Percentage of peak workload is suitable for quantification of exercise intensity during high-intensity intervals: a response to Ekkekakis, Hartman, and Ladwig

We read with interest the recent work by Ekkekakis, Hartman, and Ladwig (2023a, 2023b), in which the authors provide an excellent two-part review of methodological problems prevalent across studies investigating the affective responses to, and enjoyment of, high-intensity interval training (HIIT). The authors propose a checklist '*to help researchers, peer reviewers, editors, and critical readers appreciate possible reasons for the apparently conflicting results*' (Ekkekakis et al., 2023b, p. 1) in this research area. We applaud this much needed effort; various common pitfalls are identified, and the checklist will enable researchers in this field to enhance the methodological quality of their work. However, as the guidance offered has the potential to influence decisions taken by researchers, peer reviewers and journal editors, we feel it is important to highlight that part of the reasoning in the key section on '*operational definitions of "high" and "moderate" intensities*' in Part II of the review (Ekkekakis et al., 2023b, p. 1) is flawed. The checklist is presented as '*a core set of principles*' (p. 14), and as such should be uncontroversial and based on sound theoretical underpinning. We would like to contribute to further developing the checklist by refining the guidance provided. Specifically, we will argue that, based on basic understanding of the physiological responses to exercise, cardiorespiratory markers are often not appropriate to compare the intensities of HIIT *vs.* moderate or vigorous exercise, but, conversely, that quantifying exercise intensity during HIIT using a percentage of peak workload during an incremental test can be appropriate.

A key characteristic of HIIT is the exercise intensity used during the high-intensity bouts, which should be meaningfully higher than that used in comparator conditions involving moderate or vigorous continuous exercise (Ekkekakis et al., 2023b). However, there is no universal measure of exercise intensity, and different markers are used in different studies. The authors provide a clear explanation why oxygen uptake ($\dot{V}O_2$) and heart rate (HR) are unsuitable for prescription and quantification of exercise intensity during HIIT, e.g., '*in interval or intermittent exercise, such as HIIT, although the workload may change in square-wave fashion, physiological parameters (i.e., oxygen uptake and heart rate) do not*' (p. 3), and '*if … the target intensity exceeds the level of critical power, a steady state cannot be attained*' (p. 3). In other words: while the square-wave change in workload instantly sets the energy demand that must be met by the muscles, there is a lag in the cardiorespiratory response (Roloff et al., 2020). Moreover, during high-intensity bouts, HR and $\dot{V}O_2$ will not achieve steady-state but will continuously increase until the bout is completed (Roloff et al., 2020). It follows that quantifying exercise intensity during high-intensity bouts by using an average or peak value for HR or $\dot{V}O_2$ is meaningless: providing mean values incorrectly suggests a steady state, and peak values depend on the interaction between exercise intensity and duration rather than solely on exercise intensity.

Nonetheless, the authors subsequently fall into this trap themselves by arguing that '*in studies investigating affective and enjoyment responses to HIIT, there have been cases in which exercise intensities lower than those in a so-called moderate comparator were labeled "HIIT"*' (p. 1). Grounded in the erroneous assumption that HR can be used to compare exercise intensities during HIIT and continuous exercise comparators, the authors use studies by Kilpatrick, Greeley, and Collins (2015) and Jung, Bourne, and Little (2014) as examples to

illustrate their point. In the study by Kilpatrick et al. (2015), peak HR in the moderate-intensity continuous exercise condition was 161±18 beats·min^{-1}, compared to 154±16 beats·min^{-1} in the heavy interval condition, and 165±17 beats·min^{-1} in the severe interval condition. Based on these data, Ekkekakis et al. suggest that the intensity in the moderate-intensity condition was higher than in the heavy interval condition, and near identical to the severe interval condition. This is despite the fact that exercise intensities were clearly stated to be set at 20% below the ventilatory threshold (VT) for the moderate continuous condition, at VT for the heavy intervals, and 20% above VT for the severe intervals, i.e., objectively higher intensities for both interval sessions compared to the moderate-intensity comparator.

Similarly, Ekkekakis et al. suggest that in the study by Jung et al. (2014) '*the intensities of HIIT and continuous "vigorous-intensity" exercise were approximately equal*' (p. 4), as peak HR averaged 168±15 beats·min^{-1} for HIIT and 169±14 beats·min^{-1} for vigorous-intensity exercise. However, the HIIT intervals were performed at an intensity corresponding to 100% of the maximal intensity achieved during an incremental test (Wmax), whereas the vigorous-intensity condition was performed at 80% of Wmax. Exercise at 100% of Wmax is not vigorous, it is maximal, and the 25% higher absolute workload compared to the vigorous comparator is not trivial.

It is clear that the examples provided by Ekkekakis et al. are misplaced because HR is not a suitable measure of exercise intensity during interval exercise. If HR could be used to quantify exercise intensity, it would logically follow that because HR continuously increases during a high-intensity bout, exercise intensity also continuously increases, even though the absolute workload remains constant. Ekkekakis et al. use the classification of exercise intensities proposed by the American College of Sports Medicine (2022), but this classification is for continuous cardiorespiratory endurance exercise and should not be used to classify the intensity of intervals used in a HIIT session. It is important to note here that, whereas exercise intensity can be supramaximal (i.e., intensities higher than those achieved in an incremental fitness test), neither HR nor $\dot{V}O_2$ can. To provide an example to illustrate this key point: in one of our studies, peak HR during repeated 20-s "all-out" cycle sprints reached ~88% of HRmax (Ruffino et al., 2017). According to Ekkekakis et al. this would classify these all-out sprints as vigorous exercise, but such sprints are supramaximal. This is despite the fact that, due to the short duration of the sprint, both HR and $\dot{V}O_2$ remain submaximal.

The authors claim that if measures of HR or $\dot{V}O_2$ do not differ between HIIT and vigorous-intensity continuous exercise, then '*HIIT would clearly offer no training advantage*' (p. 5). However, we are unaware of literature suggesting that the adaptations associated with HIIT are mechanistically linked to an increase in HR or $\dot{V}O_2$ during exercise. Conversely, there is strong evidence to support that adaptations to HIIT are related to the metabolic perturbations during the high-intensity bouts (MacInnis & Gibala, 2017), and these will be different for exercise performed below, at, or above the VT, and between 80% *vs.* 100% of Wmax.

If HR and $\dot{V}O_2$ are inappropriate measures to quantify exercise intensity during HIIT, or to compare HIIT to continuous exercise comparators, then what measures should be used instead? Ekkekakis et al. suggest that '*a transition to a classification of exercise intensities that relies on metabolic landmarks, such as critical power, should help establish clarity and consistency'* (p. 9). They also argue against the case for using peak workload using the single argument that '*when the intensity of HIIT is set as a percentage of the peak workload, heart rate, or oxygen uptake achieved during a prior incremental test, one should not assume that*

participants will reach that intensity within a 60-s (or shorter) interval' (p. 9). This holds true for HR and $\dot{V}O_2$, but not for percentage of peak workload. With appropriate equipment, target intensity can be set either instantly (e.g., using an electrically-braked cycle ergometer) or with minimal delay (e.g., using a treadmill), enabling precise prescription of the desired protocol. Furthermore, as this is the case regardless of whether exercise intensity is set relative to critical power or as a percentage of peak workload, it is unclear why the percentage of peak workload is deemed inappropriate. A recent study did not find significant differences in interindividual variability in acute performance-related, physiological, or perceptual responses to HIIT with intensities prescribed relative to critical power or as a percentage of peak workload (Bossi, Cole, Passfield, & Hopker, 2023), suggesting the latter is not an inferior method for prescribing exercise intensity during HIIT. The percentage of peak workload is straightforward to determine and prescribe, and can be used to accurately differentiate between intensities used during HIIT *vs.* moderate or vigorous comparators. Thus, we propose that, contrary to the suggestions by Ekkekakis et al., the percentage of peak workload is an appropriate, practical, and accurate measure of exercise intensity during HIIT.

Going forward, we propose that Item 6 of the 'Methodological Checklist for Critically Appraising Studies Examining the Effects of High-Intensity Interval Training (HIIT) on Affect (e.g., Pleasure-Displeasure) and Enjoyment' should be amended. Firstly, Item 6 asks for researchers to provide '*evidence that the exercise intensity attained during the high-intensity intervals was at least within the "vigorous" range (e.g., per ACSM: 77–95% of maximal heart rate or 64–90% of maximal aerobic capacity)'*. This item should be removed as the HR- and $\dot{V}O_2$-based ACSM guidelines are inappropriate for quantifying exercise intensity during HIIT. Secondly, Item 6a asks for '*direct evidence that the cited level of intensity was actually attained during the high-intensity intervals (i.e., not just attained at the same workload during a prior incremental fitness test)*'. This item should be removed because the use of cardiorespiratory measures is not appropriate for this purpose, and because more appropriate measures (e.g., intensity relative to critical power / percentage of peak workload) are prescribed, not measured. Thirdly, Item 6b ask researchers to confirm that '*if the study involved a comparison to continuous-exercise conditions (e.g., moderate-intensity continuous exercise), is information provided demonstrating that the high-intensity intervals of HIIT consistently reached a meaningfully higher level of intensity than the intensity reached during the continuous conditions (e.g., complete heart rate or oxygen uptake data for the entire sessions, not just the overall average or selected intervals)*'. This should of course be the case but cannot be done by reporting HR and/or $\dot{V}O_2$. Instead, this should be clear from the description of the prescribed workload. Thus, we propose that Item 6 is modified to the single statement: "is information provided demonstrating that the high-intensity intervals of HIIT were consistently performed at a meaningfully higher level of intensity than the intensity reached during the continuous conditions?". Setting and reporting workloads relative to the maximum achieved during a prior incremental fitness test is sufficient for researchers, peer reviewers, editors, and critical readers, to understand the level of intensity, and to enable direct comparisons with the intensity applied in continuous exercise conditions.

As a final point, it is important to note that our arguments presented herein refute the intensity-related criticisms made by Ekkekakis et al. regarding the (in)appropriateness of the intensities used in HIIT protocols in various studies comparing the affective and enjoyment responses between HIIT and moderate or vigorous continuous exercise. Based on basic exercise physiological responses, the intensity of intervals during HIIT and the natural

break/rest periods do not result in steady state conditions and obscure a linear intensity-HR/ $\dot{V}O_2$ relationship. Thus, the concepts related to Item 6 from Ekkekakis et al. checklist are inappropriate.

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