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Master's thesis in Exercise Physiology
Supervisor: Jan Helgerud
June 2020

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Abstract

Aim: the aim of the present study was to investigate the effect of 4 x 4 high-intensity interval training (HIIT) versus running Tabata on endurance performance and it`s determinants in moderately trained females. **Methods:** 26 healthy, non-smoking recreationally endurance trained females were randomized to complete HIIT (N=13) or Tabata (N=13) for three times a week over 8 weeks. Both modalities included treadmill running, HIIT was performed as 4x4 minutes intervals at 90-95% (HR_{max}) interspersed with 3-minute active recovery at ~70% HR_{max} between intervals. Tabata was performed as 8x20 seconds supramaximal intensity intermittent training separated with a 10 second rest. **Results:** No significant group difference was observed between groups in VO_{2max} from pre- to post testing. VO_{2max} increased by 4.2 % after HIIT (51.4-53.5 $mL·kg^{-1}·min^{-1}$), no change occurred in Tabata. Improvements in VO_{2max} was connected to a 4.1 % increase in O_2 pulse ensuing HIIT. Work economy (C) improved significantly following both HIIT and Tabata with no significant difference between the groups. Maximal accumulated oxygen deficit MAOD improved significantly 10.4% (69.4-76.0 $mL·kg^{-1}·min^{-1}$) ensuing Tabata, while changes were not significant after HIIT. 3000-meter performance was significantly improved by 4.6 % (911-870 seconds) following HIIT and 4.5% (870-830 seconds) following Tabata, with no significant difference between the groups. 300-meter performance improved significantly more after Tabata. Within groups the improvements were 2.2% (56.4-55.1 seconds) after HIIT and 5.6% (57.7- 54.3 seconds) after Tabata. **Conclusion:** Tabata is an ineffective approach to improve VO_{2max} in moderately trained females compared with HIIT. However, when evaluating anaerobic capacity as MAOD and anaerobic performance on 300-meter run Tabata were superior to HIIT.

Keyword. Maximal oxygen uptake, Lactate threshold, Work economy, Anaerobic capacity, Maximal accumulated oxygen deficit, High-intensity interval training, Tabata, Running performance

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Table of content

Abbreviations

$a\text{-}vO_{2diff}$: Arterio-venous difference

ATP: adenosine triphosphate

C: Work economy

CK: Creatine kinase

DLO_2: Pulmonary diffusion capacity

DMO_2: Muscle diffusion capacity

HR: Heart rate

HR_{max}: Maximal heart rate

LDH: Lactate dehydrogenase

LT: lactate threshold

MAOD: maximal accumulated oxygen deficit

MCT: Moderate intensity continuous training

O_2: oxygen

O_2pulse: Oxygen pulse

PCr: Phoshopcreatine

PFK: Phosphofructokinase

Q: Cardiac output

RER: Respiratory exchange rate

SEE: Standard error of estimate

SD: Standard deviation

SIT: Sprint interval training

$_{V}LT$: Velocity at lactate threshold

V_E: Ventilation

VO_2: Oxygen uptake

VO_{2max}: Maximal oxygen uptake

VO_{2peak}: Peak oxygen uptake

vVO_{2max}: Velocity at maximal oxygen uptake

$[la^-]_b$: Concentration of blood lactate

[Hb]: Concentration of hemoglobin

Introduction

Interval training is frequently used for improvements in aerobic capacity of both elite athletes and patients. Nonetheless interval training is broad term, and there are endless many ways to integrate interval training into a training plan, variables such as duration, intensity and frequency can be manipulated to alter different physiological adaptations (Buchheit & Laursen, 2013).

High intensity interval training (HIIT) of intensity at 90-95 of maximal heart rate (HR_{max}) is shown to facilitate greater improvements in maximal oxygen uptake (VO_{2max}) than moderate continuous training (MCT) as reported in recent metanalysis (Milanovic et al., 2015; Williams et al., 2019).

HIIT protocols above 85% VO_{2max} has been suggested to optimally stress the oxygen transport and utilization system, and could therefore be the most effective stimulus to improve VO_{2max} (Baker et al., 2010). This correspond with previous findings where exercise intensity is the key to elicit improvements in VO_{2max} (Bacon et al., 2013; Helgerud et al., 2007). Tabata training has become immensely popular form of interval training the last decade, and it is thought to be an extremely time efficient way to enhance cardiorespiratory fitness (Tabata, 2019; Viana et al., 2019). To find the most effective strategy for improving health and performance, different interval training interventions incorporating high intensity should be compared.

HIIT is referred to interval training at intensities above or equal to 85% VO_{2max} where intervals last more than 2 minutes. Tabata training could be classified as “supramaximal intensity intermittent training” and refers to a workout consisting of 8 intervals of 20 seconds, with 10 seconds rest between intervals, carried out at an intensity of ~170% of VO_{2max} (Tabata, 2019; Tabata et al., 1996). This thesis will not distinguish between the original Tabata modality or other closely related modalities, unless otherwise stated. The difference in duration of work and rest periods and the intensity maintained through the intervals are the main difference between Tabata and HIIT.

This investigation will compare the 4 x 4 minutes HIIT protocol in Helgerud et al. (2007) with treadmill version of the Tabata protocol in (Tabata et al., 1996). The effect and difference between these two modalities on endurance performance will be presented in the introduction. Additionally, since most studies involving HIIT or Tabata are carried out on males, we will focus on moderately trained females.

VO_{2max}, Stroke volume (SV), hemoglobin values and anaerobic capacity in females in are lower in comparison to males, explaining most of the variation in endurance performance between genders (Hill & Vingren, 2014; Shephard, 2000; Wang et al., 2012; Åstrand et al., 1964). The difference between males and females are related to smaller body size equals less muscle mass and dimension of organs (e.g lungs and heart), highlighting the need to elucidate the effect of HIIT vs Tabata in females (Bergh et al., 1991; Shephard, 2000).

1.1 Endurance performance

The three main determinants of aerobic endurance performance are (VO_{2max}), lactate threshold (LT) and work economy (C) (Pate & Kriska, 1984). The emphasis of these factors on endurance performance is well accepted (Bassett & Howley, 2000; Jones & Carter, 2000; Joyner, 1993; Joyner & Coyle, 2008; Pollock, 1977). Additionally, Joyner & Coyle (2008) have implemented anaerobic capacity, as a determinant for endurance performance (Figure 1).

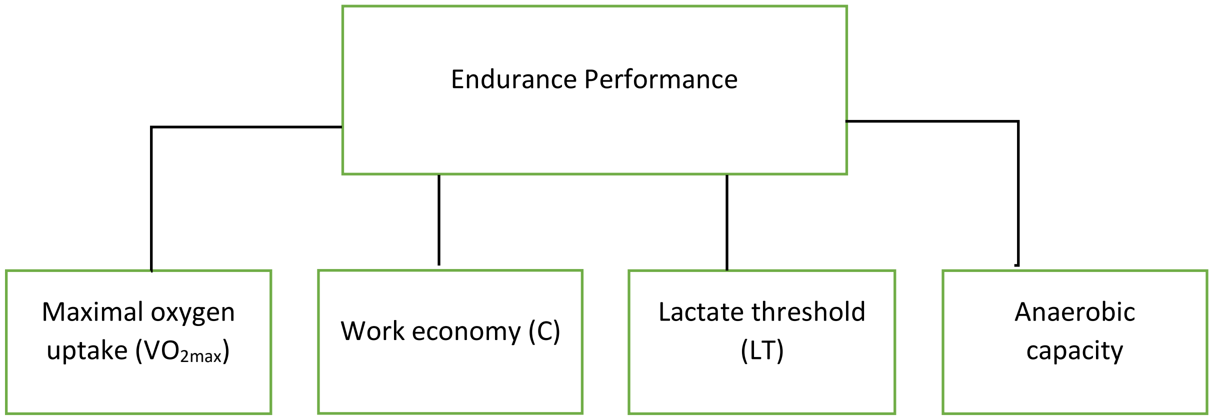

Figure 1. Model of the various factors for endurance performance adapted from Pate and Krista (1984) and Joyner and Coyle (2008).

It is well documented that HIIT leads to improved endurance performance (Cicioni-Kolsky et al., 2013; Esfarjani & Laursen, 2007). In Esfarjani and Laursen (2007) HIIT improved 3000-meter performance by 7% a significantly larger improvement than moderate intensity continuous training (MCT). Similar improvements (7.9%- 8.5%) was observed after HIIT, however the results were not significantly better than MCT (Cicioni-Kolsky et al., 2013). Additionally men and woman improved 3000-meter performance to the same extent following HIIT (Cicioni-Kolsky et al., 2013). The effect of Tabata has shown to be similar to MCT in time to exhaustion (TTE) (Schaun & Del Vecchio, 2018), and time to produce 500 kcal on a self-selected cadence (Scribbans et al., 2014b).

Endurance performance determinants

To design an appropriate interval training program it is essential to understand the energy requirements for endurance performance (Buchheit & Laursen, 2013). Muscle actions are dependent on breakdown of adenosine triphosphate (ATP). The stores of ATP are however limited, re synthesis of ATP is dependent by aerobic and anaerobic metabolic processes. Aerobic energy consumption takes place in mitochondria using oxygen (O_2), glycogen and fatty acids. Anaerobic energy breakdown occurs independent of O_2 using phosphocreatine (PCr) and glycogen through glycolysis (Åstrand & Rodal 1986, p.314; Medbo et al., 1988). The contribution of the two energy systems is highly dependent on the intensity and duration of the exercise. The aerobic energy system is the main energy supplier to maximal effort lasting more than 2 minutes, since the anaerobic energy system is inadequate in supplying ATP (Åstrand & Rodahl 1986, p.325). Baker et al. (2010) state that maximal exercise effort of 75 seconds supplies equal energy from aerobic and anaerobic energy systems. Taxing the aerobic endurance capacity should therefore be the main emphasis to improve endurance performance. Increased function of the two energy-supplying systems is an optimal way to enhance endurance performance (Ramsbottom et al., 1994)

1.2 VO_{2max}

VO_{2max} is defined as the highest rate at which oxygen can be taken up and utilized in the body during severe exercise. It is thereby considered the most important factor determining endurance performance (Bassett & Howley, 2000; Jones & Carter, 2000; Joyner & Coyle, 2008; Pate & Kriska, 1984; Weyand et al., 1994).

From the atmospheric air to the mitochondria VO_{2max} is limited by several factors, such as cardiac output (Q), hemoglobin concentration ([Hb]), ventilation (V_E), pulmonary diffusion capacity (DLO_2) and muscle diffusion capacity (DMO_2) (Wagner, 1996). However, as suggested in Wagner (1996) at sea level Q alone limits VO_{2max} to the same extent as [Hb], DLO_2 and DMO_2 together. This are in line with evidence from Richardson et al. (2000), Wagner, (2000), and di Prampero, (1985) showing that VO_{2max} is most limited by oxygen supply and not oxygen demand, in healthy humans performing maximal whole-body exercise at sea level. O_2 supply is referred to the cardiovascular systems ability to transport O_2, while O_2 demands refers to the mitochondria's capacity to utilize oxygen it is supplied with.

The heart ability to pump blood to tissues and vital organs refers to cardiac output (Q). Contractility force of the heart and blood flow plays an important role in supplying O_2 to the working tissues. The crucial factor distinguishing individuals in VO_{2max} and performance level is Q (Wang et al., 2012; Zhou et al., 2001), about 75% of VO_{2max} is thought to be determined by Q in healthy people at sea-level (di Prampero, 1985). Q is determined by stroke volume (SV) and heart rate (HR). (HR_{max}) does not change by training (Blomqvist & Saltin, 1983), thereby SV is the major factor determining Q (Helgerud et al., 2007; Wang et al., 2012). SV is determined by myocardial contractility, volume of the heart (especially the left ventricle), and capacity of refilling the heart with blood (Jones & Carter, 2000; Zhou et al., 2001). Rate of ventricular emptying and ventricular filling are 20% and 71% greater in trained versus untrained respectively, at approximately HR_{max} in both groups. (Gledhill et al., 1994). A chronic adaptations following prolonged endurance training seems to increase the thickness of the posterior and septal walls of the left ventricle resulting in bigger force contractions at high intensities and could explain the superior ejection fraction (Gledhill et al., 1994). Additional it is crucial to elicit exercise intensity close to VO_{2max}, as it overloads the diastolic stretch and ventricular emptying due to enhance afterload of the blood in the heart (Cooper, 1997). Increase in Q reflects a central cardio-circulatory adaptations (Daussin et al., 2007).

Fick equation (VO_2= Q (SV・HR)・a-vO_{2diff}) describes the connection between Q and arterio-venous difference (a-vO_{2diff}) on VO_2, every adaption influencing VO_{2max} must be reflected by a change in Q and/or a-vO_{2diff} (Barrett-O'Keefe et al., 2012; Montero et al., 2015) . a-vO_{2diff} reflects the skeletal muscle and mitochondria's ability to extract and utilize O_2 it is supplied with. This is expressed by the difference between O_2 saturation of arterial blood and mixed venous blood, and is thought to be a peripheral adaptation to training (Daussin et al., 2007; Macpherson et al., 2011). Enhanced oxygen carrying capacity of the blood, increased blood volume, and improved heart function could be displayed by a wider a-vO_{2diff} (Daussin et al., 2007; Daussin et al., 2008). In athletes with high Q reduced maximal a-vO_{2diff} is observed due to reduced transit times in the muscle and pulmonary capillaries (Saltin & Calbet, 2006; Wang et al., 2012; Zhou et al., 2001).

In recreationally trained individuals the capacity of mitochondria to utilize O_2 exceed the O_2 supply throughout whole-body work (Bassett & Howley, 2000; Richardson et al., 2000; Saltin & Calbet, 2006; Wagner, 2000). In untrained the relationship is opposite as excess supply of oxygen (hyperoxia) does not improve VO_2, evidence that DMO_2 is the limiting factor (Helgerud et al., 2009; Wang et al., 2008). A meta-analysis by Montero et al. (2015) state that Q and not a-vO_{2diff} are associated with the increase in VO_{2max} because of endurance training. However, in

Jacobs et al. (2013), and Macpherson et al. (2013) increase in VO_{2max} was not attributed SV, but increased a-$vO_{2diff.}$ A certain exercise volume is necessary to increase central capacity, while supramaximal intensity targets the peripheral (Daussin et al., 2007; Daussin et al., 2008).

Intensity, duration and frequency of training are directly related to changes in VO_{2max}(Pollock, 1977). Although exercise intensity is the most crucial factor for improving $VO_{2max.}$ Exercise time >90%VO_{2max} have been suggested to serve as a good indicator for improvements in aerobic endurance (Rønnestad et al., 2015; Thevenet et al., 2007). Work periods should reach at least 2-3 minutes to achieve sufficient training adaptations of cardiac function (Buchheit & Laursen, 2013).

Another aspect of Q is the blood O_2 carrying capacity, determined by blood volume and [Hb]. Expansion of blood volume throughout training occur as a result of increases in plasma volume and red blood cells (RBC), however the majority of change is linked to increase in plasma volume (Warburton et al., 2004). As evident in Warburton et al. (2004) three session of MCT and HIIT has the ability to significantly enhance plasma volume with concurrent increase in blood volume in untrained males .Further increase in plasma and blood volume was only shown in the HIIT group after the 6-week of training, possibly due to lower baseline values (Warburton et al., 2004). Increase in blood volume has only been shown in early stages of endurance training regarding unfit subjects (Oscai et al., 1968), with no further increased in moderately trained subjects (Helgerud et al., 2007). [Hb] seems not to be trainable in moderately trained subjects (Helgerud et al., 2007), nonetheless it is considered as an important factor in the O_2 carrier capacity (Dill et al., 1974).

Comparing populations of different body size, measurement in ($mL \cdot kg^{-1} \cdot min^{-1}$) often underestimate heavier individuals and overestimate light individuals. Scaling of VO_{2max} to ($mL \cdot kg^{-0.75} \cdot min^{-1}$) would better reflect the capacity of the oxygen transport system independent of body mass (Bergh et al., 1991; Helgerud, 1994). Comparing VO_{2max} between gender should thereby be expressed as $mL \cdot kg^{-0.75} \cdot min^{-1}$. In healthy Norwegian males and females, the average VO_{2max} in 20-29 years old population has been shown at about 54 $mL \cdot kg^{-1} \cdot min^{-1}$ / 162 $mL \cdot kg^{-0.75} \cdot min^{-1}$ and 43 $mL \cdot kg^{-1} \cdot min^{-1}$ /122 $mL \cdot kg^{-0.75} \cdot min^{-1}$, respectively (Aspenes et al., 2011; Loe et al., 2013). In Edvardsen et al. (2013) the reference value was about 10% lower, although it should be noted that their study involved less restrictive inclusions criteria. In Loe et al. (2013) the males exhibit a 19 and 23% higher VO_{2max} expressed as $mL\cdot kg^{-1}\cdot min^{-1}$ and $mL\cdot kg^{-0.75}\cdot min^{-1}$ in comparison to the females.

The inter-gender difference decrease when VO_{2max} is expressed relative body weight, decreases the sex difference to about 20-30% (Pate & Kriska, 1984). SV is smaller in females compared to males largely due to smaller body size and heart (Wang et al., 2012; Åstrand et al., 1964). The difference could be decreased by scaling to lean body mass, indicating that percentage body fat account for some of the sex differences observed (Pate & Kriska, 1984). Females also have substantially lower [Hb] compared to men (Cureton et al., 1986). The normal range for [Hb] in females is 12-16 $g\cdot 100mL^{-1}$ while men range between 14-18 $g\cdot 100mL^{-1}$ (Pate & Kriska, 1984). The difference in [Hb] concentration and body fat explain the sex difference observed when VO_{2max} is expressed relative to body mass (Joyner, 2017). Females naturally possess less blood volume compared to men (Pate & Kriska, 1984; Åstrand & Rodal 1986, p.130.). Percent increase in blood volume following exercise training appears independent of age and gender (Sawka et al., 2000). Changes in VO_{2max} does not seem to be affected by menstrual cycles (Bemben et al., 1995; De Souza et al., 1990)**.**

HIIT vs Tabata on VO_{2max}

The original Tabata protocol consist of cycling for 7-8 bouts of 20-seconds performed at 170% of VO_{2max} with 10-seconds passive recovery (Tabata et al., 1996). Tabata training 4 times a week including 1 MCT session for six week increased their VO_{2max} from 48 $mL\cdot kg^{-1}\cdot min^{-1}$ to 55 $mL\cdot kg^{-1}\cdot min^{-1}$ (15%) (Tabata et al., 1996). The result was not significantly better than MCT since their increased from VO_{2max} 53 $mL\cdot kg^{-1}\cdot min^{-1}$ to 58 $mL\cdot kg^{-1}\cdot min^{-1}$ (9%). However, the effect following Tabata was achieved with 15 times less exercising. Despite the promising result in Tabata et al. (1996) there are large deviation in the few studies who have replicated the original. To this date (Bonafiglia et al., 2016; Foster et al., 2015; Laird et al., 2016; Ma et al., 2013; Miyamoto-Mikami et al., 2018; Ravier et al., 2009; Schaun & Del Vecchio, 2018; Scribbans et al., 2014b; Scribbans et al., 2014a), are the only studies to examine the chronic effect of Tabata training on VO_{2max}

using running or cycling as modality. Bonafiglia et al. (2016), Forster et al. (2015), Schaun and Del Vecchio, (2018), and Scribbans et al. (2014b) reported increased VO_{2max} following MCT and Tabata training with no difference between modalities.

The magnitude of change in VO_{2max} from pre to post testing varies from 2.9% in Bonafiglia et al. (2016), to 18% in relatively unfit male and female (Foster et al., 2015). However, the total number of training sessions was also lower in (Bonafiglia et al., 2016). Most previous research on Tabata are done exclusively in males, only one study has been conducted exclusively in females (Laird et al., 2016). Nonetheless the females in Laird et al. (2016) were untrained (34 $mL \cdot kg^{-1} \cdot min^{-1}$).

Only Scribbans et al. (2014b) examined underlying mechanism for the increase in VO_{2max}. They observed that 13.9% improvements in VO_{2max} was followed by significant improvements in O_2 pulse, with no significant group difference between Tabata and MCT. Importantly the author does not report pre or post values for O_2pulse, calculating or mean ($mL \cdot min^{-1}$) divided by HR_{max} ($beat \cdot min^{-1}$) resulted in 17.6% improvements in O_2pulse.

Menz et al. (2019) is to the authors knowledge the only study which has increased the number of Tabata sets in a session, as the performed 3-4 sets of Tabata with 5 minutes rest between bouts. To guarantee enough training load, training frequency was increased progressively from week one to week four. Meaning that week one consisted of three sessions a week performing three sets each session. In week two they increased to four sets of Tabata each session. The last two weeks weekly sessions were increased to four with four sets each session, which totally results in 53 sets. Resulting in a 13% improvement in VO_{2max}, from 47.8 $mL \cdot kg^{-1} \cdot min^{-1}$ to 54.1 $mL \cdot kg^{-1} \cdot min^{-1}$. However, it must be noted that the sample size was low (6 females and 2 men). Additionally, the sessions were supervised, but training intensity was monitored by HR and rating of perceived exertion (RPE) scores.

Considering the popularity of Tabata in the fitness community and the lack of knowledge undoubtedly warren further investigation (Viana et al., 2019). Tabata should be compared to HIIT to further examine its potential for improvements in VO_{2max}.

HIIT

The effect of HIIT has been thoroughly studied in the past decade in healthy subjects (Astorino et al., 2017; Esfarjani & Laursen, 2007; Helgerud et al., 2007; Støren et al., 2017; Wang et al., 2014), well-trained (Bacon et al., 2013; Helgerud et al., 2001; Helgerud et al., 2011; Laursen et al., 2002) and patients/untrained (Bækkerud et al., 2016; Daussin et al., 2008; Rognmo et al., 2004; Slørdahl et al., 2005; Wisløff et al., 2007).

Meta-analysis have shown that high-volume HIIT is superior in improving VO_{2max} and other biomarkers compared to MCT (Bacon et al., 2013; Milanovic et al., 2015; Ramos et al., 2015; Weston et al., 2014; Williams et al., 2019). Another meta-analysis by Scribbans et al. (2016) state that training above 60% of VO_{2max} improves VO_{2max}, with no further benefit from increasing exercise intensity. However, they have incorporated sprint-interval training (SIT) into the HIIT group. SIT traditionally consist of low training-volume on supramaximal intensity. This type of training is very time efficient like Tabata as it generally shown the similar improvements in VO_{2max} as MCT (Burgomaster et al., 2008). The discrepancy in VO_{2max} response to exercise training in studies could be linked to the variation in volume and intensity, baseline VO_2 and genetics (Astorino et al., 2017; Støren et al., 2017). HIIT incorporating exclusively females has also shown to be effective (Bishop et al., 2008; Slørdahl et al., 2004; Talanian et al., 2007; Walter et al., 2010). Furthermore, only Slørdahl et al. (2004) have used running as exercise modality, and the studies in females lack an exercise control group (Bishop et al., 2008; Slørdahl et al., 2004; Talanian et al., 2007; Walter et al., 2010). The effect of HIIT in moderately trained females (baseline VO_{2max} >50 $mL \cdot kg^{-1} \cdot min^{-1}$) has never been published.

HIIT protocols that elicit very high percentage of VO_{2max}, has been suggested to optimally stress the oxygen transport and utilization system thereby possibly provide the most effective stimulus for enhancing VO_{2max} (Bacon et al., 2013; Milanovic et al., 2015). Exercising near VO_{2max} force involvement of large motor unites and attainment of near-maximal Q, stimulating myocardium enlargement and oxidative fiber adaptation (Buchheit & Laursen, 2013). Reaching and maintaining an elevated maximal cardiac filling is necessary for improve maximal cardiac function (Astorino et al., 2017; Daussin et al., 2007; Helgerud et al., 2007; Wang et al., 2012). In moderately trained and endurance trained individuals SV has been shown to increase with workloads up to VO_{2max}, independent of gender (Wang et al., 2012; Zhou et al., 2001).

As evident in Helgerud et al. (2007), Wisløff et al. (2007), and Astorini et al. (2017) increase in VO_{2max} following HIIT was followed by an increase in SV. The same has been observed in untrained females 36.3 $mL·kg^{-1}·min^{-1}$. As 7 HIIT session in 2 weeks at 85%VO_{2max} 13% VO_{2max} improvement was followed by a 11.4% increase in O_2 pulse (Talanian et al., 2007). In moderately trained Females (42.6 $mL·kg^{-1}·min^{-1}$) 8 weeks of HIIT exercising a 85-90%HR_{max}, VO_{2max} increased 18% and was followed a 13% increase in atrioventricular plane displacement (Slørdahl et al., 2004). To clarify alterations in atrioventricular plane displacement following exercise might indicate improved SV through improved ventricular systolic function (Slørdahl et al., 2004).

Helgerud et al. (2007), and Bækkerud et al. (2016) has previously that shown no indication of change in oxygen-carrying capacity following 4x4 HIIT and MCT. As there was no significant change in blood volume, red blood cell mass, or hemoglobin. The authors concluded that improvements in VO_{2max} was linked to improvements in oxygen supply.

As SV is the major determinants distinguishing VO_{2max} in moderately trained and elite endurance trained females, VO_{2max} improvement following HIIT is thought to be due to an increase in SV in moderately trained females (Ferguson et al., 2001; Wang et al., 2012). Tabata has never been compared to HIIT, and this should be conducted due to the potentially time efficient approach to enhance VO_{2max}. A direct comparison between these modalities, could potentially lead to better physical activity recommendation to the public, since an increase in one metabolic equivalent (3.5$mL·kg^{-1}·min^{-1}$) is associated with a 12 % and 15 % lower risk of all-cause mortality and cardiovascular disease respectively (Kodama et al., 2009; Myers et al., 2002).

1.3 Work economy

C is defined as the steady-rate VO_2 at a given velocity, and reflects the energy demand of work (Barnes & Kilding, 2015). It can be presented as the steady-rate VO_2 ($mL·kg^{-1}·min^{-1}$) at a standard velocity, or energy cost of running per meter ($mL \cdot kg^{-0.75} \cdot m^{-1}$) (Conley & Krahenbuhl, 1980; di Prampero et al., 1986; Helgerud, 1994).

Conley and Krahenbuhl, (1980), and Helgerud, (1994) have shown inter-individual variations in C. This variability are not fully elucidated, but it seems likely that anatomical traits, mechanical skill, neuromuscular skill and storage of elastic energy are important (Joyner & Coyle, 2008; Pate & Kriska, 1984). Within a group with homogenous VO_{2max} variation in C explained 65% of the variation in a 10 km race (Conley & Krahenbuhl, 1980). Simultaneous C can vary as much as 30% among trained runners with similar VO_{2max} values (Saunders et al., 2004). The mechanical determinants within C include fiber-type distribution and elastic energy utilization (Bosco et al., 1987), mitochondrial and oxidative enzyme characteristics (Saunders et al., 2004), rate of force development (Støren et al., 2008) and biomechanics (Moore et al., 2012). C is highly trainable and could be improved by endurance training (Barnes & Kilding, 2015; Helgerud, 1994; Helgerud et al., 2001; Helgerud et al., 2007), or strength training (Støren et al., 2008). Improved C is advantageous for performance in an endurance events, allowing lower $\%VO_{2max}$ at a given workload (Jones & Carter, 2000).

Whether there are gender difference in C or not is equivocal, Daniels and Daniels, (1992) indicate that male explicit preferable C. Others demonstrate equal C between genders (Bunc & Heller, 1989; Daniels et al., 1977), while in Helgerud, (1994), and Helgerud et al. (2010) females C was superior, however this was expected on the basis of more extensive running regimens. C should be allometric scaled just as with VO_{2max} to the power of 0.75, when comparing individuals with various body mass (Bergh et al., 1991; Helgerud, 1994). When C was expressed as $mL \cdot kg^{-1} \cdot m^{-1}$ in Helgerud et al. (2010) mean differences was equal, when adjusting for body mass sex differences in mean C was about 10% in favor of females ($P < 0.05$). In addition allometric scaling reveal smaller inter-individual differences in C (~5%) (Helgerud et al., 2010), compared with ~8% when not scaled (di Prampero et al., 1986). The discrepancy in C among male and females must be evaluated on the basis on amount of training and athletic background. Helgerud et al. (1990) suggest that C and the amount of training are the main difference in aerobic endurance capability between performance-matched male and female marathon runners.

HIIT vs Tabata on work economy

HIIT has been shown to improve C to the same degree as MCT (Bækkerud et al., 2016; Helgerud et al., 2007; Slørdahl et al., 2005), and more than MCT (Wisløff et al., 2007). Schaun et al. (2018) is to the author's knowledge the only study examining the effect of C on Tabata. Surprisingly, C expressed as $mL \cdot kg^{-1} \cdot min^{-1}$, worsened following 16 weeks training in both Tabata and MCT. However, expressed as $\%VO_{2max}$, C resulted in similar improvements in Tabata and MCT. The effect of HIIT and Tabata on C has so far not been conducted in moderately trained females.

1.4 Lactate Threshold

LT defines the intensity at where blood lactate concentration $[la^-]_b$ accumulate during continuous exercise (Bassett & Howley, 2000; Joyner & Coyle, 2008). LT expressed as $\%VO_{2max}$ determines the fraction of VO_{2max} that could be sustained during a prolonged duration (Joyner & Coyle, 2008; Pate & Kriska, 1984). In untrained increased $[la^-]_b$ is seen at $60\%VO_{2max,}$ trained subjects can usually exercise at $75\text{-}90\%VO_{2max}$ before a marked increase in $[la^-]_b$ is observed (Joyner & Coyle, 2008). Most of the data suggest unchanged LT expressed as $\%VO_{2max}$ in recreationally trained individuals following an training intervention (Helgerud et al., 2001; Helgerud et al., 2007; Sjodin et al., 1982). This agrees with Sjodin and Svedenhag, (1985) suggesting that an increase in LT as % of VO_{2max} occurs largely as an early response to training.

The physiological determinants of LT are complex, several factors such as mitochondrial content and enzyme activity, greater oxidative capacity, proportion of type I fibers skeletal and muscle capillary supply seems to be important and can be caused by endurance training (Holloszy & Coyle, 1984). Together these adaptations is associated with reduced glycolytic flux, larger reliance on fat as fuel, better acid-base status control and in the end lower $[la^-]_b$ at fixed submaximal workloads (Bishop et al., 2014; Hawley, 2002; Holloszy & Coyle, 1984; Jones & Carter, 2000). The mitochondrial adaptations of highly trained male and female runners seems to be similar (Costill et al., 1976). Helgerud, (1994) documented that performance matched females have the same fractional utilization as males, which indicate no gender difference in LT.

In woman the substrate utilization may change during menstrual cycle in eumenorrheic woman during submaximal exercise. The lipid metabolism rates are elevated in the luteal phase compared to the follicular phase of the menstrual cycle (Hackney et al., 1994). Which increase the dependence of glycogen oxidation and may influence female's performance during prolonged exercise during menstrual cycle.

HIIT vs Tabata on Lactate threshold

Bonafiglia et al. (2016) is the only study examine the effect on LT following Tabata training. There was no significant difference between Tabata and MCT, as both increased their watt(W) output from pre to post at LT, additional the magnitude of change was not different between genders. The author did not express the values as VO_2 or $\%VO_{2max}$, so the result must be interpreted with caution.

No studies have reported changes in LT expressed as $\%VO_{2max}$ after HIIT (Helgerud et al., 2001; Helgerud et al., 2007). In these studies, workload at LT was reported change significantly following HIIT. Improvement in LT is linked to enhanced VO_{2max} or C, or a combination of both (Helgerud et al., 2007). The effect of HIIT and Tabata on LT has so far not been examined in moderately trained females.

1.5 Anaerobic capacity

Anaerobic capacity can be defined as the maximal amount of ATP formed by anaerobic processes, mainly phosphocreatine (PCr) and glycolysis (Noordhof et al., 2010). Anaerobic re-synthesis of ATP increase muscle and $[la^-]_b$ due to accumulation of H^+ (Medbø et al., 1988). An increase in $[la^-]_b$ in active muscles shows that the lactate formation rate exceeds the lactate removal rate (Åstrand and Rodahl, 1986, p.320)**.** Lactate accumulation and the associated decrease in pH is thought to contribute to muscular fatigue (Edge et al., 2006; Hostrup & Bangsbo, 2017; Sahlin, 1992; Sahlin & Henriksson, 1984).

Supramaximal exercise intensity trigger accumulation of lactic acid and decrease pH in working muscle, limiting the working muscle ability to maintain high force production (Hostrup & Bangsbo, 2017; Sahlin & Henriksson, 1984). Anaerobic ATP regenerations is higher in Type II muscle fibers (Essen et al., 1975). Due to higher motor unit recruitment and discharge rate the Type II muscle fibers ability to produce force is greater than type I muscle fibers. Females in general possess less percentage type II muscle fiber and less absolute muscle mass compered to males (Simoneau & Bouchard, 1989), additionally the cross sectional area of muscle fibers is larger in males (Staron et al., 2000).

There is no direct method to measure anaerobic capacity. Measuring maximum accumulated oxygen deficit (MAOD) proposed by (Medbø et al., 1988), is the most used and the best non-invasive method to determine anaerobic capacity, although the method has some limitations (Noordhof et al., 2010). The Wingate test is also commonly used to access anaerobic capacity (Bangsbo et al., 2009; Burgomaster et al., 2008; Iaia et al., 2008).

Multiple regression analysis indicates that MAOD is the best metabolic predictor for 100, 200 and 400-meter performance (Weyand et al., 1994), and similar correlation between MAOD and 300- and 400-meter are reported in (Scott et al., 1991). Supporting that 300-meter performance is a good field test for anaerobic capacity.

Physiological mechanism

The improvements in anaerobic capacity can partly be explained by changes in glycolytic and oxidative marker enzymes (Hostrup & Bangsbo, 2017; Iaia & Bangsbo, 2010; MacDougall et al., 1998). Increased activity of glycolytic enzymes may have accelerated the glycolytic flux, and partly account for the improved anaerobic capacity. In addition improved Na^+ K^+ pump capacity and a positive increase in tolerance to H^+ may have contributed (MacDougall et al., 1998), as it is pivotal in maintaining the muscle membrane potential during exercise (Iaia et al.,2008).

Studies involving supramaximal intensities above VO_{2max} with a duration of 2-7 weeks in recreationally active individuals have shown increased activity of glycolytic enzymes such as lactate dehydrogenase (LDH), phosphofructokinase (PFK) and creatine kinase (CK) up to 45%, 107% and 44% respectively (MacDougall et al., 1998; Parra et al., 2000; Rodas et al., 2000). Only one study has examined the skeletal muscle adaptations following 6 weeks of Tabata training. Miyamota et al. (2018) found that enzyme activity of PFK were significantly elevated in untrained young men.

Bangsbo et al. (2009), and Iaia et al. (2008) failed to find any changes in the anaerobic enzyme activity of PFK or CK after 4-9 weeks of (SIT) in moderately trained male runners. However, the increase in enzyme activity in trained individuals is not as noticeable compared with untrained subjects, due to lower baseline values (Iaia & Bangsbo 2010). Based on these findings, it could be suggested the changes in anaerobic enzyme is not vital for the improvements in anaerobic performance, since anaerobic performance is documented to increase significantly (Bangsbo et al., 2009; Iaia et al., 2008).

There are reports about equal trainability in men and females in anaerobic capacity (Weber & Schneider, 2002). While Medbø and Burgers (1990) suggested that women have reduced trainability for anaerobic capacity.

Tabata vs HIIT on MAOD

Tabata has shown to enhance anaerobic capacity by 28% measured as MAOD, while the there was no effect following MCT (Tabata et al., 1996). Notably in, Tabata et al. (1996) relationship between steady state VO_2 was not reestablished post training, a methodological flaw most certainly leading to overestimation of MAOD post-training. To the authors knowledge only Ravier et al. (2009), and Miyamoto et al. (2018) have examined the effect of Tabata on MADO, reporting a 10% and 21% increase respectively. However, neither study included females.

Only two studies have examined the effect of HIIT on MAOD in endurance trained subjects. In Medbø and Burgers (1990) HIIT consisting of 3 x 2 minutes supramaximal running intensity at 116% VO_{2max} separated with 8 minutes active recovery, 3x per week for 6 weeks, improved MAOD by 10%. The same protocol was performed in Weber and Schneider (2002) but was performed cycling and with a 6-minute active recovery between bouts. Resulting in a 21.9% and 19.6% for the males and females, respectively, with no significant difference between the genders. However, it must be noted that MAOD values in Weber and Schneider (2002) was decreased by 9 % to correct for reductions in O_2 stores of body. Even though the reduced O_2 stores did not influence the accumulated O_2 deficit significantly (Medbø et al., 1988). Both studies were aiming for anaerobic improvements, meaning that intensity is often higher than traditional HIIT, resulting in a higher anaerobic energy contribution during exercise. Improvements in VO_{2max} was only significant in males (7.9%) (Weber & Schneider, 2002). It is however possible than 4 x 4 HIIT could improve anaerobic capacity, as the rise in $[la^-]_b$ at the end of interval are evidence of some anaerobic energy contribution (Støren et al., 2017)

Demand of Tabata training

Tabata training could maximally stress both the aerobic and anaerobic energy system (Tabata et al., 1997). As the accumulated oxygen deficit was not significantly different from the MAOD test, additionally the short rest allowed VO_2 to increase to VO_{2max}(Tabata et al., 1997).

Tabata training is quite demanding for ordinary subjects (Foster et al., 2015). Tabata (2019) highlights that use of Tabata training needs; "highly motivated elite athletes who wants to elevate both their aerobic and anaerobic energy-releasing systems, and convincing instruction to the athletes form coaches who fully understand the scientific evidence regarding this method"

Direct comparison between 4 x 4-minute HIIT and Tabata which previously has shown to improve anaerobic capacity. Will provide evidence if HIIT induce sufficient stimuli to improve anaerobic capacity.

1.6 RPE

Perceived exertion and pleasure during experience might influence future physical activity and decrease adherence to exercise programs (Follador et al., 2018). Tabata training is known to be quite demanding (Foster et al., 2015; Tabata, 2019). Forster et al (2015) shows that the enjoyment of Tabata decline over time, and that it was significantly less enjoyable in comparison to MCT. RPE following HIIT has also been shown to be significantly higher in comparison to MCT in recreationally trained individuals (Bartlett et al., 2011). Despite higher RPE, HIIT was reported to be significantly more enjoyable than MCT, as MCT was considered boring and without variation, which also could affect adherence to continue exercise (Bartlett et al., 2011).

Only two studies have directly compared the RPE after HIIT and Tabata. Follador et al. (2018) didn't use the Borg 6-20 score, but a similar one ranging from 1-10 were 4 x 4 HIIT scored 6.9 while Tabata scored 9.9. In Valstad et al. (2018) subjects performed one 4 x 4 HIIT session and 4

Tabata bouts on separate days. The RPE was significantly higher following HIIT than Tabata after the second and third interval. Valstad et al. (2018) report that Tabata training was carried out at the highest possible intensity. As subject manage to increase the velocity from the first Tabata interval to the last and final indicate that baseline exercise intensity was to low and could explain the significant higher RPE values after 4 x 4 HIIT.

12 physically active men performed Tabata at 115%, 130% and 170% of VO_{2max}, where all ended up with maximum score (20) in the BORG scale ranging from 6-20 independent of the number of bouts performed (Viana et al., 2018). Following cycling 4 x 5 HIIT in trained cyclist BORG score was 17.6 ± 0.8 (Rønnestad et al., 2015). In Menz et al. (2019) mean Borg RPE was 13.3 ± 0.6 , which it surprisingly low in comparison to (Follador et al., 2018; Viana et al., 2018). The reasons for the low RPE values in Menz et al. (2019) are unclear, but the reason could be due to unsupervised sessions.

1.7 Aim and hypothesis

The goal of this thesis is to compare the effect of 4 x 4 HIIT performed at 90-95% HR_{max}, and running Tabata consisting of 7-9x 20-s intervals separated with 10-s rest on 300-meter,3000-meter performance and endurance performance determinants (VO_{2max}, C, LT and anaerobic capacity). It is reasonable to presume that HIIT will improve VO_{2max} and 3000-meter performance more than Tabata, and that anaerobic capacity and 300-meter performance will improve more after Tabata.

Methods

2.1 Subjects

26 healthy, non-smoking, moderately endurance trained females volunteered to participate in the present study. Inclusion criteria to participate were VO_{2max} levels between 45-58 ml·kg^{-1}·min^{-1} at baseline. All subjects were engaged in endurance training once a week or leisure-time physical activity at least three times a week. Participants were excluded if they had a history of cardiovascular disease, muscular injuries, medication that could affect physiological response to training, or other reasons that could affect the training response. Participation in less than <20 training sessions (83.3%) lead to exclusion from the study. All subjects had to sign a written informed consent before the first test. The study was approved by the institutional research board at the University of science and Technology and conducted in accordance with the Helsinki declaration.

Table 1. Subjects descriptive data (mean ± SD)

	HIIT (N = 13)	Tabata (N = 13)
Age (year)	22± 2	22 ± 3
Height (cm)	170 ± 5.4	167 ± 6.7
Body mass (KG)	65.2± 4.7	62.3 ± 6.7
VO_{2max}		
(L · min^{-1})	3.35 ± 0.29	3.30 ± 0.32
(mL · kg^{-1} · min^{-1})	51.4 ± 4.6	53.2 ± 4.1
(mL · kg$^{-0.75}$ · min^{-1})	146.2 ± 11.9	148.9 ± 10.4

2.2 Testing and equipment

Subjects had to meet twice for physiological measurement in the lab and once at an indoor track for the performance test. Testing was completed within two weeks before and after the training period. All subjects had at least 48-hour rest between each test. Subjects was told to avoid strenuous activity for 24 hours before each test. In the exercise lab testing was carried out on a motorized treadmill (Woodway PPS 55 Sport, Waukesha, Germany) during training a motorized treadmill (Gymsport TX200 treadmills), both were calibrated at 5.3 % and 5.5% respectively. Measurement of VO_{2max}, C, LT, MAOD, ventilatory parameters and gas exchange was carried out using Cortex Metamax II portable test-system (Cortex Biophysik GmbH, Leipzig, Germany). This system has been validated against the Douglas bag method (Larsson et al., 2004). In order to determine $[la^-]_b$ a 20 µL sample of capillary blood from a fingertip, hemolyzed and analyzed using a Biosen C-line lactate analyzer (EKF-diagnostic GmbH, Leipzig, Germany). HR measurements in the lab was assessed using Polar heart rate monitor (Polar F11, polar Electro Oy, Kempele, Finland)

Testing day 1: VO_{2max}, C, LT

The test started with 10-minute warmup at ~ 60 % of estimated VO_{2max}. Immediately after the warmup a blood sample was drawn from the fingertip and analyzed to establish baseline $[la^-]_b$ levels. To determine LT a minimum of three 5-minutes intervals at increasing intensity between 60-90% VO_{2max}, separated by short recovery period to draw blood samples. LT was calculated as the velocity, VO_2, or HR that corresponded with $[la^-]_b$ 1.5 mmol·L higher than the lowest measured value. VO_2/ HR measurement values was recorded as an average 30-seconds within the last 60-seconds of the five-minutes bout. C in the present study was standardized at 7km·h^{-1} for all subjects.

Subjects were allowed to take of the mask and walk for some minutes after the LT and C test was finished. The VO_{2max} test were initiated at the velocity of LT and increased every minute by 1 km·h^{-1} until exhaustion. Strong verbal encouragement was given at the end of the test. Within 2 minutes after exhaustion capillary blood sample was collected to determine $[la^-]_b$. Achievement of VO_{2max} was accepted when a plateau in VO_2 despite increase in workload, Respiratory exchange ratio (RER) >1.05 and $[la^-]_b$ > 7.5 mmol·L^{-1} (Helgerud et al., 2007; Helgerud et al., 2010). The highest average 30-seconds VO_2 was given as the subjects VO_{2max}. The highest recorded HR was recorded as HR_{max}. O_2 pulse was calculated by VO_{2max} (mL·min^{-1}) divided by HR_{max} (beat·min^{-1}), calculating O_2 pulse has been shown to be acceptable and reliable measurement of SV in untrained and endurance trained individuals (Crisafulli et al., 2007; Whipp et al., 1996).

Testing day 2: MAOD

The test started with a 15-minute warmup at ~70% HR_{max}, followed by a 10 minutes rest (Medbø et al., 1988). Subjects performed two 10-seconds bouts at the velocity of the MAOD-test during the warmup. A 10-minute passive recovery period followed the warmup. Blood samples were collected after the warmup and at times at the end of the recovery period to unsure that each subject started the test at baseline levels of $[La^-]_b$. The MAOD test was performed at a constant supramaximal intensity at ~120 % (± ~10%) of maximal aerobic speed (vVO_{2max}) leading to exhaustion in 2-3 minutes. Performing all-out within this time frame is suggested to accumulate the highest O_2deficit and the lowest margin of error SD (± 4 %)(Medbø et al., 1988). Strong verbal encouragement was given at the end of the test ensure complete exhaustion. $[La^-]_b$ was measured and analyzed immediately after the test. The MAOD-test was used as a verification of VO_{2max}, expressed as VO_{2peak}, those who achieved higher VO_{2max} during the test the highest average 30 seconds was used as their new VO_{2max}. According to Poole and Jones (2017) a constant supramaximal intensity should be performed to verify the VO_{2max}, as some subjects no not reach a plateau in VO_2 in an incremental VO_{2max} test. Åstrand and Rodahl (1986, p.302.) stated that it is possible to attain VO_{2max} within a minute of heavy exercise, providing a sufficient warm-up.

A simplified procedure nr.3 in Medbø et al. (1988) with a Y-intercept of 5 $mL \cdot kg^{-1} \cdot min^{-1}$ was used due to low number of submaximal stages. At least 3 different submaximal VO_2 measurements was carefully collected on test day 1 (LT, C) and Y-intercept of 5 $mL \cdot kg^{-1} \cdot min^{-1}$ was used to establish a relationship between VO_2 and velocity for all subjects. Velocity at MAOD was calculated based on these values to extrapolate a linear regression line for each subject. Simultaneously vVO_{2max} was also calculated using the same linear regression.

The difference between theoretical accumulated O_2 and the actual accumulated O_2 uptake throughout the supramaximal bout was defined as MAOD. MAOD could be prone to several source of error (e.g effort of the subjects, linear regression slope, and duration of the supramaximal bout). According to Medbø et al. (1988) the SD of original MAOD procedure including 10 submaximal bouts is ±4-7 %. The use of the simplified procedure 3 in the present study could also reduce the precisions of the MAOD results.

Testing day 3: performance test

The performance test consisted of two running time-trails. Both tests were conducted on a 200-meter indoor running track. 10 minutes individual warm up was completed before the individual 300-meter time trail. The second test consisted of a 3000-meter time trail carried out in heats. Subjects was told to rest for 30 minutes between the trails, were the 10 last minutes was warmup. Subjects was encouraged to run as fast as possible and received verbal encouragement. Time was recorded using a stopwatch and rounded to the nearest tenth of a second for 300-meter and nearest second for 3000-meter.

2.3 Training intervention

Subjects was randomized to either HIIIT or Tabata. Duration was 8 weeks consisted of three supervises trainings sessions per week. Subjects was told to refrain for other high-intensity activity during the duration of the project but was encouraged to continue with their normal activity. Both interventions had a 10-minuted warm-up at ~70% of HR_{max}. Workload and HR were monitored to ensure correct intensity. Following the workout, the subject had a 10-minutes cooldown period. 1-2 minutes into the cooldown the subjects were asked to answer a (RPE) sheet, a subjective evaluation of how hard they experienced the workout. We choose to use Borg 6-20 scale, a score of 6 represent resting activity whereas a score of 20 represent exhaustive exercise (Borg, 1982). The Borg scale was explained thoroughly before the first exercise. The first week of training is cut off from the average for both training interventions.

HIIT

The HIIT-protocol was carried out according to the method of Helgerud et al. (2007) consisted of 4 x 4-minute intervals at 90-95% of HR_{max}, separated with 3 minutes of active recovery (~70% HR_{max}). 10 minutes cooldown at <70% HR_{max} ended each session. Through the intervention, velocity was adjusted to ensure target intensity, HR was recorded after 3.5 minutes during all intervals. Including warmup and cooldown total workout time was ~45 minutes. As illustrated in Figure 2.

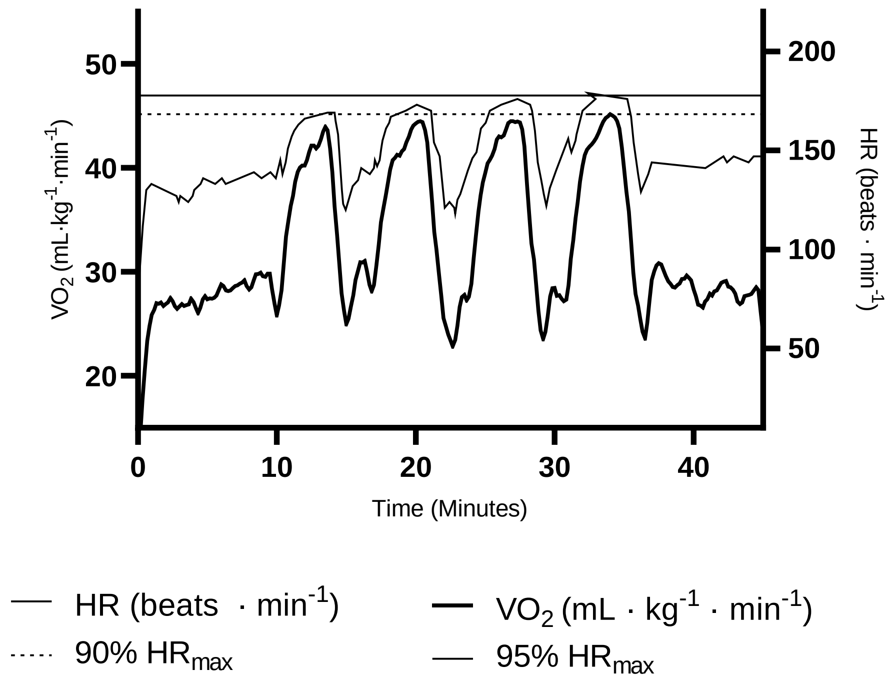

Figure 2. Example of HIIT (4x4) session performed on a female subject with a VO_{2max} of 52.1 mL · kg^{-1} · min^{-1} and a HR_{max} of 187 beats · min^{-1}.

Tabata

Tabata consist of 20-seconds intervals separated by 10-seconds rest. The velocity during the first session was set at 140% vVO_{2max}, intensity the following session was set by performance on the previous training session. If a subject completed 9 intervals or managed more than 10-seconds on bout nine, the velocity was increased the following session, aiming for exhaustion during the two last intervals. Every session was supervised, and the participants received strong verbal encouragement, ensuring that the intensity was correct. Including the warmup, the cooldown total workout time was ≈25 minutes. As illustrated is Figure 3.

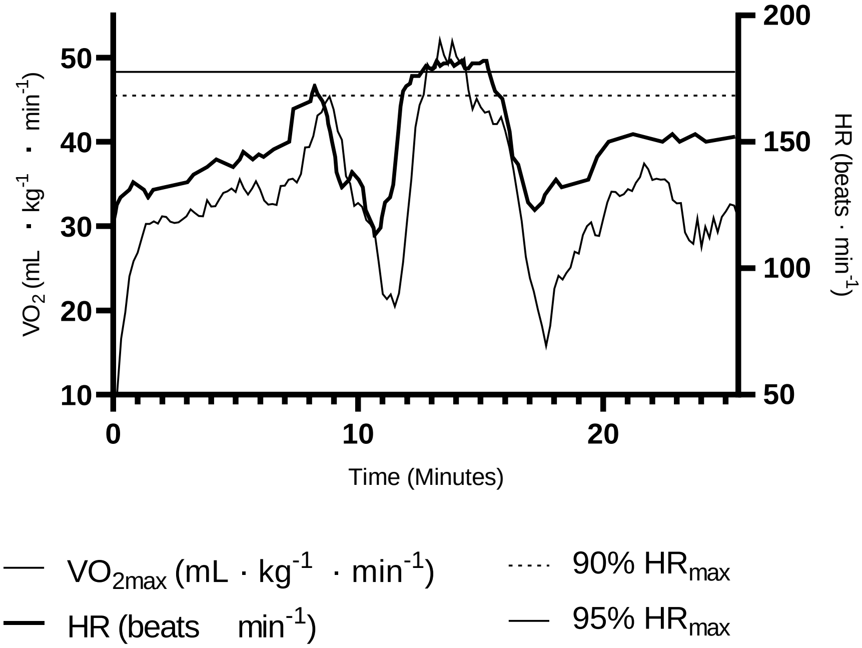

Figure 3. Example of Tabata session performed on a female subject with a VO_{2max} of 52.1 mL · kg^{-1} · min^{-1} and a HRmax of 187 beats · min^{-1}.

2.4 Statistical analysis

Statistical analysis was carried out using IBM SPSS statistics version 25.0. Figures are made using GraphPad prism version 8.0 (La Jolla, CA, USA). Normal distribution was carried by objective analysis of Shapiro-Wilk test for normality and visual inspection evaluation of quantile-quantile (QQ) plots and histograms.

Independent sample t-test were used to determine between-group differences at baseline. Paired sample t-test were used to determine changes within groups pre to post training. Repeated measure ANOVA was carried out to determine mean group differences from pre- to post-training. Correlations were calculated using Pearson correlation tests. In all cases the level of significant was set to $p<0.05$. All data are presented as mean ± SD, unless otherwise stated.

Results

32 women was randomized to HIIT of Tabata, of those 26 were included in the analysis (Figure 4). Five subjects dropped out during the intervention, two was due to injuries unrelated to the intervention and three did not have time to complete the intervention. One subject was excluded after post testing due to breathing difficulties during VO_{2max}.

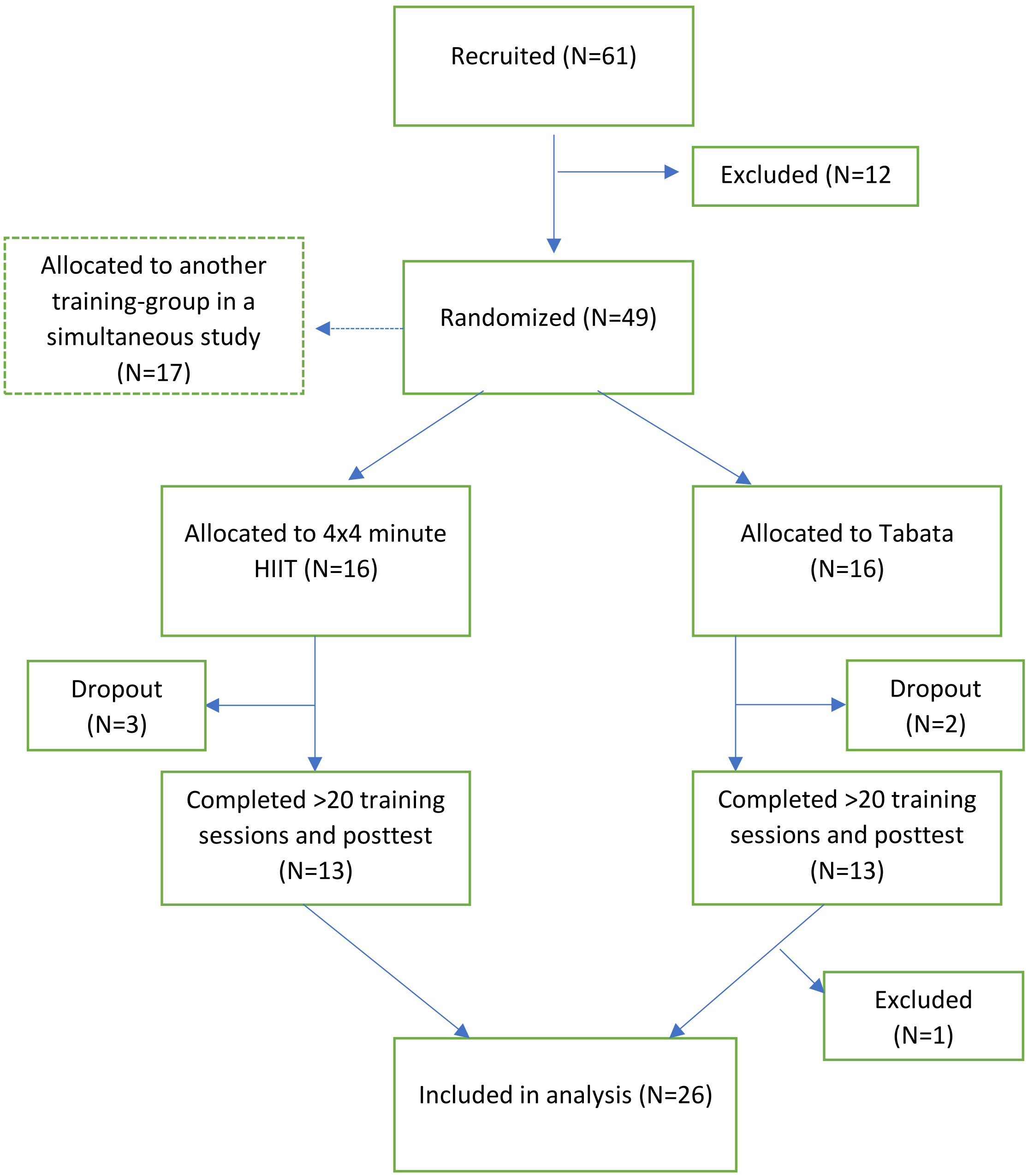

Figure 4. Flowcharts and study design

Table 2. Compliance.

	HIIT (N=13)	Tabata (N=13)
Number of training sessions	23 ± 1	22. ± 2
sessions completed %	95 ± 6	93 ± 7
Average %HR_{max} after 3.5min	92.7 ± 1.2	-
Average %HR_{max} after 3.5min last intervall	93.5 ± 1.4	-
Average number of intervals	-	8.1 ± 0.3
Average total time of intervals (sec)	-	162.5 ± 5.3
BORG	15 ± 1	18.5 ± 1.4###

Data are presented as mean ± SD. HR,heart rate. BORG ### Significant difference in changes between groups p<0.001

3.1 VO_{2max}

Increase in VO_{2max} was not significant between HIIT and Tabata. HIIT significantly increased VO_{2max} by 3.6%, 4.2%, 4.3% expressed as L $\cdot min^{-1}$, $mL\cdot kg^{-1}\cdot min^{-1}$ and $mL\cdot kg^{-0.75}\cdot min^{-1}$ respectively, while no significant changes were observed in the Tabata group. vVO_{2max} (km ・ h^{-1}) increased significantly more in HIIT 11.5% compared to Tabata 4.9%. The significant 3.6% increase in VO_{2max} (L ・min^{-1}) combined with a significant decrease in HR_{max} following HIIT resulted in a significant 4.1% increase sin O_2 pulse. Tabata increased by 1.4%, however the increase was not significant (Figure 4). There was a strong correlation between VO_{2max} (L ・min^{-1}) and O_2 pulse (R=0.93, N=26, P=0.01).

Table 3. Endurance performance and its determinants

	HIIT (N =13)		Tabata (N =13)	
	Pre-training	Post-training	Pre-training	Post-training
VO_{2max}				
VO_2 (L · min^{-1})	3.35 ± 0,29	3.46 ± 3,46**	3.30 ± 0.32	3.35 ± 0,35
$\dot{V}O_2$ (mL · kg^{-1} · min^{-1})	51.4 ± 4.6	53.5 ± 4.7***	53.2 ± 4.1	54.7 ± 5.0
$\dot{V}O_2$ (mL · kg$^{-0.75}$ · min^{-1})	146.2 ± 11.9	152.2 ± 11.3***	148.9 ± 10.4	152.82 ± 12.7
$\dot{V}_E$ (L · min^{-1})	109.3 ± 10.3	111.5 ± 11.0	104.0 ± 9.9	105.8 ± 10.3
RER	1.10 ± 0.04	1.12 ± 0.04*	1.11 ± 0.04	1.11 ± 0.03
$[La^-]_b$ (mmol· L^{-1})	12.5 ± 1.67	13.36 ± 1.5*	11.96 ± 3.11	13.01 ± 1.99
HR_{max} (beats · min^{-1})	197 ± 4	196 ± 5*	198 ± 9	198.0 ± 9
O_2 pulse (mL · beat^{-1})	17.0 ± 1.5	17.6 ± 1.4**	16.7 ± 2.2	17.0 ± 2.2
MaxV (km · h^{-1})	12.0 ± 0.79§	13.3 ± 0.95***#	12.9 ± 1.1§	13.8 ± 1.2***
(vVO_{2max} (km · h^{-1})	9.8 ± 1.1	10.9 ± 1.1***##	10.8 ± 1.5	11.3 ± 1.6**
Work economy				
$\dot{V}O_2$ (L · min^{-1})	2.51 ± 0.25§	2.37 ± 0.19**	2.26 ± 0.29§	2.18 ± 0.26***
$\dot{V}O_2$ (mL · kg^{-1} · min-^{1})	38.0 ± 3.1	36.6 ± 3.3*	36.2 ± 3.5	35.6 ± 3.7
$\dot{V}O_2$ (mL · kg$^{-0.75}$ · min^{-1})	109.7 ± 10.7	104 ± 8.4 **	102.2 ± 10.3	99.4 ± 9.80*
$\dot{V}O_2$ (mL · kg$^{-0.75}$ · m^{-1})	0.92 ± 0.07	0.89 ± 0.07*	0.87 ± 0.08	0.85 ± 0.08**
HR (beats · min^{-1})	177 ± 10.44	170 ± 9.83*	169 ± 15.	167 ± 17.
Lactate Threshold				
VO_2 (L · min^{-1})	2.60 ± 0.26	2.61 ± 0.20	2.60 ± 0.30	2.58 ± 0.31
$\dot{V}O_2$ (mL · kg^{-1} · min^{-1})	40.0 ± 3,8	40.6 ± 3.9	41.8 ± 3.7	42.3 ± 5.0
$\dot{V}O_2$ (mL · kg$^{-0.75}$ · min^{-1})	113.5 ± 10.1	115.± 10	117.2 ± 9.9	118.1 ± 13.0
% VO_{2max}	77.8 ± 2.9	75.9 ± 1.9*	78.6 ± 3.6	77.1 ± 4.4
% HR_{max}	91.8 ± 2.2	91.5 ± 1.6	91.2 ± 2.6	91.1 ± 1.9
vLT (km · h^{-1})	7.5 ± 0.8§	8.0 ± 0.7***##	8.3 ± 1.1§	8.4 ± 1.3*
$[La^-]_b$ (mmol· L^{-1})	3.0 ± 0.35	3.0 ± 0.40	3.2 ± 0.89	3.1 ± 0.66
300 meter (sec)	56.4 ± 3.9	55.1 ± 3.8***	57.65 ± 3,6	54.3 ± 2,3**#
3000 meter (sec)	911 ± 69	870 ± 68***	870 ± 66	830 ± 77***
Body mass (kg)	65.2 ± 4,7	64.6 ± 4,5	62.3 ± 6.4	61.4 ± 6.12

Data are presented as means ± SD. Testing was carries out on a treadmill at 5.3% inclination. 300m and 3000m was carried out at an indoor 200m track. VO_2, oxygen uptake; $\dot{V}_{E,}$ pulmonary ventilation; RER, respiratory exchange ratio; $[La^-]_b$, blood lactate concentration, HR_{max}, maximal heart rate; O_2 pulse, oxygen pulse; MaxV (km · h^{-1}), velocity at the end of VO_{2max} test; vVO_{2max}, minimum theoretical velocity to obtain VO_{2max}; vLT, velocity at lactate threshold. *significant difference within group (p<0.05) from pre to post training, ** Significant difference within group p<0.01 from pre to post training; *** Significant difference within group <0.001 from pre to post training; #Significant difference in changes between groups p<0.05 from pre to post training; ## Significant difference in changes between groups p<0.01 from pre to post training; § Statistically difference between groups(p<0.05) at baseline); §§ Statistically difference between groups(p<0.01) at baseline.

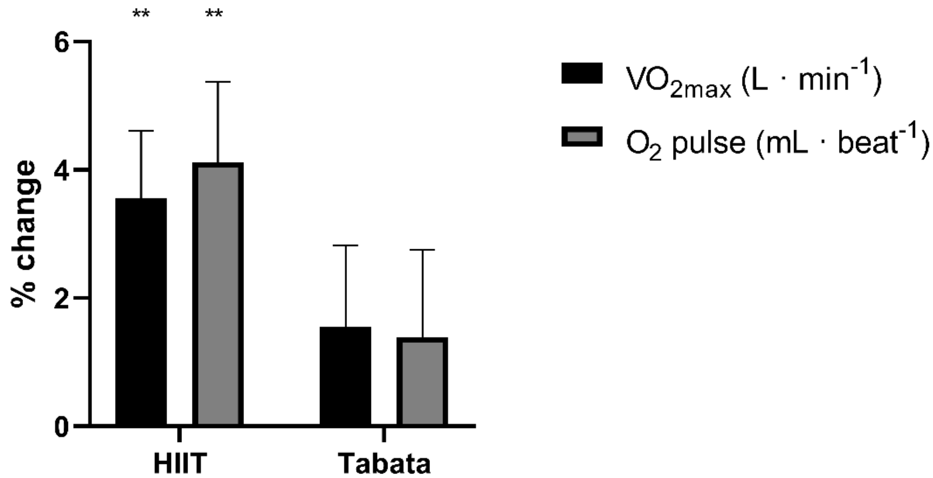

Figure 4. Percentage change in VO_{2max} and O_2 pulse from pre- to post-training presented as mean ± SEE.
** significant different within group (p<0.01) from pre- to post-training.

3.2 Lactate threshold

No significant different between groups was observed in LT expressed as $\%VO_{2max}$, VO_2, $\%HR_{max}$ or $[La^-]_b$ was found in the present study. vLT increased significant more following HIIT than Tabata, 7.5% and 1.7% respectively. Baseline vLT (km · h^{-1}) was significantly higher in the Tabata group (8.3 km · h^{-1}), compared to HIIT (7.5 km · h^{-1})

LT expressed as % of VO_{2max} significantly decreased 2.7% following HIIT. No significant change was observed following Tabata. No other significant increases were observed in HIIT or Tabata.

3.3 Work economy

C was not significantly different between groups, but both HIIT and Tabata significantly improved C, VO_2 standardized at 7km·h^{-1} as L ·min^{-1} 5.6 % and 3.6% , and mL·$kg^{-0.75}$·min^{-1} 4.9% and 2.6%, respectively. However only HIIT significantly improved 3.5% VO_{2max} (mL·kg^{-1}·min^{-1}). Improvements in C after HIIT was followed by a 3.4 % significant reduction in HR (Beat ・ min^{-1}) no changes was observed in Tabata group.

3.4 Anaerobic capacity

MOAD expressed as absolute values (L) and relative values (mL · kg^{-1}) improved significantly 8.3% and 10.4%, respectively after Tabata, no significant changes occur following HIIT. There was no significant difference between VO_{2peak} (L・ min^{-1}) obtained during MAOD and VO_{2max} (L・

min^{-1}) reached during incremental protocol. Two subjects from HIIT were excluded from MAOD analysis one due to unreliable VO^2 measurements the other one due to inaccurate supramaximal O_2 demand values obtained from extrapolation of individual regression line.

Table 4. Changes in anaerobic capacity, maximal accumulated oxygen deficit (MAOD)

	HIIT (N = 11/13)		**Tabata (N = 13)**	
	Pretraining	Post-training	Pretraining	Post-training
MAOD				
L	4.56 ± 0.68	4.76 ± 0.68	4.35 ±0.77	4.68 ± 0.83*
mL·kg^{-1}	70.5 ± 13.3	72.2 ±13,4	69.4 ± 9.77	76.0 ± 9.58**
Velocity km·h^{-1}	12.6 ± 1.§	13.3 ± 1.1***	13.3 ± 1§	14.1 ± 1.***
% vVO_{2max}	124 ± 6.1	119 ± 5.2*#	122.3 ± 9.8	123.9 ± 9.8
Time exhaustion (sec)	151 ± 24	153 ± 26	136 ± 13	134 ± 17
VO_{2peak}				
VO_2 (L · min^{-1})	3.29 ± 0.20	3.24 ± 0.2*	3.12 ± 0.36	3.09 ± 0.33
VO_2 (mL ·kg^{-1}·min^{-1})	50.5 ± 4.6	49.8 ± 4.4**	50.4 ± 3.4	50.7 ± 4.5
VO_2 (mL ·kg$^{-0.75}$·min^{-1})	143.0 ± 10.6	141.7 ± 10 **	140.7 ± 9.3	140.9 ± 11.7
RER	1.12 ± 0.07	1.14 ± 0.05	1.13 ± 0.06	1.14 ± 0.07
V_E	106.5 ± 10.2	111.5 ± 9**	99.86 ± 11.7	104.04 ± 12.9**
$[La^-]_b$ (mmol· L^{-1})	11.4 ± 1.9	11.5 ± 2.9*	10.6 ± 2.3	11.5 ± 2.2**
HR_{peak} (beats · min^{-1})	190 ± 5	188 ± 5**	187.5 ± 8.6	188.3 ± 8.1
$\%HR_{max}$ reached	96.8 ± 1.4§	96.6 ± 1.3	94.7 ± 1.7§	95 ± 1.3
$\%VO_{2max}$ reached	96.8 ± 4	92.8 ± 5.1*	95 ± 3.9	92.7 ± 2.8

Data are presented as means ± SD. Testing was carries out on a treadmill at 5.3% inclination. HIIT, high-intensity interval training; Tabata, Tabata interval training; MAOD, maximal accumulated oxygen deficit; VO_2, oxygen uptake during MAOD; RER, respiratory exchange ratio; $\dot{V}_E$, pulmonary ventilation; $[La^-]_b$, blood lactate concentration; HRpeak, peak heart rate. *significant difference within group (p<0.05) from pre to post training, ** Significant difference within group p<0.01 from pre to post training; *** Significant difference within group <0.001 from pre to post training. #Significant difference in changes between groups p<0.05 from pre to post training. § Significant difference between group at baseline p<0.05

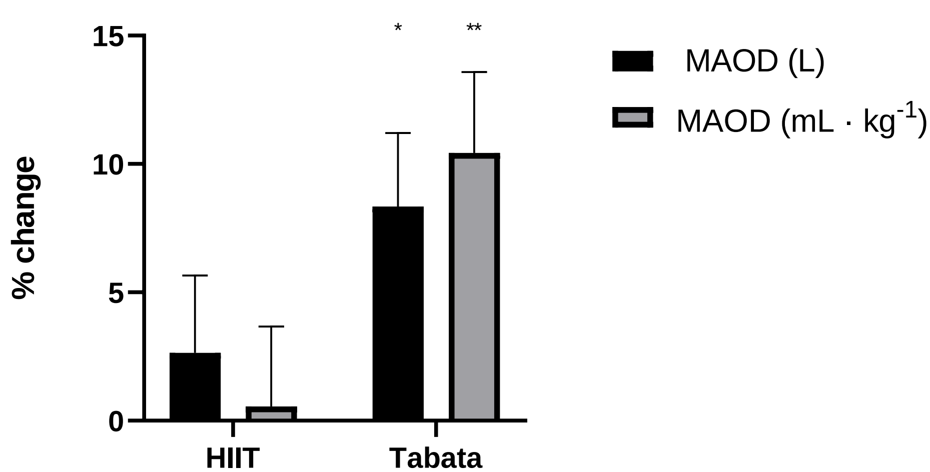

Figure 5. Percentage change in MAOD from pre- to post-training, data are presented as mean ± SE.* significant different within group (p<0.05) from pre- to post-training; ** significant different within group (p<0.01) from pre- to post-training.

3.5 Performance

Both groups significantly improved their 300-meter and 3000-meter performance. 300-meter performance improved by 2.2% in HIIT and 5.6% in Tabata. 3000-meter time was reduced by 4.6% in HIIT and 4.5% in Tabata, no significant between group difference was found.

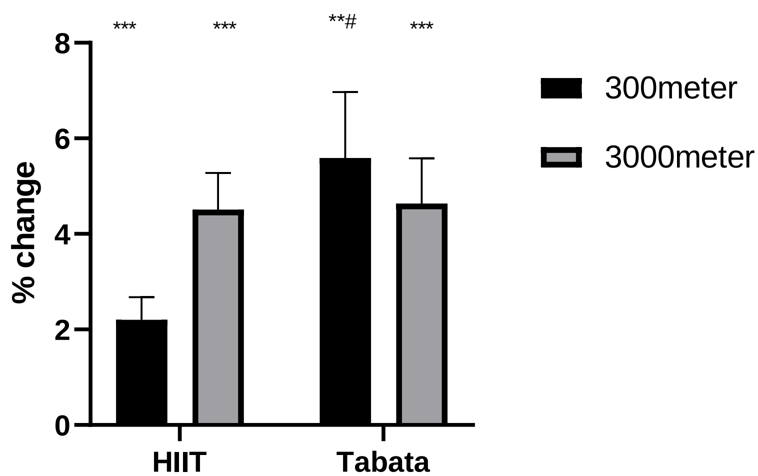

Figure 6. Percentage change in 300m and 3000m performance from pre- to post-training, data are presented as mean ± SEE. *** significant different within group (p<0.001) from pre- to post-training); # significant different between group (p<0.05) from pre- to post training

3.6 Correlations

3000-meter running performance significantly correlated with VO_{2max} in $L\cdot min^{-1}$ (R -0.51, P < 0.01), as $mL\cdot kg^{-1}\cdot min^{-1}$ (R = -0.73, P<0.001), $mL\cdot kg^{-0.75}\cdot min^{-1}$ (R= -0.74 p<0.001), vVO_{2max} (R=-0.84, P<0.001), O_2pulse as $mL \cdot beat^{-1}$ (R= 0.42, P<0.05), LT as $L\cdot min^{-1}$ (R=-056, P<0.01), LT as $mL\cdot kg^{-1}\cdot min^{-1}$ (R=-0.67, P <0.001), LT as $mL\cdot kg^{-0.75}\cdot min^{-1}$ (R=-0.71, P<0.001), vLT (R=-0.87, P<0.001), C as $L\cdot min^{-1}$ (R=0.46, p<0.05), C as $mL\cdot kg^{-0.75}\cdot min^{-1}$ (R=0.43, P<0.05), C as $mL\cdot kg^{-0.75}\cdot m^{-1}$ (R=0.40, P<0.05) and 300-meter performance (R = 0.66, P < 0.001). No significant correlation was found between 3000-meter performance and LT expressed as $\%VO_{2max}$, C as $mL\cdot kg^{-1}\cdot min^{-1}$ or MAOD ($mL \cdot kg^{-1}$).

300-meter running performance significantly correlated with VO_{2max} $L\cdot min^{-1}$ (R=-0.50, P<0.01, VO_{2max} as $mL\cdot kg^{-1}\cdot min^{-1}$ (R = -0.574, P<0.01), $\dot{V}O_{2max}$ as $mL\cdot kg^{-0.75}\cdot min^{-1}$ (R=-0.70, p<0.001),

vVO_{2max} (R=-0.44, $p<0.05$) and vLT (R= -0.48, $p<0.05$). No significant correlation was found between 300-meter performance and MAOD $mL \cdot kg^{-1}$.

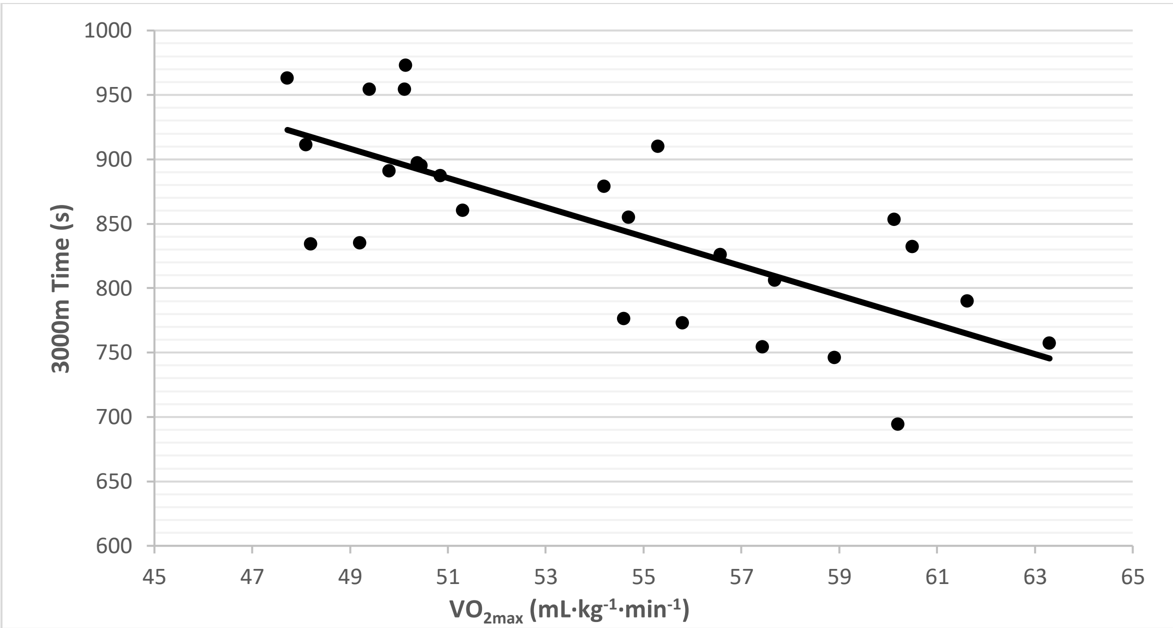

Figure 7. Correlations between post-training VO_{2max} with 3000m time. N=23, R= -0.73, $P<0.001$ and SEE 3.3

Discussion

The main findings of the present study were that eight weeks consisting of three weekly session, VO_{2max} improved following HIIT, while VO_{2max} did not chance in Tabata. C improved significantly in both modalities. LT as % VO_{2max} significantly decreased in HIIT, while vLT significantly increased in both groups. Anaerobic capacity only increased significantly after Tabata training. 300-meter and 3000-meter performance increased significantly after both HIIT and Tabata. 300-meter performance was significantly better in Tabata when compared to HIIT.

4.1 VO_{2max}

The present study is the first to investigate the effect on HIIT and Tabata on VO_{2max} and O_2 pulse on moderately trained females. VO_{2max} is considered the most important determinant on endurance performance (Bassett & Howley, 2000; Jones & Carter, 2000; Joyner & Coyle, 2008; Pate & Kriska, 1984).

The 4.2% increase in VO_{2max} following HIIT was smaller than other studies using the same protocol in moderately endurance trained males (baseline 51-61 $mL \cdot kg^{-1} \cdot min^{-1}$) (7.2-13%) improvements (Helgerud et al., 2001; Helgerud et al., 2007; Helgerud et al., 2011; Støren et al., 2017; Wang et al., 2014), although in Støren et al. (2017) half of the subjects were females. In untrained females HIIT has resulted in much greater change in VO_{2max} (Slørdahl et al., 2004; Talanian et al., 2007). The degree of change in VO_{2max} is highly dependent on initial fitness level of subjects (Støren et al., 2017). As female's response to HIIT are similar to males (Wang et al., 2012; Zhou et al., 2001).

The absence of changes in VO_{2max} and O^2 pulse after Tabata suggest that adaptations in SV did not occur. Lack of change in VO_{2max} are in disagreement with the whole Tabata literature performing running or cycling as the modality (Bonafiglia et al., 2016; Foster et al., 2015; Laird et al., 2016; Ma et al., 2013; Miyamoto-Mikami et al., 2018; Ravier et al., 2009; Schaun & Del Vecchio, 2018; Scribbans et al., 2014b; Scribbans et al., 2014a; Tabata et al., 1996).

Tabata has been shown to be equally effective as MCT on improved cardiorespiratory fitness (Bonafiglia et al., 2016; Foster et al., 2015; Schaun & Del Vecchio, 2018; Scribbans et al., 2014b). MCT exercise training, in subjects with above baseline VO_{2max} values has been shown to be ineffective (Esfarjani & Laursen, 2007; Helgerud et al., 2007). The subjects in the present study was roughly 25% above (43-53 $mL \cdot kg^{-1} \cdot min^{-1}$) the average in healthy Norwegian females between (20-29 years old) (Loe et al., 2013).

Only subjects in Ravier et al. (2009) which significantly improved their VO_{2max} from 58.7 $mL \cdot kg^{-1} \cdot min^{-1}$ to 61.4 $mL \cdot kg^{-1} \cdot min^{-1}$ following two weekly Tabata sessions for seven weeks, could be characterized as above averagely trained of all previous Tabata studies. Additionally, the subjects also performed other types of repetitive exercise which could have made an impact. As the overall training volume, intensity and frequency was greater in the present study. Further examination of the application of running Tabata should be done. Importantly the purpose of the study was to compare 4 x 4 minutes HIIT to the original Tabata protocol, it was therefore impossible to make the study isocaloric.

Cardiovascular adaptations

Modification in VO_{2max} are due to changes in Q or a-vO_{2diff} according to Fick's equation. In recreationally trained individuals O^2 supply is the predominant limiting factor of VO_{2max} (Richardson et al., 2000; Wagner, 1996). Adaptations in Q are mainly due to changes in SV, as HR_{max} does not change with training (Blomqvist & Saltin, 1983; Wagner, 1996). O_2 pulse increased significantly followed by a significant decrease in in HR_{max} following HIIT. Exercising above 85%VO_{2max} stimulated myocardium enlargement (Baker et al., 2010), although. Furthermore reaching and maintaining an elevated maximal cardiac filling is necessary to improve maximal cardiac function (Daussin et al., 2007; Helgerud et al., 2007; Wang et al., 2012), as work periods above 85%VO_{2max} should reach above 2-3 minutes (Buchheit & Laursen, 2013).

VO_{2max} are commonly reached in a Tabata session during bout 6-8 (Tabata et al., 1997; Viana et al., 2018). Additionally, Viana et al. (2018) stated that 53 ± 49 seconds are spend above 90% VO_{2max} during a Tabata session. Although the data were collected cycling, the results may be the same during running. Mean number of Tabata bouts completed in the current study was 8.1 (162.5 seconds) (Table 2), equaling that exhausting was obtained pretty immediately as bouts number nine started. Based in Viana et al. (2018) the oxygen transport chain are not eminently taxed for more than one minute. Work periods above 85%VO_{2max} should at least reach 2-3 minutes to achieve sufficient adaptation in cardiac function (Buchheit & Laursen, 2013), although Rønnestad et al. (2015), and Thevenet et al. (2007) state that exercising above 90%VO_{2max} is necessary. Based on lack of increase in VO_{2max} following Tabata, we could postulate that the relatively short time at high intensity are insufficiency to elicit increase in Q and SV in a well-trained sample. Mean HR after 3.5 minutes was 93.5% of HR_{max} During the last 4 x 4-minute interval which roughly translate to 85-90 % of VO_{2max}, evidence that exercising above 85%VO_{2max} is enough provided that the exercise duration is sufficient. The slightly higher %VO_{2max} reach during Tabata compared to HIIT is not enough to compensate for the higher volume around 90%VO_{2max}.

Improvements in SV following HIIT are in line with Helgerud et al. (2007) who used a similar intervention in moderately trained males. Helgerud et al. (2007) used a single-breath method of acetylene to measure SV. Finding are also in line with findings in untrained females (Slørdahl et al., 2004; Talanian et al., 2007). Scribbans et al. (2014b) is the only Tabata study which measured O_2 pulse. They reported that the 13.9% increase in VO_{2max} was followed by an 17.6 % increase in O_2 pulse. However no significant group difference was observed between Tabata and MCT. No significant improvements in SV following MCT in moderately endurance trained males in (Helgerud et al., 2007), and in elderly heart failure patients (Wisløff et al., 2007). The present study demonstrates that Tabata in moderately trained females is an ineffective training method to improve SV and Q.

Although not measured in this project Miyamoto-Mikami et al. (2018) proposed that significant increase of citrate synthase may have contributed to the 9.2% increase in VO_{2max} following Tabata training. Whereas no significant difference was found in maximal citrate synthase in (Ma et al., 2013). However, Bækkerud et al. (2016) found no significant group difference following MCT, 4 x 4 HIIT and 1 x 4 HIIT in an untrained population.

No studies have reported a significant increase in blood volume or [Hb] after HIIT or Tabata in moderately trained females. Increase in blood volume has only been attributed to untrained subjects (Oscai et al., 1968). Based on previous research it is unlikely that VO_{2max} changes are due to changes in O_2 carrying capacity. However, as we did not include any blood sampling in this study, we cannot exclude that some subjects were in anemia. As hemoglobin levels decline, oxygen-carrying capacity is decreased, which results in diminished VO_{2max} (McClung & Murray-Kolb, 2013; Woodson et al., 1978). This could possibly explain the diminished increase in VO_{2max} in HIIT and Tabata in comparison to previous studies.

Verification of the MAOD-protocol

Poole and Jones (2017) proposed the use of a supramaximal intensity at a constant workload (110% VO_{2max}) as verification of the incremental VO_{2max} test. In this thesis the MAOD-protocol was incorporated for this purpose. It is unclear if the MAOD-protocol is useful as a proper VO_{2max} verification due to short duration (2-3 minutes) and high intensity (120 ± 10 of vVO_{2max}). There was no significant difference between average VO_{2peak} from the MAOD-tests and the VO_{2max} values from the incremental test. Suggesting that the MAOD protocol could be used to verify VO_{2max}, although more studies using MAOD- protocol is needed.

4.2 Work economy

Improvements in C was observed in HIIT and Tabata, no significant group different were observed in C at 7 $km \cdot h^{-1}$ and 5.3 % incline. Within group comparison showed a significant improvement in C from pre to post training in HIIT 4.9% and Tabata 2.6%. However only improvements in HIIT was followed by a 3.4% significant reduction in HR. Improvements in HIIT was expected as it previously has been shown to improve following HIIT (Bækkerud et al., 2016; Helgerud et al., 2007; Slørdahl et al., 2005).

Schaun and Del Vecchio (2018) is the only study to investigate the effect on C following Tabata. They reported a worsened C following Tabata and MCT. Macpherson et al. (2011) did not find changes in C after MCT, while other studies have found improved C after MCT (Bækkerud et al., 2016; Helgerud et al., 2007). The report of worsened C in Schaun and Del Vecchio (2018) could therefore be questioned. Training status is important when evaluating changes in C, as trained runners have better C than untrained runners (Saunders et al., 2004). Although the initial training status was above average, the subject in HIIT and Tabata could not be characterized as trained runners. As they were not custom to relatively high amounts of running, and thus improvements following HIIT and Tabata was expected.

Comparison with other studies is difficult since C was measured at 5.3% inclination it the present study. Additionally, comparison of values reported are most likely due to methodological differences like: softness of treadmill belt, actual inclination and actual velocity and must be interpret with caution. Helgerud et al. (2001, 2007, 2011) reports about C measurements at 5.3-5.5%, with baseline ranging from 0.75-0.85 $mL \cdot kg^{-0.75} \cdot m^{-1}$ and 0.70-0.82 $mL \cdot kg^{-0.75} \cdot m^{-1}$ post training. These improvements are better than the results in the present study.

4.3 Lactate threshold

LT describes the intensity where $[La^-]_b$ starts to accumulate during exercise (Bassett & Howley, 2000; Joyner & Coyle, 2008). There was no significant group difference of effect in HIIT or Tabata on LT as $\%VO_{2max}$. However, in HIIT a 2.7% significant decrease was observed after HIIT on LT as $\%VO_{2max}$. The decrease found following HIIT, comes as a surprise as LT as $\%VO_{2max}$ is reported to be unchanged in recreationally trained individuals (Helgerud et al., 2001; Helgerud et al., 2007; Sjodin et al., 1982). A potential increase in LT as $\%VO_{2max}$ is observed in untrained and is attributed as an early response to endurance training (Sjodin & Svedenhag, 1985).

Changes in vLT was significantly larger in HIIT in comparison to Tabata. The 7.5% improvement in vLT after HIIT are similar to results following HIIT in moderately-endurance trained males (Helgerud et al., 2001; Helgerud et al., 2007). The 1.7% increase in vLT after Tabata, could be explained by a significant higher baseline values, additionally alteration in performance at vLT are a consequence of changes in VO_{2max}, C or both (Helgerud et al., 2007).

The results in LT have to be interpreted with caution. In order to establish LT we used individual warm up $[la^-]_b$ plus a constant of 1.5 $mmol \cdot L^{-1}$ as described in (Helgerud et al., 1990). We later noted that lactate measurements in Helgerud et al. (2007) were made using YSI 1500 sport Lactate measurements (Yellow Spring Instruments, Yellow Springs, OH) which analyses nonhemolyzed blood. Nonhemolyzed blood samples does not record lactate inside the red blood cells, and the fact that ≈ 75% of lactate is found in blood plasma (Medbø et al., 2000). We should have used a constant of 2.3 mmol·L^{-1} as applied by (Støren et al., 2014). The discrepancy in constant value, most certainly resulted in "wild values" in determining LT. This could also explain the significant decrease in LT as %VO_{2max} following HIIT training in this study, so the results must be interpreted with caution.

4.4 Anaerobic capacity

Anaerobic capacity measured as MAOD, did not change from pre to post training following HIIT, Following Tabata MAOD increased significantly 10.4 % as (mL·kg^{-1}). The present study is the first intervention to examine the effect of 4 x 4 HIIT and Tabata in females on MAOD. The finding that 4 x 4 HIIT anaerobic capacity was unaltered are not in agreement with Medbø and Burgers, (1990), and Weber and Schneider, (2002) which improved MAOD by 10 and 21.9/19.6% respectively. However, exercise intensity was higher in both studies as they were aiming for anaerobic improvements. The significant improvement in MAOD following Tabata are in agreement with (Ravier et al., 2009), but lower than finding in (Miyamoto-Mikami et al., 2018; Tabata et al., 1996). Tabata et al. (1996), and Miyamoto et al. (2018) did not reestablish relationship between VO_2 and velocity often based on unchanged C in running or cycling, this is also the case in other studies (Medbø & Burgers, 1990; Weber & Schneider, 2002). The increase in C highlights the need to reestablish relationship between VO_2 and velocity.

Baseline mean MAOD values of ~70 mL·kg^{-1} in this study are just below MAOD values reported from middle-distance and sprint athletes~ 75 mL·kg^{-1} (Medbø et al., 1988; Scott et al., 1991). Nevertheless MAOD values in this study are higher than in endurance trained subjects in (Ravier et al., 2009; Scott et al., 1991). Hill and Vingren (2014) reports a mean running MAOD of 60 mL·kg^{-1} and 80 mL·kg^{-1} based on 119 woman and 103 men, respectively. The anaerobic capacity could thereby be characterized as well above normal MAOD values. Comparing MAOD values between studies should be interpret with caution, as MAOD values are generally higher during running as opposed to than cycling, due to more muscle mass recruited (Hill & Vingren, 2011; Medbø & Tabata, 1989; Åstrand et al., 1986), and that MAOD increase with uphill running (Olesen, 1992; Sloniger et al., 1997). Additionally, other methodological differences may impact the results. This study shows than training at supramaximal intensity is needed to change the anaerobic capacity significantly in moderately endurance-trained subjects.

Although not measured in the present thesis, Miyamoto et al. (2018) found that Tabata training resulted in a significant increase in PFK in agreement with other studies with supramaximal intensity (MacDougall et al., 1998; Parra et al., 2000; Rodas et al., 2000). Even though Bangsbo et al. (2009), and Iaia et al. (2009) state that changes in anaerobic enyme activity is not vital for increase in anaerobic capacity. Other factors creatin kinase, lactate dehydragenase, Na^+ k^+ pump capacity and lactate H^+ transporters are associated with improvements in anaerobic capacity (Bangsbo et al., 2009; Hostrup & Bangsbo, 2017; Iaia & Bangsbo, 2010; Iaia et al., 2008). It is therefore likely that faciliation of glycolysis in skeletal muscle contribute to the increase in anaerobic capacity following Tabata.

4.5 Time-trail performance

3000-meter running performance

3000-meter performance improvements were not significantly different between groups. 3000-meter performance improved by 4.6% (41-s) and 4.5% (40-s) following HIIT and Tabata, respectively. Percentage change after HIIT are in slightly lower than the 8-9% Cicioni-Kolsky et al. (2013) and 7% change in (Esfarjani & Laursen, 2007). Allowing the subjects to get familiarization to a performance test could improve the reliability and pacing strategy for any given test (Borg et al., 2018), and could be a reason for the nonsignificant difference between groups. The effect of Tabata in a running time trail has so far not been conducted.

Similar improvements in 3000-meter performance disagree with the out hypothesis that HIIT would improve 3000-meter performance to a higher degree than Tabata. As VO_{2max} are considered the most important determinants on endurance performance (Bassett & Howley, 2000; Jones & Carter, 2000; Joyner & Coyle, 2008; Pate & Kriska, 1984). During 12-15 minutes of maximal exercise anaerobic energy contribution are estimated to 15%, making aerobic energy sources the main energy source during a 3000-meter performance run (Åstrand & Rodal 1986, p.314**).** The similar improvements in 3000-meter performance might be due to the fact that no group differences in VO_{2max}, C or LT as $\%VO_{2max}$. vLT were the factor which best correlated ($R=-0.87$, $P<0.001$) with 3000m performance, which was expected as vLT are dependent on VO_{2max}, C and LT as $\%VO_{2max}$ (Bassett & Howley, 2000; Joyner & Coyle, 2008).

Although the HIIT-group improved vLT significantly more than the Tabata group, the improvement in this variable did not result in a necessary advantage to perform better at the 3000-time trial performance.

One reason might be that the combined effect of all performance determinants such as anaerobic capacity, VO_{2max}, C and LT $\%VO_{2max}$ was equal between groups**.** The superior improvements in MAOD following Tabata could have contributed to the improvements in 3000-meter performance. Improved anaerobic capacity could enhance the ability tolerate(resist) alterations in intracellular pH (Støa et al., 2010), thereby combating muscular fatigue and push the limit further. There were no changes in time to exhaustion during the MAOD test, however there was an significant difference in changes between groups from pre to post testing in $\%vVO_{2max}$. Evidence that enhanced anaerobic capacity have contributed to run the same duration on a higher relative supramaximal intensity in the MAOD test. Allowing the subjects to run at a higher speed or maintaining the intensity for a longer time period. Considering this, as no significant increase in VO_{2max} occurred after Tabata, the significant increase in MaxV and vVO_{2max} following Tabata must be attributed to increase in Anaerobic capacity,

3000-meter running performance was significantly correlated with VO_{2max} $mL \cdot kg^{-1} \cdot min^{-1}$ (R=-0.73, P<0.001) and $mL \cdot kg^{-0.75} \cdot min^{-1}$ (R=-0.74, P<0.001). Intermittent exercise at vVO_{2max} are likely to produce increased performance in a 3000-meter performance test, due to cardiovascular or muscular adaptation (Billat, 2001). The absence of cardiovascular adaptation following Tabata, muscular adaptation associated with a higher exercise intensity could have contributed. Additionally fast force production (anaerobic capacity and neuromuscular systems to produce power) during maximal and submaximal running was related to 5000-meter performance (R=.077, P<0.001) a weaker correlation was found between VO_{2max} and 5000-meter performance (R=0.49, P<0.05) (Nummela et al., 2006).

The performance improvement in 300-meter might indicate that the subjects in the Tabata group might have become better in running at supramaximal speeds, which may become an advantage during the last rounds on a 3000-meter time trial.

300-meter running performance

300-meter performance changes were significantly better after Tabata in comparison to HIIT. Both HIIT 2.2% (1.3 seconds) and Tabata 5.6% (3.4 seconds) increased their 300-meter performance from pre to post. To the authors knowledge no other studies have investigated 300-meter performance in HIIT or Tabata.

The strongest correlation was found between 300m and VO_{2max} ($mL \cdot kg^{-0.75} \cdot min^{-1}$) (R= -0.7, P<0.001. This was expected as energy contribution from aerobic and anaerobic sources are similar in a running event lasting 50-60 seconds (Spencer & Gastin, 2001).

Mean power during a Wingate test have been shown to correlates with 300m performance (R=-0.64, P<0.05) (Scott et al., 1991). Several previous Tabata studies have implemented the Wingate test as a measure of anaerobic capacity (Foster et al., 2015; Laird et al., 2016; Scribbans et al., 2014b). Forster et al. (2015) reported similar anaerobic improvements following Tabata and MCT. Scribbans et al. (2014b) reports that Tabata were superior to MCT. While Laird et al. (2016) state that significant increase in mean and peak power output following Tabata. Although there are some major differences between a Wingate test and 300-meter time trail for example cycling vs running and time to complete the test (~ 55 vs 30 seconds). The improved performance in 300-meter performance in this study are in agreements previous Tabata intervention demonstrating improved performance in Wingate test.

No correlation was found between 300-meter performance and MAOD. Which are in disagreements with previous studies were MAOD correlated with 300-meter performance (R=-0.76, P=0.01) Scott et al. (1991), while MAOD correlated with 200-meter and 400-meter performance (R=-0.71, P<0.05) (Weyand et al., 1994). However, running performance lasting <60 seconds rely on several other parameter such maximal sprint velocity, sprint economy, counter movements jump and VO_{2max} (Dal Pupo et al., 2013; Nummela et al., 1996)

Especially sprint economy could be a factor explaining the significant group difference between Tabata and HIIT. The improvements in submaximal C following HIIT and Tabata are only valid up to 90% VO_{2max} (Helgerud et al., 2010). C measured at submaximal velocity does not reflect C at supramaximal time-trail velocity (Daniels & Daniels, 1992). Tabata performed at 170% VO_{2max} is an intensity that will exhaust subjects after approximately 50-seconds of bicycling (Tabata, 2019). In this regard it is likely that Tabata subject improved their C at higher velocity and running strategy for the 300m performance test.

4.6 Study limitations

Establishing LT with a constant of 1.5 mmol instead of 2.3 mmol as applied by Støren et al. (2014) is a major limitation in this project. Due to use of hemolyzed blood samples.

O^2 pulse is not considered the gold standard method of measuring cardiovascular adaptations. Follow up studies should implement more accurate measurement (e.g single-breath acetylene uptake method) for evaluating cardiovascular adaptation after HIIT and Tabata. We did not include hematological or muscular biopsy measurements, which could possibly address changes in aerobic and anaerobic capacity.

The present study did not control for menstrual cycle in the present study, even though changes in VO_{2max} seems to be unaffected (Bemben et al., 1995; De Souza et al., 1990). Menstrual cycle could affect physiological responses to training (Oosthuyse & Bosch, 2010).

Due to limited time in the lab the use of the simplified procedure nr.3 in Medbø et al. (1988) were used to establish a relationship between VO_2 and velocity, which increase the standard deviation and thus the likelihood for error in MAOD results. Consequently, two subjects in the HIIT group were excluded from MAOD-analysis. Future studies should consider the original MAOD protocol over the simplified MAOD-procedure, to decrease the likelihood of losing subjects in the analysis. However, the original MAOD protocol is very time consuming, thus the simplified procedure nr.3 could be a preferred choice is data is collected carefully.

4.7 Practical implication

Despite promising results from previous studies, running Tabata training is an ineffective approach to enhance VO_{2max} in moderately trained females. 4 x 4 HIIT is an excellent choice if you want to improve your VO_{2max} and overall health. However supramaximal intensity is necessary if the goal is to improve anaerobic capacity, and Tabata training seems to be a time efficient alternative.

Average RPE was significantly higher after Tabata in comparison to 4x4 HIIT, in agreement with (Follador et al., 2018; Viana et al., 2018). The low mean RPE data 13.3 reported by Menz et al. (2018) is difficult to understand, the author did not report exercise intensity but an exercise intensity as low as 115%VO_{2max} was reported to result in 20 in the BORG PRE scale (Viana et al., 2018). Adherence to long term Tabata training could be questioned due to high Borg values.

Starting Tabata training at 140% vVO_{2max} seems to be a good starting point for running Tabata. The intensity should thereafter be progressively increased and lead to exhausting during the seventh of ninth set, if less than six sets are completed the intensity should be reduced.

4.8 Future research

Future research should investigate the discrepancy on increase in VO_{2max} between the present investigation and previous studies in Tabata training in moderately trained females and males, by Incorporating a more direct measurement for SV. Future research should also include hematological and muscle biopsy measurements which will clarify the cause for improvements in aerobic and anaerobic capacity, and if there are any sex differences between males and females.

Additionally, as most previous Tabata studies have used cycling as the modality, further studies should use running as the exercise modality. It would also be interesting to increase to number of bouts in a session to four like in (Menz et al., 2019), to make protocols more isocaloric.

4.9 Conclusion

The present study demonstrates that 4 x 4 HIIT performed at 90-95 % HR_{max} is an effective way to improve VO_{2max}, while Tabata is an ineffective way to improve VO_{2max} in a sample of moderately trained females. C was significantly improved in both groups. LT as %VO_{2max} was unaltered following Tabata but was significantly worsened after HIIT. Improvements in anaerobic capacity was significantly improved following Tabata, no changes occurred after HIIT. Similar improvements were observed in 3000-meter performance. While 300-meter performance improvements were superior in Tabata in comparison to HIIT.

This is the first Tabata study incorporating moderately trained females, the absence of improvements in VO_{2max} disagree with previous intervention conducted. Tabata therefore need further investigation in moderately to trained males and females.

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