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Recovery Methodologies and High Intensity Interval Training

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ABSTRACT

The purpose of this study was to determine recovery from Tabata bodyweight high intensity interval training (HIIT) exercise using different recovery assessment methodologies across 24- and 48-hour time intervals. Participants (23.2 ± 3.1 years old, 163.1 ± 19.9 lbs., and 22.8 ± 9.6 % body fat) consisted of 3 females and 7 males (n=10) Individuals who were recreationally trained (4+ days per week, 30+ minutes per day at moderate to vigorous intensity) and conducted both Trial A (24-hours between HIIT sessions) and Trial B (48-hours between HIIT sessions). Before and during each session, heart rate, countermovement jump, perceptual, and psychological measures were recorded. There were two statistically significant results. The first was the Perceived Recovery Status scale (PRS) for both trials (A, p = 0.005. B, p = 0.007) and the second was the Brunel Mood Scale assessment within Trial B (p = 0.012). These results support the assertion that assessment of perceptions of recovery are sensitive methodologies in measuring recovery from Tabata bodyweight HIIT exercise.

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INTRODUCTION

High intensity interval training (HIIT) has become an increasingly useful mode of exercise across many different populations to increase performance (11), fat oxidation (8), and enjoyment during exercise (28). High intensity interval training has also become incredibly popular for its dexterous nature, as it can be applied across many different modes of exercise. At its core, HIIT consists of several intervals of vigorous intensity which can be defined as ~76-96% of an individual's age predicted max heart rate (APMHR) according to the American College of Sports Medicine (1). Each work interval is followed by a rest interval and, depending on the type of exercise being conducted, these work and rest intervals can vary in duration. For example, Laurent et al. (19) determined that a 2:1 work to rest ratio was an optimal amount of work and rest during a running HIIT session. Another form of HIIT, known as Tabata, finds its early beginnings with stationary cycling with 20 seconds of work and 10 seconds of rest (27). Each Tabata trial consists of 5 bouts that each last about 4 minutes and a larger rest interval (1 minute) can be used between bouts. Tabata has recently been tailored to utilize bodyweight calisthenic movement. Practically, this style of exercise (Tabata HIIT with functional movements) is implemented within fitness programs such as CrossFit, F45, or Peloton classes. In fact, Herodek et al. (10) describe Tabata as an optimal form of HIIT due to its versatility to cover a wide range of exercise types. With this novelty, versatility, and popular application, engagement in any sort of exercise facilitates the need for recovery

(3). Specifically, the understudied area of HIIT exists within recovery between sessions of HIIT. Optimal recovery metrics have not been well-studied, and recovery is generally defined as the ability to replicate performance in the same activity (25). While much is still not known about the mechanisms by which day-to-day (DTD) recovery from exercise takes place, it plays a crucial role in a training program and cannot be overstated (3). Day-to-day recovery must be monitored so as to avoid prolonged overtraining resulting in injury or overtraining syndrome. Since High intensity interval training is extensively used in athletic populations to increase VO2max, aerobic fitness, and aerobic capacity (20) it is therefore deserving of recovery monitoring so as to optimize its implementation. For example, since this mode of exercise is an incredibly time-efficient form of exercise – in that intervals can last anywhere from 10 seconds to 4 minutes, optimizing time spent at high intensity (9) – recovery may look different for each day depending on the work to rest intervals. Most coaches, however, lack the time, tools, and know-how to implement invasive methods of determining whether their athletes are fully recovered from the previous HIIT session. Without determining optimal recovery, an athlete may not receive the physiological benefits of engaging in HIIT, as they may not be able to produce the work necessary at the intensity necessary to illicit the desired, specific gains from HIIT. Thus, the need for a practical and non-invasive metric (or metrics) to expose recovery from bodyweight HIIT exercise is necessary to optimize HIIT use in an exercise program.

The novelty and recent introduction of HIIT requires more study to understand day-to-day recovery from training and recovery metrics so coaches and trainers know when to engage in the next session of HIIT. The purpose of this review is to investigate the application of different recovery methodologies on day-to-day recovery from HIIT and develop the need for further study on this topic.

REVIEW OF LITERATURE

Day-to-Day HIIT Recovery

Day-to-day recovery from any type of exercise can be monitored several different ways from hormone levels and blood-borne muscle damage markers to neuromuscular performance and perceptual measurements. While there may be many different ways to measure recovery, not all methodologies are non-invasive or practical for coaches or trainers to implement on a day-to-day basis. Measuring recovery is important to optimize performance and desired improvement from training (3). While recovery from exercise remains highly individual (30), measurement of any outcome variable in comparison to its previous baseline seems to be the standard of recovery across recovery literature. Additionally, a return to or exceeding of performance (via repetitions, time, power, etc.) in the same activity the day (or days) following a given activity is also used as the standard to delineate full recovery (21, 25). Just like any exercise, HIIT can be taxing on the body and recovery must be taken seriously so as to optimize its use within an exercise program.

Heart Rate Measures

Much research on HIIT is closely associated with heart rate (HR). Since HIIT involves intense cardiovascular strain with various types of dynamic exercise, HR is utilized in several different ways. Metrics like peak heart rate (HRpeak) (maximal heart rate during exercise) and heart rate recovery (HRrecov), which is recorded as the beats between cessation of exercise and 1-5 minutes after, are important to consider when studying HIIT to assess intensity, measure acute recovery from each session to indicate training status (6), and DTD recovery from each session (25). For example, in one study on 14 well-trained cyclists, HR was recorded after exercise to determine the effects of different training methods, including HIIT, on heart rate recovery (HRrecov) (17). In the same study by Lamberts et al. (17) HIIT was shown to improve HRrecov, which is an indicator used to track long-term training status (6) and is a tool to measure cardiorespiratory fitness (7). Combining HIIT HRrecov and aerobic fitness, a study on 197 infantry soldiers reported that HRrecov from high intensity training (HIT) was associated with higher levels of aerobic fitness (12). In athletics, HRrecov may also be a useful metric to measure training adaptation, as it can display an athlete's ability to adapt to his or her training and subsequent improvements in fitness from HIIT (26). Thus, HRrecov can be a particularly useful metric to determine recovery from HIIT.

In terms of HRrecov as a daily measure, a review article written by Daanen et al. (6) determined that HRrecov has the potential to be useful when measuring long-term training and coping status. When in proper balance, the autonomic nervous system is able to appropriately respond to exercise and rest accordingly. However, when an abrupt increase in training load occurs, supine resting heart rate variability (HRV) can decrease due to sympathetic activity (2). Since HRrecov and HRV from exercise is modulated by the autonomic nervous system (14), heart rate recovery and after exercise may be useful to display individual DTD recovery from exercise via autonomic nervous system balance when compared to a baseline. Schneider et al. (24) notes that HRV and HR measurements are best used when rolled into two to four-day averages rather than looking at single-day numbers and Plews et al. (23) agree that HRV measures should be taken into context of a given individual.

Of course, the modulation of the autonomic nervous system is not the only physiological facet effecting HR. Aspects such as hydration status, stress, medications, and caffeine intake among many other things can have a major effect on heart rate changes. Another factor important to this review is individual training load and its effects on heart rate. Individual training load, or the amount of exercise induced strain on the heart, can vary in regard to each individual and each training program. In the context of HIIT, HR can be used as an index of recovery when engaging in the same exercise on consecutive days (25). Sjokvist et al. (25) found that session HR was not recovered after 24 hours of engaging in HIIT and that athletes spent more time in the 80-100% HR zone at the 48-hour interval during the same workout. In other words, session HR may be sensitive to DTD recovery from HIIT, thus it is an important variable to track across performance during consecutive HIIT workouts.

Neuromuscular Performance Measures

Two widely used metrics to gauge recovery from HIIT are countermovement jump (CMJ) and repeated sprint ability (RSA). The RSA test has been shown as a reliable recovery metric in athletes, as well as CMJ (30). Sjokvist et al. (25) used 14 D1 female soccer players and it was determined that sprinting and bounding assessments measured full recovery (back to baseline, pre-exercise score) from a HIIT training session after 24 hours and CMJ was recovered at 48 hours. In that same study, physiological mechanisms behind these recovery metrics seemed to be associated with neuromuscular fatigue from HIIT and may be sensitive to under recovery (25). Neuromuscular metrics like CMJ, RSA, and bounding-type assessments have been used to better understand recovery from HIIT and they tend to be used in athletic populations. Other measures, like sport-specific drill performance and bounding have also been implemented (25) to determine recovery from HIIT. Within the parameters of recovery in the form of a return to baseline performance in the same activity or intervention, RSA and CMJ movements also offer a highly individual response (30). Using performance metrics like RSA and CMJ also come at a potential cost, as they can be time-consuming and may disrupt an athlete's training program on the day that these tests are implemented (18).

The CMJ assessment, however, is less physically taxing than a sprinting test and can be done rather quickly. The CMJ test appears to be reliable predictors of recovery from HIIT (30). In a study on resistance training and its effect on vertical jump, there was a correlation in decrement between vertical jump and back squat (29). In the same study conducted by Watkins et al., the mechanism behind this correlation had to do with back squat and vertical jump sharing similar movement patterns and muscle recruitment. This is to say that if CMJ is to be utilized as a recovery metric, the exercise intervention should have a movement similar to the vertical jump in order to illicit any sort of response. The CMJ test as a neuromuscular assessment of fatigue seems to be sensitive to DTD changes and should be assessed within a HIIT program consisting of lower body intensive movements to determine effectiveness of measuring recovery.

Perceptual Measures

The use of perceptual measures of recovery are extremely common when studying exercise. A keystone of perceptual measures for exercise research is the Rating of Perceived Exertion Scale (RPE). The American College of Sports Medicine (ACSM) endorses the use of the Borg RPE to subjectively measure intensity (22). For HIIT specifically, Sjokvist et al. (25) used session RPE (S-RPE) measurements to assess how difficult the session was for each athlete. Also RPE has been used to help monitor recovery via internal training load. Impellizzeri et al. (13) conducted research on soccer players and the use of RPE as a gauge of individual training load and found that RPE was a viable indicator of global internal training load. The use of RPE as a perceptual scale with recovery is non-invasive and requires no expensive equipment, making it useful when applied properly (13). Physiologically, if an individual is not well-recovered from previous day(s) exercise, conducting the same type of exercise may be perceived as more difficult and performance has the potential to show decrement.

Other perceptual measures of recovery are perceived delayed onset muscle soreness (PDOMS) and fatigue indices. Wiewelhove et al. (30) used perceived DOMS to indicate recovery from HIIT exercise and reported that PDOMS returned to baseline levels at the 72-hour mark, denoting recovery. Fatigue indices measure how fatigued an individual is from exercise and can be measured before or after exercise. In one study, researchers developed a Perceived Recovery Status (PRS) Scale that was useful in predicting performance after 24, 48, or 72 hours of recovery (18). This particular PRS scale was used in addition to a visual analogue scale (VAS) and timed sprint performance (18). Recovery scales like PRS and VAS can be useful in monitoring DTD recovery from intermittent bouts of exercise (18), however, PRS has not been utilized to measure DTD recovery from Tabata bodyweight calisthenic HIIT.

Future Research and Conclusions

The purpose of this review was to explain the use and effectiveness of different recovery methodologies on day-to-day recovery from HIIT and cultivate the necessity for further study on this topic. The overall utilization of non-invasive metrics to measure DTD recovery from HIIT has largely been understudied. Practically, monitoring DTD recovery from HIIT could be indispensable for coaches and trainers as one measure or a combination of measures may allow for the optimization of this modality of exercise. For athletes, or those who engage in regular exercise, participating in a HIIT training session after recovering to the fullest extent should yield the best performance (18) and, theoretically, help mitigate the risk for overtraining syndrome and injuries.

The modality of bodyweight calisthenics with the timing used in Tabata HIIT deserves further study. The few studies that measure DTD recovery from HIIT have generally used sprint intervals and one study used sport specific drills (25). This gap exists due to the novelty of using bodyweight calisthenics with the timing of Tabata HIIT as a form of HIIT. This modality is becoming more and more popular as general exercisers trend toward “at-home” fitness. Also, the ability to complete full-body movements with no equipment is attractive to many who lead less-active lifestyles. The amount of time it takes to conduct a Tabata HIIT session is also appealing, as the most cited reason for not exercising is lack of time (5).

Over the past decade, DTD recovery has come into greater focus for those who engage in exercise so that they are getting the most out of their training. In a review article written by Bonilla et al. (4), the importance of refueling, resting, rehydrating, and repairing is emphasized heavily within the context of exercise. Exercise, a major disrupting force to homeostasis, creates a challenge for the physiology of the human body. In the context of the recently popular HIIT modality, those who conduct HIIT for performance enhancement, body composition alteration, or due to a lack of time to spend on exercise would benefit greatly from the optimization of DTD recovery. The gap in the literature leaves much to be desired in the way of measuring DTD recovery from HIIT. As there are evermore ways to track recovery through the use of wrist-based heart rate technology, power output via jump height, neuromuscular function, and perceptual measures, the effectiveness of different recovery methodologies on HIIT is worth studying to better implement HIIT in any program.

METHODS

Participants (n=10)

This study used a crossover design in that each participant was compared to their own baseline measures taken from each trial. Participants were recruited via word of mouth and flyers. Participant inclusion criteria consisted of apparently healthy (not diagnosed disease that may affect exercise responses) males and females aged 18-35 who were recreationally trained (exercise at a moderate to high intensity approximately 30 minutes, 4 or more days a week) and had prior experience with HIIT. Exclusion criteria consisted of having a musculoskeletal injury/disease, currently taking medication that affects physiological response to exercise, and tobacco/recreational drug use in any form. Also, prior (and during) each trial, participants were asked to abstain from caffeine and any ergogenic aids that could affect exercise performance 24 hours before and throughout each trial. All participants were read aloud the procedures of the research as explained by the researcher and were asked to sign an informed consent form prior to participation in the study. Approval to conduct the research was obtained from Stephen F. Austin State University's Institutional Review Board (IRB) prior to the any data collection for this study.

Protocol

Prior to the trial, each participant was made familiar with the movements and timing of the workout by engaging in the HIIT trial at a low intensity. Then, in a second familiarization session, the individual completed the entire protocol at high intensity to address any initial learning effect. After the second familiarization, each subject waited at least 72 hours to washout any effects of exercise before engaging in either research trial. Also, each participant engaged in a standardized warm up prior to each HIIT trial consisting of two rounds of 5 minutes on a cycle ergometer (Precor, WA, USA) at 50 revolutions per minute, 20 arm circles, 10 air squats, 10 pushups, and 5 inchworms. Each Tabata trial (Appendix A) was made up of five cycles that each lasted 4 minutes total. Within each cycle, there were four exercises. Each exercise was performed for 30 seconds with a rest interval of 15 seconds before moving on to the next exercise. Traditionally, Tabata exercise is implemented with a 20:10 second work:rest ratio (10). However, Tabata was originally meant to be implemented on a fixed, stationary bicycle. To allow for optimal time for bodyweight movements to be conducted and for the transitions between exercises to be efficient, a work:rest ratio of 30:15 seconds was used. This timing is an optimal work:rest ratio (2:1) according to Laurent et al. (19). After each exercise was completed once through in circuit fashion (first exercise completed, second, etc.), the participant then completed round two. After the second round, that cycle was over and the participant rested actively by walking around the room for one minute. After that one minute of active rest, the next cycle began. This sequence was repeated a total of five times totaling 32 minutes and 45 seconds. Heart rate and Session-RPE (S-RPE) were taken at the end of each cycle and at the end of the entire trial. To ensure each session was completed at high intensity, the participant was asked to complete as many repetitions as possible during every 30 second work set, and heart rate was monitored by the researcher. Should the subject's heart rate drop below 64% maximal heart rate during a work set, the researcher verbally encouraged the participant to increase their intensity to maintain high intensity during the work set. After the first HIIT trial, each participant completed a subsequent HIIT trial during the following 24 hours (Trial A) or 48 hours (Trial B). The trials were randomized for each participant and a washout period of at least 72 hours was implemented between each trial for every individual.

Measurements of heart rate, visual analogue scale, countermovement jump, Perceived Recovery Scale (18) (Appendix B), Brunel Mood Scale assessment (BRUMS) (Appendix C), and perceived DOMS (P-DOMS) were taken pre-exercise (day of trial), post-exercise (day of trial), 24-hours, and 48 hours. During each HIIT trial, HRpeak, HRavg, and S-RPE were recorded. For the purpose of this study, the definition of DTD recovery was the replication or exceeding of performance measurements obtained from the baseline trial (25). For this reason, total repetitions were counted throughout the entire workout. Also, for the purposes of this study and within the context of bodyweight calisthenic movement, participants were asked to work with maximal output and effort to achieve high-intensity. Correspondingly, our parameters surrounding high intensity and

HR will be within 76-96% of age-predicted max heart rate (APMHR) to allow for the self-paced nature and accumulation of bodyweight movements to provide an adequate heart rate response (1). Optimally, by monitoring heart rates, we ensured each participant operated at least ~76% of APMHR during each work cycle (25). These parameters are consistent with the American College of Sports Medicine standard of vigorous activity (1). To accommodate this mode of exercise, these parameters were set as such to allow for the undulation of HR during a novel form of HIIT. Finally, each 24- or 48-hour session was completed the same time of day as the respective initial baseline day.

Heart rate data was measured and collected using a Polar chest strap (Polar H7, Finland). A pre-exercise HR was taken after the subject rested seated for 3 minutes. During exercise, HR was measured throughout and at the completion of each cycle of the Tabata trial. The HRpeak of the session and HRavg were measured as well to provide insight into intensity and effort throughout each session. After the last repetition of the last exercise of the cycle, the subject rested in a seated position for 3 minutes and HRrecov was recorded. This process was repeated when the participant came back to the lab at either 24 (Trial A) or 48 (Trial B) hours to complete the second HIIT session.

Two visual analogue scales (VAS) were used to measure overall perceived readiness to complete each trial, the VAS for Perceived Readiness (HIIT Readiness) and the VAS for Perceived Muscle Soreness (P-DOMS). These scales were assessed pre-exercise and post-exercise at the baseline trial, 24-hour, and 48-hour intervals. These anchors used to measure perceived readiness to complete a HIIT trial were “Not Ready at

All" and "Completely Ready" (Appendix D). The anchors used to delineate P-DOMS were "No Soreness Present" and "Extremely Sore" (Appendix D). The mark left by the participant was measured in millimeters. Psychologically, the BRUMS (15) was measured pre-exercise to evaluate psychological status markers such as fatigue, vigor, and tension (among other psychological items). The BRUMS, a shortened derivative of the Profile of Mood State, assessed various perceptual items indicating individual perceived recovery.

Counter movement jump (CMJ) was measured using a vertical jump height device (Vertec, CA, USA) to assess neuromuscular fatigue (29). Jump height was assessed allowing two jumps for each pre- and post-exercise data collection within Trial A and B, with the best attempt of the two recorded in inches (25). Several jump attempts were allowed during the familiarization in order to assure each participant was competent with this movement. During the jump, each participant was asked to lower themselves to self-selected depth before jumping vertically as high as possible, reaching for the jump height device (29). Participants were also instructed to have both feet completely set before jumping so as to prevent any inertial momentum from being used.

The PRS scale (18) was used to assess each individual's perceived recovery after the baseline day. This scale uses a 0-10 scale ranging from "very poorly recovered" to "very well recovered" (Appendix B). Each of these measurements are associated with different expectations of performance in the same workout. Participants circled their perceived recovery on the scale at each pre-exercise interval at 24 and 48 hours post HIIT trial after the respective baseline day. To this researcher's knowledge, this is the first time this particular perceptual measure of recovery will be used to assess perceived recovery with self-paced Tabata bodyweight HIIT.

Statistical Analysis

One way analysis of variance was used to analyze RHR, HRavg, HRrecov, and repetitions. Wilcoxon Signed Ranks Test was used to analyze S-RPE, post-exercise RPE, PRS, HIIT readiness, PDOMS, and BRUMS. Significance for all analyses was set at $p \leq 0.05$.

RESULTS

Session HRavg from Day 1 to Day 2 on Trial A did not display any statistical significance ($p = 0.442$), nor did they during Trial B ($p = 0.908$) (Figure 1). There was a small effect size for HRavg (ES = 0.033) for Trial A. The RHR displayed no change during Trial A or B ($p = 0.811$, $p = 0.908$), but there was a small effect size for Trial B (ES = 0.011). The HRrecov was not statistically significant for either Trial A ($p = 0.831$) or Trial B ($p = 0.205$), but there was a medium effect size for Trial B (ES = 0.088). The HRpeak was not statistically significant within Trial A ($p = 0.507$) or Trial B ($p = 0.869$). Additionally, pre-exercise CMJ did not display significance in Trial A ($p = 0.960$) or in Trial B ($p = 0.881$) (Figure 2).

The VAS for pre-exercise perceived readiness saw a general decrease from Trial A Day 1 (76.6 ± 20.6mm) to Trial A Day 2 (58.2 ± 19.4mm), but was not significant ($p = 0.097$) (Figure 3). Trial B averages from Day 1 to Day 2, however, were much closer from Day 1 (71.6 ± 18.7mm) to Day 2 (69.1 ± 25.9mm) and was not significant ($p = 0.919$). The VAS for PDOMS saw an increase in average across participants in Trial A from 24.9 ± 31.5mm (Day 1) to 36 ± 21.6mm (Day 2) and was not significant ($p = 0.203$). Trial B was also not significant from Day 1 to Day 2 ($p = 0.799$). BRUMS scores were not significant between days for Trial A ($p = 0.258$) but were significantly different in Trial B between Day 1 and Day 2 ($p = 0.012$) (Figure 4). S-RPE was not statistically significant for Trial A ($p = 0.720$) or Trial B ($p = 0.748$). Post-exercise RPE was also not statistically significant in Trial A ($p = 0.589$) or Trial B ($p = 1.00$). PRS scores were statistically significant in Trial A ($p = 0.005$) with an average score of 6.2 ± 2.04 (Figure 5, Figure 6). PRS scores for Trial B were also statistically significant in Trial B ($p = 0.007$) with an average score of 7.7 ± 1.64. Repetitions were not statistically significant for Trial A ($p = 0.642$) but a small effect size was analyzed (ES = 0.012) as repetitions increased from Day 1 (1372.8 ± 174.78) to Day 2 (1411.7 ± 193.17). Trial B repetitions were also not statistically significant ($p = 0.733$, ES = 0.007), increasing from Day 1 (1363.6 ± 226.06) to Day 2 (1399 ± 230.13).

DISCUSSION

High intensity interval training has become an increasingly popular and useful (8, 11) way to structure exercise. Using bodyweight exercises with Tabata (27) and HIIT timing (30:15 work:rest) is a novel mode of exercise that has not been investigated thoroughly. More specifically, DTD recovery from HIIT has been understudied. As athletes, coaches, and the general population aim to get the most out of their own training, it is important to consider optimal recovery time from exercise because it is one of the most important factors to improving performance. Supercompensation adaptation responses from exercise may only go so far as adequate recovery will allow (3). The aim of this study was twofold: (a) to investigate the effects of HIIT training on different recovery methodologies and (b) to determine if there were any differences in recovery in 24-hour or 48-hour time intervals. In the present investigation there was statistical significance demonstrated with use of the PRS and BRUMS measurements indicating sensitivity to assessing recovery.

Session HRavg indicated that the exercise intervention was sufficient in intensity, as HRavg across all exercise trials and all participants (158.7±9.3 bpm) was 80.6% percentage of APMHR overall (calculated via average age of all participants). Thus, this exercise protocol induced the proper heart rate responses during exercise for it to be deemed as high intensity interval training. This is important to note because this mode of exercise incorporated with Tabata HIIT timing has not been extensively studies for its ability to illicit high intensities. Thus, using this form of HIIT is viable for inducing an intense stimulus that can be classified as HIIT. Additionally, pre-exercise RHR values, HRavg, HRpeak, and HRrecov heart rates displayed no statistically significant difference from session to session across both trials. While this novel form of HIIT did create a sufficient HR response – enough to classify it as high intensity cardiovascular work – these HR methodologies may not be sensitive as a recovery metric for this form of exercise.

Counter movement jump as a measure of neuromuscular readiness and fatigue described by Watkins, et al. (29) was used in this study to determine whether CMJ was sensitive to recovery. As delineated by Watkins et al., resistance training (most specifically back squat) is shown to decrease neuromuscular control and function (29). To the knowledge of these researchers, determining CMJ sensitivity as a recovery methodology from Tabata bodyweight HIIT is novel. Additionally, Watkins et al. (29) emphasized that the exercise protocol must correspond to the musculature used in the jump (i.e. back squat). For this reason, this study included exercise movements specific to CMJ to remain congruent with previous research. Overall, no statistical significance was found with CMJ as a recovery methodology. Pre-exercise CMJ generally increased (not significantly) from Day 1 to Day 2 in both Trial A and Trial B. This indicates that, while the workout provided enough stimulus to induce some soreness via exercise induced muscle damage (a factor in neuromuscular control), CMJ may not be sensitive to recovery from bodyweight HIIT.

Perceptual VAS was used to gauge individual perceptions of readiness and perceived soreness from the Tabata bodyweight HIIT sessions. Using the HIIT readiness VAS, participants perceived themselves as less ready for Trial A Day 2 because Trial A Day 1 induced a physiological response. While this was not statistically significant, the data does indicate that participants were less ready for Trial A Day 2. Trial B, however, demonstrated that 48 hours of recovery time was more sufficient than 24 hours in determining readiness to complete a HIIT session. Additionally, PDOMS VAS suggested that participants perceived more soreness on Day 2 of both trials, but these values were not significantly different. Anecdotally, participants described more soreness than they were used to with their normal training. As stated, this exercise protocol did involve some plyometric exercises, which participants in this study may not have used regularly in their own training regimens. The sheer volume of work with the bodyweight HIIT exercise may have played a role in participants' perceived soreness.

The BRUMS questionnaire was used to analyze psychological and emotional state changes throughout this study. Trial A BRUMS values did not indicate any noticeable change in emotional changes. Trial B displayed a statistically significant (p=0.012) difference from Day 1 to Day 2. This data suggests that participants were less psychologically and emotionally stimulated by Day 2, as emotional values decreased from Day 1 to Day 2. This change indicates that this metric may be sensitive to recovery, as there was no change in Trial A. Similar to the physiological findings of Mclester et al. with resistance training (21), perhaps the more time given to recover from the Tabata bodyweight HIIT intervention, the more indication of psychological and emotional recovery. Thus, 48 hours between sessions may allow for psychological and emotional recovery according to the BRUMS.

The PRS scale (Appendix B) was used to investigate perceptions of recovery from Day 1 to Day 2 within the same trial for both trials. Both Trial A and Trial B PRS responses were statistically significant ($p=0.005$, $p=0.007$ respectively). Trial A displayed a lower PRS average score across all participants than Trial B, but both were indicative of decreased perceived recovery from the intervention between days 1 and 2. This suggests that the PRS scale is sensitive to recovery from Tabata bodyweight HIIT exercise. This metric was previously used to measure repeated sprint ability DTD recovery (18). This is the first time that this scale has been used to measure recovery from Tabata bodyweight HIIT exercise. As with any sort of high intensity activity, recovery is crucial (3), and this is the case with Tabata bodyweight HIIT. Without the use of the PRS scale, this study would have been tasked to utilize common methodologies to help add to the lack of research on DTD recovery from HIIT. It seems that the PRS is useful when implemented in this type of training, as it delivers specific insight to recovery much like RPE does for exercise intensity. In congruence with Laurent et al. (18), there may be a link between maximal intensity exercise and the use of the PRS. Repeated sprint ability – used in previous research (18) – and HIIT are similar in that maximal intensity is required on behalf of the participant to meet definitions of "sprint" and "high-intensity". This scale, therefore, may be useful when maximal intensity is required of the exerciser. More research may be required of this scale in context with low to moderate intensity exercise. Practically, the PRS scale was the easiest recovery methodology to implement for the researchers and undoubtedly among the simplest and most recovery-specific methodologies for the participants to utilize. It seems reasonable to assume this methodology would translate well to coach-athlete or trainer-client assessments of recovery from this form of exercise.

Overall data indicates that 48 hours allowed for more consistency in recovery methodologies between Day 1 and Day 2 whereas methodologies in Trial A were less consistent across days. In other words, Trial A with the 24-hour time interval seems more disruptive to methodologies such as HR and perceptual measures (VAS, BRUMS, PRS). Other methodologies (CMJ and Reps) seem undisturbed by either trial. Even still, these changes were not statistically significant, with the exception of PRS and BRUMS. That is to say that perceptions of this exercise intervention may be sensitive to measuring recovery.

Limitations

One limitation of this study was the sequence of the exercises. Consequently, repetitions were not a useful methodology of measuring recovery with this mode of exercise, as repetitions displayed an overall increase from Day 1 to Day 2 within each trial. The definition of recovery for this study was the ability to replicate or exceed initial performance (25). In this study, repetitions alone would have indicated that performance generally increased, thus participants would largely be more recovered on the second day of each trial. There are a few possible explanations for this. This is the first time this definition of recovery has been used for Tabata bodyweight HIIT exercise. Therefore, repetitions may not have been useful in determining recovery in the context of this exercise mode, like they may be in resistance training exercise (21). The exercises were also not shuffled from session-to-session. In an attempt to control the HIIT protocol for each session and avoid performance variability due to exercise sequence variation, researchers took care to ensure each session had the same exercise sequence across each day of each trial. The opposite, however, may have mitigated the increase in repetitions. That is to say, since the exercise sequence stayed the same across all sessions, participants may have become more efficient in the transitions between each exercise. This may have also enabled participants to complete the exercises more comfortably. An in-depth familiarization session was implemented before Trials A and B to mitigate this effect as much as possible but may have enabled this phenomenon further. In the future, researchers may consider shuffling the exercises to mitigate desensitization of the workout session. Overall, it does not seem that repetition performance may not be a useful criterion when measuring recovery.

Another possible limitation of this study is intra-subject variability. Intra-subject variability can be defined as the same exerciser performing the same exercises slightly (or majorly) differently each session. This may also explain repetition increase from session-to-session. The researchers were vigilant in keeping each exercise for each participant the same throughout each trial, but an argument can be made that intra-subject variability is nearly unavoidable. Standards for each exercise were covered during the extensive familiarization session, however the nature of Tabata bodyweight HIIT exercise is that it must be self-paced. Researchers studying this mode and structure of exercise must understand that the only feasible way to control the intensities with this form of exercise is to verbally encourage. Unlike a treadmill or a cycle ergometer, Tabata bodyweight HIIT pace is exclusively paced by the participant. This is an inherent challenge with this mode and structure of exercise.

Future Research and Practical Applications

A clear avenue of future research would be to include heart rate variability (HRV) as a recovery methodology. Analyzing HRV (especially nocturnal HRV) gives an insight of the relationship between sympathetic and parasympathetic drive from the autonomic nervous system to assess fatigue (2, 23). With the recent advent and popularity of wearable technology that gives access to this data, it would seem reasonable to include HRV as a recovery methodology by which to measure recovery from Tabata HIIT.

Another avenue of future research would be to complete this mode and structure of exercise exclusively with females while controlling for the full spectrum of the menstrual cycle. This study and others (19, 25) included females. Further research is necessary to understand how this type of exercise is affected by the menstrual cycle and how individuals recover from this type of exercise throughout the menstrual cycle.

Arguably the next step in the evolution of recovery research from this type of HIIT exercise is to analyze differences of recovery methodologies with high-intensity functional training (HIFT). Exercise with HIFT can be defined as exercise like HIIT using different implements such as barbells, kettlebells, sandbags. This is increasingly popular in exercise settings like CrossFit and exercise bootcamps. This kind of training requires more manipulation of external weight and implements, which has the potential to induce a physiological response that necessitates recovery (3). This could benefit exercise programming to better optimize its use in communities that value HIFT.

Practically, the one major takeaway from this study is the use of the PRS scale. The attractiveness of the PRS scale exists with its ease of use for both the assessor and the participant. The scale, in and of itself, is designed to be extremely easy to use and it is recovery specific. While it is perceptual, this scale is directed explicitly toward recovery. Again, the application of this scale to maximal intensity exercise seems to be sensitive to recovery at both 24 and 48 hours. The PRS developed by Laurent et al. (18) was designed and endorsed to be tested with different types of exercise moving forward to increase the breadth of its usefulness.

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Table 1 Anthropometric and Descriptive Statistics

n=10	**Age (yr)**	**Weight (lbs)**	**Weight (kg)**	**Height (in)**	**Height(cm)**	**Comp (% fat)**
Mean	23.2	163.1	74.1	68.5	173.9	22.8
SD	3.1	19.9	9.0	3.0	7.7	9.6

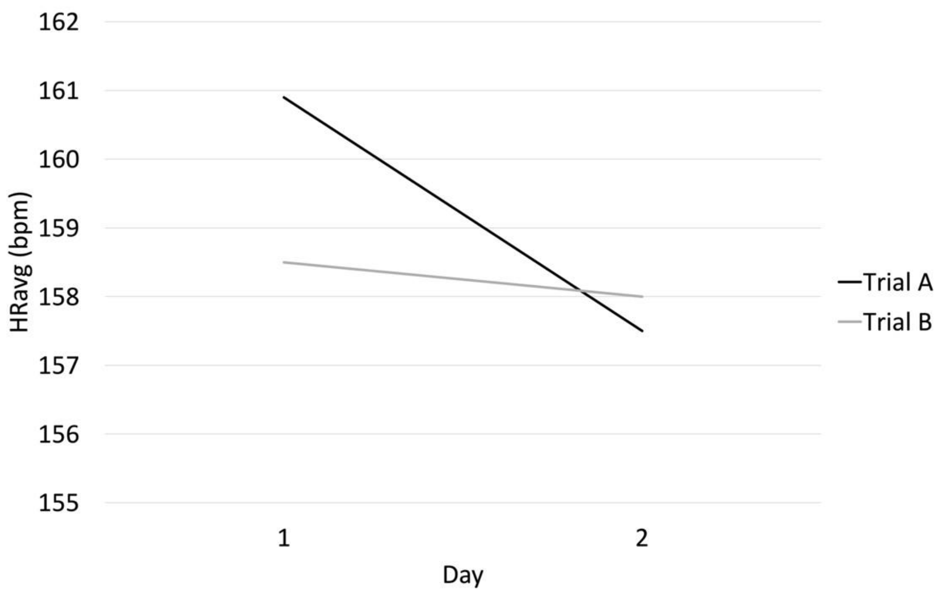

Figure 1. HRavg (bpm) was calculated during each trial session over the course of the entire exercise session. HRavg means from both days of Trial A and B are shown here. Neither trial saw significant change between days.

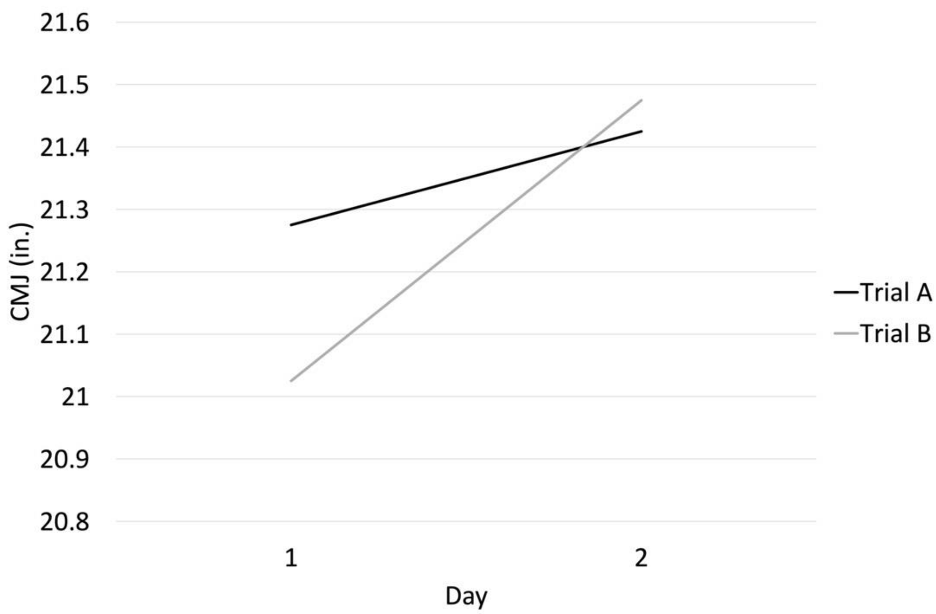

Figure 2. CMJ was recorded each day before each exercise session. CMJ means from both days of Trial A and B are shown here. CMJ increased from Day 1 to Day 2. There was no statistical significance between each day of either trial.

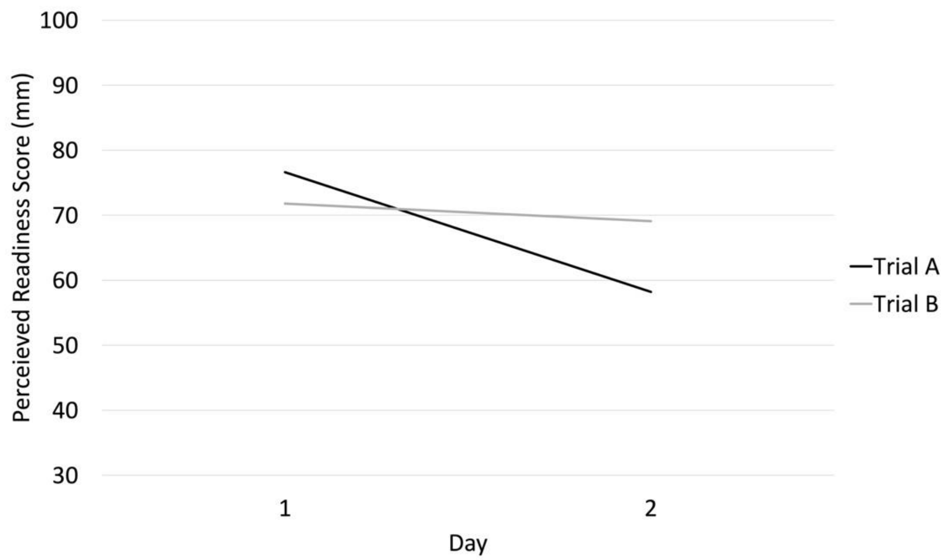

Figure 3. Perceived readiness VAS was measured using a 10cm line and was measured in mm. Perceived readiness VAS means from both days of Trial A and B are shown here. There were no statistically significant changes DTD from either trial.

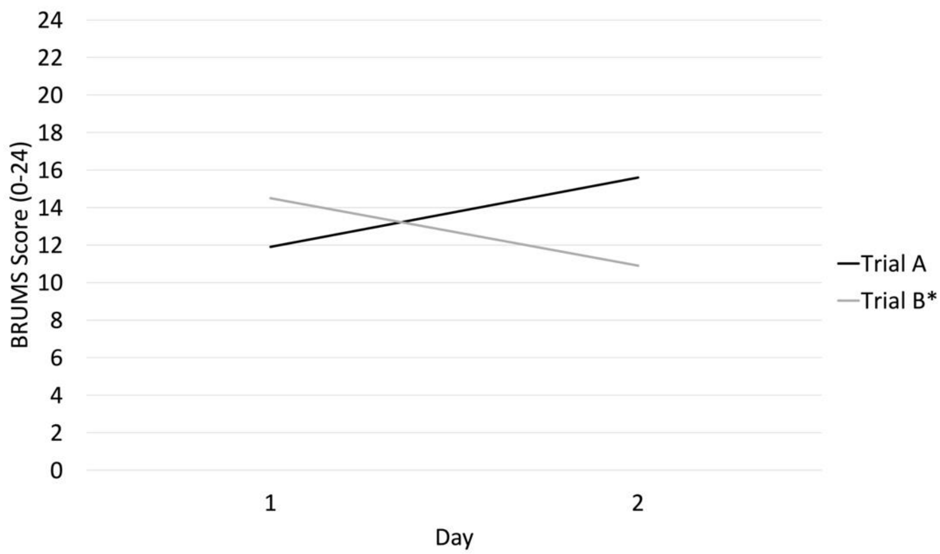

Figure 4. The BRUMS assessment was implemented before each exercise session on each day. BRUMS assessment means from both days of Trial A and B are shown here. *indicates a statistical significance in Trial B (p=0.012).

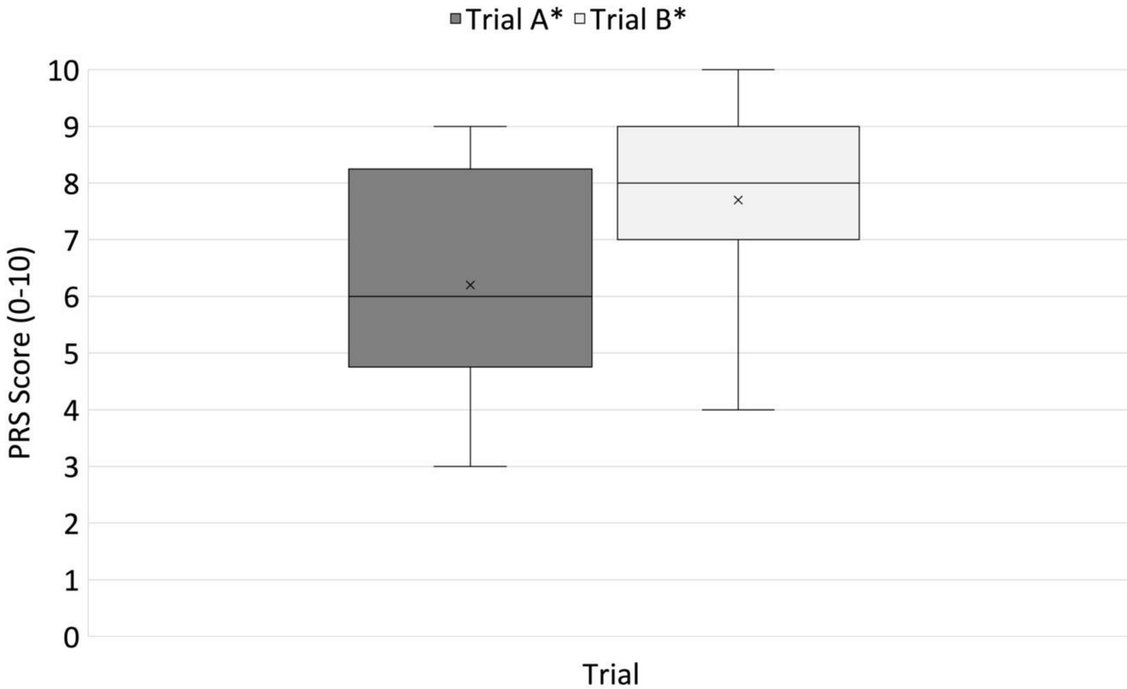

Figure 5. PRS scores were taken before Day 2 of each trial to measure perceived recovery from Tabata bodyweight HIIT. * indicates PRS scores were both statistically significant. (Trial A, p=0.005. Trial B, p=0.007)

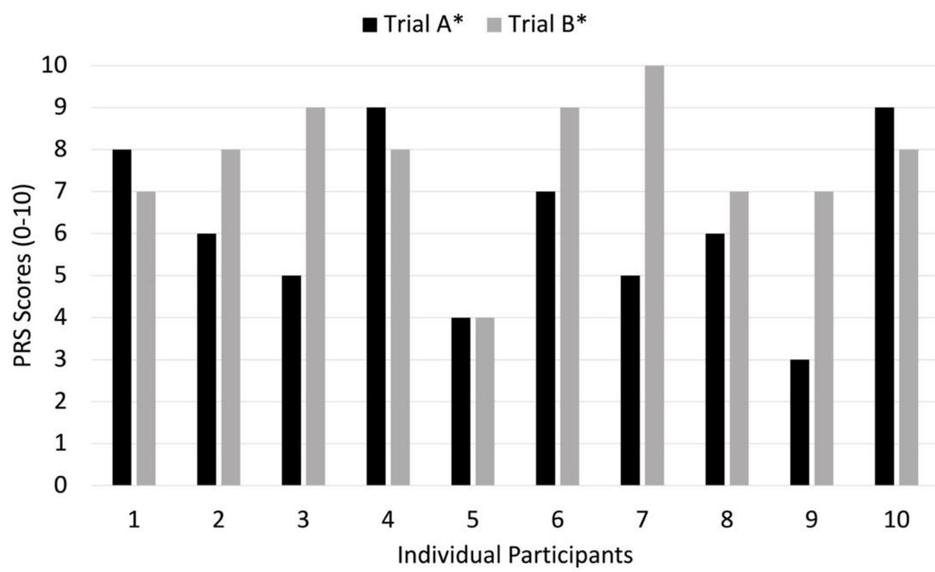

Figure 6. PRS scores among participants across each trial. PRS scores from each participant on both days of Trial A and B are shown here. Across most participants, Trial A displayed less perceived recovery in comparison to Trial B, according to the PRS scale. * indicates both Trial A and B were statistically significant.

Appendix A: Tabata HIIT Trial

Cycle 1						
Round 1	**In-Place Skips**	**Plank Punch**	**Jumping Jacks**	**Side Skaters**	**HR**	**RPE**
Round 2	Repeat	Repeat	Repeat	Repeat		

Rest for 1-minute (walk around)

Cycle 2						
Round 1	**Squat Jump**	**Bicycle Abs**	**Star Jumps**	**Push Ups**	**HR**	**RPE**
Round 2	Repeat	Repeat	Repeat	Repeat		

Rest for 1-minute (walk around)

Cycle 3						
Round 1	**Burpees w/Jump**	**Jackknife Crunches**	**Squats**	**Side Lunges**	**HR**	**RPE**
Round 2	Repeat	Repeat	Repeat	Repeat		

Rest for 1-minute (walk around)

Cycle 4						
Round 1	**Mountain Climbers**	**Diamond Push Ups**	**Side-to-Side High Knees**	**Supine Marching**	**HR**	**RPE**
Round 2	Repeat	Repeat	Repeat	Repeat		

Rest for 1-minute (walk around)

Cycle 5						
Round 1	**Depth Jump**	**Supine Flutter Kicks**	**Hand Release Pushup**	**Alt. Jumping Lunge**	**HR**	**RPE**
Round 2	Repeat	Repeat	Repeat	Repeat		

Rest for 1-minute (walk around)

Appendix B: Perceived Recovery Scale (Laurent et al., 2011)

Perceived Recovery Status Scale

10	Very well recovered / Highly energetic	Expect Improved Performance
9		
8	Well recovered / Somewhat energetic	
7		
6	Moderately recovered	Expect Similar Performance
5	Adequately recovered	
4	Somewhat recovered	
3		
2	Not well recovered / Somewhat tired	Expect Declined Performance
1		
0	Very poorly recovered / Extremely tired	

Appendix C: Brunel Mood Scale assessment (BRUMS)

Below is a list of words that describe feelings. Please read each one carefully. Then select the option that best describes ***how you feel right now***. Make sure you answer every question.

1. Panicky	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely
2. Lively	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely
3. Confused	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely
4. Worn Out	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely
5. Depressed	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely
6. Downhearted	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely
7. Annoyed	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely
8. Exhausted	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely
9. Mixed-Up	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely
10. Sleepy	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely
11. Bitter	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely
12. Unhappy	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely
13. Anxious	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely
14. Worried	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely
15. Energetic	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely
16. Miserable	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely
17. Muddled	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely
18. Nervous	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely
19. Angry	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely
20. Active	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely
21. Tired	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely
22. Bad Tempered	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely
23. Alert	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely
24. Uncertain	○ Not At All	○ A Little	○ Moderately	○ Quite A Lot	○ Extremely

Appendix D: Visual Analogue Scales

VAS for Perceived Readiness

Perceived readiness to complete a HIIT session…

Not Ready at All ———————————————— Completely Ready

VAS for Perceived Delayed-Onset Muscle Soreness

My perceived soreness is…

No Soreness Present ———————————————— Extremely Sore

Vita

Blake Johnson, a graduate of Valor Christian High School in Highlands Ranch, CO, received his Bachelor's degree from TCU in Communication Studies in December 2018. After graduating, he pursued his certification in personal training which led to finding his passion in kinesiology exercise science, fitness, and human performance. Blake began pursuing his Master's degree in 2020 as a Graduate Teaching assistant at Stephen F. Austin State University and has been the instructor of record for several labs and two full lecture courses. He will graduate in December 2021 from SFASU with his Master's degree. Blake holds a NASM CPT and NSCA CSCS and plans to continue putting his skills and educational background to practice in the fitness industry.

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This thesis was typed by Blake Johnson.