Reduced-Exertion High-Intensity Interval Training (REHIT): A Feasible Approach for Improving Health and Fitness?

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Abstract

In recent years, research investigating the dose-response to sprint interval training (SIT) has provided evidence that the number and duration of repetitions in a SIT session can be reduced whilst preserving the beneficial health-related adaptations. Together this research has led to the development of protocols involving minimal doses of SIT: regularly performing just two or three 20-30-s all-out sprints in a 10-min training session has been shown to elicit beneficial metabolic and cardiovascular adaptations. These SIT protocols, which we originally termed 'reduced exertion HIT' (or REHIT), have the potential to remove many of the common barriers associated with other SIT protocols, as well as with HIT and aerobic exercise. Here, we critically review the evidence on the efficacy, feasibility and acceptability, and effectiveness of REHIT for improving health and fitness.

Introduction

The remarkable finding that six sessions of sprint interval training (SIT) over two weeks, involving a total of 15 minutes of supramaximal sprint exercise, substantially improves both aerobic function (Burgomaster et al., 2005) and insulin sensitivity (Babraj et al., 2009), now nearly two decades ago, has driven a proliferation of research investigating time-efficient exercise paradigms for improving health. The SIT protocol applied in those seminal studies consisted of 4-6 x 30-s all-out Wingate sprints (Babraj et al., 2009; Burgomaster et al., 2005). Despite its lab-based efficacy, it has been widely dismissed as a viable exercise option for inactive, unfit and/or overweight target populations, on the basis that it is extremely fatiguing (Biddle and Batterham, 2015; Hardcastle et al., 2014). As a result, several research groups shifted focus towards studying (sub)maximal high-intensity interval training (HIT) protocols, reasoning that the lower absolute exercise intensities would make these protocols more tolerable (Little et al., 2011, 2010; Tjønna et al., 2008). However, whilst these HIT protocols have also been shown to elicit beneficial health-related adaptations, to compensate for the lower exercise intensities they have typically involved a greater number and longer duration of high-intensity efforts (Little et al., 2011, 2010; Tjønna et al., 2008). This is important because it reduces the proclaimed time-efficiency that is proposed to be a key benefit of HIT in general (Vollaard and Metcalfe, 2017), but also because both the duration and the number of sprints in HIT and SIT sessions are key drivers of fatigue, perceived exertion, and the decrease in affective valence (Frazão et al., 2016; Metcalfe et al., 2022).

At the same time, a separate line of investigation, stimulated by our group's initial interest (Metcalfe et al., 2012), has focused on determining the dose response to SIT and the potential to reduce both the number and duration of all-out sprints in a SIT session whilst preserving the beneficial health-related adaptations (Vollaard and Metcalfe, 2017). Together this research has led to the development of protocols involving minimal doses of SIT: regularly performing (i.e. 2 or 3 times week) just two or three 20-30-s all-out sprints in a 10-min training session has been shown to elicit beneficial metabolic and cardiovascular adaptations (Vollaard and Metcalfe, 2017). These SIT protocols, which we originally termed 'reduced-exertion HIT' (or REHIT) (Metcalfe et al., 2012), have the potential to remove many of the common barriers associated with other SIT protocols, as well as with HIT and aerobic exercise (Vollaard and Metcalfe, 2017). In this paper, we discuss the theoretical justification for development of the REHIT protocol. We then critically evaluate the current evidence to support the efficacy, feasibility and acceptability, and effectiveness of REHIT, as well as its potential role as an alternative or adjunct to traditional aerobic exercise paradigms, for improving cardiovascular and metabolic health.

How can such a low volume of sprint exercise possibly lead to training adaptations?

The suggestion that regularly performing as little as 40 seconds of (very) high-intensity exercise might be sufficient to stimulate adaptations that improve health could be considered an extraordinary claim (Ekkekakis and Tiller, 2023). Yet, when interrogated through the lens of our basic understanding of the mechanisms of exercise-induced adaptations (Perry et al., 2010), and the acute physiological responses to sprinting (Parolin et al., 1999), the potential for REHIT to elicit health-related adaptations is far less surprising.

Training adaptations are invariably the result of a disturbance of physiological homeostasis (Egan and Sharples, 2023; Egan and Zierath, 2013). The magnitude of the disturbance of homeostasis associated with aerobic exercise is small, as the human body is good at keeping most physiological parameters stable (Hawley et al., 2014). As a result, a relatively large volume of aerobic exercise is required to disturb homeostasis sufficiently to lead to training adaptations. In contrast, the disturbance of homeostasis associated with even very short durations of supramaximal exercise is rapid and severe; for instance, intramuscular ATP concentrations can decrease by ~50% during a single 30-s supramaximal sprint, with corresponding large increases in intramuscular ADP and AMP (Esbjornsson-Liljedahl et al., 2002, 1999). To our knowledge, the only physiological event leading to a greater drop in intramuscular ATP levels is death (Erdös, T, 1943). This substantial and instantaneous demand for ATP creates severe metabolic stress in skeletal muscle, resulting in rapid depletion of phosphocreatine stores, a rapid decrease in glycogen concentrations by ~20-30%, the accumulation of various glycolytic and other metabolic intermediates in the muscle, and an increase in skeletal muscle and blood lactate by ~50-fold and ~15-fold, respectively (Esbjornsson-Liljedahl et al., 2002; Gibala et al., 2009; Metcalfe et al., 2015; Parolin et al., 1999).

As a result of the substantial energy demand placed upon skeletal muscle during sprint exercise, there are also subsequent dramatic effects upon the cardiovascular and respiratory systems. Not only is there a large aerobic component to each sprint, but the utilisation of phosphocreatine and glycogen in the initial seconds of the sprint also creates a substantial oxygen deficit (Parolin et al., 1999). Thus, oxygen demands during the latter part of the sprint and early on in recovery are high; in fact, $\dot{V}O_2$ approaches maximal values following each sprint effort (Hazell et al., 2012; Townsend et al., 2014), and excess post-exercise oxygen consumption following REHIT is substantially higher than following 30 minutes of moderate-intensity continuous exercise (Metcalfe et al., 2015). At the same time, buffering of the drop in intramuscular pH associated with predominant reliance of ATP resynthesis from glycolysis and phosphocreatine breakdown (Robergs et al., 2004) rapidly increases blood CO_2 levels, leading to a pronounced increase in ventilation. Heart rate will approach maximal levels during an 'all-out' sprint, in part as a result of the large spike in circulating epinephrine (Esbjornsson-Liljedahl et al., 2002; Williams et al., 2013). Concomitantly, blood flow to active muscles can increase by ~100-fold during maximal exercise (Hawley et al., 2014). Despite this, active skeletal muscles will experience localised hypoxia, particularly during the early onset of sprints (Bhambhani et al., 2001; Bhambhani, 2004). In addition, the increase in heart rate and cardiac output combined with peripheral hyperaemia is associated with an increase in mean arterial blood pressure and endothelial shear stress (Hawley et al., 2014). During recovery there is a transient but pronounced decrease in plasma volume (Mandić et al., 2021; Metcalfe et al., 2015), which far exceeds that observed following 30 mins of moderate intensity continuous exercise (Esbjörnsson et al., 2012; Metcalfe et al., 2015). This is likely driven by the influx of water into the exercised skeletal muscle secondary to the development of a hypertonic intramyocellular environment associated with the large increase in glycolytic intermediates (Mandić et al., 2021).

Although not fully understood, some of these rapid and severe acute perturbations associated with supramaximal exercise will activate various signalling kinases which will, in turn, target downstream transcriptional/translational coactivators and regulators and lead to transient increases in gene expression and protein synthesis that can persist for several hours into recovery (Egan and Sharples, 2023; Egan and Zierath, 2013; Perry et al., 2010). Indeed, even a single 30-s all-out cycling sprint elicits a strong skeletal muscle signalling response (e.g. increased AMPK phosphorylation) and increases in skeletal muscle gene expression (e.g. increases in PGC-1a expression) (Fuentes et al., 2012; Guerra et al., 2011, 2010). Furthermore, we have observed a substantial activation of ACC-β and a 15-fold increase in PGC-1a gene expression in skeletal muscle following a single bout of REHIT (2 x 20-s sprints) specifically (Metcalfe et al., 2015). When repeated on a regular basis, the cumulative effect of these transient increases in gene expression, combined with an increase in protein synthesis, are thought to underpin the cellular and tissue specific adaptations that ultimately explain a change in phenotype following exercise training (e.g., improved $\dot{V}O_2$max) (Egan and Sharples, 2023; Egan and Zierath, 2013; Perry et al., 2010). The specific initial perturbations are numerous and complex, but are thought to include intracellular calcium release/signalling, disruptions in energy status (e.g., AMP/ATP ratio), accumulation of metabolites (e.g., lactate), disruptions to intracellular and whole-body acid-base balance, catecholamine signalling, mechanical force and stretch, fluid shifts and osmotic stress, heat production and alterations in muscle temperature, localised tissue hypoxia, vascular shear stress, and increased circulating concentrations of adrenaline and other hormones (Egan and Sharples, 2023; Egan and Zierath, 2013).

When considering the potential for low volumes of sprint exercise to elicit adaptations, it is important to recognise that even untrained patients will typically produce a peak power output of between 500-

1000 W and a mean power output of between 300-600 W during an all-out sprint on a cycle ergometer (e.g., (Metcalfe et al., 2018; Ruffino et al., 2017)). This will exceed the power that elicits maximal oxygen uptake by at least 2-4-fold, the power output during a typical HIT session by 2-4-fold, and the power range for moderate intensity continuous exercise by at least 5-8-fold (Metcalfe et al., 2018; Ruffino et al., 2017). The associated metabolic stress and molecular response is completely unique to all-out sprint exercise and vastly different from moderate-intensity continuous exercise (Esbjornsson-Liljedahl et al., 1999; Metcalfe et al., 2015; Parolin et al., 1999). There can be little doubt that the extent and magnitude of the stimulus will be sufficient to induce adaptations, particularly given that such exercise intensities will be a completely unfamiliar stimulus for almost all individuals (such power outputs cannot be achieved in any other setting). Moreover, because the perturbation of homeostasis following early sprints is already rapid and severe, there is limited potential for this to be exacerbated further with additional sprint repetitions. Accordingly, we are unaware of any data suggesting that performing a greater volume of supramaximal exercise in a SIT session will result in either a more severe disruption of homeostasis or a more pronounced activation of signalling molecules related to training adaptations. To date, the available evidence suggests that performing a greater volume of SIT does not lead to additional training benefits (Vollaard et al., 2017; Yin et al., 2023). Thus, we contend that research involving 'classic' SIT protocols involving as many as 6 repeated 30-s supramaximal sprints is redundant. Such protocols are unlikely to provide additional benefits compared to REHIT but are less time-efficient, associated with greater fatigue, and require greater motivation to complete.

What evidence is there that REHIT improves markers of cardiometabolic health?

Maximal Oxygen Uptake

When we originally designed the REHIT protocol, our primary *a priori* hypothesis was that it would improve whole-body insulin sensitivity via mechanisms related to regular skeletal muscle glycogen breakdown and turnover (Metcalfe et al., 2012). However, a somewhat surprising finding to emerge from this initial study was a marked improvement in maximal oxygen uptake ($\dot{V}O_2$max), the gold standard measure of cardiorespiratory fitness and one of the most powerful modifiable predictors of future health and longevity (Laukkanen et al., 2022; Ross et al., 2016). This initial RCT was limited by a small sample size (n=11 for $\dot{V}O_2$max), but our finding has since been consistently replicated, both in our own work incorporating >115 REHIT trained participants (Metcalfe et al., 2016a; Metcalfe and Vollaard, 2021; Nalçakan et al., 2018; Thomas et al., 2020), and by several other independent laboratories (Cuddy et al., 2019; Gillen et al., 2016, 2014; Mandić et al., 2023, 2022). From this work it can be concluded that 6 weeks of REHIT improves $\dot{V}O_2$max by on average ~10% (Metcalfe et al., 2016a; Metcalfe and Vollaard, 2021; Nalçakan et al., 2018; Thomas et al., 2020) and larger improvements are observed with longer training interventions (Bostad et al., 2021; Gillen et al., 2016). Similar to aerobic exercise, the magnitude of improvement is highly variable between individuals, with approximately 50% of individuals expected to accrue a clinically meaningful improvement in $\dot{V}O_2$max (Metcalfe and Vollaard, 2021). Importantly, these improvements have been observed in previously unfit individuals (mean baseline of 35 ml/kg/min (Metcalfe and Vollaard, 2021)) who were not meeting guidelines for aerobic-based physical activity, i.e., the key target population for an intervention like REHIT. Although the exact mechanisms by which REHIT improves $\dot{V}O_2$max are unknown, recent studies have demonstrated that REHIT increases blood volume, providing evidence for the important role of central hemodynamic adaptations (Mandić et al., 2023, 2022).

We have performed a number of studies which have examined the effects of different protocol permutations on the improvements in $\dot{V}O_2$max with SIT/REHIT (Nalçakan et al., 2018; Thomas et al., 2020; Vollaard et al., 2017). One of the most important protocol parameters is the number of sprint repetitions, as this is the major determinant of session duration and of the affective and perceptual responses to SIT/HIT (Metcalfe et al, 2022; Vollaard and Metcalfe, 2017). In a comprehensive meta-analysis of 34 SIT studies (38 unique trials) and 418 participants, we found that reducing the number of sprint repetitions in an acute SIT session did not diminish the improvements in $\dot{V}O_2$max following training; in other words, the improvement in $\dot{V}O_2$max following REHIT was similar compared to SIT protocols involving a greater number of sprints (Vollaard et al., 2017). In this light it is perhaps surprising that in two RCTs we observed no significant effect of performing single 20-s sprint training sessions on $\dot{V}O_2$max in 35 low active men and women (baseline $\dot{V}O_2$max between 30 and 40 ml/kg/min), although in both these studies the training intervention was 4 weeks rather than the more commonly used 6-week duration (Songsorn et al., 2017, 2016). We have also conducted studies to examine the effect of sprint duration (Nalçakan et al., 2018) and training frequency (Thomas et al., 2020) on the changes in $\dot{V}O_2$max. We found no difference in the improvement in $\dot{V}O_2$max with training frequencies of 2, 3 or 4 sessions/week over 6 weeks (Thomas et al., 2020), but reducing the duration of the sprints from 20 s to 10 s diminished the observed improvement in $\dot{V}O_2$max by approximately 50% (Nalçakan et al., 2018). Taken together, the currently available evidence suggests that performing two 20-s sprint repetitions twice per week is the most time efficient SIT protocol for eliciting worthwhile improvements in $\dot{V}O_2$max. Most of the research has been conducted using cycling sprints but there is some evidence that similar improvements can be elicited with stair climbing sprints (Allison et al., 2017).

An important question is whether REHIT elicits similar improvements in $\dot{V}O_2$max compared to MICT. This question has only been directly addressed in three small studies, but together the findings suggest that REHIT results in either similar or superior improvements in $\dot{V}O_2$max compared with doses of MICT that are commensurate with current physical activity recommendations (Cuddy et al., 2019; Gillen et al., 2016; Ruffino et al., 2017). The first study to address this question was conducted by Gillen and colleagues and they reported an improvement in $\dot{V}O_2$max of 15.4% following 12 weeks of thrice weekly 10-minute REHIT sessions (3 x 20-s all-out sprints) and an improvement of 18.5% following 12 weeks of MICT which involved five 45-minute sessions at ~70% of maximal heart rate (Gillen et al., 2016). They reported no statistically significant difference in the improvement between REHIT and MICT and concluded that they were similarly effective (Gillen et al., 2016). However, it is worth noting that this conclusion has been criticised on the basis that the study had low statistical power to be able detect an interaction effect and they did not specifically address the question of whether effects were statistically equivalent (Ekkekakis and Tiller, 2023). Nevertheless, two subsequent studies provided support for the findings of Gillen et al (2016) and reported *superior* effects of REHIT compared with MICT. Cuddy et al (2019) found a 12% increase in $\dot{V}O_2$max following 8-weeks of REHIT (4 x 10-min sessions involving 2 x 20-s all out sprints) and this was greater than the 7% improvement observed following 8-weeks of moderate intensity walking (4 x 30 minutes at 55-65% of heart rate reserve). Similarly, in our lab, we performed a randomised within-subjects crossover intervention study comparing 8-weeks of REHIT and 8-weeks of moderate intensity walking in 16 middle-aged men with type 2 diabetes. The strength of this study design is the removal of between subjects' variability in the comparison of the two exercise training protocols and therefore an increase in statistical power. Similar to Cuddy et al (2019), we also found a greater increase in $\dot{V}O_2$max following REHIT compared with moderate intensity walking (+7% vs. +1%, respectively) (Ruffino et al., 2017). Taken together, the currently available evidence indicates that the effects of REHIT upon VO_2max are at least comparable to MICT and certainly provides justification for further sufficiently powered and definitive comparative studies of the effects of REHIT and MICT on $\dot{V}O_2$max and other health parameters.

Other Health Outcomes

The second most studied outcome following REHIT is insulin sensitivity and glycaemic control and there is more uncertainty about whether REHIT can improve these outcomes. Part of this uncertainty stems from the range of different measurements that can be employed to assess different aspects of fasting or postprandial insulin sensitivity and glycaemic control, the fact that they are inherently more unreliable outcomes, and the challenge of disentangling transient acute effects observed during the post-exercise recovery period from longer term adaptations. Our initial small RCT demonstrated an improvement in oral glucose tolerance test (OGTT)-derived insulin sensitivity in young sedentary men but not in women following 6 weeks of REHIT (Metcalfe et al., 2012). Two studies by Gillen and colleagues provided independent support for this finding: in a comparable population of sedentary men, they reported improved fasting insulin sensitivity, improved postprandial insulin sensitivity measured using an intravenous glucose tolerance test, and improved 24-h glycaemic control measured by continuous glucose monitoring (Gillen et al., 2016, 2014). They also found large increases in skeletal muscle glucose transporter 4 (GLUT4) protein content in skeletal muscle, providing a potential mechanistic driver of the improvements in whole-body insulin sensitivity (Gillen et al., 2014). Interestingly, a sex-difference was also apparent in their studies, with no improvement in 24-h glycaemic control and smaller increases in skeletal muscle GLUT4 protein reported in women (Gillen et al., 2014). In all of these studies, the post-training assessments of insulin sensitivity and glycaemic control were performed two or three days following the last training session, suggesting that the effects were driven by training adaptations rather than transient acute effects of the final training session, an assertion that is supported by our observation that a single bout of REHIT performed in the evening had no effect on OGTT-derived insulin sensitivity the following morning (Metcalfe et al., 2016b).

On the other hand, it is important to note that an improvement in insulin sensitivity is not a universal finding following REHIT. Indeed, in a larger follow up study to our initial RCT (n=35 participants with mean baseline $\dot{V}O_2$max of 35 ml/kg/min), we were unable to replicate the sex difference or demonstrate an overall effect of REHIT on fasting or OGTT-derived insulin sensitivity, although we did observe a non-significant 8% mean decrease in the insulin area-under-the-curve during the OGTT (Metcalfe et al., 2016a). The lack of agreement across studies is likely to be driven, at least in part, by the substantial levels of technical, biological and random error associated with performing repeated OGTTs over time (Metcalfe et al., 2023). On balance, the available evidence tentatively suggests insulin sensitivity may be improved in young sedentary populations with REHIT, but further research is certainly needed, ideally using the more reliable and gold standard euglycaemic hyperinsulinemic clamp method to measure insulin sensitivity directly.

There is also some work that has investigated both the acute and chronic effects of REHIT on insulin sensitivity and glycaemic control in men with type 2 diabetes (Metcalfe et al., 2018; Ruffino et al., 2017). Ruffino et al (2017) reported that neither 8 weeks of REHIT nor 8 weeks of moderate intensity walking improved either fasting, OGTT-derived insulin sensitivity, or 24-h glucose concentrations in men with type 2 diabetes. Interestingly, they did report a reduction in plasma fructosamine concentrations following both REHIT and walking (Ruffino et al., 2017). As plasma fructosamine is an indicator of average blood glucose concentrations in the preceding 4 weeks, this indicates that there may have been improved glycaemic control during the intervention period, i.e., cumulative acute effects of the exercise sessions. As a result, we investigated the effect of an acute bout of REHIT performed in the morning on subsequent 24-h glycaemic control under dietary-controlled but otherwise free-living conditions in a comparable cohort of men with T2D (Metcalfe et al., 2018). We observed lower 24-h mean glucose concentrations and a reduction in the % of the day spent in hyperglycaemia following REHIT, an effect that appeared to be driven predominantly by a lower glycaemic response to the evening meal (Metcalfe et al., 2018). The magnitude of the improvements were similar compared to those observed following 30 mins of moderate-vigorous intensity cycling (Metcalfe et al., 2018). Further work is needed to confirm these observations in men with T2D and to investigate whether they are also observed in other populations such as women with T2D and people with normal or impaired glucose tolerance.

The effect of REHIT on other common markers of cardiometabolic health has received less attention and evidence is mixed. Several studies have reported reductions in brachial artery systolic and mean arterial blood pressure following REHIT (Cuddy et al., 2019; Gillen et al., 2014; Ruffino et al., 2017), but others have found no changes in blood pressure or other markers of vascular health such as brachial artery flow-mediated dilation (Shenouda et al., 2017). Similarly, some studies have reported beneficial changes in fasting lipid concentrations following REHIT (Cuddy et al., 2019), while others have found no significant changes (Ruffino et al., 2017). As expected, no studies have reported reductions in body mass following REHIT (Cuddy et al., 2019; Gillen et al., 2016, 2014; Metcalfe et al., 2012; Metcalfe et al., 2016; Ruffino et al., 2017); however, some studies have reported positive changes in body composition, including small reductions in waist circumference (Cuddy et al., 2019), total fat mass measured by air displacement plethysmography (Gillen et al., 2016), and gynoid fat mass reductions measured by dual X-ray absorptiometry (Ruffino et al., 2017). Overall, there is a clear need for further large and well-controlled studies to investigate the acute and chronic effects of REHIT on a wide variety of cardiometabolic health measures.

How does REHIT address common barriers to exercise and common criticisms of HIT/SIT?

The most cited justification for studying the health benefits of HIT and SIT is that a perceived lack of time is a common barrier to exercise. However, despite the low exercise volume, the need for recovery intervals means that the weekly time commitment of many HIT and SIT protocols is not that different from current recommendations to perform either 150 minutes of moderate intensity continuous exercise, 75 minutes of vigorous intensity continuous exercise, or a combination of the two (Metcalfe et al., 2012). For example, the total time commitment with the commonly applied HIT protocol requiring 10 x 1-minute efforts is approx. 22 minutes per session or 66 minutes per week (assuming a frequency of 3 sessions/week) (Little et al., 2010). If considered on a per session basis, 22 minutes per session is not much less than 30 minutes per session (recommendation for moderate intensity exercise), whilst if considered on a per week basis, the 66 minutes per week is very similar to the 75 minutes required to meet the recommendation for vigorous intensity exercise. In contrast, the 20 (two sessions) or 30 (three sessions) minutes total time commitment required with REHIT is substantially lower than both recommendations, as well as many other HIT and SIT protocols, and therefore offers a genuinely time efficient exercise option. Furthermore, the low exercise volume with REHIT is associated with minimal heat production and, in our experience, REHIT does not elicit a strong sweat response. Most participants in our studies choose to perform the exercise in regular clothes and there is no need for a shower afterwards, thus reducing the total required time commitment further and removing other potential barriers to exercise (e.g. dislike of sweating) (Korkiakangas et al., 2009).

The main concern for the application of SIT in the general population are the high exercise intensities involved and therefore high levels of effort and/or exertion required to perform the sprint efforts, and whether people who do not currently do much moderate or vigorous intensity physical activity are likely to do SIT instead. The main pillar of this argument centres on the proposed causal chain linking expected negative affective responses during supramaximal exercise intensities with poor exercise enjoyment, and subsequently poor uptake of, and adherence to, SIT (Biddle and Batterham, 2015; Hardcastle et al., 2014). However, it is important to note that there is actually very little research data to either support or refute poor adherence to SIT when implemented as a real-world intervention. In addition, while there is some support for the hypothesis that changes in affective valence during continuous exercise are associated with future PA behaviour (Rhodes and Kates, 2015), a recent study found no such association for HIT (Stork et al., 2023). The debate also often homogenises SIT (and HIT) protocols together as a single entity, rather than recognising that the different possible protocol permutations that are possible with SIT (and HIT) are also likely to impact the perceptual responses (Metcalfe et al., 2022). There are several arguments that can be made to support the case that criticisms of SIT in general may not hold true for REHIT.

Firstly, we do not dispute that performing exercise at higher intensities will generally be associated with greater decreases in in-task affective valence, and a meta-analysis by Niven et al (2020) did indeed demonstrate that HIT/SIT in general tend to be associated with a greater decrease in affective valence compared to MICT. However, the same meta-analysis also demonstrated that despite the greater decline in affective valence with HIT/SIT, participants tend to enjoy HIT/SIT more than MICT, suggesting that the proposed link between changes in affective valence and exercise enjoyment does not hold true for HIT/SIT (Niven et al., 2020).

Secondly, while exercise intensity is known to affect changes in affective valence, the moderating effect of exercise duration is consistently overlooked (Brand and Ekkekakis, 2018; Ekkekakis et al., 2020; Ekkekakis and Brand, 2019). We recently meta-analysed the effects of protocol parameters in SIT protocols on changes in affective valence and demonstrated that the magnitude of the decrease in affective valence with SIT strongly depends on the interaction between the number and duration of sprints (Metcalfe et al., 2022). Thus, if sprint duration is similar (e.g. 20-s or 30-s), then protocols with fewer sprints will be associated with less of a decrease in affective valence (Metcalfe et al., 2022). Similarly, if sprint duration is sufficiently short (e.g. 5-6-s), then the slope of decline in affective is much less steep and multiple sprints can be completed without in-task affective valence becoming negative (Metcalfe et al., 2022). With REHIT, for example, the decrease in affective valence was no greater than that observed during a 30-min continuous exercise session at 65% of HRmax (0.6±2.4 vs 0.7±1.4 units for lowest reported affect, respectively) (Songsorn et al., 2019). The relatively quick recovery of affective valence following the sprints during REHIT (Songsorn et al., 2019) also raises interesting considerations regarding the length of exposure to lower affective valence during REHIT when compared with both MICT and HIT. For example, in the study of Songsorn et al (2019), the absolute change in affective valence was not significantly different during MICT compared with REHIT, but exercise duration is substantially different between these protocols, so the *exposure* to the decrease in affective valence was much greater during MICT (~10-15 mins) compared with SIT (~2-3 minutes, taking account of sprint and recovery). The relevance of this for influencing exercise intensions and future exercise adherence is currently unknown, but it is an important consideration in the debate of the relative merits of REHIT compared to both MICT and HIT.

Taken together, it is becoming clear that when considering perceptions of exercise, SIT and REHIT are not 'MICT but harder'. While REHIT incorporates supramaximal sprints that will lead to a rapid decline in affective valence, the two sprints are sufficiently short and are interspersed with several minutes of recovery in between, such that in-task affective valance does not become negative (at least on average) (Astorino et al., 2020; Songsorn et al., 2019). At the same time, it should be noted that the standard deviation for affective valence taken immediately following the second sprint is large (Astorino et al., 2020; Metcalfe et al., 2022; Songsorn et al., 2019), indicative of substantive inter-individual differences in the affective response to REHIT that need to be characterised and explained in future research. There is a clear need for further large studies investigating the perceptions and acceptability of REHIT compared with other types of exercise across a range of different populations, and as well as the perceptions and acceptability of REHIT when implemented as a real-world intervention.

Can REHIT be implemented as a 'real world' intervention?

Until recently, all published work involving REHIT has been lab-based and few studies have examined the effectiveness of REHIT in ‘real world’ settings. However, we recently conducted a mixed-methods feasibility study involving an RCT which compared REHIT (2 sessions/week for 6 weeks; n=13) to a no-intervention control group (n=12) in an office setting (Metcalfe et al., 2020). The REHIT intervention was delivered unsupervised using a specialised ergometer and software package. The adherence to the REHIT intervention was good with 90% of the (unsupervised) exercise sessions completed (Metcalfe et al., 2020). Importantly, and in contrast to real-world HIT studies where participants have been shown to exercise below the prescribed intensities (Ekkekakis and Biddle, 2023), the fidelity of the all-out sprints during REHIT was maintained in an unsupervised setting in our study (Metcalfe et al., 2020). Indeed, during the sprints, participants achieved peak power outputs (535 W or 6.65 W/Kg) approximately 2.8-fold higher than the power at $\dot{V}O_2$max (Metcalfe et al., 2020), which is comparable to values achieved in cohort of similar age, fitness and body composition in a supervised laboratory setting (~540 W or 5.9 W/Kg) (Metcalfe et al., 2018). We observed a significant improvement in $\dot{V}O_2$max in the exercise group (+7.4%) compared to the control group (-2.3%) after 6 weeks. Subjective ratings of enjoyment and acceptability were generally positive, and participants were confident in their ability to continue to perform REHIT over the longer term (7.8±1.2 out of 9) (Metcalfe et al., 2020). At the same time, qualitative interviews indicated that participants had negative perceptions of the intervention at the point where sprint duration increased from 15 s to 20 s during latter weeks and this should be taken into account during future effectiveness studies (Metcalfe et al., 2020).

Apart from the protocol considerations discussed above, in our experience there are a number of further practical considerations to ensure REHIT can be implemented as a real-world intervention. Firstly, although it is unknown whether performing a brief warm up before the initial supramaximal sprint provides any benefits, incorporating active rather than passive recovery intervals directly after completing each sprint is important to minimise light-headedness and risk of syncope. The rapid glycogenolysis during supramaximal sprints leads to a hyperosmotic state in active muscle that is counteracted by rapid fluid influx from the extramuscular space, resulting in a transient ~15% drop in plasma volume during recovery (Mandić et al., 2021; Metcalfe et al., 2015). Passive recovery would compound this drop in plasma volume by increasing the risk of orthostatic hypotension due to cessation of the muscle pump in combination with pooling of blood in the lower extremities secondary to exercise-induced vasodilation (Halliwill et al., 2014). In our experience, even unloaded pedalling is sufficient to counteract these risks. Secondly, as supramaximal exercise is unfamiliar for the vast majority of people (even if well-trained), the unique, transient, but substantial perturbation of homeostasis associated with SIT may explain the commonly observed minor adverse effects, such as feelings of nausea, following all out sprints (Astorino et al., 2012; Tucker et al., 2016). In our studies, we incorporate a familiarisation period into the REHIT intervention, whereby sprint duration is increased from 10 s in the first week of training (and a single sprint in session 1), to 15 s during the second two weeks, and then 20 s from week 4 onwards (Metcalfe et al., 2012; Metcalfe et al., 2016). In our experience this has been sufficient to prevent any adverse effects other than fatigue.

Terminology of REHIT in Future Research

When we originally coined the REHIT (reduced exertion HIT) acronym in our 2012 paper (Metcalfe et al., 2012), there was limited agreement amongst researchers about how to best categorise and define the various interval training protocols that were being studied and, as a result, the terms HIT/HIIT/SIT were used interchangeably. We and others have since retained the use of REHIT in various follow up publications of the same exercise protocol. Since then, research in the area of HIIT and SIT has benefited from more standardised terminology, with HIIT referring to repeated (sub)maximal sprints, and SIT referring to repeated supramaximal sprints (Gillen and Gibala, 2018; Weston et al., 2014). In addition, protocols involving very short sprints (e.g. <10 s) now tend to be referred to as Repeated Sprint Training (RST; (Thurlow et al., 2023)). REHIT currently does not fully adhere to the proposed terminology, as the use of supramaximal sprints would make the term ‘reduced-exertion sprint interval training’ (RESIT) more appropriate. We intend to use the term RESIT in future manuscripts and propose a definition of ‘any exercise protocol with a total duration of 10 minutes or less, involving two or three supramaximal sprints of 10-30-s duration’. We encourage other researchers to adhere to this terminology. Based on the currently available evidence, we suggest that of the various permutations of RESIT, a protocol involving 2 x 20-s all-out sprints in a 10-min otherwise low-intensity exercise session seems to be most promising

Conclusions

There is convincing evidence that REHIT can enhance VO_2max in a variety of populations and to a similar extent as other high volume SIT protocols. Although there is some evidence for the efficacy to improve other health-related parameters such as insulin sensitivity and blood pressure, there is more uncertainty, and further large and well controlled lab-based efficacy studies are warranted. Relatively less work has been done investigating the acceptability, feasibility, and effectiveness of REHIT, but one recent small pilot study has provided evidence that REHIT can feasibly be delivered in an unsupervised workplace setting and that the fidelity to improve VO_2max is maintained. There is a clear need for further large studies investigating the feasibility, perceptions, acceptability, and effectiveness of REHIT when implemented as a real-world exercise intervention.

Data Availability

This manuscript is a review and does not report data.

Conflict of Interest Statement

Niels BJ Vollaard declares research grant funding from Integrated Health Partners Ltd, manufacturer of the CAROL exercise ergometer. Richard S Metcalfe has no conflict of interest to declare.

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