014 (Thompson, 2018). An appeal of HIIT is the shorter time commitment compared to traditional MICT. One of the top barriers to engaging in physical activity is a perceived lack of time, and HIIT may help individuals overcome this barrier (Teixeira, Carraca, Markland, Silva, & Ryan, 2012; Trost et al., 2002). Individuals are able to achieve similar physiological outcomes with HIIT when compared to MICT in a much shorter time commitment, as indicated by previous research (Gibala et al., 2012). Specifically, equal or greater improvements in cardiorespiratory fitness can be achieved in nearly half the amount of time, as HIIT sessions are often less than 20 minutes (Burgomaster et al., 2008) where MICT protocols are commonly 45 minutes or more in length (Bartlett et al., 2011; Jung et al., 2014; Stork et al., 2018). This is supported by Wisløff et al. (2007), who found a 46% increase in VO_2peak after 25 minutes of HIIT three times per week for 12 weeks in individuals with cardiovascular disease. Additionally, HIIT has demonstrated similar improvements in cardiometabolic markers, such as decreased resting systolic blood pressure (Baseline: 144 ± 5 mmHg, post-intervention: 135 ± 5 mmHg; Tjønna et al., 2008), improved high-density lipoprotein cholesterol levels (Cuddy et al., 2019; Tjønna et al., 2008) and improvements in inflammatory markers such as interleukin-6 (Fu et al., 2013), in overweight individuals and individuals with cardiovascular disease, when compared to MICT of an equal or greater time commitment. Fu et al. (2013) utilized time-matched HIIT and MICT; however, the HIIT protocol utilized by Tjønna et al. (2008) and Wisløff et al. (2007) was 38 minutes, including warm-up and cool down, compared to 47 minutes of MICT. Therefore, individuals may be able to achieve similar health benefits with HIIT, when compared to MICT, in almost 20% less time.

Physiological responses to high-intensity interval training. There are several proposed mechanisims that may contribute to the greater increases in cardiorespiratory fitness for HIIT when compared to MICT. Peripheral mechanisms such as increases in mitochondrial biogenesis and calcium cycling may improve muscular function and therefore, indirectly improve cardiorespiratory fitness (Weston et al., 2014). Increases in oxidative enzymes (i.e., citrate synthase and cytochrome c oxidase) by about 30% and peroxisome-proliferator activated receptor γ coactivator (PGC1-α), a critical factor and indicator of mitochondrial biogenesis, by about 24% have been demonstrated in recreationally active individuals after two weeks of HIIT (Little, Safdar, Wilkin, Tarnopolsky, & Gibala, 2010). Additionally, Wisløff et al. (2007) found PGC1-α was increased by 47% and calcium reuptake was increased by 60% in heart failure patients following 12 weeks of HIIT. Further, these peripheral improvements were correlated with significant improvements in VO_2peak (Wisløff et al., 2007). There are also cardiovascular adaptations, such as improvements in ejection fraction and myocardial contractile function, which suggests an improvement in preload or the amount of ventricular compliance at the end of diastole (Kenney, Wilmore, & Costill, 2015; Molmen-Hansen et al., 2012). These cardiovascular adaptations likely contribute to the greater increases in cardiorespiratory fitness seen with HIIT when compared to MICT (Molmen-Hansen et al., 2012; see Table 1). While improvements in cardiorespiratory fitness have been demonstrated to be greater for HIIT than MICT, the intensity and duration of the intervals used in HIIT may influence the magnitude of these changes (Wen et al., 2019).

A recent meta-analysis by Milavaonic and colleagues demonstrated that improvements in cardiorespiratory fitness were greater for HIIT than MICT; however, this increase was greater for HIIT protocols with longer work intervals (> 2-minutes) and a greater work-to-rest ratio (Milanović, Sporiš, & Weston, 2015). When comparing HIIT with short (30-seconds) and long intervals (4-minutes) in physically active young men, Naves et al. (2018) found that longer intervals elicited a significantly greater session oxygen consumption and peak heart rate than HIIT with shorter intervals or MICT. This difference may be due to the greater amount of overall work completed and increased energy expenditure during longer HIIT intervals compared to shorter intervals. The differences in acute physiological responses, depending on interval length, indicate that the length and intensity of the intervals used in HIIT may be an important consideration when selecting an appropriate HIIT protocol.

In addition to changes in cardiorespiratory fitness, HIIT has been shown to improve other health markers including cardiometabolic risk factors such as blood pressure, blood cholesterol levels, and insulin sensitivity (Cassidy, Thoma, Houghton, & Trenell, 2017; Gibala et al., 2012; Weston et al., 2014). Following 16 weeks of HIIT three times per week, adults with metabolic syndrome significantly improved insulin sensitivity by 15%, systolic blood pressure by about 6%, and diastolic blood pressure by about 9%; however, no changes were observed in total cholesterol, low-density lipoprotein cholesterol, or triglyceride levels (Tjønna et al., 2008). Further, these findings are supported by Molmen-Hansen et al. (2012) who reported significant decreases in both systolic and diastolic blood pressure after 12 weeks of HIIT in hypertensive individuals. While significant improvements in systolic (2.9% reduction) and diastolic (3.8% reduction) blood pressure for MICT were also demonstrated, it is important to note that the magnitude of this improvement was greater for people engaging in HIIT (7.8% reduction in systolic blood pressure; 8.6% reduction in diastolic blood pressure; Molmen-Hansen et al., 2012). Findings by Vella et al. (2017) and Fisher et al. (2015) contradict Tjønna et al. (2008) and Molmen- Hansen et al. (2012), reporting no differences in blood pressure or insulin sensitivity in overweight and obese adults after six to eight weeks of HIIT. This disagreement in findings may be due to different populations being investigated and/or methodological differences with the HIIT protocols utilized. Tjønna et al. (2008) and Molmen-Hansen et al. (2012) both utilized similar treadmill HIIT protocols with 4-minute work intervals, whereas Vella et al. (2017) and Fisher et al. (2015) used different modes of training (i.e., cycle ergometer and elliptical) and protocols with shorter work intervals. Additionally, the training interventions in Vella et al. (2017) and Fisher et al. (2015) were approximately half the length of those in the other studies (i.e., six to eight weeks compared to twelve to sixteen weeks). It is possible that the training interventions in Vella et al. (2017) and Fisher et al. (2015) were not long enough to elicit significant improvements in cardiometabolic health outcomes, such as blood pressure and insulin sensitivity. Previous research has shown that a minimum of 12 weeks of training is required to see improvements in most cardiometabolic outcomes (Kessler et al., 2012). However, the length of time required to see improvements may depend on the outcome variable and the population being studied. Research in individuals with type 2 diabetes has shown significantly lower peak and average post-prandial blood glucose levels after one HIIT session (Gillen et al., 2012) and significantly lower (13.5% decrease) 24-hour blood glucose concentrations and area under the curve blood glucose levels following two weeks of HIIT (Little et al., 2011). These results suggest that it may be important to consider all factors when interpreting health outcomes of HIIT as population, protocol, intervention length, and choice of outcome measures may all influence the results. Overall, HIIT has been shown to elicit equivalent or greater physiological adaptations and improvements in cardiometabolic health markers and cardiorespiratory fitness when compared to MICT, despite differing results with regards to the magnitude of improvement (Gibala et al., 2012; Weston et al., 2014).

High-intensity interval training as a public health strategy. While HIIT has been shown to induce beneficial physiological adaptations similar to those of MICT, there is currently debate as to whether HIIT may be an advantageous public health strategy to increase levels of physical activity. Proponents of HIIT argue that interval training may be more interesting and enjoyable for participants than traditional MICT (Biddle & Batterham, 2015). In particular, as more practical modes of HIIT are developed, HIIT is becoming more accessible to a wide range of individuals. Despite the array of HIIT protocols of varying intensities, opponents of HIIT argue that this type of training may be too physically demanding for the general population and evoke negative emotions discouraging engagement and adherence (Frazão et al., 2016; Hardcastle et al., 2014; Perri et al., 2002; Roy et al., 2018). Further, there is conjecture that previously inactive individuals may compensate for engaging in exercise by decreasing total physical activity levels or increasing sedentary behavior levels (Goran & Poehlman, 1992; Paravidino, Mediano, & Sichieri, 2017). However, recent research suggests that both HIIT and MICT may replace sedentary time in adults with prediabetes (Nugent et al., 2018). This is an important consideration as time spent in sedentary behaviors has been shown to have deleterious effects on cardiovascular (Warren et al., 2010) and metabolic disease risk factors (Healy et al., 2008). Further, sedentary behavior has been shown to have distinct associations with cardiometabolic health when compared to physical activity (Katzmarzyk, Church, Craig, & Bouchard, 2009). A recent study by Green et al. (2014) demonstrated that sedentary behavior is associated with blood cholesterol levels, such as triglycerides (β = 0.31, $p = 0.03$). Thus, it is important for future research to examine both physical activity and sedentary behavior levels with regards to HIIT. Finally, the practicality of HIIT as a public health strategy has been questioned since the majority of HIIT research has been short-term and conducted in laboratory settings. Little research has investigated the efficacy of HIIT in free-living conditions, particularly with regards to psychological responses to HIIT over a period of training.

Psychological responses to high-intensity interval training. Recently, HIIT research has shifted from predominantly investigating the physiological responses to training to the psychological effects of HIIT on physical activity behaviors. While it appears that HIIT evokes similar physiological adaptations when compared to traditional MICT (Gibala et al., 2014; Kilpatrick et al., 2015; Weston et al., 2014), the psychological responses to HIIT are less understood. The acute psychological responses to HIIT training, including variables such as affect, enjoyment, and self-efficacy, have been investigated in recent research (Decker & Ekkekakis, 2017; Heisz et al., 2016; Hu et al., 2007; Thum et al., 2017). Yet, there is currently a lack of consensus about the affective and enjoyment responses to an acute bout of HIIT. Methodological differences such as instrument used, protocol utilized, and timing of the measurements may contribute to the differing results across studies (see Table 2).

Affect. Affect, which is defined as a valence response relating to pleasure and displeasure that occurs instinctively without much thought (Ekkekakis & Petruzzello, 2000), is a common psychological factor investigated during HIIT and MICT. Affect tends to be equal or more negative during HIIT when compared to MICT, specifically during the work intervals (Niven et al., 2018; Stork, Banfield, Gibala, & Martin Ginis, 2017). It has been demonstrated that affect is significantly more negative for an acute bout of HIIT than MICT in physically inactive adults (Decker & Ekkekakis, 2017; Jung et al., 2014). Further, the decline in affect is greater during HIIT than MICT suggesting that HIIT may be more aversive than MICT (Decker & Ekkekakis, 2017). These results are supported by Kilpatrick et al. (2015) and Malik et al. (2018) who replicated the findings in healthy, active, young adults. It is important to understand the affective response to HIIT since affect has shown to be associated with important physical activity behaviors such as engagement and adherence.

Affective responses during exercise have shown to be positively correlated with exercise intentions, attitudes towards exercise, and engagement in physical activity (Kwan, Cairney, Faulkner, & Pullenayegum, 2012; Rhodes & Kates, 2015). Further, after controlling for past physical activity behavior, affect during exercise was positively associated with participation in physical activity three to twelve months later (Rhodes & Kates, 2015). Thus, affect is thought to be an important factor in exercise adherence. However, it should be noted that the associations between affect and physical activity outcome measures have only been found with regards to MICT (Kwan et al., 2012; Rhodes & Kates, 2015). Relationships between engagement in physical activity and affective responses during HIIT are still largely unknown. In addition, most research investigating affect during HIIT and MICT have only involved a single bout of each mode of training in a laboratory environment, limiting the ecological validity of these findings (Decker & Ekkekakis, 2017; Malik et al., 2018). Therefore, it is important for future research to investigate the affective responses to HIIT and MICT over time with

Table 1. Summary of reported physiological responses to high-intensity interval training.

Study	Participants	Outcome Variables	Design	Protocol	Findings
Helgerud et al. (2007)	40 healthy, male university students	VO_2peak, HR, BL & stroke volume	Treadmill running 3x/week for 8-weeks, training supervision status unknown	MICT: 45-min at 70% HR_{max} VICT: 24.25-min at 85% HR_{max} Short HIIT: 47x15-sec at 90% HR_{max} Long HIIT: 4x4-min at 90% HR_{max} Recovery equal duration to work interval at 70% HR_{max}	VO_2peak increased significantly for HIIT compared to MICT and VICT.
Little et al. (2011)	Eight adults with type 2 diabetes	Blood glucose, skeletal muscle protein, HR, & RPE	Cycling, six sessions in 2-weeks, supervised	HIIT: 10x1-min at 90% HR_{max} 1-min self-selected passive recovery or active recovery at 50 watts	24-hour glucose concentration was reduced while mitochondrial protein content and mitofusin 2 protein content increased.
Molmen Hansen et al. (2012)	88 hypertensive adults	BP, HR, VO_2peak, stroke volume & TPR	Treadmill walking/running, 3x/week for 12-weeks, supervised	HIIT: 4x4-min at 90-95% HR_{max} 3-min recovery at 60-70% HR_{max} MICT: 47-min at 70% HR_{max}	BP, VO_2peak, and TPR improved for both HIIT and MICT. Stroke volume improved only for HIIT.
Naves et al. (2018)	10 physically active, young adults	O_2 consumption, HR & RPE	Treadmill running, four sessions, supervised	Long HIIT: 3x4-min at 90% VO_2peak 3-min recovery at 60% VO_2peak Short HIIT: 29x30-sec at VO_2peak 30-sec passive rest recovery	Session VO_2peak, peak HR and RPE were higher for long HIIT than short HIIT or MICT.

Note: BL = blood lactate; BP = blood pressure; HR = heart rate; HR_{max} = maximal heart rate; HIIT = high-intensity interval training; MICT = moderate-intensity continuous training; RPE = rating of perceived exertion; TPR = total peripheral resistance; VICT = vigorous intensity continuous training; VO_2peak = peak oxygen uptake.

relation to other psychological factors, such as enjoyment, in order to develop a greater understanding of the role affect plays in physical activity behavior.

Enjoyment. While affect is a visceral feeling, enjoyment is a positive emotion, which requires substantial cognition to sum feelings of an entire experience (Wankel, 1993). Enjoyment is thought to be influential to physical activity participation and adherence, as individuals are more likely to engage in activities which are enjoyable to them (Wankel, 1993). Enjoyment has been repeatedly investigated during acute bouts of HIIT and MICT with varying results (Stork et al., 2017). The majority of the research indicates that enjoyment is equal or greater for acute HIIT when compared to MICT in recreationally active individuals (Bartlett et al., 2011; Kilpatrick et al., 2015; Oliveira et al., 2013; Thum et al., 2017), healthy inactive adults (Jung et al., 2014), and overweight or obese inactive populations (Martinez et al., 2015). The majority of studies investigating enjoyment of HIIT have been conducted using a cycle ergometer as the mode of exercise (Jung et al., 2014; Kilpatrick et al., 2015; Martinez et al., 2015; Thum et al., 2017). A few studies have utilized other modes of HIIT such as the treadmill or elliptical (Bartlett et al., 2011; Oliveira et al., 2013; Vella et al., 2017).

Although there is consensus in the literature that enjoyment for an acute bout of HIIT is equal to or greater than that of MICT, there are methodological differences that may influence results and make it difficult to compare across studies. Firstly, different measures of enjoyment have been used within the current literature. The PACES (Kendzierski & DeCarlo, 1991) is the most common instrument used to measure enjoyment in the HIIT literature. Despite its popularity, the PACES has noted limitations. Foremost, the PACES includes 18 items, which can take individuals a considerable amount of time to complete. Therefore, this instrument can only be utilized to measure enjoyment after the completion of exercise, which may influence an individual's responses. Alternatively, the Exercise Enjoyment Scale (Stanley & Cumming, 2010) is a single-item measure that can be utilized throughout the duration of an exercise bout. This instrument allows researchers to determine change in enjoyment throughout a bout of exercise since it can be administered quickly. However, since the Exercise Enjoyment Scale is comprised of a single item it may provide a more restricted view of enjoyment than the PACES. In addition to the instrument used to measure enjoyment, the timing of measurements may influence reported enjoyment scores. The PACES was originally validated to be administered directly following a bout of exercise (Kendzierski & DeCarlo, 1991). Most HIIT research investigating enjoyment has administered the PACES immediately after exercise as intended (Bartlett et al., 2011; Decker & Ekkekakis, 2017; Heisz et al., 2016; Stork et al., 2018; Vella et al., 2017). However, there is debate in the literature concerning whether the measurement of enjoyment after participants have had time to rest may provide a more valid measure of enjoyment (Coswig et al., 2016; Decker & Ekkekakis, 2017; Stork et al., 2017). Therefore, a few studies have measured enjoyment as long as 20-minutes following the exercise bout (Thum et al., 2017; Martinez et al., 2015; Jung et al., 2014). It is difficult to make comparisons across results of studies investigating enjoyment following HIIT and to generalize their findings due to these methodological differences. Importantly, research measuring enjoyment for an acute bout of HIIT cannot be generalized to enjoyment of HIIT over time, particularly if the participants are not familiar with HIIT (Decker & Ekkekakis, 2017; Heisz et al., 2016; Stork et al., 2018; Vella et al., 2017).

Enjoyment of HIIT and MICT over a period of training has been investigated in a few studies; however, there is a lack of consensus about how enjoyment of HIIT changes with training (Foster et al., 2015; Heisz et al., 2016; Vella et al., 2017). Heisz et al. (2016) found that enjoyment of HIIT was greater than that of MICT and that enjoyment of HIIT increased over six weeks of training. Findings by Foster et al. (2015) contradict that of Heisz et al. (2016) showing that enjoyment of HIIT and MICT in physically inactive adults decreased over the course of the eight-week intervention with the Tabata HIIT protocol (i.e., 8x20-seconds of cycling at 170% peak power separated by 10-seconds of active recovery) having significantly higher enjoyment than MICT. Vella et al. (2017) found distinct results from either of the aforementioned studies, as no significant differences were found in the enjoyment of HIIT and MICT in overweight and obese adults over eight weeks of training. It is important to consider that these studies utilized different HIIT protocols with varying modes of exercise (i.e., bike, elliptical, and treadmill). Further, the studies measured enjoyment at varying times using a variety of different instruments. These methodological differences, among others such as the use of different HIIT protocols (i.e. Tabata versus the 10x1-minute HIIT protocols), may have contributed to the varying results.

It is important to understand changes in enjoyment of HIIT and MICT over time as enjoyment has been associated with engagement in physical activity (Burn & Niven, 2019; Dishman et al., 2005). In a year-long study investigating the relationships between enjoyment and engagement in physical activity, Dishman et al. (2005) found that increased enjoyment was related to increased physical activity levels in high school girls. Burn and Niven (2019) found similar results in their qualitative study examining why

Table 2. Summary of psychological responses to acute high-intensity interval training.

Study	Participants	Outcome Variables	Protocol	Findings
Bartlett et al. (2011)	Eight recreationally active, young men	RPE & enjoyment	HIIT: 6x3-min at 90% VO_2peak 3-min recovery at 50% VO_2peak MICT: 50-min 70% VO_2peak	Enjoyment: ↑ HIIT (88 ± 6) compared to MICT (61 ± 12; *p* = 0.004).
Decker & Ekkekakis (2017)	24 low-active, obese women	RPE, affect & enjoyment	HIIT: 4x3-min at 115% VT 2-min recovery at 85% VT MICT: 25-min at 90% VT	Affect: ↓ HIIT (0.0 ± 1.9) compared to MICT (1.1 ± 1.3) Enjoyment: ↓ HIIT (82 ± 22) compared to MICT (91 ± 23; *p* = 0.04).
Jung et al. (2014)	44 physically inactive adults	Affect, self-efficacy, enjoyment, intentions & preference	HIIT: 10x1-min at 100% PPO 1-min recovery at 20% PPO MICT: 40-min at 40% PPO VICT: 20-min at 80% PPO	Affect: ↓ HIIT (1.4 ± 2.5) & VICT (0.8 ± 2.5) compared to MICT (2.9 ± 1.6) post-exercise (*p* < 0.01). Enjoyment: ↑ HIIT than VICT (*p* = 0.01) but not MICT (*p* = 0.08).
Martinez et al. (2015)	20 insufficiently active, overweight or obese adults	RPE, affect & enjoyment	HIIT 1: 24x30-sec HIIT 2: 12x1-min HIIT 3: 6x2-min Recovery equal duration at 10-20% VO_2peak MICT: 20-min at 10% of distance between AT and VO_2peak	Affect: ↓ over time for all (*p* < 0.05 for all). Enjoyment: ↑ HIIT 2 (96 ± 14) compared to HIIT 3 (81 ± 24; *p* = 0.01) & MICT (83 ± 21; *p* = 0.02).
Thum et al. (2017)	12 recreationally active adults	RPE, affect & enjoyment	HIIT: 8x1-minute at 85% PPO 1-min recovery at 25% PPO MICT: 20-min at 45% PPO	Enjoyment: ↑ HIIT (104 ± 9) compared to MICT (84 ± 19; *p* = 0.01). Affect: ↓ HIIT (0.0 ± 3.2) compared to MICT (1.5 ± 1.9; *p* < 0.05).

Note: AT = anaerobic threshold; HIIT = high-intensity interval training; HR = heart rate; MICT = moderate-intensity continuous training; PPO = peak power output; RPE = rating of perceived exertion; VICT = vigorous-intensity continuous training; VO_2peak = peak oxygen uptake; VT = ventilatory threshold.

individuals participate in HIIT. While improving fitness and appearance were major reasons for choosing to try HIIT, positive health, challenge, and enjoyment were reasons for continuing to participate in HIIT (Burn & Niven, 2019). These findings suggest that enjoyment may play an influential role in adherence to physical activity; however, little is currently known about the factors that influence exercise enjoyment.

Competence. Researchers have proposed that exercise competence may be an important factor in exercise enjoyment, particularly for exercise at vigorous intensities (Heisz et al., 2016). Competence, an individual's ability to interact with their environment (White, 1959), is one of the three needs that must be met in the self-determination theory framework (Deci & Ryan, 2000). Self-determination theory is centered around the concept that the psychological needs of competence, autonomy, and relatedness need to be met for an individual to be motivated to complete a task (Deci & Ryan, 2000). In self-determination theory there are three primary forms of motivation, amotivation, extrinsic motivation and intrinsic motivation, which lie along a continuum ranging from non-autonomous to completely autonomous, respectively (Texeria et al. 2012). Intrinsic motivation (i.e., autonomous motivation) has been significantly, positively associated with engagement in vigorous physical activity ($r = 0.33$, $p < 0.01$) and self-reported overall physical activity levels ($r = 0.27$, $p < 0.01$; Edmunds, Ntoumanis, & Duda, 2006). This was supported by Standage, Sebire, & Loney (2008) who demonstrated that autonomous motivation is significantly and positively associated, while extrinsic motivation was negatively associated, with objectively assessed moderate-intensity physical activity ($r = 0.42$, $p < 0.01$). This evidence, supporting a positive relationship between intrinsic motivation and physical activity engagement, suggests that intrinsic motivation may be a good predictor of participation in physical activity. Although the psychological needs (i.e., competence, autonomy, and relatedness) have also been associated with physical activity levels ($r = 0.16$ to 0.29, $p < 0.01$; Edmunds et al., 2006), much less research has been conducted in this area.

In the context of HIIT, there are two forms of competence discussed within the literature: (1) perceived competence and (2) physiological competence. Perceived competence, measured with self-report instruments, (i.e., the Psychological Need Satisfaction in Exercise Scale; Wilson et al., 2006), indicates an individual's belief about being able to interact with an exercise environment and achieve a desired outcome (Texeria et al., 2012). In contrast, physiological competence is measured using outcomes such as cardiorespiratory fitness and indicates an individual's physiological ability to complete an exercise task (Heisz et al., 2016). Both forms of competence are thought to play an important role in an individual's enjoyment and adherence to physical activity.

Little research has investigated competence with regards to HIIT and MICT; however, competence with regards to engagement in physical activity has been investigated in a variety of populations. Bai et al. (2015) found perceived competence to be a significant predictor of physical activity at school ($\beta = 0.19$ to 0.33, $p < 0.05$) and at home ($\beta = 0.44$ to 0.65, $p < 0.05$) in students in 3rd through 12th grade. This finding is supported by Haslem et al. (2016) who found that perceived competence significantly contributed to time spent in physical activity ($r = 0.32$, $p < 0.001$) in high school students. In adults, perceived competence has been shown to have a positive correlation ($r = 0.20$ to 0.25; $p < 0.05$) with physical activity levels (Fortier et al., 2007; Markland & Tobin, 2010). These findings demonstrate the importance of investigating perceived and physiological competence with HIIT as it has the potential to be an efficacious public health strategy to promote long-term physical activity. Furthermore, although competence and self-efficacy are independent constructs (Rodgers, Markland, Selzler, Murray, & Wilson, 2014), increased competence may allow for increased mastery experiences thus resulting in increased levels of self-efficacy.

Self-efficacy. Self-efficacy is an individual's belief in their ability to perform a specific behavior (Bandura, 1977). Self-efficacy has been shown to change over time and to be an important factor in engaging in regular physical activity (Trost et al., 2002). Self-efficacy is influenced by four different components: mastery, vicarious experiences, verbal persuasion, and physiological or affective states (Bandura, 1977). Therefore, self-efficacy is not a completely independent psychological construct, but one that is intertwined with affect, enjoyment, and perceived competence. Hu et al. (2007) found that post-exercise self-efficacy had a significant and positive association with exercise enjoyment ($r = 0.33$, $p < 0.05$), supporting the collaborative nature of these psychological constructs. Self-efficacy has also been positively associated with affect and intentions to exercise ($r = 0.26$, $p < 0.01$; Kwan & Bryan, 2010) highlighting the importance of investigating these variables concurrently to better understand their relationships with physical activity behavior.

To date few studies have investigated self-efficacy with regards to HIIT. When comparing task self-efficacy of acute bouts of HIIT, MICT, and continuous vigorous exercise, Jung et al. (2014) found participants felt significantly more confident that they could complete a bout of HIIT than continuous vigorous exercise ($p < 0.05$). No significant differences were found between HIIT and MICT in this study. Importantly, this study utilized self-efficacy as a static construct and did not take into consideration that self-efficacy can change over time (Jung et al., 2014). In a recent study, Locke et al. (2018) demonstrated the importance of examining self-efficacy over time with HIIT and MICT in a free-living environment. The authors found that task self-efficacy scores, which ranged from 0 to 100, increased by 22-points for HIIT and 32-points for MICT following the two-week HIIT and MICT interventions in adults with a high-risk of type 2 diabetes mellitus (Locke et al., 2018). There were no significant differences in self-efficacy scores between the HIIT and MICT groups for any time point. Further, in a 12-month study examining adherence to HIIT, Roy et al. (2018) found that participants who adhered to the intervention had significantly higher self-efficacy than non-adherent participants (+2.5-point difference). This suggests self-efficacy may play an important role in the engagement and adherence of HIIT; however, the direction of this relationship is unknown.

Overall, HIIT has become a popular, time-efficient alternative to MICT in recent years (Thompson, 2018), which has led some researchers to suggest it as a potential public health strategy to increase physical activity levels (Biddle & Batterham, 2015). While it has been well-established that HIIT produces similar physiological adaptations as MICT (Gibala et al., 2012; Weston et al., 2014), opponents argue that the aversive psychological responses will decrease HIIT engagement and adherence (Decker & Ekkekakis, 2017; Frazão et al., 2016; Hardcastle et al., 2014). However, the majority of research with regards to psychological responses to HIIT have focused on an acute bout of HIIT and are largely limited to the laboratory setting, which reduces generalizabilty and ecological validity of these findings (Bartlett et al., 2011; Decker & Ekkekakis, 2017;

Kilpatrick et al., 2015; Thum et al., 2017). Thus, it may be beneficial for future research to focus on investigating HIIT in free-living environments. Additionally, little research has investigated the psychological responses to HIIT, such as enjoyment and affect, over time and with regards to influential factors such as perceived competence and self-efficacy in free-living conditions. Therefore, the primary aim of this study is to determine the effects of six weeks of HIIT and MICT on psychological constructs such as affect, enjoyment, perceived competence, and self-efficacy in healthy, inactive young adults. This study also seeks to investigate the change in physiological variables including cardiorespiratory fitness, body composition, physical activity and sedentary behavior levels across six weeks of partially supervised HIIT and MICT training.

Chapter 3: Methods

Participants

Twenty physically inactive young adults, between the ages of 18 and 44 years old, volunteered to participate in this research study. Sample size was determined by power calculations in G*Power 3.1.9.2 (Universitat Kiel, Germany). Using a two-way repeated measures analysis of variance (ANOVA) and an effect size between 0.4 and 0.5 (Jung et al., 2014; Kilpatrick et al., 2015; Martinez et al., 2015), eight participants per group were required to achieve a power of 95% and an alpha level of 0.05. Ten participants per group were recruited to allow for potential drop-out. To be eligible to participate in the study participants engaged in less than 150 minutes of moderate and 75 minutes of vigorous physical activity per week for the previous three months. Additionally, all participants were free of cardiovascular, metabolic, and renal diseases at the time of the study. Further, participants did not have any musculotendinous injury that limited exercise nor were pregnant.

Research Design

A mixed experimental research study design was used with participants randomized to one of two groups (i.e., HIIT or MICT), using stratified block randomization, for a six-week training intervention. Testing occurred over an eight-week period with measures taken prior to, at the midpoint, and following the six-week training intervention. All training sessions were separated by a minimum of 24-hours, and participants were asked to refrain from engaging in strenuous exercise 12-hours prior to testing sessions. Training sessions occurred three times per week for six weeks. For the first three weeks, participants completed supervised training sessions in the Jack R.

Leighton Human Performance Laboratory. During the last three weeks of the training intervention, participants completed all training sessions unsupervised in the University Recreation Center.

Instrumentation

Physiological data was collected using a metabolic cart (TrueOne 2400, Parvo Medics Inc, Sandy, UT), heart rate monitor (Polar, Kempele, Finland) and BOD POD® (COSMED USA Inc, Concord, CA). Supervised training was conducted on an electronically-braked cycle ergometer (Lode Corvival, Lode BV, Groningen, Netherlands). During unsupervised training it was suggested that participants utilize the indoor spin bikes (Carbon Blue™, Schwinn, Vancouver, WA) to most closely simulate the supervised training. Psychological data was collected using a variety of instruments including the PACES (Kendzierski & DeCarlo, 1991), Exercise Enjoyment Scale (Stanley & Cumming, 2010), Feeling Scale (Hardy & Rejeski, 1989), Psychological Need Satisfaction in Exercise Scale (Wilson et al., 2006) and Task Self-Efficacy Scale (Jung et al., 2014).

Physical Activity Enjoyment Scale. The PACES is an 18-item instrument that measures an individual's enjoyment of physical activity (Kendzierski & DeCarlo, 1991). This scale is commonly used following a bout of exercise (Bartlett et al., 2011; Heisz et al., 2016; Kong et al., 2016) and was originally validated for use immediately following an exercise bout (Kendzierski & DeCarlo, 1991). Each item is rated on a 7-point Likert scale with two opposing options (i.e., I enjoy it and I hate it) anchoring each end of the scale. Scores range from 18 to 126 with higher scores indicating higher levels of enjoyment. The PACES has been shown to have good internal consistency with a

Cronbach's alpha value of 0.93 (Kendzierski & DeCarlo, 1991). Additionally, the PACES has been validated in a variety of populations ranging from children (Moore et al., 2009) to older adults (Mullen et al., 2011).

Exercise Enjoyment Scale. The Exercise Enjoyment Scale developed by Stanley and Cumming (2010) is a single-item measure of exercise enjoyment. This instrument is often used during exercise bouts because it can be administered more quickly than a longer, multi-item measure, particularly during interval training (Kilpatrick et al., 2015; Malik et al., 2018; Martinez et al., 2015). Participants are asked to indicate how much they are enjoying the exercise session using a 7-point Likert scale ranging from one (not at all) to seven (extremely) with a higher score indicating greater enjoyment. To date, no validity or reliability information has been reported for this scale.

Feeling Scale. Affect, which is defined as a visceral pleasure/displeasure response (Ekkekakis et al., 2011), was measured using the single-item Feeling Scale. The Feeling Scale asks participants to rate how they feel in the moment using an 11-point bipolar scale ranging from +5 (very good) to -5 (very bad; Hardy & Rejeski, 1989). Although Feeling Scale scores are related to rating of perceived exertion, they are not isomorphic constructs (Hardy & Rejeski, 1989). The Feeling Scale measures how you feel, whereas the rating of perceived exertion scale measure what you are feeling (Hardy & Rejeski, 1989). To our knowledge, there is currently no reliability and validity information available for this scale.

Psychological Need Satisfaction in Exercise Scale. The Psychological Need Satisfaction in Exercise Scale (Wilson et al., 2006) was used to measure perceived competence, which is defined as a need to master personally challenging tasks (Bandura, 1997). The Psychological Need Satisfaction in Exercise Scale is an 18-item instrument representing feelings people have when they exercise. Participants were asked to consider how they typically feel during exercise and rate the extent to which items are true (six) or false (one) on a 6-point Likert scale. The Psychological Need Satisfaction in Exercise Scale has been shown to have good internal consistency in undergraduate students (α = 0.91; Wilson et al., 2006).

Task Self-efficacy Scale. Self-efficacy, or an individual's belief in their ability to complete a task (Bandura, 1997), was measured using a 5-item self-efficacy scale adapted from Jung et al. (2014). Participants were asked to rate how confident they are that they can 'perform one to five bouts of exercise a week for the next four weeks like the one they performed today' on a scale of 0% to 100% in 10% increments (Jung et al., 2014) This scale has been utilized with both HIIT and MICT and has shown to have high internal consistency in physically inactive adults (α = 0.95; Jung et al., 2014).

Rating of Perceived Exertion. Perceived exertion, defined as how hard an individual feels like they are working, was measured using Borg's Rating of Perceived Exertion CR10 Scale (Borg, 1982). The CR10 Borg scale, which was adapted from the original 6-20 Borg Scale, is an 11-point scale ranging from zero to ten with verbal markers indicating intensity (i.e., 0 = nothing at all, 2 = weak, 4 = somewhat strong) at most points on the scale (Borg & Kaijser, 2006). The Borg Scale and Borg CR10 Scale have been positively correlated with heart rate; however, both heart rate and rating of perceived exertion measures are required to get an overall picture of physical strain (Borg, 1982; Noble, Borg, Jacobs, Ceci, & Kaiser, 1983). The Borg CR10 scale has been shown to have acceptable validity and reliability (Chen, Fan & Moe, 2002).

Procedures

Following approval from the Institutional Review Board at Eastern Washington University, physically inactive young adults were recruited to participate in the study. Participants were recruited via word-of-mouth with assistance from the Eastern Washington University Exercise Science Club. Additionally, flyers were posted around campus in areas such as classroom buildings, the union building, and library. Informed consent was provided by all participants prior to testing, and all testing was conducted in accordance with the principles outlined in the Declaration of Helsinki.

Prior to data collection, participants were screened for their eligibility to participate in this study. Participants were screened for their ability to safely participate in exercise using the Physical Activity Readiness Questionnaire Plus (PARQ+; Warburton et al., 2006). Additionally, participants completed a pre-participation questionnaire to ensure that they adhered to inclusion and exclusion criteria for the study. Participants were males and females between 18 and 44 years of age who engaged in less than 150 minutes of moderate and 75 minutes of vigorous physical activity per week over the last three months. Further, participants were free of any cardiovascular, metabolic, or renal diseases, free of musculotendinous injuries that limit exercise, and not currently pregnant. If participants exhibited any signs or symptoms suggestive of cardiovascular, metabolic or renal disease they were also excluded from the study. After screenings, participants meeting inclusion criteria were scheduled for their first visit. Participants were asked to refrain from engaging in strenuous physical activity and consuming caffeine or alcohol for at least 12-hours prior to testing. Further, participants were instructed to avoid consumption of large meals for at least three hours prior to their scheduled visit.

Anthropometric measures and body composition. At week zero and week seven, anthropometric data was collected from all participants. Height was measured to the nearest 0.1 cm using a stadiometer (SECA, Hamburg, Germany) and weight was measured to the nearest 0.1 kg using a scale (Continental Scale Corp., Bridgeview, IL). Body composition was estimated using air displacement plethysmography using standard procedures (COSMED USA Inc, Concord, CA).

Cardiorespiratory fitness testing. Participants completed a maximal incremental exercise test to exhaustion on a cycle ergometer (Lode Corvival, Lode BV, Groningen, Netherlands) at week zero and week seven. Oxygen consumption (VO_2), production of carbon dioxide, and ventilation were measured using breath-by-breath analysis with a metabolic cart system (TrueOne 2400, ParvoMedics, Sandy, UT). Heart rate was monitored continuously throughout the test (Polar Electro, Lake Success, NY). Resting expired gases were collected for two minutes during seated rest followed by a 3-minute warm-up at 50 watts and at a cadence of greater than or equal to 50 revolutions per minute (rpm). Following the warm-up workload increased by 1-watt every 3-seconds until the pedal cadence fell below 50 rpm or the participant reached volitional exhaustion. This protocol has been used in previous interval training research with good results (Jenkins et al., 2019; Jung et al., 2014, Little et al., 2019; Stork et al., 2018). Additionally, ramp protocols have been shown to produce more reliable results than step protocols for maximal cycle ergometer exercise tests (Beltz et al., 2016).

For all analyses of VO_2, data were smoothed using a 15-breath moving average with the highest values obtained within exercise being recorded (Robergs, Dwyer & Astorino, 2010). Power output at the end of the test was also recorded to determine peak power. Enjoyment, affect, and rating of perceived exertion were measured during the maximal cardiorespiratory fitness test to familiarize participants with the use of the scales. These psychological variables were measured at the end of the warm-up and at 75% and 85% of age-predicted maximum heart rate during the incremental exercise test.

Physical activity and sedentary behavior measurements. Physical activity and sedentary behavior levels were measured at week zero and week seven using a hip-mounted, triaxial accelerometer (ActiGraph GT3X+; ActiGraph, Pensacola, FL) for three consecutive days, including one weekend day. Previous research has shown that at least three days of accelerometer wear provides reliable estimates of habitual physical activity in adults (Trost, McIver, & Pate, 2005). Accelerometers were worn on the anterior axillary line of the right hip on an elasticized belt for three full days except during water activities. Participants were provided with an activity log to record all daily activity in 15-minute intervals (see Appendix 1). Participants were reminded to maintain normal activities while wearing the accelerometer.

A valid day of accelerometer wear consisted of a minimum of 10-hours of wear time during waking hours (Rich et al., 2013; Troiano et al., 2008). A non-wear period was defined as ≥ 60 minutes of consecutive zeros (Tudor-Locke, Ainsworth, Thompson, & Matthews, 2002). Physical activity was categorized into moderate (2690-6166 counts per minute) and vigorous (≥ 6167 counts) physical activity (Sasaki, John, & Freedson, 2011). Sedentary behavior was defined as < 150 counts per minute during waking hours (Kozey-Keadle, Libertine, Lyden, Staudenmayer, & Freedson, 2011).

Exercise training. Following baseline testing, participants were randomized to either the HIIT or MICT group for the six-week training intervention. The first three weeks of the training intervention were supervised in the laboratory. Participants visited the laboratory three times a week for training sessions. Supervised HIIT consisted of 10x1-minute intervals cycling at 80% peak power interspersed with 1-minute rest intervals at 20% peak power. This protocol has been used frequently in previous research investigating HIIT in inactive and active adults (Stavrinou, Bogdanis, Giannaki, Terzis, & Hadjicharalambous, 2019; Stork et al., 2018; Thum et al., 2017; Wood et al., 2016). Supervised MICT involved cycling at an intensity of 40% peak power for 40-minutes (Jung et al., 2014). Both HIIT and MICT sessions had a 3-minute warm-up and 2-minute cool down at 50 watts. Therefore, HIIT sessions were 25-minutes in duration and MICT sessions were 45-minutes in duration (Bartlett et al., 2011; Jung et al., 2014; Stork et al., 2018).

Affect, in-task enjoyment using the Exercise Enjoyment Scale, and rating of perceived exertion were measured at the beginning, midpoint, and end of each training session for both HIIT and MICT. Self-efficacy, perceived competence, and post-exercise enjoyment were measured five minutes following the completion of the first testing session. Participants were also asked if they had engaged in HIIT in the last 6-months, and if so, how frequently they participate in HIIT. After three weeks, participants repeated the initial psychological measures including self-efficacy, perceived competence, and post-exercise enjoyment.

Participants began unsupervised training at the University Recreation Center at Eastern Washington University at the beginning of week four. Participants were asked to continue the training intervention (i.e., HIIT or MICT) three times per week in an unsupervised setting. All training sessions took place on a stationary bike. It was suggested that participants utilize the indoor spin bikes (Carbon Blue^{TM}, Schwinn, Vancouver, WA) to most closely replicate the supervised training sessions in free-living conditions. Training intensity for unsupervised training was prescribed using rating of perceived exertion values, heart rate, and power output. Since rating of perceived exertion has been shown to increase during HIIT and MICT training (Thum et al., 2017), participants were instructed to achieve the prescribed rating of perceived exertion by the end of the third work interval for HIIT and by minute 12 for MICT.

Participants kept a log of all completed training sessions (see Appendix 2 and 3). This log included a record for date and time of session as well as psychological measures such as affect, in-task enjoyment, and rating of perceived exertion scores for each training session. Participants continued to report affect, enjoyment and rating of perceived exertion at the beginning, midpoint, and end of each training session. Specifically, participants recorded affect, in-task enjoyment, and rating of perceived exertion at the beginning of the first, fifth, and tenth rest interval during HIIT and at 4-, 20-, and 40-minutes during MICT. Participants were sent an email halfway through the free-living training period of testing to remind them of the measures they should be recording during training.

Statistical Analyses

Preliminary analyses were conducted to test for outliers, normality, skewness, and kurtosis. Normality was assessed using the Shapiro-Wilk test for normality. Skewness and kurtosis were assessed using z-scores. If assumptions were not met, data were transformed as necessary. Data were presented as means and standard deviations for all variables. Manipulation checks were performed to determine if there were differences in descriptive variables, adherence rates, and outcome variables between groups at baseline using independent samples t-tests. Difference scores between the beginning and end of training session were calculated for both affect and in-task enjoyment and used for the analysis of within-session psychological outcome measures. Differences in affect and in-task enjoyment (i.e., within-session psychological outcomes) were analyzed using a two (group) by six (time across the training intervention: weeks 1-6) repeated measures factorial analysis of covariance (ANCOVA). Additionally, end of exercise affect and in-task enjoyment scores were analyzed using a two (group) by six (time across the training intervention: weeks 1-6) ANCOVA. Sex and initial scores were used as covariates for analysis of within-session psychological variables. Differences in psychological outcomes across the training intervention, between HIIT and MICT, were analyzed using a two (group) by three (time across the training intervention: pre-, mid-, and post-training intervention) repeated measures factorial ANOVA. Differences in physiological outcomes across the training intervention were analyzed using a two (group) by two (time: pre- and post-training intervention) repeated measures factorial ANCOVA. Sex was used as a covariate in analysis of physiological variables (i.e., VO_2peak and body composition). When necessary, Bonferroni post hoc analyses were used to determine where differences occurred. All data were analyzed in SPSS v25.0 (IBM Corporation, Armonk, NY) with an alpha level set at 0.05.

Chapter 4: Results

Participant Characteristics

Twenty, self-reported physically inactive, young adults, with a mean age of 21.4 ± 2.2 years, were randomized to either the HIIT (n = 10) or the MICT group (n = 10). Of the 20 participants, the majority were female (65%). Additionally, 75% of all participants reported at least some experience with HIIT prior to study enrollment. There were no differences at baseline between the HIIT and MICT groups with respect to age, weight, body fat percentage, VO_2peak, peak power output, moderate-to-vigorous physical activity levels, or sedentary behavior levels (all $p > 0.05$; see Table 3). Eight participants (40%) were classified as at least overweight as indicated by a body mass index of at least 25.0 $kg{\cdot}m^{-2}$.

Adherence to the Training Intervention

There were no known or reported adverse events during the HIIT or MICT sessions across the six-week intervention. Adherence to both training interventions was good with participants completing 99% and 98% of HIIT and MICT sessions, respectively. There was no significant difference in adherence rates between HIIT and MICT ($p = 0.36$). In terms of training intensity, rating of perceived exertion was significantly higher during HIIT (supervised: 5.1 ± 1.7; unsupervised: 5.2 ± 1.2) compared to MICT (supervised: 2.9 ± 1.0; unsupervised: 3.6 ± 1.5; $p = 0.004$) with no significant difference between supervised and unsupervised training ($p = 0.09$). Significantly higher heart rates were achieved at the midpoint of HIIT sessions compared to MICT for both supervised (HIIT: 168 ± 16 bpm; MICT: 143 ± 12 bpm; $p < 0.001$) and unsupervised training (HIIT: 168 ± 14 bpm; MICT: 141 ± 12 bpm; $p = 0.004$). There were no significant differences in heart rate between supervised and unsupervised training ($p = 0.71$).

Table 3. Baseline participant characteristics (mean ± SD).

Variable	HIIT (n = 10)	MICT (n = 10)	Total (N = 20)
Age (years)	21.1 ± 0.5	21.6 ± 0.8	21.4 ± 2.2
Sex (% females)	60	70	65
Body mass (kg)	73.4 ± 14.6	65.6 ± 17.4	69.5 ± 16.2
Body mass index ($kg \cdot m^{-2}$)	25.5 ± 4.4	23.6 ± 3.0	24.6 ± 3.8
Body fat percentage (%)	23.8 ± 4.4	22.0 ± 2.6	22.7 ± 11.2
VO_2peak ($ml \cdot kg^{-1} \cdot min^{-1}$)	34.5 ± 7.5	36.6 ± 7.4	35.5 ± 7.3
Peak power output (watts)	211.4 ± 41.2	206.1 ± 62.7	208.8 ± 51.7
MVPA* ($min \cdot day^{-1}$)	87.3 ± 48.0	63.4 ± 27.7	74.0 ± 37.5
Sedentary behavior* ($min \cdot day^{-1}$)	502.1 ± 106.1	489.3 ± 120.8	495.0 ± 107.5

Note: $p > 0.05$ for all
*Due to missing data N = 9 (HIIT: n = 4; MICT: n =5)
HIIT = high-intensity interval training; MICT = moderate-intensity continuous training; MVPA = moderate-to-vigorous physical activity; n = sample size; SD = standard deviation; VO_2peak = peak oxygen consumption.

Physiological Responses to Training

Physiological responses to training are depicted in Table 4. VO_2peak (pre: 35.5 ± 1.7 $ml \cdot kg^{-1} \cdot min^{-1}$; post: 38.3 ± 1.7 $ml \cdot kg^{-1} \cdot min^{-1}$; $p = 0.03$) and peak power output (pre: 208.8 ± 11.9 watts; post: 229.0 ± 11.8 watts; $p = 0.01$) significantly improved across the training intervention. There were no significant main effects of group (VO_2peak: $p = 0.20$; peak power output: $p = 0.74$) or interaction effects (VO_2peak: $p = 0.38$; peak power output: $p = 0.40$) for cardiorespiratory fitness. Additionally, there were no significant differences in body fat percentage ($p = 0.68$), fat mass ($p = 0.44$), or fat free mass ($p = 0.33$) across the training intervention and no significant differences due to training group (p = 0.39 – 0.66). Further, there were no significant interaction effects for any of the body composition variables (p = 0.19 – 0.27).

Table 4. Physiological variables across the training intervention (mean ± SD).

	HIIT		MICT	
Variable	Pre	Post	Pre	Post
Absolute VO_2peak ($L \cdot min^{-1}$)	2.48 ± 0.16	2.62 ± 0.14*	2.46 ± 0.30	2.67 ± 0.29*
Relative VO_2peak ($ml \cdot kg^{-1} \cdot min^{-1}$)	34.46 ± 2.38	36.51 ± 2.27*	36.58 ± 2.33	40.12 ± 2.60*
Peak power output (watts)	211.40 ± 13.04	229.50 ± 11.82*	206.10 ± 19.83	228.40 ± 20.32*
Relative peak power output ($watts \cdot kg^{1}$)	2.95 ± 0.20	3.13 ± 0.21*	3.14 ± 0.16	3.48 ± 0.17*
Time to exhaustion (min)	8.13 ± 2.06	9.03 ± 1.86*	7.87 ± 3.13	8.97 ± 3.20*
Respiratory exchange ratio	1.22 ± 0.03	1.24 ± 0.03	1.19 ± 0.02	1.21 ± 0.01
Peak heart rate (bpm)	187 ± 2	184 ± 4	186 ± 4	190 ± 3
Body fat percentage (%)	23.38 ± 4.42	22.91 ± 4.01	21.96 ± 2.59	22.56 ± 2.44
Fat mass (kg)	17.87 ± 4.24	17.63 ± 4.00	14.41 ± 2.02	14.87 ± 1.94
Fat free mass (kg)	55.54 ± 3.71	57.79 ± 3.43	51.20 ± 4.64	51.15 ± 4.58

Note: *$p < 0.05$ when compared to baseline

bpm = beats per minute; HIIT = high-intensity interval training; MICT = moderate-intensity continuous training; SD = standard deviation; VO_2peak = peak oxygen consumption.

Of the 20 participants, only nine participants (HIIT: n = 4; MICT: n = 5) achieved adequate accelerometer wear time for their data to be used in the analyses. Accelerometer data was not included for eleven participants due to technological difficulties (n = 3), illness (n = 1), and not meeting the wear time requirements (i.e., at least 10 hours of waking data on three days; n = 7). On average, participants engaged in 74.0 ± 37.5 minutes·day^{-1} of moderate-to-vigorous physical activity and spent 495.0 ± 107.5 minutes·day^{-1} in sedentary behaviors at baseline. For sedentary behavior, there was no effect of time (p = 0.88), training group (p = 0.53), or interaction between time and training group (p = 0.40). Additionally, for moderate-to-vigorous physical activity levels there was no effect of time (p = 0.61), training group (p = 0.74), or interaction (p = 0.47).

Psychological Responses to Training

Within-session psychological responses to training. One participant was unable to complete the last week of the training intervention due to scheduling issues; therefore, 19 participants were included in the analyses for within-session psychological variables. There were no significant differences in the Δ affect within a session (p = 0.48) or end of exercise affect (p = 0.65), after controlling for initial affect score and sex, across the six-week intervention (see Figure 1). There were also no significant differences observed in the Δ in-task enjoyment scores (p = 0.20) or end of exercise in-task enjoyment scores (p = 0.28) across the training intervention. However, there was a slight, but not significant, decrease in Δ in-task enjoyment across a training session from week one to week three of the training intervention (week one: -0.42 ± 0.79; week three: -0.05 ± 0.86 see Figure 2). There were no significant group differences in the Δ affect (p = 0.05), end of exercise affect ($p = 0.06$), Δ in-task enjoyment ($p = 0.65$), or end of exercise in-task enjoyment ($p = 0.65$).

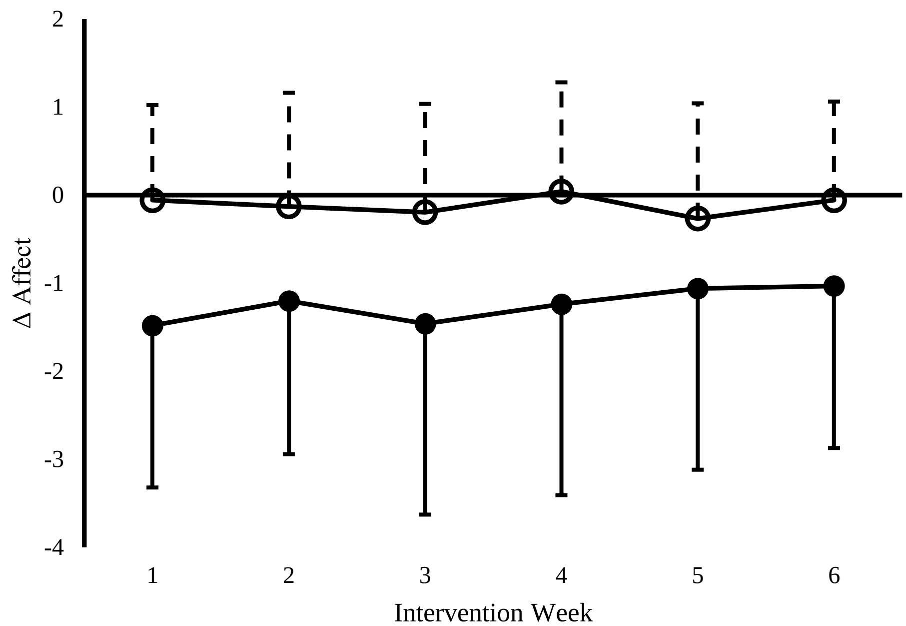

Figure 1. Change in affect within a training session across the intervention for high-intensity interval training (closed circles, solid line) and moderate-intensity continuous training (open circles, dashed line), $p > 0.05$.

Across-session psychological responses to training. No significant differences in post-exercise enjoyment were observed during the supervised portion of the exercise intervention (i.e., week one to week three; $p = 0.07$). However, post-exercise enjoyment significantly decreased from midpoint to the end of the training intervention during unsupervised training ($p = 0.003$; see Figure 3). There were no significant differences in post-exercise enjoyment between week one and week six ($p > 0.99$). Additionally, there was a significant interaction between time and training group ($p = 0.02$). There were no significant differences in post-exercise enjoyment between training groups ($p = 0.79$).

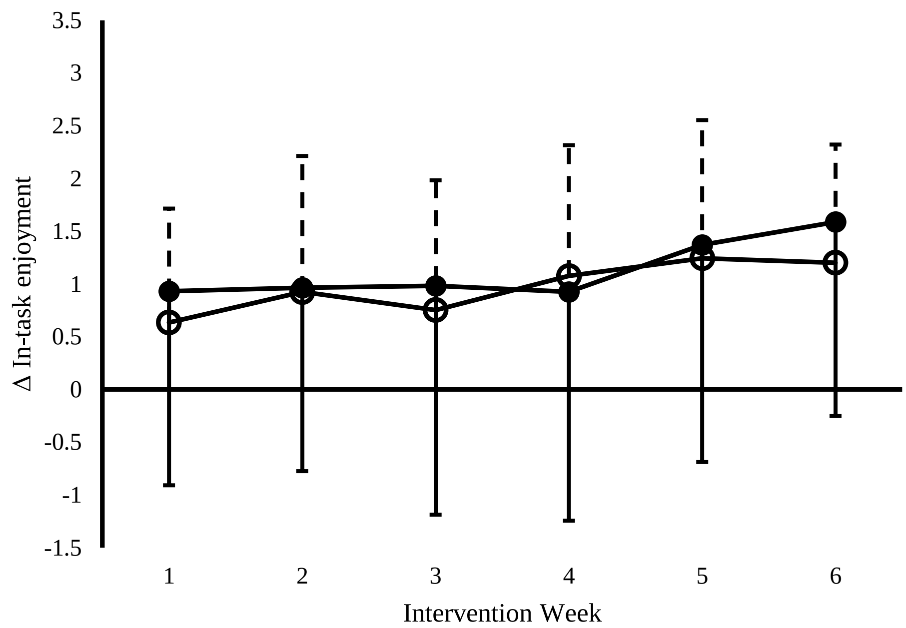

Figure 2. Change in in-task enjoyment within a training session across the intervention for high-intensity interval training (closed circles, solid line) and moderate-intensity continuous training (open circles, dashed line), $p > 0.05$.

Alternatively, perceived competence scores significantly improved from week one (4.7 ± 0.2) to week three (5.4 ± 0.1; $p = 0.01$) and week six (5.2 ± 0.2; $p = 0.03$). There was no significant difference between week three and week six ($p = 0.18$). No significant group differences were observed in perceived competence scores ($p = 0.67$). Further, there were no significant main effects of time ($p = 0.07$), training group ($p = 0.40$) or interaction ($p = 0.77$) for task-self-efficacy across the training intervention (see Figure 4).

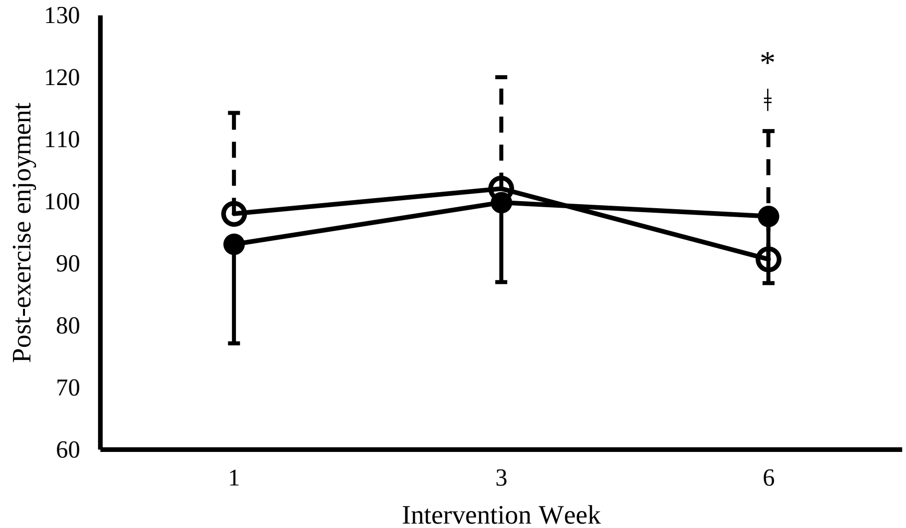

Figure 3. Post-exercise enjoyment across the training intervention for high-intensity interval training (closed circles, solid line) and moderate-intensity continuous training (open circles, dashed line). *Significantly different from week 3, $p = 0.003$ ǂSignificantly different between training groups, $p = 0.02$

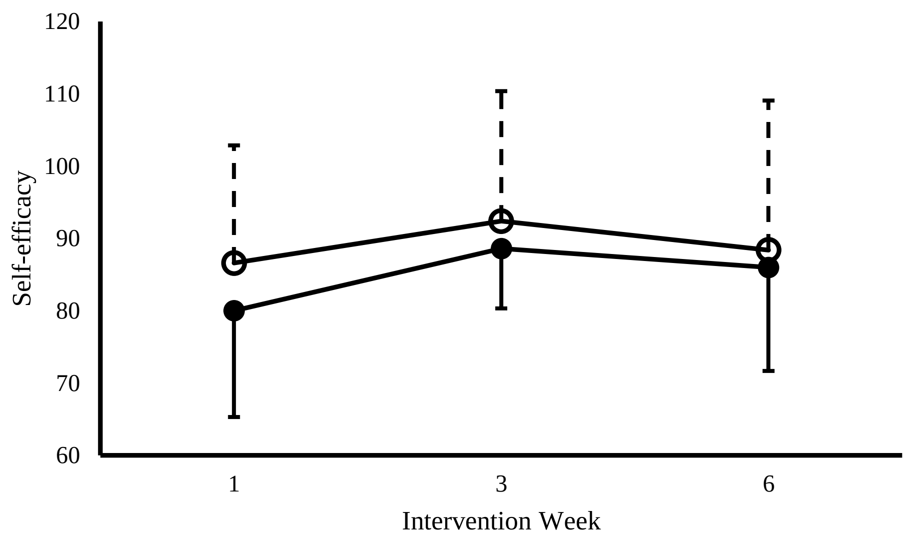

Figure 4. Task self-efficacy across the training intervention for high-intensity interval training (closed circles, solid line) and moderate-intensity continuous training (open circles, dashed line), $p > 0.05$.

Chapter 5: Discussion

The aim of this study was to determine the effects of six weeks of HIIT and MICT on physiological responses to training such as cardiorespiratory fitness, body composition, physical activity levels and sedentary behavior levels in previously inactive, young adults. Further, we aimed to determine the effects of six weeks of HIIT and MICT on psychological responses to training, such as affect, enjoyment, perceived competence, and self-efficacy. Our findings demonstrated that six weeks of training improved VO_2peak and peak power output; however, training protocol (i.e., HIIT versus MICT) did not significantly impact this change. This suggests that six weeks of structured physical activity in previously inactive adults may improve cardiorespiratory fitness, independent of training type. Therefore, in terms of promoting physical activity participation and adherence, it may be beneficial to let other factors, such as psychological responses to exercise, guide the choice in training type. Our findings indicate there were no significant differences in within-session psychological variables (i.e., affect and in-task enjoyment) across the training intervention or between the training groups. However, perceived competence significantly improved during supervised training (i.e., weeks one to three), while post-exercise enjoyment significantly decreased during unsupervised training (i.e., weeks three to six). There were also no significant differences between the training groups for any across-session psychological variables. These findings suggest that although participant's perceptions of training during exercise did not change over the six-week training intervention, their perceptions of the training after the completion of exercise may have differed. Further, at the end of the intervention, participants in the HIIT training group reported significantly higher enjoyment scores compared to those in the MICT group. These findings suggest that HIIT may be more enjoyable than MICT in unsupervised free-living conditions in this population.

Physiological Responses to Training

The average VO_2peak in the present study was 32.3 ± 6.3 ml·kg^{-1}·min^{-1} for women and 41.5 ± 5.2 ml·kg^{-1}·min^{-1} for men, which rank in the 30th and 25th percentiles, respectively, compared to normative data (Riebe, 2018). The present study found an overall increase of approximately 7% (2.8 ml·kg^{-1}·min^{-1}) in VO_2peak and 9% (20 watts) in peak power output with no between-group differences. This supports previous research that has demonstrated significant improvements in cardiorespiratory fitness, between 6% and 8%, during a period of HIIT or MICT ranging from six-weeks to 12-months in duration (Dunham & Harms, 2012; Foster et al., 2015; Heisz et al., 2016; Jung et al., 2020). Although moderate, these improvements in VO_2peak may be clinically meaningful as previous research has demonstrated that improvements in VO_2peak as little as 3.5 ml·kg^{-1}·min^{-1} are associated with a 20% decrease in the risk of cardiovascular-related mortality in healthy adults (Nes, Vatten, Nauman, Janszky, & Wisløff, 2014). In contrast, some studies have also demonstrated greater improvements in VO_2peak for HIIT compared to MICT in equivalent (Helgerud et al., 2007) or greater intervention lengths (Vella et al., 2017). However, these studies utilized different protocols or modes of exercise than the present study, which may have contributed to the differences in findings. Moreover, it is important to consider that in the current study there were comparable improvements in VO_2peak for HIIT and MICT, despite a substantially smaller time commitment for HIIT. The HIIT group trained for approximately 50% less time (25 minutes per session) compared to that of the MICT group (45 minutes per session). Therefore, our findings support previous research that suggests HIIT may be a beneficial, time-efficient alternative to traditional MICT, particularly for previously inactive individuals.

However, despite changes in cardiorespiratory fitness, there were no significant changes in moderate-to-vigorous physical activity or sedentary behavior levels during the training intervention. HIIT has previously been shown to improve cardiorespiratory fitness (Gibala et al., 2012) and improve cardiometabolic health (Cuddy et al., 2019; Weston et al., 2014); yet, it may not be an efficacious strategy to increase moderate-to-vigorous physical activity and reduce sedentary behavior levels. HIIT has been suggested as a potential public health strategy to improve the current physical inactivity pandemic (Biddle & Batterham, 2015). To date, no changes have been reported for time spent in sedentary behaviors across a HIIT intervention (Bruesghini et al., 2020; Nugent et al., 2018). Our findings support this, suggesting that HIIT may not be efficacious in combating sedentary behaviors in physically inactive young adults.

Previous research has investigated the effect of HIIT on physical activity levels in a variety of populations including adolescents (Costigan et al., 2018), older adults (Bruesghini et al., 2020), and overweight-to-obese adults (Jung et al., 2020; Nugent et al., 2018). The findings from these studies demonstrate comparable increases in physical activity levels during HIIT and MICT training interventions, with a decline in physical activity following the intervention (Bruesghini et al., 2020; Costigan et al., 2018; Nugent et al., 2018). In the current study, moderate-to-vigorous physical activity and sedentary behavior levels were measured following the intervention, as opposed to during the intervention, which may have contributed to differences in findings. A decline in physical activity following a training intervention may be due to a lack of autonomy, self-efficacy, or increased barriers to exercise (Kinnafick, Thøgersen-Ntoumani, & Duda, 2014). Findings from Jung et al. (2020) demonstrated increases in physical activity up to 9-months following the combination of a two-week exercise intervention and exercise behavior counselling for HIIT and MICT. Therefore, exercise behavior counselling may be important for adherence to exercise following the intervention. Further, it may be beneficial for future research investigating physical activity and sedentary behavior levels during exercise interventions to incorporate exercise behavior counselling to support long-term adherence following the intervention.

Currently, there is a lack of consensus in the literature regarding changes in body composition over a period of HIIT (Sultana et al., 2019; Viana et al., 2019). The current findings are aligned with those of Vella et al. (2017) who found no significant changes in body composition across a period of HIIT and MICT. This may be attributed to the short length of the intervention (i.e., six- to eight-weeks), which may not be an adequate amount of time to allow for changes in body composition. Although significant changes in body composition have been demonstrated over a 12-month period of HIIT (Jung et al., 2020), these findings are inconsistent (Roy et al., 2018). Alternatively, six- to twelve-weeks of sprint interval training has shown to significantly improve body fat percentage (Macpherson, Hazell, Olver, Paterson & Lemon, 2011; Lunt et al., 2014). The intensity of the work intervals in sprint interval training tends to be substantially greater than that of HIIT, suggesting that exercise intensity may be an important factor for body composition. Additionally, our findings should be interpreted with caution relating to body composition as dietary intake was not monitored in the current study. Previous research has suggested that dietary changes combined with exercise, improve body composition more than exercise alone (Pederson et al., 2019; Volpe, Kobusingye, Bauluir, & Stanek, 2009).

Psychological Responses to Training

Within-session psychological responses to training. Findings from the current study indicate that within-session affect declined for HIIT and remained relatively stable for MICT across the intervention; although, the difference in affective responses were not significantly different between training groups. Despite the decline in affect during HIIT, affect at the end of exercise remained positive for both HIIT and MICT. Previous research aligns with our findings by demonstrating a significantly greater decline in affect during HIIT than MICT (Decker & Ekkekakis, 2017; Niven et al., 2018; Olney et al., 2018; Stork et al., 2018; Thum et al., 2017). Although there is some variance in the findings, as little or no difference in affect between HIIT and MICT have also been reported (Alicea, Parrott, Manos & Kwon, 2020; Kilpatrick et al., 2015). The decrease in affect observed in the current study during HIIT compared to MICT is likely attributed to the overall higher relative exercise intensity of the HIIT protocol (i.e., HIIT: 85% age-predicted maximum heart rate; MICT: 71% age-predicted maximum heart rate). According to the Dual Mode Theory, at exercise intensities above the ventilatory threshold, such as those commonly experienced during HIIT, affect responses are driven primarily by interoceptive cues such as respiration (Niven et al., 2020). While at exercise intensities below the ventilatory threshold, such as traditional MICT, cognitive parameters, such as self-efficacy, play a more influential role in affect (Niven et al., 2020). However, the Dual Mode Theory was developed using affective responses to continuous exercise and therefore should be applied to HIIT with caution (Jung, Little, & Batterham, 2015). Interestingly, we found no significant differences in affect responses across the six-week training intervention. To our knowledge there is currently only one other study that has investigated affect across a period of HIIT (Bottoms et al., 2019). Bottoms et al. (2019) found no significant differences in end of exercise affect values across 12-weeks of HIIT and MICT in individuals with Crohn's disease. More research is needed to understand affect responses across a HIIT intervention in free-living settings.

There were no significant differences with regards to in-task enjoyment across the training intervention between HIIT and MICT. This finding contrasts previous research which has found interval exercise to be more enjoyable when compared to continuous exercise (Martinez et al., 2015; Kilpatrick et al., 2015). Training duration may be a consideration for in-task enjoyment as the MICT protocol in the present study was more than double the time commitment of the 20-minute protocol utilized by Martinez et al. (2015) and Kilpatrick et al. (2015). In-task exercise enjoyment remained relatively constant across training for both HIIT and MICT in the present study. This is supported by research by Martinez et al. (2015) who found that in-task exercise enjoyment was stable for HIIT protocols with a 1:1 work-to-rest ratio and intervals 1-minute or shorter in length, such as the protocol utilized in the present study. Alternatively, in-task enjoyment significantly declined for HIIT protocols with longer intervals (i.e., 2-minute intervals) and vigorous-intensity continuous exercise (Martinez et al., 2015). This suggests the length and intensity of the protocol may be important factors in the change in affect across a single exercise bout.

Across the training intervention, we observed an 11% increase in in-task exercise enjoyment through supervised training followed by a 17% decrease during unsupervised training. This contradicts findings from Foster et al. (2015) who observed a significant decline in in-task exercise enjoyment across an eight-week supervised intervention for HIIT and MICT. However, Foster et al. (2015) did not report when enjoyment was measured during exercise, which can make direct comparisons difficult. Further, Foster et al. (2015) utilized HIIT protocols with shorter, more intense work intervals compared to the protocol in the current study, which may have influenced participant's enjoyment levels. Alternatively, Smith-Ryan (2017) found that in-task exercise enjoyment increased significantly across a three-week supervised training intervention in overweight and obese adults. Smith-Ryan (2017) utilized similar HIIT protocols to the current study; however, enjoyment was only measured prior to and immediately following exercise. Therefore, the research suggests that intensity and duration of HIIT and MICT protocols may be important factors related to in-task enjoyment. Future research is important to investigate the effects of protocol parameters, such as intensity, duration, and work-to-rest ratio, on in-task enjoyment in both laboratory and free-living training settings.

Across-session psychological responses to training. Our findings show a nonsignificant increase in post-exercise enjoyment across supervised training (i.e., week one to week three) for both HIIT and MICT. However, during unsupervised training post-exercise enjoyment was maintained for HIIT and decreased to slightly below baseline for MICT. These findings are similar to those of Heisz et al. (2016) who demonstrated an increase in post-exercise enjoyment of HIIT across six weeks of supervised training in physically inactive, young adults, with no change in enjoyment of MICT. The decrease in enjoyment of MICT in the current study may be attributed to the change in training setting at the midpoint of the training intervention (i.e., supervised to unsupervised training). This suggests that post-exercise enjoyment of HIIT and MICT may be influenced by training environment in physically inactive adults. Alternatively, Vella et al. (2017) found no significant differences between enjoyment of HIIT and MICT across an eight-week training intervention. Although Vella et al. (2017) utilized a similar study design to the present study (i.e., included supervised and unsupervised training), they did not measure enjoyment at the end of the supervised training period making it difficult to compare results. The majority of research investigating enjoyment of HIIT has been conducted completely (Bartlett et al., 2010; Bottoms et al., 2019; Heisz et al., 2016; Oliveria et al., 2013; Thum et al., 2017) or partially in laboratory-based settings (Vella et al., 2017). This limits the application of the research to the general population and reduces the ecological validity necessary to generalize the findings to public health. Therefore, future research should aim to strengthen our understanding of enjoyment of HIIT across differing exercise settings, particularly as enjoyment has been positively associated with exercise adoption and adherence (Burn & Niven, 2019; Dishman et al., 2005).

A novel finding of the current study is that perceived competence improved significantly during three weeks of supervised HIIT and MICT. This is the first study, to our knowledge, that has investigated perceived competence of HIIT compared to MICT across a training intervention. It is important to note that although perceived competence did not increase during unsupervised training, the improvement from the supervised training was maintained. Therefore, it may be beneficial to provide individuals with support when beginning a training program to help facilitate improvements in perceived competence. This has important implications as perceived competence is one of the central tenets of the self-determination theory (Deci & Ryan, 2000), and has been positively associated with exercise adherence (Vlachopoulos & Neikou, 2007) as well as increased physical activity levels (Fortier et al., 2007; Markland & Tobin, 2010). According to the self-determination theory, an individual will be motivated to complete a task if their needs for competence, autonomy and relatedness are met (Deci & Ryan, 2000).

The mechanism for the observed increase in perceived competence in this intervention is unknown; however, we hypothesize it may be attributed to several factors. First, participants may have felt more capable after three weeks of training due to familiarity with the training modality. Although over half of the participants had some experience with HIIT prior to training, few participants expressed they had regularly cycled prior to the study which may have influenced their perceived competence. This is supported by Kinnafick et al. (2018) who found that adults participating in a 10-week, group-based HIIT intervention experienced increases in perceived competence through learning a new training modality. Additionally, training may have started to feel ‘easier’ to participants after three weeks due to short-term physiological training adaptations, such as increases in oxidative enzymes (Little et al., 2010). However, there was no additional increase in competence during the unsupervised training portion, which we would expect if training adaptations were the primary mechanism. This suggests that having an investigator present to oversee the supervised training sessions may have played a role in the improvement in perceived competence across the first three weeks of training. Previous research has shown that an exercise instructor may positively influence an individual's perception of social support during group-based HIIT (Kinnafick et al., 2018). Although the current study did not involve an exercise instructor, having an investigator oversee the training sessions may have influenced competence by satisfying the need for relatedness through social facilitation.

Task self-efficacy scores remained relatively constant over the training intervention, with a marginal increase noted at the midpoint of the training intervention. This supports previous research that demonstrated no significant differences in task self-efficacy scores between HIIT and MICT (Jung et al., 2014; Locke et al., 2018). Further, Locke et al. (2018) found an increase in task self-efficacy across a two-week supervised HIIT and MICT intervention, but this increase was not maintained during free-living training. This suggests that participants may be more confident in their ability to complete HIIT and MICT in supervised settings. However, self-regulatory efficacy, which is a form of self-efficacy that involves an individual's confidence to carry out self-management behaviors (Locke et al., 2018), was not monitored in our study. Therefore, it is unknown whether the increase in confidence to complete an exercise session observed in our study was supported by confidence to overcome perceived barriers to engaging in exercise. Additionally, previous research has suggested that age may influence task self-efficacy scores with regards to HIIT (Poon et al., 2018). Poon et al. (2018) found significantly lower task self-efficacy scores for HIIT in middle-aged men when compared to MICT, but no differences for active young men. Therefore, the age of the participants in the present study (i.e., young adults) may have influenced the findings with regards to self-efficacy. Self-efficacy is an important consideration with regards to HIIT as it has been associated with enjoyment of exercise (Hu et al., 2007) and may therefore, indirectly influence exercise adherence.

Applications

With the growing popularity of HIIT over recent years (Thompson, 2018), there has been increased interest in the application of HIIT in public health (Biddle & Batterham, 2015; Gray, Ferguson, Birch, Forrest, & Gill; 2016; Stamatakis et al., 2019). Although research has begun to investigate HIIT in a ‘real-world’ setting, most previous research has examined acute bouts of HIIT (Bartlett et al., 2011; Decker & Ekkekakis, 2017; Jung et al., 2014; Kilpatrick et al., 2015; Thum et al., 2017) and been conducted in laboratory settings (Bartlett et al., 2011; Niven, Thow, Holroyd, Turner, & Phillips, 2018; Oliveria, Slama, Deslandes, Furtado, & Santos, 2013) which limits the generalizability of the findings in terms of public health policy. By examining HIIT over a period of weeks, partially in free-living conditions, we sought to work towards a better understanding of the potential use of HIIT for public health.

Physiological applications. Many studies, including our current findings, have demonstrated that HIIT improves cardiorespiratory fitness to an equal or greater extent when compared to MICT (Cuddy et al., 2019; Gibala et al., 2012; Milanović et al., 2015). This is an important public health outcome as cardiorespiratory fitness has been inversely related to risk of cardiovascular disease and all-cause mortality (Kodama et al., 2009). This suggests that HIIT may have the potential to make a positive impact on the public health of a nation. However, we did not find any significant improvements in body composition, physical activity, or sedentary behavior levels across the six-week intervention for HIIT or MICT. More research is needed to determine the effect of HIIT on physical activity and sedentary behavior levels in physically inactive adults. Although it is unknown whether physical activity or cardiorespiratory fitness levels are more important for health outcomes (Blair, Cheng, & Holder, 2001), HIIT should support improvements in both physical activity and cardiorespiratory fitness levels to be an effective public health strategy to promote physical well-being.

Psychological applications. With increased interest surrounding HIIT, some individuals have questioned the practicality and adherence rates of HIIT due to its challenging nature (Biddle and Batterham, 2015; Hardcastle et al., 2014). Opponents of HIIT argue that the health benefits of this training modality will only be beneficial if the general public regularly participates in it (Hardcastle et al., 2014). While this is true, our findings suggest good adherence to HIIT when compared to adherence to MICT. Moreover, psychological variables that influence exercise adherence such as affect, enjoyment, self-efficacy, and perceived competence were investigated in this study, in an effort to better understand contributors to adherence.

Our findings indicate affect, defined as a visceral emotional response, declined slightly more during HIIT when compared to MICT. Affect during exercise has been directly related to physical activity behavior (Rhodes & Kates, 2015). Therefore, it has been suggested that a more negative affect during HIIT, when compared to MICT, may negatively impact adherence to HIIT (Decker & Ekkekakis, 2017). Though the implications of affect responses to HIIT are not currently well understood (Niven et al., 2020). Our findings suggest that enjoyment, perceived competence, and self-efficacy of HIIT were comparable to that of MICT. Enjoyment, perceived competence and self-efficacy have all been shown to be positively correlated with engagement in physical activity (Dishman et al., 2005; Edmunds et al., 2006; Trost et al., 2002). Further, enjoyment, perceived competence, and self-efficacy tended to increase across three weeks of supervised training. Perceived competence was the only variable that maintained this increase across unsupervised training for both HIIT and MICT. Enjoyment and self-efficacy returned to baseline at the end of unsupervised training. These findings suggest that psychological constructs related to adherence may change as individuals gain more experience with HIIT or with the training environment (i.e., supervised versus unsupervised). Therefore, it may be beneficial to provide physically inactive individuals with education on HIIT and social support when beginning a HIIT regime to facilitate adoption and adherence. Particularly as initial improvements in perceived competence were maintained when participants were exercising on their own.

Overall, there is still a substantial amount of research that needs to be conducted to determine if HIIT is an efficacious public health strategy. More long-term studies examining HIIT in ‘real-world’ conditions, such as home, work, and community settings, are needed to determine the feasibility of this training modality. Additionally, it may be beneficial for future research to examine adherence to combined HIIT and MICT training compared to HIIT or MICT alone. HIIT was not originally developed as a standalone training method but a supplement to regular training. Yet, little research has investigated the efficacy of combined training (i.e., HIIT and MICT) on health outcomes (Roxburgh, Nolan, Weatherwax, & Dalleck, 2014), physical activity levels, and psychological variables. Although there is not one exercise modality that will work the best for everyone, our findings suggest HIIT may be a beneficial public health tool to promote physical activity and fitness in previously inactive, young adults.

Strengths and Limitations

The study has many strengths including investigating enjoyment and affect in free-living conditions, the use of gold standard measures for cardiorespiratory fitness and body composition, measures of physical activity and sedentary behavior using wearable technology, familiarizing participants with psychological scales, and using heart rate and rating of perceived exertion as manipulation checks. Psychological variables including affect and enjoyment were measured throughout each training session, which is also a strength of the current study. Further, this is the first study to our knowledge to investigate perceived competence with regards to HIIT.

However, this study is not without limitations. Namely, this study lacks a non-exercise control group which increases the risk of bias through the Hawthorne effect (McCambridge, Witton, & Elbourne, 2014). The decision to utilize two exercise training groups was informed by the research question comparing physiological and psychological variables between HIIT and MICT across six weeks of training. In this way, we were able to determine the relative effects of supervised and unsupervised HIIT as compared to traditional MICT. Additionally, the HIIT and MICT protocols used in this study were not matched for time or energy expenditure which is a limitation. However, the shorter duration for the HIIT protocol highlights the acknowledged benefit of this training compared to traditional MICT (i.e., overcoming the commonly perceived time barrier for exercise with a reduced time commitment). Further, the training intervention was short in overall duration, with only six weeks of training, which may not be sufficient time to see changes in physiological and psychological responses to training. Last, moderate-to-vigorous physical activity and sedentary behavior levels were measured using triaxial accelerometers for three days prior to and following the training intervention. The measurement of physical activity and sedentary behavior following the intervention does not allow us to determine the effect of the intervention itself on activity levels. Further, the short wear period made it difficult to obtain sufficient valid wear time for participants, which limited the sample size for these outcome variables.

Conclusions

Our findings demonstrated that six weeks of HIIT and MICT resulted in comparable improvements in cardiorespiratory fitness in previously inactive, young adults. This suggests that with similar physiological outcomes between protocols, psychological responses may be important to predict future exercise adherence. Further, post-exercise enjoyment values changed across the training intervention suggesting that enjoyment is a dynamic construct. This highlights the importance of determining psychological responses over a period of training and in free-living settings, as both may influence how individuals perceive HIIT and MICT. Additionally, perceived competence increased during supervised training suggesting that it may be important to provide individuals with support at the beginning of a new training program to promote exercise adherence. However, there was inter- and intra-individual variability in within-session psychological responses to training indicating that perception of training may depend on individual factors such as preference and enjoyment. In conclusion, the findings from the current study suggest that HIIT is an enjoyable alternative to traditional MICT in previously inactive, young adults, but there is no one-size fits all exercise prescription. Therefore, individuals should explore different combinations of HIIT and MICT to optimize their exercise enjoyment and adherence.

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Appendix One: Accelerometer Log

Accelerometer Log

Participant: ___________________________________

Your next visit is scheduled for ____________________ at the Jack R. Leighton Human Performance Lab.

If you have any questions please contact Emily Dunston at emilydunston@eagles.ewu.edu or 425-280-4099

- You should wear the accelerometer on the front portion of your right hip with the black 'button' facing upwards. You can shift the accelerometer if needed during sleep.
- The accelerometer should be worn at all times, except for any activities involving water (i.e., showering, swimming, etc.).
- You can add your own codes in as necessary if your activity does not fit into one of the premade categories

Accelerometer Activity Codes													
S	Sleeping	5	Running (hard)	13	Swimming (hard)	21	Weight lifting (hard)	29	Ice hockey	37	Cleaning
L	Lying down	6	Stretching	14	Flag football	22	Golf	30	Climbing	38	Sitting
G	Grooming	7	Yoga	15	Volleyball	23	Archery	31	Zumba	39	Studying
C	In Class	8	Cycling (light)	16	Basketball	24	TRX	32	Table tennis		
1	Walking (easy)	9	Cycling (hard)	17	Badminton	25	Pilates	33	Skiing		
2	Brisk walking	10	Elliptical	18	Soccer	26	Rowing (indoors)	34	Driving		
3	Running (easy)	11	Dancing	19	Tennis	27	Rowing (outdoors)	35	Cooking		
4	Running (moderate)	12	Swimming (easy)	20	Weight lifting (easy)	28	Ice skating	36	Reading		

		EXAMPLE ACTIVITY LOG										Date: 10/19/19
		:00	:15	:30	:45			:00	:15	:30	:45	
AM	12:00	S →			→	PM	12:00	34	1	1	34	Wake: 7:00 am
	1:00	→			→		1:00	C	C	C	C	On:
	2:00	→			→		2:00	C	C	C	C	Off: 9:15 pm
	3:00	→			→		3:00	1	4	4	4	On: 9:45 pm
	4:00	→			→		4:00	6	1	35	35	Off:
	5:00	→			→		5:00	38	38	38	38	On:
	6:00	→			→		6:00	36	36	36	36	Off:
	7:00	G	G	G	1		7:00	36	36	37	37	On:
	8:00	C	C	C	C		8:00	38	38	38	L	Off:
	9:00	C	C	C	C		9:00	L			G	On:
	10:00	1	38	38	38		10:00	S	→		→	Off:
	11:00	38	38	1	1		11:00	→			→	Sleep: 10:00 pm

Structured Exercise Description:

35 minute run plus a 5 minute warm up and a 5 minute cool down followed by 15 minutes of stretching

Comments:
Removed accelerometer from 9:15-9:45 pm for shower

		DAY 1										Date:
		:00	:15	:30	:45			:00	:15	:30	:45	
AM	12:00					PM	12:00					Wake:
	1:00						1:00					On:
	2:00						2:00					Off:
	3:00						3:00					On:
	4:00						4:00					Off:
	5:00						5:00					On:
	6:00						6:00					Off:
	7:00						7:00					On:
	8:00						8:00					Off:
	9:00						9:00					On:
	10:00						10:00					Off:
	11:00						11:00					Sleep:

Structured Exercise Description:

Comments:

		DAY 2										Date:
		:00	:15	:30	:45			:00	:15	:30	:45	
AM	12:00					PM	12:00					Wake:
	1:00						1:00					On:
	2:00						2:00					Off:
	3:00						3:00					On:
	4:00						4:00					Off:
	5:00						5:00					On:
	6:00						6:00					Off:
	7:00						7:00					On:
	8:00						8:00					Off:
	9:00						9:00					On:
	10:00						10:00					Off:
	11:00						11:00					Sleep:
Structured Exercise Description:												
Comments:												

		DAY 3										Date:
		:00	:15	:30	:45			:00	:15	:30	:45	
AM	12:00					PM	12:00					Wake:
	1:00						1:00					On:
	2:00						2:00					Off:
	3:00						3:00					On:
	4:00						4:00					Off:
	5:00						5:00					On:
	6:00						6:00					Off:
	7:00						7:00					On:
	8:00						8:00					Off:
	9:00						9:00					On:
	10:00						10:00					Off:
	11:00						11:00					Sleep:
Structured Exercise Description:												
Comments:												

Appendix Two: HIIT Training Log

Training Log

Participant: ________________________________

Your next visit is scheduled for _____________________ at the Jack R. Leighton Human Performance Lab.

Please record your heart rate, rating of perceived exertion, enjoyment, and affect scores at three time points during each training session. The scales for each measure are attached for your reference.

If you have any questions please contact Emily Dunston at emilydunston@eagles.ewu.edu or 425-280-4099

Exercise Enjoyment Scale:

Use the following scale to indicate how much you are enjoying this exercise session.

7	Extremely
6	Very much
5	Quite a bit
4	Moderately
3	Slightly
2	Very little
1	Not at all

Rating of Perceived Exertion:

0	Nothing at All
1	Very Weak
2	Weak (light)
3	Moderate
4	Somewhat Strong
5	Strong (heavy)
6	
7	Very Strong
8	
9	
10	Extremely Strong (almost max)

Feeling Scale (Affect):

While participating in exercise, it is common to experience changes in mood. Some individuals find exercise pleasurable, whereas others find it to be unpleasant. Additionally, feeling may fluctuate across time. That is, one might feel good and bad a number of times during exercise. Scientists have developed this scale to measure such responses.

+5	Very Good
+4	
+3	Good
+2	
+1	Fairly Good
0	Somewhat Strong
-1	Fairly Bad
-2	
-3	Bad
-4	
-5	Very Bad

Week 4: Session 1		**Date: _______________**	**Time: _____________**
	Rest Interval 1	Rest Interval 5	Rest Interval 10
Heart Rate			
RPE			
Enjoyment			
Affect			
Notes:			

Week 4: Session 2		**Date: _______________**	**Time: _____________**
	Rest Interval 1	Rest Interval 5	Rest Interval 10
Heart Rate			
RPE			
Enjoyment			
Affect			
Notes:			

Week 4: Session 3		**Date: _______________**	**Time: _____________**
	Rest Interval 1	Rest Interval 5	Rest Interval 10
Heart Rate			
RPE			
Enjoyment			
Affect			
Notes:			

Week 5: Session 1		**Date: ______________**	**Time: ____________**
	Rest Interval 1	Rest Interval 5	Rest Interval 10
Heart Rate			
RPE			
Enjoyment			
Affect			
Notes:			

Week 5: Session 2		**Date: ______________**	**Time: ____________**
	Rest Interval 1	Rest Interval 5	Rest Interval 10
Heart Rate			
RPE			
Enjoyment			
Affect			
Notes:			

Week 5: Session 3		**Date: ______________**	**Time: ____________**
	Rest Interval 1	Rest Interval 5	Rest Interval 10
Heart Rate			
RPE			
Enjoyment			
Affect			
Notes:			

Week 6: Session 1		**Date: ______________**	**Time: ____________**
	Rest Interval 1	Rest Interval 5	Rest Interval 10
Heart Rate			
RPE			
Enjoyment			
Affect			
Notes:			

Week 6: Session 2		**Date: ______________**	**Time: ____________**
	Rest Interval 1	Rest Interval 5	Rest Interval 10
Heart Rate			
RPE			
Enjoyment			
Affect			
Notes:			

Week 6: Session 3		**Date: ______________**	**Time: ____________**
	Rest Interval 1	Rest Interval 5	Rest Interval 10
Heart Rate			
RPE			
Enjoyment			
Affect			
Notes:			

Appendix Three: MICT Training Log

Training Log

Participant: _________________________________

Your next visit is scheduled for ______________________ at the Jack R. Leighton Human Performance Lab.

Please record your heart rate, rating of perceived exertion, enjoyment, and affect scores at three time points during each training session. The scales for each measure are attached for your reference.

If you have any questions please contact Emily Dunston at emilydunston@eagles.ewu.edu or 425-280-4099

Exercise Enjoyment Scale:

Use the following scale to indicate how much you are enjoying this exercise session.

7	**Extremely**
6	**Very much**
5	**Quite a bit**
4	**Moderately**
3	**Slightly**
2	**Very little**
1	**Not at all**

Rating of Perceived Exertion:

0	**Nothing at All**
1	**Very Weak**
2	**Weak (light)**
3	**Moderate**
4	**Somewhat Strong**
5	**Strong (heavy)**
6	
7	**Very Strong**
8	
9	
10	**Extremely Strong (almost max)**

Feeling Scale (Affect):

While participating in exercise, it is common to experience changes in mood. Some individuals find exercise pleasurable, whereas others find it to be unpleasant. Additionally, feeling may fluctuate across time. That is, one might feel good and bad a number of times during exercise. Scientists have developed this scale to measure such responses.

+5	**Very Good**
+4	
+3	**Good**
+2	
+1	**Fairly Good**
0	**Somewhat Strong**
-1	**Fairly Bad**
-2	
-3	**Bad**
-4	
-5	**Very Bad**

Week 4: Session 1		**Date:_______________**	**Time:_____________**
	Minute 2	Minute 22	Minute 45
Heart Rate			
RPE			
Enjoyment			
Affect			
Notes:			

Week 4: Session 2		**Date:_______________**	**Time:_____________**
	Minute 2	Minute 22	Minute 45
Heart Rate			
RPE			
Enjoyment			
Affect			
Notes:			

Week 4: Session 3		**Date:_______________**	**Time:_____________**
	Minute 2	Minute 22	Minute 45
Heart Rate			
RPE			
Enjoyment			
Affect			
Notes:			

Week 5: Session 1		**Date:_______________**	**Time:_____________**
	Minute 2	Minute 22	Minute 45
Heart Rate			
RPE			
Enjoyment			
Affect			
Notes:			

Week 5: Session 2		**Date:_______________**	**Time:_____________**
	Minute 2	Minute 22	Minute 45
Heart Rate			
RPE			
Enjoyment			
Affect			
Notes:			

Week 5: Session 3		**Date:_______________**	**Time:_____________**
	Minute 2	Minute 22	Minute 45
Heart Rate			
RPE			
Enjoyment			
Affect			
Notes:			

Week 6: Session 1		**Date:_______________**	**Time:_____________**
	Minute 2	Minute 22	Minute 45
Heart Rate			
RPE			
Enjoyment			
Affect			
Notes:			

Week 6: Session 2		**Date:_______________**	**Time:_____________**
	Minute 2	Minute 22	Minute 45
Heart Rate			
RPE			
Enjoyment			
Affect			
Notes:			

Week 6: Session 3		**Date:_______________**	**Time:_____________**
	Minute 2	Minute 22	Minute 45
Heart Rate			
RPE			
Enjoyment			
Affect			
Notes:			

Appendix Four: IRB Approval

TO: Emily Dunston, Department of Physical Education, Health and Recreation

FROM: Ruth A. Galm, Human Protections Administrator

DATE: October 10, 2019

SUBJECT: Physiological and Psychological Responses to Six Weeks of High-intensity Interval and Moderate-intensity Continuous Training in Physically Inactive Young Adults (HS-5810)

With the amendments provided on October 10, 2019, human subjects protocol HS-5810 entitled “Physiological and Psychological Responses to Six Weeks of High-intensity Interval and Moderate-intensity Continuous Training in Physically Inactive Young Adults” has been approved by an expedited review.

A signed and approved copy of your application is being sent in hardcopy.

This student research qualifying for an expedited review is valid through Spring Quarter 2020. If after initial approval, the research protocol requires minor changes, the Office of Grant and Research Development should be notified of those changes. Any major departure from the original proposal must be reviewed through a Change of Protocol application submitted to the IRB before the protocol may be altered. Please refer to HS-5810 on future correspondence as appropriate as we file everything under this number.

Cc: HS-5810 file
Dr. Katie Taylor, RPI
Dr. Christi Brewer, IRB Rep.
Graduate Office

Curriculum Vita

Author: Emily Dunston

Education:

Master of Science – Exercise Science (2018-2020)
Eastern Washington University, Cheney, WA

- Major Professor: Katrina Taylor Ph.D.

Bachelor of Science – Exercise Science (2015-2018)
Eastern Washington University, Cheney, WA

- *Summa cum laude* and *ad valorem* honors
- Minor in Psychology

Awards/Honors:

- *Eastern Washington University* Department of Wellness and Movement Sciences Master's Student of the Year Award (2020)
- *American College of Sports Medicine Northwest* President's Cup Poster Competition First Runner-up (2020)
- *American College of Sports Medicine Northwest* Outstanding Master's Student Oral Presentation Award (2019)
- *Eastern Washington University* Graduate Service Teaching Assistantship (2018-2020; $17,700 over 2 years)
- *Eastern Washington University* Dean's Student Excellence Award (2018)
- *American College of Sports Medicine Northwest* Outstanding Undergraduate Research Thematic Presentation Award (2018)
- *American College of Sports Medicine Northwest* Student Recruitment & Engagement Activities using Multimedia Program Award (2018; $500)
- *Eastern Washington University* Facilitator of the Month Award (2018)
- *American College of Sports Medicine Northwest* Student Travel Award (2017; $250)
- *American College of Sports Medicine Northwest* Student Knowledge Bowl Winner (2017; $750)
- *Washington State* Opportunity Scholarship (2015-2018; $15,000 over 3 years)
- *Eastern Washington University* Honors Program Scholarship (2015-2018; $4000/yr)

Research Experience:

1. Grants

1. American College of Sports Medicine Regional Chapter Grant
   2/1/2019-12/31/2019
   ACSM Northwest Student Mentorship Program ($3000)

2. American College of Sports Medicine Northwest 2019 Student Research Grant
   10/5/2018-6/18/2019
   Psychological responses during high-intensity interval training and moderate-intensity continuous exercise as predictors of engagement. ($800)

2. Peer Reviewed Manuscripts

1. **Dunston ER,** Messina ES, Coelho AJ, Chriest SN, Waldrip MP, Vahk A, & Taylor K. (2020). Physical activity is associated with grit and resilience in college students: Is intensity the key to success?
   Impact factor 1.455

3. Published Abstracts and Conference Proceedings

1. **Dunston ER**, Coelho AJ, & Taylor K. (2020). Heart rate and rating of perceived exertion during high-intensity interval training: Implications for prescribing intensity. *Medicine & Science in Sports & Exercise.* (Accepted).
2. **Dunston ER**, Coelho AJ, & Taylor K. (2020). Measures of competency over six weeks of training: Does it pay to commit to HIIT? *International Journal of Exercise Science: Conference Proceedings* (In press).
3. Sanchez K, **Dunston E** & Brewer C. (2019). Knowledge of heart disease and indices of physical activity in health and non-health based majors. *Medicine & Science in Sports & Exercise. 51*(6).
4. **Dunston E**, Waldrip M, Chriest S, Skillingstad A, Vahk A, & Taylor K. (2019). Physical activity is associated with grit and resilience in college students: Is intensity the answer? *Medicine & Science in Sports & Exercise. 51*(6).
5. Sanchez K, **Dunston E,** & Brewer C. (2019). Knowledge of heart disease and indices of physical activity in health and non-health based majors. *International Journal of Exercise Science: Conference Proceedings. 8(7).*
6. Howard D, **Dunston E,** Hammermeister, J & Taylor K. (2019). Physical activity, sedentary behavior, and stress in graduate students: The PASS study. *International Journal of Exercise Science: Conference Proceedings. 8(7).*
7. **Dunston E**, Waldrip M, Chriest S, Skillingstad A, Vahk A, & Taylor K. (2019). Physical activity is associated with grit and resilience in college students: Is intensity the answer? *International Journal of Exercise Science: Conference Proceedings.8(7).*

8. **Dunston E**, Chriest S, Avena S, Taylor K, & Vahk A. (2018). The effect of pretest instructions and between day test-retest reliability of air displacement plethysmography. *Medicine & Science in Sports & Exercise*. *50*(S5).
9. Chriest S, **Dunston E**, Halverson S, Crusch M, Johnson B, & Taylor K. (2018). Stress, academic load, and physical activity in college students: A pilot study. *International Journal of Exercise Science*: *Conference Proceedings. 8*(6).
10. **Dunston E,** Chriest S, Avena S, Taylor K, & Vahk A. (2018). The effect of pretest instructions and between day test-retest reliability of air displacement plethysmography. *International Journal of Exercise Science: Conference Proceedings*. *8*(6).
11. **Dunston E**, Sherman J, Pederson T, Magana J, Vahk A, & Brewer C. (2017). The effects of different recovery positions post-anaerobic work in collegiate sprinters. *International Journal of Exercise Science: Conference Proceedings*. *8*(5).

4. Conference Presentations (without published abstracts):

1. **Dunston, E.** & Taylor, K. *Physical activity, stress and sedentary behavior in graduate students: The PASS study.* Congress of the European College of Sport Science, Prague, Czech Republic, July 2019 (poster).
2. **Dunston, E.**, Chriest, S., Waldrip, M., Skillingstad, A., Vahk, A. & Taylor, K. *Stepping it up: Light but not moderate-to-vigorous physical activity is associated with grit in college students.* Eastern Washington University Research Symposium, Cheney, Washington, May 2018 (oral presentation).

5. Non-Peer Reviewed Publications

1. Bennion T, Taylor K, Vahk A, **Dunston ER**. (2018). *HIITCAST 029: Health risks of sitting … even if you exercise!* [Audio podcast].

<u>Teaching Experience:</u>

- **Eastern Washington University,** Department of Wellness and Movement Sciences

Instructor of Record

PHED 125 PE Activities

Archery
Badminton
Beginning Golf
Beginning Soccer
Racquetball
Skiing and Snowboarding
Tennis

PHED 296 Physical Activity, Wellness & Behavior Change

Graduate Student Teaching Assistant

EXSC 455 Research and Analysis
EXSC 481 Electrocardiograph Interpretation
HLED 372 Applied Nutrition and Physical Fitness
HLED 374 Intro to Epidemiology
PHED 334 Personal Training
PHED 350 Physiological Kinesiology
PHED 519 Statistics in Physical Education

Undergraduate Student Teaching Assistant

EXSC 455 Research & Analysis
EXSC 481 Electrocardiograph Interpretation

Other Work Experience:

- **Scholar Lead:** Washington State Opportunity Scholarship (2018-2019)
  Job Duties: Mentor 10-15 first year undergraduate scholars as they navigate the transition to tertiary education.
- **Sports Specialist:** YMCA (Summer 2018)
  Job Duties: Plan, implement, and lead sports camp lessons and activities in camp programs serving 1st through 6th grades.
- **Physical Therapy Aide:** ProAction Physical Therapy (June 2017 to January 2018)
  Job Duties: Assist multiple physical therapists with patient care to include assisting patients with exercises, using modalities such as ice, heat, and ultrasound, and maintaining clinic cleanliness and organization.
- **Tutor/Study Group Facilitator:** EWU (January 2017 to June 2018)
  Job Duties: Provide guidance and academic assistance to undergraduate students in challenging core classes such as general chemistry, anatomy and physiology, anatomical kinesiology, physiological kinesiology and mechanical kinesiology.

Professional Memberships

- European College of Sport Sciences (2019)
- American College of Sports Medicine (2017-Present)
- American College of Sports Medicine Northwest Chapter (2016-Present)
- Eastern Washington University Exercise Science Club (2015-2020)
  - President (2016-2018)

Professional Development:

Attendance at relevant regional, national, and international conferences:

- American College of Sports Medicine Northwest Annual Meeting
  Boise, Idaho, (2020)

- European College of Sports Sciences Congress
  Prague, Czech Republic, (2019)
- American College of Sports Medicine Annual Meeting
  Orlando, Florida, (2019)
- Eastern Washington University Research Symposium
  Cheney, Washington, (2019)
- American College of Sports Medicine Northwest Annual Meeting
  Bend, Oregon, (2019)
- American College of Sports Medicine Annual Meeting
  Minneapolis, Minnesota, (2018)
- Eastern Washington University Research Symposium
  Cheney, Washington, (2018)
- American College of Sports Medicine Northwest Annual Meeting
  Bend, Oregon, (2018)
- Society for Health and Physical Educators Idaho Conference
  Lewiston, Idaho, (2017)
- American College of Sports Medicine Annual Meeting
  Denver, Colorado, (2017)
- Eastern Washington University Research Symposium
  Cheney, Washington, (2017)
- American College of Sports Medicine Northwest Annual Meeting
  Bend, Oregon, (2017)
- American College of Sports Medicine Northwest Annual Meeting
  Tacoma, Washington, (2016)

External Courses

- Essential Epidemiologic Tools for Public Health Practice (2020)

<u>Professional Service:</u>

- Undergraduate Thematic Poster Presentation Judge, ACSM Northwest Annual Meeting (2020)
- Session Moderator, ACSM Northwest Annual Meeting (2020)
- Abstract Reviewer, ACSM Northwest Annual Meeting (2020)
- Observer, ACSM Membership Committee Meeting (2019)
- Undergraduate Poster Presentation Judge, ACSM Northwest Annual Meeting (2019)
- Mentorship Luncheon Co-Organizer, ACSM Northwest Annual Meeting (2019)

Certifications:

- CITI Human Subjects in Research Training for Student Investigators (2019)
- College Reading and Learning Association Level Three: Master Certified Tutor (2018)
- American Red Cross Basic Life Support and First Aid Certified (2018)
- NIH Human Subjects Protections Training Certificate (2017)

Community Service:

- Player Adaptive Sports Skills Adaptive Soccer Volunteer (2019)
- Spokane Marathon Volunteer (2018)
- Parasport Spokane Showdown Wheelchair Basketball Tournament Volunteer (2017)
- Josephine's Caring Community Physical Therapy Volunteer (2017)
- Bloomsday Tradeshow Volunteer (2016-2019)
- EWU Employee Benefits Fair Volunteer (2016)
- EWU Harvest Fest Volunteer (2016)
- Cheney School District Physical Therapy Volunteer (2016)
- Super Science Saturday Volunteer (2015, 2016)