Interval running with self-selected recovery

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Abstract

This study: 1) compared the physiological responses and performance during a high-intensity interval training (HIIT) session incorporating externally-regulated (ER) and self-selected (SS) recovery periods; and 2) examined the psychophysiological cues underpinning self-selected recovery durations. Following an incremental maximal exercise test to determine maximal aerobic speed (MAS), fourteen recreationally-active males completed two HIIT sessions on a non-motorised treadmill. Participants performed 12 x 30s running intervals at a target intensity of 105% MAS interspersed with 30s (ER) or SS recovery periods. During SS, participants were instructed to provide themselves with sufficient recovery to complete all 12 efforts at the required intensity. A semi-structured interview was undertaken following the completion of SS. Mean recovery duration was longer during SS (51 ± 15s) compared to ER (30 ± 0s; P<0.001; *d*=1.46 ± 0.46). Between-interval heart rate recovery was higher (SS: 19 ± 9 $b \cdot min^{-1}$; ER: 8 ± 5 $b \cdot min^{-1}$; P<0.001; *d*=1.43 ± 0.43) and absolute time ≥90% maximal heart rate (HR_{max}) was lower (SS: 335 ± 193s; ER: 433 ± 147s; P=0.075; *d*=0.52 ± 0.39) during SS compared to ER. Relative time ≥105% MAS was greater during SS (90 ± 6%) compared to ER (74 ± 20%; P<0.01; *d*=0.87 ± 0.40). Different sources of afferent information underpinned decision-making during SS. The extended durations of recovery during SS resulted in a reduced time ≥90% HR_{max} but enhanced time ≥105% MAS, compared with ER exercise. Differences in the afferent cue utilization of participants likely explain the large levels of inter-individual variability observed.

Key Words: Fatigue; Exercise; Performance; Physiology; Recovery

Introduction

High-intensity interval training (HIIT) has received considerable attention in research and applied domains given the reported benefits for general and athletic populations (Buchheit & Laursen, 2013). HIIT, characterised by the alternation of high-intensity exercise bouts with periods of lower-intensity recovery, has been advocated as a means of enhancing exercise performance with improvements likely mediated by favorable alterations in physiological parameters such as maximal oxygen uptake ($\dot{V}O_{2max}$) (MacPherson & Weston, 2015), lactate thresholds (Inoue et al., 2016), and peak power output (Ní Chéilleachair, Harrison, & Warrington, 2017). From a clinical standpoint, improvements in prognostic and diagnostic health indicators such as cardiorespiratory fitness (Weston, Taylor, Batterham, & Hopkins, 2014), glucose regulation (Jelleyman et al., 2015), and vascular function (Ramos, Dalleck, Tjonna, Beetham, & Coombes, 2015) have been reported in response to HIIT.

The premise underpinning the cardiovascular and peripheral adaptations induced by HIIT stems from the ability of such exercise modalities to augment the duration of training spent at near-maximal intensities (Laursen & Jenkins, 2002). Specifically, time spent ≥ 90% of maximal heart rate (T ≥ 90% HR_{max}) has been suggested to be particularly important in cases where enhancements in $\dot{V}O_{2max}$ are sought (Bacon, Carter, Ogle, & Joyner, 2013). The characteristics of work and recovery periods are therefore important components in the prescription of HIIT as their interaction will likely determine the acute physiological load (Buchheit & Laursen, 2013). Attempts have been made to document the physiological responses associated with HIIT formats utilising work/recovery durations (in seconds) of 15/15 and 30/30 (Helgerud et al., 2007; Zuniga et al., 2011). A shared feature of such HIIT formats is the utilisation of a standardised and externally-prescribed work-to-rest ratio. Specifically, work-to-rest ratios of 1:1 are commonly adopted during HIIT incorporating short intervals (Dupont, Akakpo, & Berthoin, 2004; Wong, Chaouachi, Chamari, Dellal, & Wisløff, 2010).

Notwithstanding the practicality of organising training in this manner, standardised recovery durations may not always result in the highest physiological load (Gibson, Brownstein, Ball, & Twist, 2017).

It is well established that improvements in health and performance are maximised when the intensity of exercise is tailored to an individual's training status and physiological capacity (McPhee, Williams, Degens, & Jones, 2010). In the context of HIIT, this is often achieved by manipulating the velocity, speed or power output prescribed during work intervals (Laursen & Jenkins, 2002). Whilst the appropriateness of such practices is widely accepted, little attention has been paid to the individualisation of recovery durations. This is somewhat surprising given the large variability evident amongst individuals in the ability to recover between bouts of high-intensity exercise (Tomlin & Wenger, 2001). The extent to which standardised or externally-regulated recovery durations accommodate such differences is therefore questionable. Crucially, misjudging required recovery may compromise an individual's ability to complete a given session and/or exercise at the desired intensity. As the intensity at which work intervals are performed remains central to the effectiveness of HIIT (Munoz, Seiler, Alcocer, Carr, & Esteve-Lanao, 2015), the programming of inappropriate recovery durations may prove counterproductive.

The prescription of self-selected recovery durations may represent a practically useful means of individualising recovery periods during HIIT. Nevertheless, research investigating the efficacy of this approach remains relatively sparse. To date, investigations examining self-selected recovery periods have primarily utilised repeated sprint protocols, reporting conflicting results (Gibson et al., 2017; Glaister et al., 2010; Phillips, Thompson, & Oliver, 2014). When instructed to self-select between-sprint recovery durations, Gibson and colleagues (2017) reported the performance of elite male youth footballers to be likely compromised and the physiological load to be likely increased during a repeated sprint protocol

(10 x 30 m maximal sprints). Conversely, recreationally-active males overestimated required recovery by at least 10% and were able to maintain performance during 10 x 6 s cycle sprints when self-selected recovery periods were utilised (Phillips et al., 2014). Moreover, when self-selected recovery was adopted during HIIT incorporating longer intervals (5 x 1000 m), the physiological load imposed was similar to that achieved when standardised work-to-rest ratios were prescribed, despite self-selection resulting in significantly less recovery (Edwards, Bentley, Mann, & Seaholme, 2011). The use and efficacy of self-selected recovery periods may be aided by a greater understanding of the goals and decision-making processes associated with the length of self-selected recovery periods, an area, as yet underrepresented in the literature.

The aim of this study was to investigate physiological, perceptual, and performance responses during HIIT incorporating 30 s work intervals, when between-interval recovery durations were self-selected and externally-regulated. Furthermore, an exploratory investigation of the decision-making processes underpinning self-selected recovery periods was performed. We hypothesised that when compared to externally-regulated recovery periods, self-selection of recovery duration would result in: 1) extended durations of recovery; 2) a reduced $T \geq 90\%\ HR_{max}$; and 3) better maintenance of the target running speed.

Methodology

Participants

Fourteen recreationally-active males participated (age: 30 ± 7 years; stature: 179.7 ± 4.7 cm; body mass: 78.8 ± 9.0 kg; $\dot{V}O_{2peak}$: 54.0 ± 7.9 $ml \cdot kg \cdot min^{-1}$). All participants regularly participated in different forms of HIIT and disclosed no contraindications to exercise of this nature via a health screening questionnaire. Written informed consent was obtained from all participants prior to data collection. The study protocols were submitted to and approved by the School of Science and Sport Ethics Committee at the University of the West of Scotland and all procedures conformed to the Declaration of Helsinki.

Experimental design and overview

A randomised crossover design was used with participants attending the laboratory on three separate occasions. During the first visit, $\dot{V}O_{2peak}$ and maximal aerobic speed (MAS) were established during an incremental exercise test on a non-motorised treadmill (Woodway Force 3.0, USA). Participants then completed a HIIT protocol on each of the two remaining visits where physiological and perceptual responses were collected and participant interviews were conducted. Each session lasted no longer than 45 min, with a minimum of 48 h separating each session. Participants were requested to refrain from strenuous exercise, alcohol and caffeine intake for 24 h preceding each trial. Given the impact of alterations in diet upon performance and mood state, participants were asked to replicate dietary intake prior to each session (Jeacocke & Burke, 2010).

Familiarisation and preliminary measurements

Participants' stature and body mass were measured using a free-standing stadiometer (Seca Model 213, Germany) and self-zeroing digital scales (Seca Model 888, Germany), respectively. A standardised warm-up comprising 5 min jogging at a self-selected pace on a motorised treadmill (Woodway PPS 55sport-I, USA) was then performed. The non-motorised treadmill was utilised for all HIIT sessions as in addition to the physiological responses elicited, we were also interested in examining the impact of self-selected recovery periods on various measures of performance during HIIT. Given that the majority of participants had not previously utilised this apparatus, they were provided with a brief period of habituation. Having first been instructed on the correct technique, participants were tethered to a strut at the rear of the treadmill and were permitted a series of short practice runs whereby they were asked to maintain a running speed of 7 $km \cdot h^{-1}$. A velocity trace plotted against a line representative of the target running speed was visually depicted on the user interface of the treadmill. Practice runs were ~15 s in duration and performed until participants were comfortable with the apparatus, demonstrating an ability to maintain the target running speed with minimal fluctuations.

The $\dot{V}O_{2peak}$ and MAS of participants were then assessed during an incremental test to volitional exhaustion on the non-motorised treadmill (Morgan, Laurent, & Fullerkamp, 2015). Participants were instructed to perform to the best of their ability and received encouragement throughout. To help maintain the appropriate running speed, participants were again provided with real-time feedback in the form of a visual velocity trace. Participants were instructed to commence running at 7 $km \cdot h^{-1}$ for the first minute with the target speed increasing by 1 $km \cdot h^{-1}$ every minute thereafter. Participants were instructed to maintain a consistent running speed and reminders were provided by the lead investigator when fluctuations occurred. Exact running speeds achieved were ascertained by averaging data over 20 s periods. To measure respiratory variables, participants breathed through a one-way directional valve system connected to an online gas analyser (Medgraphics Ultima, USA). $\dot{V}O_{2peak}$ was taken as the single highest VO_2 value recorded using 15-breath moving averages (Scheadler, Garver, & Hanson, 2017). Heart rate (HR) was monitored throughout the test via a chest-worn HR monitor (Polar Electro, Finland) with HR_{max} being taken as the highest value recorded. MAS was defined as the lowest running speed at which $\dot{V}O_{2peak}$ was attained (Hill & Rowell, 1996).

HIIT protocol

In a counterbalanced order, participants completed an adapted version of the HIIT protocol utilised by Millet and colleagues (2003) whereby between-interval recovery was either externally-regulated at 30 s (ER) or self-selected (SS). Twelve 30 s intermittent runs at a target intensity of 105% MAS were completed during each session. Between-interval recovery periods were fixed at 30 s during ER so as to maintain a 1:1 work-to-rest ratio – a practice commonly adopted during HIIT incorporating short intervals (Dupont et al., 2004; Wong et al., 2010). Running intervals commenced from a standing start with participants instructed to attain the target speed as soon as possible from the onset of each effort. Participants were not provided with any verbal encouragement. To replicate the programming of HIIT within the applied setting (Buchheit & Laursen, 2013), participants did not have access to continual feedback concerning running speed or physiological parameters during work intervals; however, a single verbal cue was provided during each interval to affirm attainment of 105% MAS. On receiving this cue, participants were instructed to "*maintain this speed as best as possible for the remainder of the work interval*". During SS, participants were required to self-select the duration of their between-interval recovery periods. In this regard, participants were instructed to "*provide yourself with sufficient recovery so as to enable yourself to complete all twelve efforts at the required intensity*". Instructions were carefully considered to ensure no expectation of recovery was set with the term "*sufficient*" being deemed appropriate. Participants were not provided with any verbal or visual feedback on recovery duration.

Outcome measurements

Physiological. HR data was collected at a sampling rate of 1 Hz with the absolute T ≥ 90% HR_{max} during each session recorded. Heart rate recovery (HRR), defined as the absolute difference between HR taken at the start and end of each recovery period (Buchheit, Simpson, Haddad, Bourdon, & Mendez-Villanueva, 2012) was recorded whilst the cardiovascular drift (HR_{drift}) in peak and recovery HR was also analysed. Peak HR_{drift} was defined as the difference between the HR recorded at the end of the first and final work intervals. Recovery HR_{drift} was defined as the difference between the HR recorded at the end of the first and final recovery periods.

Blood lactate concentrations ($[La^-]_b$) were assessed prior to the warm-up, immediately after, and 5 min post-HIIT. Fingertip blood samples were collected in 20 µl capillary tubes and analysed within 30 min of collection using a commercially available bench top analyser (Biosen C Line, Germany).

Performance. Mean recovery duration during SS was calculated. Running speed data were obtained during each repetition of the HIIT protocol at a sampling rate of 4 Hz. Mean running speed was calculated for each 30 s work interval whilst the relative time ≥ 105% MAS (T ≥ 105% MAS) was determined.

Perceived exertion. Differential ratings of perceived exertion (d-RPE) were collected within 2 min of completion of each HIIT session (McLaren, Smith, Spears, & Weston, 2017; Weston, Seigler, Bahnert, McBrien, & Lovell, 2015). Participants used the centiMax scale (CR100) to differentiate between local muscle (RPE-muscular) and central (RPE-breathlessness) effort experienced during each protocol. A measurement of total exertion (RPE-total) was also obtained. Participants were instructed on the correct use of the scale during habituation sessions and ratings were collected in a counterbalanced manner to eliminate order effects.

Semi-structured interview. Participants completed a semi-structured interview ~10 min after the SS trial. A list of open-ended questions were used to guide the interview and assess participants' goals for the HIIT session as well as the internal/external cues utilised during the decision-making process. Prior to the commencement of the study, questions were reviewed and adapted by a researcher experienced in qualitative research so as to ensure that they would not lead participants to particular responses. All interviews were conducted by the lead researcher in a quiet room and lasted 14 ± 4 min (range: 10-21 min). With the permission of participants, interviews were audio recorded. Whilst all participants were interviewed, malfunctions with audio recordings occurred with two participants resulting in modest data attrition (n = 12 interviews were analysed).

Statistical and thematic analyses

Data were checked for normality using the Shapiro-Wilk test and were deemed appropriate for parametric analyses ($P > 0.05$). Differences between trials were examined using paired sample t-tests with mean differences and 95% confidence intervals (CI) for real change calculated. Mean standardised differences are reported as Cohen's d and are reported alongside the standard error of the effect size estimate. Mean standardised differences were interpreted as small ($d \geq 0.2$), moderate ($d \geq 0.5$), and large ($d \geq 0.8$) (Cohen, 1992). Statistical significance was set at $P \leq 0.05$ and unless otherwise stated, quantitative data are presented as means and standard deviations (mean ± SD). All statistical procedures were completed using Statistical Package for Social Sciences (SPSS 22.0, IBM, USA).

Qualitative data were analysed using concurrent deductive and inductive content analysis (Sparkes & Smith, 2013) whereby the analysis was based upon two *a priori* research themes (goals and internal/external cues) whilst remaining open to emergent findings within participants' responses. Firstly, the audio-recordings were transcribed verbatim and subsequently double-checked to ensure accuracy. Close reading of the text was then undertaken by the lead researcher to ensure familiarity with the data. Raw data units were then created from participants' words before being grouped into categories and then higher order themes. During analysis, internal homogeneity (that data within a category share clear characteristics) and external heterogeneity (clear differences exist between different categories) was sought (Patton, 2001). In order to ensure the trustworthiness of the aforementioned analyses, the lead and second researchers discussed and confirmed the allocation of raw data units to specific categories through constructive debate.

Results

Physiological, performance, and perceptual data are presented in Table I.

Physiological

No differences were observed in $T \geq 90\%$ HR_{max} between conditions ($P = 0.075$); however, $T \geq 90\%$ HR_{max} was increased to a moderate extent during ER compared to SS ($d = 0.52 \pm 0.39$; 95% CI -11-207 s). Mean HRR was lower during ER compared to SS ($P < 0.001$) with a large effect size being evident ($d = 1.43 \pm 0.43$; 95% CI 7-15 $b \cdot min^{-1}$). No differences were observed in peak HR_{drift} between conditions ($P = 0.272$); however, peak HR_{drift} was reduced to a small extent during ER compared to SS ($d = 0.31 \pm 0.38$; 95% CI -2-8 $b \cdot min^{-1}$). Recovery HR_{drift} was greater during ER compared to SS ($P < 0.01$) with a large effect size being evident ($d = 0.96 \pm 0.40$; 95% CI 6-23 $b \cdot min^{-1}$). The HR dynamics of a representative participant during ER and SS is in Figure 1. No differences were observed between conditions in $[La^-]_b$ at any time point.

Performance

Mean recovery duration was longer ($P < 0.001$) during SS compared to ER with large effect sizes being evident ($d = 1.46 \pm 0.46$; 95% CI 13-30 s; Figure 2). Mean running speed was greater ($P < 0.05$) during SS compared to ER with a medium effect size being evident ($d = 0.73 \pm 0.38$; 95% CI 0.07-0.64 $km \cdot h^{-1}$). Relative $T \geq 105\%$ MAS was greater ($P < 0.01$) during SS compared to ER with a large effect size being evident ($d = 0.87 \pm 0.40$; 95% CI 5-27%).

Perceptual

No differences in RPE-breathlessness ($P = 0.134$) were observed between conditions; however, RPE-breathlessness was increased to a small extent in ER compared to SS ($d = 0.43 \pm 0.38$; 95% CI -2-12 AU). No differences were observed in RPE-muscular ($P = 0.442$) between conditions; however, RPE-muscular was reduced to a small extent during ER compared to SS ($d = 0.21 \pm 0.38$; 95% CI -15-7 AU). No differences were observed between conditions in RPE-total ($P = 0.338$); however, RPE-total was increased to a small extent during ER compared to SS ($d = 0.27 \pm 0.38$; 95% CI -4-10 AU).

Qualitative data

In relation to the objectives of participants during SS, three distinct types of goal were identified: performance-related, outcome-related, and those related to the maintenance of a positive affective state (Figure 3). Performance goals included the maintenance of the appropriate running speed across each work interval (n = 7) whilst outcome goals related to the completion of the session (n = 10) as well as the optimisation of the physiological stimulus for training adaptations to be achieved (n = 5). Other objectives highlighted by participants were to remain comfortable and avoid unnecessary physiological stress (n = 5) and to generally feel good (n = 1).

When determining when to recommence the next high-intensity interval, participants were found to use a range of afferent feedback cues (Figure 3). Amongst these, the stabilisation of respiratory rate (n = 10) and the magnitude of the drop in HR occurring between intervals (n = 6) were commonly mentioned as being pivotal in determining the length of recovery. Additional cues related to feelings of muscular recovery (n = 6), general feelings of being ready to recommence the next interval (n = 7), and subjective feelings of being comfortable again (n = 1).

Discussion

In agreement with our hypotheses, the self-selection of between-interval recovery durations resulted in the following: 1) significantly extended durations of recovery; 2) a moderately reduced $T \geq 90\%\ HR_{max}$; and 3) an enhanced ability to perform at the target running speed. The present study is also the first to examine the goals and decision-making processes underpinning self-selected recovery intermissions. Whilst our relatively small sample size and the exploratory nature of the qualitative arm of the investigation compromises our ability to provide firm conclusions surrounding the psychophysiological mechanisms, our qualitative data may provide an insight into the disparate responses observed during HIIT incorporating self-selected recovery periods. Specifically, differences in the afferent cues used and goal orientations of participants may explain the large inter-individual variability shown to exist in the performance and physiological and perceptual responses.

Physiological, performance, and perceptual responses

Central to the effectiveness of HIIT is the ability to maximise the duration of training undertaken at high relative intensities (Laursen & Jenkins, 2002). Where enhancements of cardiorespiratory fitness are sought, T ≥ 90% HR_{max} may be important (Bacon et al., 2013). In the present investigation, we report the T ≥ 90% HR_{max} to have been moderately lower (d = 0.52 ± 0.39) during SS compared to ER. Consequently, when HIIT is utilised as a conditioning tool for the enhancement of $\dot{V}O_{2max}$, our data suggest the use of self-selected recovery periods to be potentially unfavorable. The moderately reduced T ≥ 90% HR_{max} observed during SS may be viewed as a direct consequence of the extended recovery taken during this condition. Indeed, self-selected recovery durations were 21 s (95% CI 13-30 s) longer than the 30 s afforded during ER and coincided with a significantly greater mean HRR. Given the passive nature of these recovery periods, the impact of extended recovery durations upon participants' HR dynamics is unsurprising (Figure 1). Whilst peak HR_{drift} was comparable between conditions, recovery HR_{drift} was significantly reduced when between-interval recovery periods were self-selected. Additionally, inspection of individual responses revealed that the recovery HR (recorded at the end of each recovery period) of several participants (n = 5) declined as the session continued, a finding which may be explained by our qualitative data (Figure 3).

Notwithstanding the importance of peripheral feedback in the regulation of effort (St Clair Gibson, Swart, & Tucker, 2017), our findings suggest a reliance on cardiopulmonary sources of afferent information when self-selecting recovery periods. Indeed, qualitative data revealed six participants waited for their HR to recover to a rate they perceived to be sufficient to commence the next effort. Additionally, 10 participants suggested that the stabilisation of respiratory rate was their major cue for initiating the next interval. Such data may therefore help explain the extended recovery periods adopted during SS and the concomitantly greater HRR. Although disputed within the literature (Inzlicht & Marcora, 2016), the integrative governor theory suggests that exercise regulation is the result of a dynamic competition between physiological and psychological drives (St Clair Gibson, 2017). Specifically, this model suggests that individuals who have a strong physiological protective drive will likely always complete a given exercise event but will do so in a manner by which excessive disruption to bodily homeostasis is avoided. In the current investigation, the completion of HIIT sessions (n = 10) and completion of sessions whilst maintaining a comfortable state (n = 5) were identified as common goals set by participants. Interestingly, all participants who cited the completion of HIIT sessions as their objective were also found to have utilised HR and/or respiratory rate when gauging their perceived readiness to commence the next interval.

In line with the moderately reduced T ≥ 90% HR_{max}, we found a small non-significant reduction in RPE-breathlessness following SS compared to ER. Interestingly, no differences in RPE-total were evident between the two conditions. Given the slightly reduced cardiorespiratory load perceived when self-selected recovery periods were adopted, RPE-total during SS may have been mediated by a perceived increase in peripheral demand. Indeed, although non-significant, a small effect size indicated RPE-muscular to be slightly greater during SS compared to ER. Interestingly, although McLaren et al., (2017) have previously reported greater $[La^-]_b$ to coincide with increased perceptions of peripheral demand, no differences in $[La^-]_b$ were evident between conditions at any time point post-HIIT. An alternative explanation for the slightly greater RPE-muscular observed during SS may reside in the greater time above 105% MAS in this trial. Although $[La^-]_b$ remained unchanged between the two conditions, the faster running speeds attained during SS are likely to have imposed a greater stress on the musculoskeletal system, thereby offering a partial explanation for the slightly greater peripheral demand perceived by participants during this condition.

Furthermore, results from the present study would suggest that the afferent feedback influencing subject's decision to commence exercise as identified in the qualitative analysis were undetected by the d-RPE scales. Whilst easy to administer, our data may question the usefulness of such approaches when attributing exertion to specific physiological systems.

Although resulting in a moderately reduced T ≥ 90% HR_{max} (d = 0.52 ± 0.39), self-selected recovery periods facilitated an enhanced T ≥ 105% MAS and the attainment of significantly higher running speeds (~3%). Our findings are consistent with those of Seiler and Hetlelid (2005) who documented a 2% increase in running performance during HIIT (six 4 min work periods) when recovery durations were increased from 1 to 2 min. Two possible explanations may be offered. Firstly, the extended recoveries may have allowed for greater recovery of phosphocreatine stores. Secondly, whilst target intensities of 105% MAS were set, actual running speed was self-regulated by participants in an autonomous manner. The disparate mechanical output profiles exhibited during the work intervals of SS and ER may therefore highlight the adoption of pacing strategies and differences in the central neural drive provided to the exercising muscles (Mendez-Villanueva, Hamer, & Bishop, 2007). In addition to knowledge regarding the demands of the activity, muscle activation and recruitment is a consequence of the available between-interval recovery (Billaut, Bishop, Schaerz, & Noakes, 2011). It could be suggested that when recovery periods are externally-regulated during HIIT, pacing tactics aimed at the prevention of significant homeostatic disturbance and premature exercise termination may be adopted (Tucker, 2009). Conversely, a greater neural drive might be allocated to a task when between-interval recovery periods are self-selected; however, this remains speculative and represents an avenue for future research.

Inter-individual variability

Whilst we set out to document the responses observed within a homogenous group of recreationally-active males, the very nature of self-regulation exposes our results to high levels of inter-individual variability. Consequently, the primary limitation of the current study resides in our ability to extrapolate our results to different populations. For instance, the range in mean self-selected recovery durations was substantial (30-88 s) as were physiological and performance responses. Indeed, the range in T ≥ 90% HR_{max} was substantially greater during SS (27-772 s) compared to ER (152-642 s). A potential explanation for such variation may reside in the different goal orientations of participants (Figure 3). For example, participants who set outcome goals such as the completion of the HIIT series (n = 10) are likely to have "managed" the session differently to those who aimed to optimise the physiological load required for training adaptations to be achieved (n = 5) (St Clair Gibson et al., 2017). Furthermore, performance-related goals such as the maintenance of the specified running speed across each work interval (n = 7) were also commonly set; when participants' attention is on the maintenance of performance, longer recoveries are likely to be taken. In support of these suggestions, Phillips et al., (2014) reported self-selected recovery durations during a repeated cycle sprint protocol to be overestimated by at least 10% when participants were instructed to take sufficient recovery so that they were able to replicate the performance achieved during a criterion sprint.

Practical applications

As self-selected recovery periods resulted in a moderately reduced T ≥ 90% HR_{max} (d = 0.52 ± 0.39) during HIIT, such modes of recovery may be unfavorable when enhancements of aerobic fitness are sought. However, in instances where maintaining the prescribed intensity is the aim, self-selected recovery may be beneficial. Such examples may include tapering periods whereby the primary goal is to minimise accumulated fatigue from previous training through reductions in training volume and frequency with the maintenance of training intensity (Pyne, Mujika, & Reilly, 2009).

Conclusions

When afforded autonomy over between-interval recovery durations during an acute bout of HIIT, recreationally-active males adopted longer recovery periods than the 30 s permitted during an externally-prescribed trial. A moderately reduced T ≥ 90% HR_{max} but enhanced running performance was therefore exhibited in response to self-selected recovery periods. Our findings were subject to large levels of inter-individual variability with qualitative data highlighting a wide variety of goal orientations and sources of afferent information utilised by participants. Consequently, our findings should not be interpreted as being generalisable and additional research is required to elucidate the efficacy of such training modalities within individuals of varying demographics.

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Tables

Table I. Physiological, performance and perceptual responses elicited during externally-regulated (ER) and self-selected (SS) recovery conditions (n = 14)

	Externally-regulated recovery (ER)	Self-selected recovery (SS)
Physiological		
$T \geq 90\%$ HR_{max} (s)	433 ± 147 (27-772)	335 ± 193 (152-642)
Mean HRR ($b \cdot min^{-1}$)	8 ± 5 (2-20)	19 ± 9 (6-34) ***
Peak HR_{drift} ($b \cdot min^{-1}$)	20 ± 6 (11-30)	18 ± 10 (4-38)
Recovery HR_{drift} ($b \cdot min^{-1}$)	20 ± 9 (5-36)	6 ± 20 (-31-35) **
$[La^-]_b$ baseline ($mmol \cdot L^{-1}$)	1.01 ± 0.33 (0.55-1.64)	1.04 ± 0.30 (0.53-1.66)
$[La^-]_b$ post-HIIT + 0 min ($mmol \cdot L^{-1}$)	9.39 ± 3.16 (5.74-16.50)	8.78 ± 3.59 (3.44-15.25)
$[La^-]_b$ post-HIIT + 5 min ($mmol \cdot L^{-1}$)	7.15 ± 2.61 (4.12-14.60)	6.95 ± 2.92 (2.83-12.60)
Performance		
Mean recovery duration (s)	30 ± 0 (30-30)	51 ± 15 (30-88) ***
Mean running speed ($km \cdot h^{-1}$)	12.37 ± 0.93 (10.54-13.62)	12.72 ± 1.11 (11.15-14.50) *
$T \geq 105\%$ MAS (%)	74 ± 20 (31-96)	90 ± 6 (46-95) **
Perceptual		
RPE-breathlessness (AU)	85 ± 12 (55-100)	80 ± 10 (68-98)
RPE-muscular (AU)	71 ± 17 (37-95)	75 ± 19 (25-95)
RPE-total (AU)	87 ± 11 (55-100)	84 ± 11 (60-95)

Data are presented as mean ± SD (range). $T \geq 90\%$ HR_{max}, absolute time ≥ 90% of maximal heart rate; HRR, magnitude of between-interval heart rate recovery; HR_{drift}, cardiovascular drift; $T \geq 105\%$ MAS, relative time ≥ 105% of maximal aerobic speed; RPE, rating of perceived exertion. * Significant difference ($P < 0.05$) from ER; ** significant difference ($P < 0.01$) from ER; *** significant difference ($P < 0.001$) from ER.

Figures

Figure 1. Heart rate dynamics of a representative subject during externally-regulated (ER; A) and self-selected (SS; B) recovery conditions.

Figure 2. Durations of between-effort recovery adopted across each recovery interval during externally-regulated (ER) and self-selected (SS) recovery conditions (n = 14). Data are presented as mean ± SD.

Figure 3. Psychophysiological cues and goals reported by participants during semi-structured interviews to have underpinned self-selected recovery durations (n = 12).