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A Systematic Review and Meta-Analysis of Affective Responses to Acute High Intensity Interval Exercise Compared with Continuous Moderate- and High-Intensity Exercise.

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Abstract

There is evidence for the physical health benefits of high intensity interval exercise (HIIE), but its public health potential has been challenged. It is purported that compared with moderate-intensity continuous exercise (MICE) the high intensity nature of HIIE may lead to negative affective responses. This systematic review (PROSPERO CRD42017058203) addressed this proposition and synthesised research that compares affective responses to HIIE with MICE and vigorous intensity continuous exercise (VICE), during-, end-, and post-exercise. Searches were conducted on five databases, and findings from 33 studies were meta-analysed using random effects models or narratively synthesised. A meta-analysis of affect showed a significant effect in favour of MICE vs HIIE at the lowest point, during and post-exercise, but not at end, and the narrative synthesis supported this for other affective outcomes. Differences on affect between VICE vs HIIE were limited. Pooled data showed arousal levels were consistently higher during HIIE. For enjoyment there was a significant effect in favour of HIIE vs MICE, no difference for HIIE vs VICE at post-exercise, and mixed findings for during-exercise. Although the findings are clouded by methodological issues they indicate that compared to MICE, HIIE is experienced less positively but post-exercise is reported to be more enjoyable.

Keywords: perception, affect, enjoyment, physical activity

A Systematic Review and Meta-Analysis of Affective Responses to Acute High Intensity Interval Exercise Compared with Continuous Moderate- and High-Intensity

The benefits of physical activity on physical and mental health outcomes are well established (Chekroud et al., 2018; Lear et al., 2017; Lee et al., 2012). In order to achieve these benefits, the USA guidelines recommend that throughout each week adults should at least do strength training twice a week, and 150 minutes of moderate-intensity aerobic activity, or 75 minutes of vigorous-intensity aerobic activity, or an equivalent combination of each (U.S. Department of Health and Human Services, 2018). However large sectors of the population fail to meet these recommendations (Guthold, Stevens, Riley, & Bull, 2018), and the inactivity problem has been labelled as ‘pandemic’ (Kohl et al., 2012). The determinants of physical inactivity are complex and multi-factorial (Bauman et al., 2012; Sallis, Owen, & Fisher, 2008), but a consistently cited reason for inactivity is that individuals perceive they do not have time to be active (Pagnan, Seidel, & Wadsworth, 2017; Salmon, Owen, Crawford, Bauman, & Sallis, 2003; Trost, Owen, Bauman, Sallis, & Brown, 2002). Several researchers have used the often-cited ‘lack of time’ barrier to promote the potential of high intensity interval exercise (HIIE) as a time-efficient method of activity that may overcome this barrier (Biddle & Batterham, 2015; Gillen & Gibala, 2014; Jung, Little, & Batterham, 2015).

HIIE has been defined as brief repeated bursts of relatively intense or all-out exercise separated by rest or low intensity exercise (Gillen & Gibala, 2014). Review-level evidence is now available which indicates that HIIE elicits meaningful improvements in aerobic fitness ($\dot{V}O_{2max}$), blood pressure, blood glucose concentration, body composition, and vascular function (Batacan, Duncan, Dalbo, Tucker, & Fenning, 2017; Milanovic, Sporis, & Weston, 2015; Ramos, Dalleck, Tjonna, Beetham, & Coombes, 2015; Viana et al., 2019). As a result of the strength of the evidence of the physical health benefits of HIIE, this method of activity has been included for the first time in recent UK physical activity recommendations (Department of Health and Social Care, 2019)

The improvements in physical health markers observed following HIIE are often comparable to or greater than those observed from moderate-intensity continuous exercise (MICE)(Burgomaster et al., 2008; Gillen et al., 2016), but with the benefit of potentially reducing total training time, dependent on the characteristics of the specific HIIE protocol employed. However, the public health potential of HIIE has been subject to debate with opponents arguing that HIIE is not an appropriate method of activity, due in part to the negative affective responses individuals may experience during the activity (Biddle & Batterham, 2015; Hardcastle, Ray, Beale, & Hagger, 2014).

There has been a growth of interest in how affective responses may influence health behaviour generally (Williams, Rhodes, & Conner, 2018), and physical activity specifically (Ekkekakis, 2017). Affective responses can be viewed as an umbrella term for numerous inter-related constructs including core affect (e.g., hedonic response/valence (pleasure/displeasure) and arousal), emotions, mood, and affect processing (Williams et al., 2018; Williams, Rhodes, & Conner, 2019). This interest in affective responses has emerged from recognition of the shortcomings of the dominant cognitive-based theories in explaining health behaviour, and informing behaviour change interventions (Williams et al., 2018). Reflecting broader developments in health psychology, within physical activity research dual process approaches to understanding physical activity behaviour have been developed (e.g., (Brand & Ekkekakis, 2017; Hagger & Chatzisarantis, 2014). These developments have advanced the field by moving the focus away from the dominant cognitive-focused theories to also include consideration of non-deliberative processes, including affective responses (Ekkekakis, 2017; Rhodes, McEwan, & Rebar, 2018). Affective responses do appear to be important in understanding physical activity behaviour, with review evidence suggesting that core affect during (but not after) moderate-intensity exercise, is related to future behaviour (Rhodes & Kates, 2015). Although the relationship between affective responses during high-intensity exercise, such as HIIE, and future behaviour is not yet clear (Rhodes & Kates, 2015; Stork, Banfield, Gibala, & Martin Ginis, 2017), the potential influence on future behaviour has lead researchers to examine affective responses to HIIE.

Dual Mode Theory (DMT; Ekkekakis, 2003) provides a helpful perspective to understand affective responses to exercise, and especially HIIE because DMT indicates that intensity is a key moderator of affective responses to exercise. In DMT, affective responses to exercise, and specifically affective valence, are considered from an evolutionary perspective, which suggests responses have been shaped through natural selection and are adaptive. According to DMT, affective responses to exercise are based on the interplay between two factors; i) cognitive parameters (e.g., self-efficacy), and ii) interoceptive cues (i.e., those emerging from the body such as muscular and respiratory cues). The dominant influence of these two factors is dependent on the exercise intensity, with an increase in the contribution of anaerobic metabolism (often operationalised as ventilatory threshold; VT) identified as a critical tipping point. At intensities below VT, cognitive parameters influence affect, and affective responses are consistently positive. As exercise intensity approaches VT, there is variation in responses with some individuals reporting increases and others decreases in pleasure. As exercise intensity increases beyond VT, interoceptive cues gain salience and maintaining physiological steady state becomes difficult, and at this point most individuals will report reduced pleasure (Ekkekakis, Parfitt, & Petruzzello, 2011). From an evolutionary perspective, the reduced pleasure has an adaptive function to encourage the individual to stop prior to the depletion of anaerobic resources (Ekkekakis, 2003). Finally, DMT predicts that any decline in affect during exercise will be consistently followed by a rebound to positive affect.

Empirical research supports tenets of DMT. Specifically, continuous exercise above VT typically leads to more unpleasant affective responses than continuous exercise at, and below VT (Ekkekakis, Hall, & Petruzzello, 2005; Kilpatrick, Kraemer, Bartholomew, Acevedo, & Jarreau, 2007). However, DMT is based on continuous exercise, and may not be directly applicable to the intermittent nature of HIIE that allows periods of recovery between bouts of exercise above VT (Jung et al., 2015). An increasing number of studies have examined affective response to HIIE compared with continuous exercise, and there is now review level evidence available.

In a scoping review of psychological responses to interval exercise, Stork et al. (2017) concluded from nine studies that affect was similar or more negative during interval exercise protocols (i.e., HIIE and Sprint Interval Training; SIT) compared to MICE and vigorous intensity continuous exercise (VICE). In relation to post-exercise affect, from six studies the majority of studies reported no difference. However, the authors classified post-exercise as from immediately post- to 30 minutes post-exercise when it may not be appropriate to do so because differences may vary across that time period depending on the time of 'rebound' to more positive affect. In relation to arousal, three studies reported higher arousal in HIIE compared with continuous exercise. One study reported findings of lower negative mood disturbance following MICE compared with HIIE. Whilst this review is helpful, more conclusive evidence could be drawn from a systematic review and meta-analysis to pool the studies and quantitatively compare the conditions of HIIE with MICE and VICE, and with more granular consideration of the timing of the affective responses.

Recently, Oliveira, Santos, Kilpatrick, Pires, and Deslandes (2018) completed a systematic review and meta-analysis. In this review, Oliveira et al. (2018) limited their analysis of affective responses to include only studies that used the Feeling Scale (FS; Hardy and Rejeski (1989), thus also addressing a shortcoming identified by Stork et al. (2017)

relating to inconsistency in the use of measures making it difficult to compare outcomes, but potentially excluding other relevant variables. From six studies (12 comparisons), Oliveira et al. (2018) reported that there was variation in the findings, but overall there was a trivial effect in favour of HIIE, which is inconsistent with the Stork et al. (2017) conclusion. The authors explained these findings by highlighting the differences between studies in participants' physical fitness, and exercise characteristics. However, a shortcoming of this review that may also explain the findings, and questions the conclusions, relates to how the authors treated the data. Specifically, in studies that reported multiple time-points for assessing affect (i.e., pre, during and post exercise), the authors calculated a mean value. This is problematic for two reasons; firstly, and as illustrated above in DMT, the manipulation of intensity is likely to have a differential effect during-exercise compared with post-exercise where a rebound is expected (Ekkekakis, Zenko, Ladwig, & Hartman, 2018). Additionally, the mean data used in the analysis are likely to be skewed by a non-significant baseline value, where there would be no expectation that there would be differences in conditions. There is a need for further research where the strategy for the analysis of the data is more theoretically-driven. Specifically, consideration of the differences between HIIE and continuous exercise during and post-exercise would be of value. In addition to these time points, it has been suggested that consideration of the lowest point of negative affect, and affect at the very end of exercise may also be important to consider because they are potentially meaningful in influencing future behaviour (Decker & Ekkekakis, 2017; Hargreaves & Stych, 2013; Kahneman, Fredrickson, Schreiber, & Redelmeier, 1993; Stork et al., 2017).

William et al's (2019) (2018) broad definition of affective responses also includes affect processing that relates to cognitive processing of previous or anticipated affective responses to the target behaviour. Within physical activity research, affect processing is often operationalised as affective judgements about exercise, and specifically enjoyment (Rhodes, Fiala, & Conner, 2009). There is strong correlational evidence that affective judgements are related to physical activity behaviour (Rhodes et al., 2009), so enjoyment is also an important affective response to consider regarding the feasibility of HIIE. The review evidence comparing enjoyment of HIIE with continuous exercise is more consistent than the finding for affect**.** From 17 studies, Stork et al. (2017) concluded that exercise enjoyment was similar or greater following interval exercise compared to continuous. Oliveira et al. (2018) also reported a small effect in favour of HIIE for seven studies (10 comparisons), using the Physical Activity Enjoyment Scale (PACES; Kendzierski & DeCarlo, 1991) at post-exercise. Stork and colleagues did not include studies that examined enjoyment during exercise, and Oliveira et al. identified only two studies (7 comparisons) using the Exercise Enjoyment Scale (EES; Stanley, Williams, & Cumming, 2009) reporting an overall small positive effect in favour of HIIE. However, these data were also mean values based on pre-, during and post-exercise, so for the reasons outlined above, there is a need to conduct an alternative analysis.

Although there now exists review evidence on affective responses to HIIE compared with continuous exercise (Oliveira et al., 2018; Stork et al., 2017), there are shortcomings in these studies that support the need for a further review to more comprehensively synthesise the current research. In addition to the concerns of the treatment of the outcome variables, there are further limitations to and errors in the Oliveira et al. (2018) review that question its quality (e.g., no pre-published protocol, a limited search strategy with only 6 search terms, double entry of comparison trials).

The physical benefits of HIIE are well-evidenced, however there is a need to more fully understand individuals' affective responses during and after HIIE in order to inform promotion of HIIE for public health benefits. The aim of this systematic review was to synthesise the existing literature that compares the effect of HIIE vs MICE and VICE on the range of affective responses (i.e., core affect (including valence and arousal), emotion, mood and enjoyment) during and after exercise in adults.

Method

This study was reported in accordance with PRISMA guidelines (Moher, Liberati, Tetzlaff, Altman, & The, 2009) (see Supplementary file 8 for PRISMA checklist), and registered with PROSPERO database (reference number CRD42017058203). We searched five electronic bibliographic databases to identify studies for inclusion: MEDLINE, EMBASE, PsycINFO, SPORTDiscus and ProQuest Dissertations & Theses Global. Search terms included a combination of subject headings and free text terms of intervention terms and outcome terms (see Table 1). The search strategy was adapted for each database and was piloted and refined prior to the final searches being conducted (Medline search included as supplementary file 9). Studies published anytime until 15th May 2019 were eligible for inclusion. We also searched reference lists of relevant reviews.

Eligibility Criteria

The inclusion criteria for selection of studies were as follows: 1) adults aged 18 years or over; 2) HIIE compared with continuous exercise; 3) reported a measure of affect, arousal, enjoyment, intention, self-efficacy or competence (or other outcomes related to affect); 4) parallel group or cross-over design. Peer reviewed publications and masters and doctoral theses were eligible for inclusion; and 5) studies published in English. There were no geographical constrictions on study eligibility.

For the purpose of this review, HIIE was defined as either repeated short (less than 45 seconds) to long (45 seconds-4 minutes) bouts of high- but not maximal-intensity exercise, or short (less than 10 seconds) to long (10-30 seconds) all-out sprints, interspersed with recovery periods (Buchheit & Laursen, 2013). Continuous exercise included bouts classified as moderate (mean intensity ≤76% maximum heart rate / 64% $\dot{V}O_{2max}$) or vigorous (mean intensity >77% maximum heart rate / 64% $\dot{V}O_2max$)(Garber et al., 2011). It is important to acknowledge that these intensity guidelines do not incorporate more accurate individual intensity thresholds, such as the VT, which are considered to influence the affective response. Therefore, a limitation of this bandwidth classification approach is that it could potentially misclassify participants, and likely cause variance in affective responses. For example, a participant may reach VT at 65% maximum HR, which would be categorised as moderate intensity, but this activity may be experienced as unpleasant. However, current exercise prescription guidelines do not prescribe exercise intensity in relation to individualised physiological thresholds, and we felt it appropriate to use the most established criteria for intensity prescription in our method. A minimum duration of continuous exercise was not defined as current exercise prescription guidelines do not provide a recommended minimum duration of continuous exercise to improve health (Department of Health and Social Care, 2019; Garber et al., 2011).

Screening

Two of three reviewers (AN, SP, YL) with prior experience of systematic reviews independently screened search results using Covidence, an online systematic review management program. Firstly, all identified titles and abstracts were screened against the eligibility criteria. Where titles and abstracts met the eligibility criteria, full texts were located and screened for eligibility. Any disagreements were resolved through discussion with the third reviewer.

Data Extraction, Risk of Bias and Publication Bias Assessment

Data extraction and risk of bias assessment was carried out independently by two of the three reviewers (AN, SP, YL). Data from the included studies were extracted onto an electronic data extraction form. The extracted data included general study information,

information on study participants, outcomes measured, the intervention, analysis and results. We contacted corresponding authors of included studies to request relevant data. Where data were unavailable but a figure was presented, we extracted data using a freely available web-based data extraction tool (WebPlotDigitizer version 4.0.0, USA).

Included studies were assessed for risk of bias using the Cochrane Risk of Bias tool (Higgins, 2011). This included a risk of bias assessment for random sequence generation, allocation concealment, incomplete outcome data, selective outcome reporting, and other sources of bias. We did not assess risk of bias for blinding of participants and personnel or blinding of outcome assessment, as it is not ethically possible to achieve these criteria in the type of study designs evaluated in this review. Using the information reported in the studies, the risk of bias for each risk category was categorised as “low”, “high” or “unclear” for each study. Data extraction and risk of bias assessments were compared between two of the three reviewers, with any disagreements resolved by the third reviewer.

Where there were sufficient number of studies included (≥10), we created funnel plots of effect size vs standard error to inspect evidence of asymmetry, which could indicate publication bias.

Analysis

Affective responses can be viewed as an umbrella term for numerous constructs (Williams et al., 2018), and in the analysis we made a distinction between the outcomes of basic affect (i.e., valence (referred to as affect) and arousal), mood, emotions, and the affective-judgement of enjoyment (Rhodes et al., 2009). We compared these variables between conditions at a number of time points including pre, during (at 50% or at the measurement point closest to 50% of exercise), end, immediately post (and for some this was after the cool down), and post+ (defined as >2 mins following completion of exercise), and for affect assessed by the Feeling Scale (Hardy & Rejeski, 1989) we also compared the lowest reported score.

For affect and arousal, studies that used the Feeling Scale and Felt Arousal Scale (Svebak & Murgatroyd, 1985), respectively, were pooled using meta-analysis. Cross-over designs dominate the research in this area. This is problematic as they are rarely reported in a way suitable for meta-analyses (Mills et al., 2009). Therefore, we implemented an approximate analysis of cross-over trials for meta-analyses (Higgins, Deeks, & Altman, 2008). This involved imputing the typical standard deviation of differences between the experimental and control trial from the individual data of a related study (Niven, Thow, Holroyd, Turner, & Phillips, 2018) to estimate the standard error of the mean difference under a generic inverse variance-outcome (Higgins et al., 2008). The standard deviation of differences from Niven et al. (2018) for FS was 1.8. We pooled similar data within each outcome variable in a meta-analysis using RevMan software (version 5.3). All meta-analyses implemented the generic inverse-variance method using a random effects analysis model as different treatment effects would be expected with different study designs, population and HIIE doses. We calculated effect sizes as mean differences (MD) with 95% confidence intervals (95% CI). Heterogeneity was explored by estimating the between-study variance (I^2).

For all other affective responses, we were guided by Popay et al. (2006) and narratively synthesised the findings around the outcomes measured (i.e., affect not assessed by FS, emotions, and mood) to describe patterns across the studies in the direction and size of effects comparing HIIE with MICE and VICE. In order to do this, the findings were tabulated to highlight the direction of any statistically significant effects in terms of which condition is favoured, the number of statistically significant effects that favour each condition compared with the number of comparisons (i.e., vote-counting), and size of effects. Where size of effect was not reported in the study, we accessed the data to calculate appropriate effect sizes (i.e., partial eta squared for main effects; standardised mean differences for univariate comparisons), and interpreted these as small, medium or large (Cohen, 1992; Ellis, 2010)

For the affective-judgement of enjoyment, we undertook a meta-analysis of the data on post-exercise enjoyment following the procedures outlined above, and undertook a narrative synthesis of enjoyment during exercise to describe patterns across the studies and size of effects (Popay et al., 2006) . Although included in our original protocol, due to the small number of studies examining self-efficacy (n=5), and intention (n=1) we excluded these from further analysis.

Results

Inclusion of Studies

The literature search identified 2,906 potentially eligible studies, and Figure 1 illustrates the PRISMA flow of study selection. A total of 31 publications involving 1,060 participants met the inclusion criteria. We contacted the authors of nineteen studies and relevant data were received directly from 17 authors (Astorino & Thum, 2016; Bartlett et al., 2011; Farias-Junior et al., 2019; Good & Dogra, 2017; Greene, Greenlee, & Petruzzello, 2018; Hoekstra, Bishop, & Leicht, 2017; Monroe et al., 2016; Niven et al., 2018; O'Neill & Dogra, 2017; Olney et al., 2018; Poon, Sheridan, Chung, & Wong, 2018; Rizk et al., 2015; Songsorn et al., 2019; Stork, Gibala, & Martin Ginis, 2018; Thum, Parsons, Whittle, & Astorino, 2017; Tsukamoto et al., 2016; Wilke et al., 2019), and we extracted data from three figures in the original papers (Foster et al., 2015; Saanijoki, Nummenmaa, et al., 2018; Siemens, 2013). Data reported in Decker and Ekkekakis (2017) were extracted from the published thesis (Decker, 2009), but additional data from the thesis were unavailable and these outputs are reported as one study. Two publications are only partially reported due to unavailable data (Jung, Bourne,

& Little, 2014; Little, Jung, Wright, Wright, & Manders, 2014). Two publications (Poon et al., 2018; Songsorn et al., 2019) both included two separate studies. For each publication, the two studies are analysed separately in the meta-analysis (total studies n=33).

Nine studies used more than one HIIE protocol (Astorino & Thum, 2016; Kilpatrick, Greeley, & Collins, 2015; Martinez, Kilpatrick, Salomon, Jung, & Little, 2015; Olney et al., 2018; Poon et al., 2018a, b; Songsorn et al., 2019a, b; Stork et al., 2018). For each of these studies, the protocol that was most similar to the other protocols in the meta-analysis in terms of work bout duration and intensity was used. However, the influence of each protocol on the outcome of the meta-analysis was tested with a sensitivity analysis.

Descriptive Study Characteristics

Study characteristics are summarised in Table 2. Nineteen of the 33 included studies used a cross-over design comparing HIIE with MICE (Astorino & Thum, 2016; Bartlett et al., 2011; Decker & Ekkekakis, 2017; Farias-Junior et al., 2019; Gomes et al., 2018; Good & Dogra, 2017; Greene et al., 2018; Hoekstra et al., 2017; Little et al., 2014; Monroe et al., 2016; O'Neill & Dogra, 2017; Olney et al., 2018; Ong, Wallman, Fournier, Newnham, & Guelfi, 2016; Saanijoki, Tuominen, et al., 2018; Songsorn et al., 2019a, b; Stork et al., 2018; Thum et al., 2017; Tsukamoto et al., 2016).

Three studies used a cross-over design comparing HIIE with a MICE and VICE condition (Jung et al., 2014; Kilpatrick et al., 2015; Niven et al., 2018). Four studies used a cross-over design comparing HIIE with VICE (Martinez et al., 2015; Oliveira, Slama, Deslandes, Furtado, & Santos, 2013; Poon et al., 2018a, b). Five studies used a between-participants design comparing HIIE and MICE (Foster et al., 2015; Namekata, 2017; Saanijoki, Nummenmaa, et al., 2018; Vella, Taylor, & Drummer, 2017; Wilke et al., 2019), one used the same design comparing HIIE and VICE (Siemens, 2013) and one study used the same design to compare HIIE with a MICE and VICE condition (Rizk et al., 2015).

A total of 1060 participants aged ≥18 years were allocated to trials/groups in the studies (where reported males = 483, females = 493). Five studies recruited overweight to obese participants (Decker & Ekkekakis, 2017; Farias-Junior et al., 2019; Gomes et al., 2018; Martinez et al., 2015; Vella et al., 2017), five recruited physically active participants (Bartlett et al., 2011; Monroe et al., 2016; Niven et al., 2018; Olney et al., 2018; Thum et al., 2017), eight recruited inactive participants (Farias-Junior et al., 2019; Foster et al., 2015; Gomes et al., 2018; Jung et al., 2014; Little et al., 2014; Poon et al., 2018a, b; Stork et al., 2018), and three recruited predominantly or exclusively university students (Greene et al., 2018; Hoekstra et al., 2017; Kilpatrick et al., 2015), or a general population with no specified pertinent characteristics (Oliveira et al., 2013; Saanijoki, Tuominen, et al., 2018; Siemens, 2013). Two studies recruited participants with exercise-induced bronchoconstriction (Good & Dogra, 2017; O'Neill & Dogra, 2017). Other pertinent participant characteristics included chronic spinal cord injury (Astorino & Thum, 2016), depressive symptoms (Namekata, 2017), pregnant participants (Ong et al., 2016), participants diagnosed with chronic obstructive pulmonary disease (Rizk et al., 2015), insulin resistant participants (Saanijoki, Nummenmaa, et al., 2018), a combination of sedentary and recreationally active participants (Songsorn et al., 2019a), type II diabetics (Songsorn et al., 2019b), and participants experienced at high-intensity exercise (Tsukamoto et al., 2016).

Outcome Variables

Affect assessed by the Feeling Scale. Data from studies assessing affect using the Feeling Scale were pooled into two meta-analyses. Figure 2 illustrates the findings from HIIE vs MICE, and Figure 3 shows the HIIE vs VICE results (see also Supplementary File 1).

HIIE vs MICE. Data from 15 studies (n=625) examined affect during and/or after HIIE and MICE (Astorino & Thum, 2016; Decker & Ekkekakis, 2017; Farias-Junior et al., 2019; Good & Dogra, 2017; Greene et al., 2018; Hoekstra et al., 2017; Jung et al., 2014;

Kilpatrick et al., 2015; Niven et al., 2018; O'Neill & Dogra, 2017; Olney et al., 2018; Songsorn et al., 2019a, b; Stork et al., 2018; Thum et al., 2017). Data from the Little et al. (2014) study could not be accessed, so this study was not included in the meta-analysis. Within the meta-analysis, the findings of O'Neill and Dogra (2017) appeared incongruent with the other studies.

Affect at 50% duration. Fifteen studies reported during exercise data. For seven studies the assessment was at 50% of the duration, and for the remaining studies this assessment point ranged from 42.5-60% of the exercise. The timing of assessment varied with three studies collecting data during the exercise bout, seven immediately after the end of a bout, two during recovery, and for three studies it was unclear exactly when the assessment was taken. Meta-analysis of affect at this time point shows a significant effect in favour of MICE (MD -1.07, 95% CI -1.47 to -0.67, $P < 0.00001$; Figure 2). There was a large degree of heterogeneity within the analysis. However, 11/15 studies reported significant findings in favour of MICE.

Affect at end of exercise. Thirteen studies reported end-exercise data. Meta-analysis of affect at the end of exercise shows a non-significant effect (MD -0.72, 95% CI -1.64 to 0.20, $P = 0.12$; Figure 2). There was a large degree of heterogeneity in the analysis, with 7/13 studies reporting significant findings in favour of MICE.

Affect post-exercise. Eight studies reported immediately post-exercise data, two of which included assessments into the cool-down period. Meta-analysis of affect post-exercise shows a significant effect in favour of MICE (MD -1.07, 95% CI -1.44 to -0.70, $P < 0.0001$; Figure 2). There was a large degree of heterogeneity in the analysis, with 7/8 studies reporting significant findings in favour of MICE.

Affect post+. Nine studies reported post+ data, which ranged from 5-20 minutes post-exercise. Meta-analysis of affect post+ shows a significant effect in favour of MICE (MD -0.22, 95% CI -0.40 to -0.04, $P = 0.02$; Figure 2). There was a large degree of heterogeneity in the analysis, with 3/9 studies reporting significant findings in favour of MICE.

Affect lowest value. Meta-analysis of the lowest affect value in HIIE and MICE shows a significant effect in favour of MICE (MD -1.18, 95% CI -1.96 to -0.41, P = 0.003; Figure 2). There was a large degree of heterogeneity within the analysis, with 9/14 studies reporting significant findings in favour of MICE.

HIIE vs VICE. Data from seven studies (n=139) examined affect during and/or after HIIE and VICE (Jung et al., 2014; Kilpatrick et al., 2015; Martinez et al., 2015; Niven et al., 2018; Oliveira et al., 2013; Poon et al., 2018a, b) (Figure 3; Supplementary file 1). Data were extracted from a figure for Siemens (2013), but the study was an independent groups design and therefore was not included in the meta-analysis. Siemens (2013) reported that end-exercise affect in the first training session was significantly lower in the HIIE group vs. the VICE group (-0.5 ± 3.0 vs. 2.3 ± 1.9, P < 0.05). Meta-analyses for each measurement point were non-significant and all showed a large degree of heterogeneity (50% duration: MD 0.33, 95% CI -0.46 to 1.12, P = 0.41; End exercise: MD 0.36, 95% CI -0.99 to 1.71, P = 0.60; Post-exercise: MD 0.95, 95% CI -0.16 to 2.06, P = 0.09; Post+: MD 0.15, 95% CI -0.40 to 0.69, P = 0.60; Lowest value: MD 0.13, 95% CI -1.08 to 1.34, P = 0.84). The findings of Oliveira et al. (2013) were inconsistent with the other studies in the meta-analysis.

Affect (non-FS measurement), emotion, and mood. Data from studies assessing affective responses using measures other than the FS, were narratively synthesised to describe patterns across the studies in the direction and size of effects (Popay et al., 2006). The synthesis was ordered by affective outcome (i.e., affect, emotions and mood), and within these outcomes the studies were ordered by instrument used. Table 3 illustrates the summary findings detailing the direction and time-frame of statistically significant effects, number of statistically significant differences favouring each condition, and the effect sizes for these differences (data available in Supplementary File 2).

Six studies reported findings using different measures to assess affect including the AD-ACL (Thayer, 1986) (Greene et al., 2018; Jung et al., 2014) and PANAS (Watson, Clark, & Tellegen, 1988) (Rizk et al., 2015; Saanijoki, Nummenmaa, et al., 2018; Saanijoki, Tuominen, et al., 2018), which are based on the circumplex model of affect. Rizk et al. (2015) also used the Global Vigor and Affect scale (Monk, 1989) and Saanijoki, Tuominen, et al. (2018) also used the Self-Assessment Manikin scale (Bradley & Lang, 1994) to assess valence. From these studies, there were statistically significant main effects between conditions for all but one study (i.e., Rizk et al's comparison of PANAS). In comparing HIIE with MICE, there were 21 comparisons including 11 statistically significant differences that favoured MICE, three that favoured HIIE, and seven non-significant comparisons. The statistically significant differences had effect sizes from medium to large. For Saanijoki, Nummenmaa et al. (2018) first bout data were extracted from a figure showing differences between HIIE and MICE on pre and post-affect across six bouts of training, and although not statistically analysed effect sizes were calculated and the findings suggest changes in positive and negative affect in favour of MICE vs HIIE (large effect sizes). In comparing HIIE with VICE, there were 14 comparisons including one statistically significant difference that favoured VICE (large ES), and no other differences between the conditions.

In terms of time-frame of effect, only two statistically significant comparisons were evident during exercise with one comparison in favour of HIIE (large ES) and the other in favour of MICE (larges ES). A number of studies reported statistically significant differences in change of affect (pre-post) and there were eight comparisons in favour of MICE (including Saanijoki, Nummenmaa et al.), and two for HIIE (ES range small-large). One study reported a statistically significant difference at 100% of exercise in favour of MICE (large ES). At post+, significant findings were reported in favour of MICE (n=3), and VICE (n=1) (medium-large ES).

Two studies used a version of the POMS (McNair, Lorr, & Droppleman, 1971). Findings from Monroe et al. (2016) indicated main effects for both fatigue and energy assessed during active recovery favoured HIIE (large ES), although this was compared with in-exercise assessment for MICE after equivalent work. In Oliveira et al. (2013), assessment of fatigue favoured VICE compared with HIIE, from pre to post exercise (large ES), and was lower at post exercise (small ES), but there were no differences in the other five POMS subscales or in total mood disturbance from pre-post, and post.

One study reported findings for an unpublished single item measure of the emotion anxiety (Namekata, 2017), and two studies included a visual analogue scale (VAS) scale that was unpublished and included a range of variables including individual emotions (Saanijoki, Nummenmaa, et al., 2018; Saanijoki, Tuominen, et al., 2018). Given the unsubstantiated quality of the measures, we have not included these data.

Arousal. Saanijoki, Tuominen, et al. (2018) assessed arousal using the Self-Assessment Manikin Scale, and reported that HIIE increased more than MICE. Seven studies reported data on arousal during exercise assessed using Felt Arousal Scale (FAS) (Svebak & Murgatroyd, 1985), but data from Decker (2009) were unavailable. These FAS data are typically collected in tandem with FS so that data can be plotted on the circumplex model, although only three studies presented these models (Farias-Junior et al., 2019; Niven et al., 2018; Oliveira et al., 2013). Data from studies assessing arousal using the FAS were pooled into two meta-analyses. Figure 4 illustrates the findings from HIIE vs MICE, and Figure 5 shows the HIIE vs VICE results (see also Supplementary File 3).

HIIE vs MICE. Data from five studies (n=88) examined arousal during and/or after HIIE and MICE (Farias-Junior et al., 2019; Hoekstra et al., 2017; Niven et al., 2018; Stork et al., 2018; Tsukamoto et al., 2016).

Arousal at 50% duration. Four studies report arousal data at this time-point. Meta-analysis of arousal at this time point shows a significant effect in favour of HIIE (MD 1.08, 95% CI 0.71 to 1.44, $P < 0.00001$; Figure 4).

Arousal at end of exercise. Three studies reported end-exercise data. Meta-analysis of arousal at the end of exercise shows a significant effect in favour of HIIE (MD 1.68, 95% CI 1.11 to 2.25, $P < 0.0001$; Figure 4).

Arousal post-exercise. Four studies reported immediately post-exercise data. Meta-analysis of arousal post-exercise shows a significant effect in favour of HIIE (MD 0.62, 95% CI 0.23 to 1.0, $P = 0.002$; Figure 4).

Arousal post+. Five studies reported post+ data. Meta-analysis of arousal post+ shows a non-significant effect (MD 0.24, 95% CI -0.05 to 0.54, $P = 0.11$; Figure 4). There was a large degree of heterogeneity in the analysis, with 2/5 studies reporting significant findings in favour of HIIE.

HIIE vs VICE. Data from two studies (Niven et al., 2018; Oliveira et al., 2013) (n=27) examined arousal during and/or after HIIE and VICE (Figure 5; Supplementary file 3). Only one study reported data for immediately post-exercise, therefore meta-analysis was not possible.

Arousal at 50% duration. Meta-analysis of arousal at this time point shows a significant effect in favour of HIIE (MD 0.91, 95% CI 0.12 to 1.69, $P = 0.02$; Figure 5).

Arousal at end of exercise. Meta-analysis of arousal at the end of exercise shows a significant effect in favour of HIIE (MD 1.16, 95% CI 0.50 to 1.81, $P = 0.0005$; Figure 5).

Arousal post+. Meta-analysis of arousal post+ shows a non-significant effect (MD 0.63, 95% CI -0.21 to 1.48, $P = 0.14$; Figure 5).

Affective judgment: Post-exercise enjoyment assessed by PACES. Data from studies assessing enjoyment using the Physical Activity Enjoyment Scale (PACES) were pooled into two meta-analyses. Figure 6 illustrates the findings from HIIE vs MICE, and Figure 7 shows the HIIE vs VICE results (see also Supplementary File 4).

HIIE vs MICE. Data from 15 studies (n=576) examined enjoyment post-HIIE and MICE using the PACES (Astorino & Thum, 2016; Decker & Ekkekakis, 2017; Farias-Junior et al., 2019; Gomes et al., 2018; Good & Dogra, 2017; Greene et al., 2018; Hoekstra et al., 2017; Little et al., 2014; O'Neill & Dogra, 2017; Olney et al., 2018; Ong et al., 2016; Songsorn et al., 2019a, b; Stork et al., 2018; Thum et al., 2017) (Figure 6 and Supplementary File 4). Jung et al. (2014) was excluded as the data were not available. Vella et al. (2017) and Namekata (2017) used independent groups designs, therefore were not included in the meta-analysis. Vella et al. (2017) reported that acute post-exercise enjoyment following the third session of week 1 was not significantly different between HIIE and MICE (99.9 ± 15.7 vs. 97.6 ± 10.7, P > 0.05), and Namekata also reported no difference between HIIE and MICE (86.8 ± 3.3 Vs 87.7 ± 3.8, P>0.05). Meta-analysis shows a significant effect in favour of HIIE (MD 6.73, 95% CI 2.45 to 11.01, P = 0.002; Figure 6). There was a large degree of heterogeneity within the analysis, with 8/15 studies reporting significant findings in favour of HIIE. One study (Wilke et al., 2019), assessed post-exercise enjoyment using a non-validated scale, so given the unsubstantiated quality of this measure, we have not included these data.

HIIE vs. VICE. Data from three studies (n=43) (Bartlett et al., 2011; Martinez et al., 2015; Oliveira et al., 2013) examined enjoyment post-HIIE and VICE using the PACES. Meta-analysis shows a non-significant effect (MD 12.16, 95% CI -0.45 to 24.77, P = 0.06; Figure 7).

Affective judgment: During-exercise enjoyment. Data from studies assessing enjoyment during exercise, were narratively synthesised to describe patterns across the studies in the direction and size of effects (Popay et al., 2006) (Table 4; Supplementary file 5). Four studies assessed enjoyment during exercise using the single item 7-point Exercise Enjoyment Scale (Stanley et al., 2009) (Astorino & Thum, 2016; Foster et al., 2015; Kilpatrick et al., 2015;

Martinez et al., 2015). MICE was favoured compared with HIIE during and at the end of exercise in one study, but there were no other differences evident. Out of 28 comparisons, enjoyment during HIIE was statistically significantly higher in 13 comparisons compared with VICE, with medium effect sizes.

Risk of Bias

The frequency of 'high', 'low' and 'unclear' risk of bias across all studies included in the meta-analyses were reported in the relevant figures, and risk of bias for all studies is summarised in Figure 8. In general, the quality of reporting for most risk of bias categories was insufficient to make a specific judgement. This issue was particularly pertinent for the reporting of allocation concealment and selective reporting. Funnel plots (see Supplementary Files 6 & 7) were examined for asymmetry in affect (HIIE vs MICE mid, end, and lowest) indicating limited asymmetry and a large degree of heterogeneity. Inspection of the funnel plot for post-exercise enjoyment (HIIE vs MICE) suggested some asymmetry in favour of positive findings of HIIE.

Discussion

The physical health benefits of HIIE are well established. However, the potential of HIIE for health promotion cannot be fully realised until there is greater understanding of individuals' affective responses to this activity. Opponents of HIIE have argued that individuals are likely to experience HIIE as more unpleasant compared with moderate intensity activity, and will therefore not continue to engage in this form of activity (Biddle & Batterham, 2015; Hardcastle et al., 2014; Rhodes & Kates, 2015). The aim of this systematic review was to synthesise the existing research that compares responses to HIIE with both MICE and VICE across a number of affective responses, and at different time points during and after the activity.

Characteristics of the Studies

From the review, it was evident that there has been a recent and increased interest in this area of research with 19 of the 33 included studies published since 2017. The overall sample was made up of both male and female participants with a range of characteristics including being active and inactive, overweight, and having clinical conditions. This finding counters suggestions by others that most of the research in this area has included young, healthy and active participants (e.g., Decker & Ekkekakis, 2017), and suggests that the findings of the review may have implications for a broad range of participants. The protocols adopted varied in terms of mode, although the majority (n=21/33) of the studies were based on cycle ergometers, and all but three studies were based in the laboratory providing an environment to rigorously manipulate the exercise intensity. However, this laboratory focus may limit the generalisability of the findings to more ecologically valid environments, such as a HIIE gym class, which would be worthy of future research.

There was a large degree of inter-study variability in participant demographics and the nature of the HIIE protocols employed, which are likely to be dominant contributing factors to the high degree of heterogeneity in the meta-analyses of the current review. Specifically, the protocols included in the meta-analyses varied around seven parameters: i) number of intervals per HIIE session (range 4-10, e.g.,Good & Dogra, 2017; Jung et al., 2014); ii) interval duration (range 6 sec - 4 min e.g., Niven et al., 2018; Tsukamoto et al., 2016); iii) interval intensity (range 75-80% heart rate reserve to all-out effort, e.g., Good & Dogra, 2017; Vella et al., 2017); iv) total session work duration (range 1 – 18 mins e.g., Niven et al. (2018), Bartlett et al. (2011)); v) recovery duration between intervals (range 10 sec – 4.5 min, e.g.,Good & Dogra, 2017; Wilke et al., 2019); vi) recovery intensity (range passive to 60% VO_{2peak} e.g.,Greene et al., 2018; Tsukamoto et al., 2016) e); and vii) total session duration: (range 14 – 50 mins e.g., Niven et al. (2018), Bartlett et al. (2011)).

Although the flexibility of HIIE is one of its strengths (Stork et al., 2017), it is also a potential source of bias and a clear confounder in terms of synthesising the evidence. Although it was not feasible within this review, as the literature base grows future reviews should examine the moderating role of the physical demands of HIIE protocols on affective responses. Such variability in key protocol parameters will influence the physical demand participants experience during HIIE, which will likely have implications for affective responses. Indeed, a recent review of the area made the specific recommendation that research should focus on developing acceptable and effective HIIE protocols that utilise minimal work durations and repetitions (Vollaard & Metcalfe, 2017). In order to determine whether HIIE has a contribution to make to public health, future research should focus on examining affective responses to the most 'palatable' approaches. Such steps may also reduce inter-study variability in HIIE protocols, and facilitate synthesis of studies to draw stronger conclusions.

The majority of the included studies compared HIIE with MICE (n=23), and a smaller number compared HIIE with VICE (n=6), or both MICE and VICE (n=4). It is important to acknowledge that the classification of continuous exercise into MICE and VICE is based on the %max HR and %VO_{2max} bandwidths classification approach (Garber et al., 2011). Although this approach is consistent with recognised guidelines and a previous review (Stork et al., 2017) a potential limitation is that this approach does not accommodate individual differences in metabolism. Consequently, this approach could potentially misclassify the intensity at which individuals are exercising, which would impact affective responses.

Finally, the risk of bias assessment highlighted the need to enhance the quality of reporting of studies in this field to more fully evaluate study quality. Additionally, a number of studies did not report effect sizes, or only reported these in relation to statistically significant findings potentially biasing study synthesis. In order to fully report the size and meaningfulness of differences between conditions, future research should aim to incorporate effect sizes (Lakens, 2013).

Affective Responses to HIIE Compared with MICE and VICE

From the included studies, there was a range of affective responses assessed. The most commonly assessed affective response was the valence component of basic affect measured by the single-item 10-point Feeling Scale (FS) (Hardy & Rejeski, 1989). The findings of the meta-analysis comparing HIIE with MICE on the FS indicated that at 50% of exercise, immediately post-exercise, post+, and the lowest value there was a significant effect in favour of MICE with a mean difference that ranged from 1.07 to 0.22. This effect was not significant at the end of exercise (100%). Whilst it is important to acknowledge that there was a large degree of heterogeneity evident for each of these analyses, with the exception of post+, at each time point a majority of the studies reported a significant finding in favour of MICE. The narrative synthesis of studies assessing affect using alternative measures from FS generally supported the meta-analyses with 11 out of 21 comparisons favouring MICE over HIIE, and MICE also being favoured at most of the time-points. Overall, these findings indicate that participants experience HIIE as less pleasant than MICE throughout and after the exercise session. In comparing FS responses during and after HIIE with VICE, the findings were more consistent showing no significant differences between conditions from the meta-analysis, although again there was a large degree of heterogeneity evident. These findings are supported by the narrative, where only one out of 14 comparisons favoured VICE. Two studies used versions of POMS (McNair et al., 1971), a measure of mood, and findings were mixed. In addition to examining the effect on basic affect, three studies assessed individual emotions, but used measures of unsubstantiated quality, so these were not considered further.

Overall, the findings relating to affective responses to exercise indicate that where there are significant differences in responses to exercise, these are typically in favour of a more positive response to MICE compared with HIIE. These findings are broadly in line with the tenets of DMT because in comparison to moderate-intensity continuous activity, participants experience HIIE as less pleasurable during exercise potentially reflecting a dominance of interoceptive cues as intensity exceeds VT. The findings of this study counter suggestions that the negative affective responses expected above VT in continuous exercise may not be evident in HIIE due to the periods of recovery during bouts of exercise (Jung et al., 2014). It was unexpected that at post and post+ exercise the findings indicated a response in favour of MICE, when DMT would suggest that a decline in affect during exercise would rebound to positive affect following activity. Affective responses to HIIE are similar to responses to VICE during and after exercise, perhaps suggesting that the intensity may explain the responses, rather than the interval or continuous nature of the activity.

These findings build on previous review level evidence. In their scoping review, Stork et al. (2017) examined findings relating to in-task affect from nine studies, and concluded affect is similar or more negative during interval compared to continuous exercise. However, this scoping review did not explicitly distinguish between MICE and VICE, and this distinction appears to be important in understanding responses more clearly. Specifically, with the inclusion of additional studies and a quantitative synthesis, the conclusion from Stork et al. (2017) can be extended to highlight that compared to MICE, HIIE is experienced more negatively, but responses are not different from VICE. Stork et al also considered post-exercise affect and reported that the majority of the studies showed no difference between interval and continuous exercise, which is contrary to the findings of the current study where there was a significant difference at both immediately post and post+ exercise, but only in comparison with MICE. The reason for these different findings is unclear, but may be explained partly by quantitative synthesis of MICE and VICE data, addition of further studies, and a more granular consideration of the post-exercise period to distinguish between immediately post and later in the post-exercise period. In their systematic review, on the FS variable Oliveira et al (2018) reported a trivial effect in favour of HIIE compared with MICE with 6/12 studies showing a favourable response for HIIE. However, as discussed above creating a composite measure of FS responses from across the bout of exercise is not theoretically appropriate.

In total, eight studies compared the levels of arousal between HIIE and continuous exercise during, end, post, and post+-exercise. The meta-analysis indicated greater arousal during HIIE compared with continuous exercise (MICE and VICE). These differences were not evident at post-exercise, at which point participants in each condition returned to similar arousal levels. These findings are consistent with Stork et al. (2017) who reported that participants in three studies experienced HIIE with higher levels of arousal than continuous exercise. However, the meaningfulness of these findings cannot be fully interpreted, as the assessment of arousal on its own is not indicative of an affective response and therefore has limited value. Indeed, it is unsurprising that participants working at a higher intensity report higher arousal. Within the context of affective responses, arousal is best considered alongside an assessment of affect valence. Specifically, drawing from the circumplex model of affect (Russell, 1980), arousal (or activation) and valence represent the two bipolar orthogonal dimensions of basic affect. Within this model affective states are conceptualised as a combination of these two dimensions of valence and activation. Therefore, high arousal paired with pleasant valence would represent feelings of energy, whereas high arousal paired with unpleasant valence represents feelings of tension, and these reflect very different affective responses. Only three studies in this review examined affect and arousal in tandem, by plotting the findings on a circumplex diagram and narratively describing group differences (Farias-Junior et al., 2019; Niven et al., 2018; Oliveira et al., 2013).

Future research considering affective responses to HIIE would benefit from standardisation of concepts and measurement to enhance theoretical integrity. In a broader discussion relating to affective responses to physical activity, Ekkekakis et al. (2018) reiterated earlier propositions (Ekkekakis & Petruzzello, 2002) that an assessment of basic affect is the most appropriate concept to understand in-exercise responses. Ekkekakis and Petruzzello (2002) present a compelling case for the previously-mentioned circumplex model of affect (Russell, 1980) as an appropriate framework, and this clearly has currency for HIIE research. The Felt Arousal Scale (Svebak & Murgatroyd, 1985) and the Feeling Scale (Hardy & Rejeski, 1989) are theoretically appropriate instruments that offer the potential to assess core affect both during and after activity, and consideration of both measures to fully assess core affect would be appropriate in future research. However further consideration is needed as to how to best inferentially analyse circumplex data, and ultimately synthesise findings from studies.

Enjoyment of HIIE Compared with MICE and VICE

In contrast to the varied measures used to assess affective responses, there was consistency in the assessment of post- and during- exercise enjoyment. The available data from 15 studies that assessed post-exercise enjoyment using the 18-item PACES scale (Kendzierski & DeCarlo, 1991) were meta-analysed and the findings indicated a significant effect in favour of HIIE compared with MICE. However, again there was a large degree of heterogeneity and only 8/15 studies reported significant findings in favour of HIIE with the funnel plot also flagging potential publication bias. There was no difference in enjoyment evident between participation in VICE vs HIIE. These findings are consistent with Stork et al. (2017)'s scoping review where in most studies it was reported that enjoyment was similar or greater following HIIE compared with MICE and VICE. Oliveira et al. (2018) also reported a beneficial effect of HIIE compared to MICE. Collectively, these findings point in the direction of enjoyment favouring HIIE. However, due to the heterogeneity in studies, further research with more standardised protocols would be appropriate. In contrast, albeit based on few studies, findings for enjoyment during exercise did not favour HIIE vs MICE with limited differences evident. Further, there was some evidence of greater enjoyment during HIIE compared with VICE, especially later in the exercise bout. These findings somewhat mirror the findings related to affect and could suggest that these constructs have some similarities and overlap.

In understanding why participants may find HIIE less pleasant, but overall more enjoyable than MICE it is appropriate to consider more fully the construct of enjoyment. Enjoyment can be defined as an affective judgement relating to reflections or expectations about engaging in physical activity (Rhodes et al., 2009). Previous research has suggested a positive relationship between in-exercise affect following moderate and light activity, and subsequent affective judgements like enjoyment (Rhodes & Kates, 2015), but this relationship may be different for high-intensity exercise. By its nature, enjoyment is cognitive and following HIIE individuals may incorporate feelings of competence, sense of accomplishment and pride into their judgement regarding whether the activity was enjoyable (Burn & Niven, 2018). Further research is warranted to explore what influences enjoyment of HIIE, and its relationship with future behaviour.

Potential implications of Affective Responses to HIIE for Behaviour

Affective responses to HIIE are of interest because it is anticipated that they will influence future behaviour. Although it was not the purpose of this review to examine the relationship between affective responses and behaviour, consideration of the implications of the review findings for the potential relationship with behaviour is warranted. In a review, Rhodes and Kates (2015) reported that core affect during exercise was predictive of future behaviour, although this finding was not evident for the one high intensity study included in the review. The review also demonstrated that post-exercise affect was not predictive of future behaviour. If these findings hold true for HIIE, then it would suggest that the less pleasant experience of HIIE vs MICE during exercise would lead to lower levels of engagement. A recent study reported that in-task affect during MICE was related to subsequent MICE behaviour in the next 4-weeks, but this relationship was not evident for two HIIE conditions (Stork et al., 2018). These findings may suggest that the relationship between affective responses during exercise and future behaviour varies dependent on exercise type, although there is clearly a need for further research.

Further research is also needed to determine at which time-point affect is most meaningful for future behaviour. Specifically, the lowest point of negative affect, and affect at the very end of exercise have been identified as being important (Decker & Ekkekakis, 2017; Hargreaves & Stych, 2013; Kahneman et al., 1993). Interestingly, we identified no difference in affect between HIIE and MICE and VICE at the end of exercise potentially suggesting that if this time point is important, then the relationship with future behaviour may not differ by type of exercise.

It is anticipated that affect responses during exercise will influence future behaviour by impacting on affective judgements (including enjoyment) related to future behaviours (Rhodes & Kates, 2015). However, the findings of this review highlight an inconsistency in this relationship with HIIE showing less positive in-exercise affect but more positive overall enjoyment compared with MICE, and further research is needed to explore this and empirically test these relationships. The potential consequences of this greater enjoyment of HIIE compared to MICE on future behaviour also requires further consideration, as there is strong correlational evidence that affective judgements are related to physical activity behaviour (Rhodes et al., 2009). There is a clear need for future research to consider how affective responses (including affect and enjoyment) at various time points during and after HIIE influence subsequent behaviour. Framing this research around recent integrative frameworks of affect and health behaviour (e.g., Williams et al., 2019) would be appropriate to consider the relationship, and potential mediating pathways.

Conclusion

This is the first review to rigorously synthesise the existing literature on affective responses to HIIE compared with continuous exercise, and as such makes an important contribution to the debate regarding the public health viability of HIIE. Findings of this review suggest that HIIE is experienced as less pleasant than MICE but similar to VICE during and post-exercise. In contrast, the evidence points towards participants reporting HIIE as more enjoyable than MICE, but equivalent to VICE. These apparently contradictory findings highlight the need for further research to unpick the relationship between affect and enjoyment, and importantly also subsequent behaviour. However, these findings are clouded by a number of issues evident in the field that contribute to high levels of study heterogeneity. A limitation of this current review is that moderator analysis was not undertaken to explore the potential reasons for such high level of heterogeneity (e.g., fitness status of participants, physical demands of HIIE), and future research could aim to do this. Nevertheless, an important outcome of this review has been to articulate some of the issues that may influence heterogeneity and offer suggestions for future directions to mitigate them. Specifically, we identify the need for more standardised HIIE protocols, enhanced theoretical coherence, and standardised outcome measures. Such steps would generate a body of work that is more comparable and provide clearer direction regarding the suitability of HIIE for public health.

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Figure Captions:

Figure 1. PRISMA flow chart data extracted from www.covidence.org.

Figure 2. Random effects meta-analyses for the influence of high-intensity interval exercise versus moderate-intensity continuous exercise on affect. Effect sizes are shown as mean difference and 95% confidence intervals

Figure 3. Random effects meta-analyses for the influence of high-intensity interval exercise versus vigorous-intensity continuous exercise on affect. Effect sizes are shown as mean difference and 95% confidence intervals

Figure 4. Random effects meta-analyses for the influence of high-intensity interval exercise versus moderate-intensity continuous exercise on arousal. Effect sizes are shown as mean difference and 95% confidence intervals

Figure 5. Random effects meta-analyses for the influence of high-intensity interval exercise versus vigorous-intensity continuous exercise on arousal. Effect sizes are shown as mean difference and 95% confidence intervals

Figure 6. Random effects meta-analyses for the influence of high-intensity interval exercise versus moderate-intensity continuous exercise on post-exercise enjoyment. Effect sizes are shown as mean difference and 95% confidence intervals

Figure 7. Random effects meta-analyses for the influence of high-intensity interval exercise versus vigorous-intensity continuous exercise on post-exercise enjoyment. Effect sizes are shown as mean difference and 95% confidence intervals

Figure 8. Summary of risk of bias assessment