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The Pleasure and Displeasure People Feel When they Exercise at Different Intensities

Decennial Update and Progress towards a Tripartite Rationale for Exercise Intensity Prescription

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Abstract

The public health problem of physical inactivity has proven resistant to research efforts aimed at elucidating its causes and interventions designed to alter its course. Thus, in most industrialized countries, the majority of the population is physically inactive or inadequately active. Most theoretical models of exercise behaviour assume that the decision to engage in exercise is based on cognitive factors (e.g. weighing pros and cons, appraising personal capabilities, evaluating sources of support). Another, still-under-appreciated, possibility is that these decisions are influenced by affective variables, such as whether previous exercise experiences were associated with pleasure or displeasure. This review examines 33 articles published from 1999 to 2009 on the relationship between exercise intensity and affective responses. Unlike 31 studies that were published until 1998 and were examined in a 1999 review, these more recent studies have provided evidence of a relation between the intensity of exercise and affective responses. Pleasure is reduced mainly above the ventilatory or lactate threshold or the onset of blood lactate accumulation. There are pleasant changes at sub-threshold intensities for most individuals, large inter-individual variability close to the ventilatory or lactate threshold and homogeneously negative changes at supra-threshold intensities. When the intensity is self-selected, rather than imposed, it appears to foster greater tolerance to higher intensity levels. The evidence of a dose-response relation between exercise intensity and affect sets the stage for a reconsideration of the rationale behind current guidelines for exercise intensity prescription. Besides effectiveness and safety, it is becoming increasingly clear that the guidelines should take into account whether a certain level of exercise intensity would be likely to cause increases or decreases in pleasure.

1. The Exercise Paradox: A 'Best Buy' But a 'Tough Sell'

In a landmark paper, the late Jeremy Morris characterized physical activity as "today's best buy in public health."[1] The evidence that has accumulated on the causal relationship between physical activity and numerous aspects of health supports this characterization.[2-4] At the same time, however, promoting exercise to the public has proven a very 'tough sell'.[5] Despite the issuance of evidence-based recommendations, the advent of social marketing campaigns, the institution of public health policy and the investment of considerable research funds, the rates of physical inactivity in most industrialized countries have not shown signs of change.[6-10] Thus, combating physical inactivity was recently characterized as "the biggest public health problem of the 21st century."[11]

Although the current situation calls for what the Chief Medical Officer[12] in the UK described as "a mass shift in current activity levels" (p. iv), activity-promotion interventions have shown limited effectiveness.[13,14] Moreover, of those individuals who initiate exercise programmes, there is an estimated 45% dropout (range from 9% to 87%).[14] Since these data come from research trials, most of which include intervention components designed to improve adherence and retention, it is reasonable to speculate that, in real-life conditions, where no such support is usually present, dropout is probably even higher.

1.1 The Role of Affect in Exercise Behaviour

One assumption underpinning the theories that are commonly used to explain and predict exercise behaviour and to design interventions (e.g. the theory of planned behaviour, social-cognitive theory or the trans-theoretical model) is that people make behavioural decisions after they collect pertinent information, weigh pros and cons, appraise sources of support and make probabilistic predictions about the consequences of their actions. Consequently, to improve the chances of choosing exercise over sedentary alternatives, interventions focus on providing information about such parameters as the health benefits of an active lifestyle or the individual's physical readiness to perform the recommended amount of exercise. However, evidence indicates that interventions based on education and modifications of cognitive appraisals are minimally effective.[13]

Another assumption that is implicit in the application of these theories in the field of exercise behaviour is that the factors that influence this particular behaviour are the same as those underlying other health behaviours (such as brushing one's teeth, quitting smoking, eating fruits and vegetables or practicing safe sex). However, data from 250 000 respondents in North America indicate that other health behaviours share virtually no common variance with exercise.[15] Therefore, exercise appears to be driven by at least some unique mechanisms. Nevertheless, the unique mechanisms underlying exercise behaviour remain unexplored and have yet to be targeted in intervention efforts.

One feature of exercise that has been identified as having potential motivational significance is the affective response (e.g. pleasure or displeasure, tension or relaxation, energy or tiredness) that exercisers experience. Dishman et al.[16] noted that "feelings of enjoyment and well-being seem to be stronger motives for continued participation [than] knowledge of and belief in the health benefits of physical activity" (p. 162), as well as "more important to maintaining activity than concerns about health" (p. 166). Dishman[17] also wrote that "knowledge and belief in the health benefits of physical activity may motivate initial involvement and return to activity following relapse, but feelings of enjoyment and well-being seem to be stronger motives for continued participation" (p. 83).

It was not until recently that the first direct evidence linking affective responses and exercise behaviour emerged. Williams et al.[18] recorded pleasure ratings during an exercise test at the minute at which sedentary adults reached a 'moderate' level of intensity (64% of age-predicted maximal heart rate [HR_{max}]). These ratings were significantly correlated with self-reported physical activity at 6-month ($r = 0.50$) and 12-month ($r = 0.47$) follow-ups. A 1-unit increase on the 11-point rating scale of pleasure[19] was associated with 38 additional minutes of at least moderate physical activity per week at the 6-month follow-up and 41 minutes at the 12-month follow-up.

Schneider et al.[20] measured pleasure while 124 adolescents exercised on a cycle ergometer for 30 minutes at 80% of their previously determined ventilatory threshold (VT) workload. Participants who reported increases in pleasure averaged 54.25 minutes of daily moderate-to-vigorous physical activity, assessed by accelerometers. Those who reported no change averaged 46.94 minutes and those who reported declines averaged 39.83 minutes. After controlling for aerobic fitness and sex, a 1-unit increase on the 11-point rating scale of pleasure[19] predicted 4.18 minutes of additional daily moderate-to-vigorous physical activity.

Kwan and Bryan[21] assessed positive affect (e.g. enthusiastic, energetic), negative affect (e.g. crummy, miserable), tranquility (e.g. calm, relaxed) and fatigue (e.g. fatigued, tired) during and after 30 minutes of treadmill exercise at 65% maximal oxygen uptake ($\dot{V}O_{2max}$) in 129 adults. Larger increases in positive affect and decreases in fatigue during exercise were associated with more frequent self-reported aerobic exercise 3 months later. More tranquility and less fatigue during recovery were also related with more frequent exercise.

Although preliminary, these findings raise the possibility that exercise-induced increases or decreases in pleasure may contribute to the formation of a positive or negative memory trace for exercise. In turn, this memory, consciously or subconsciously, may influence subsequent decisions to engage in, adhere to or drop out from exercise.[22]

1.2 The Role of Intensity in Exercise Behaviour

Intensity is a key component of exercise prescriptions because, according to the American College of Sports Medicine (ACSM),[23] it is both "the most important exercise prescription variable to maintain a cardiovascular training response" (p. 161) and "associated with an increased risk of orthopedic injury [and] cardiovascular incidence" (p. 147). Moreover, characterizing intensity as "the most important exercise prescription variable" is justified by its apparent impact on adherence. According to ACSM,[23] "adherence is lower with higher-intensity exercise programs" (p. 142). Although a recent review casts doubt on the strength of this link,[24] the role of intensity is supported by several large studies.[25-28] Furthermore, a meta-analysis showed that activity-promotion efforts were more effective when the intensity was lower rather than higher.[13] Other components of the exercise 'dose', such as duration or frequency, do not seem to have similar relations to adherence.[13,27]

1.3 A Possible Intensity-Affect-Exercise Behaviour Causal Chain

Among the variables likely to mediate the relationship between intensity and adherence, affect has long been postulated to play a key role. Pollock[29] proposed an intensity-affect-adherence causal chain in 1978: ''People participate in programs they enjoy. The lower intensity effort makes the programs more enjoyable'' (p. 59). This intuitively appealing idea reappeared in the text of the Healthy People 2010[30] programme: ''each person should recognize that starting out slowly with an activity that is enjoyable [is] central to the adoption and maintenance of physical activity behavior'' (chapter 22, p. 4). However, no studies to date have examined this mediational relationship. One possible explanation for this void is that the first link, between intensity and affect, has remained enigmatic.[22]

1.4 Necessity of the Present Update

Several reasons necessitate a re-examination of the evidence on the intensity-affect relationship, a decade after Ekkekakis and Petruzzello's[22] review of this literature. First, in the last decade, the studies investigating the intensity-affect relationship have more than doubled. Compared with 31 studies published between 1971 and 1998, 41 new articles were published from 1999 to 2009. Therefore, interest in this topic has been growing stronger.

Second, there has been a change in the rationale behind the newer studies. The purpose of most of the earlier studies was to investigate the utility of exercise as an intervention for improving mental health (i.e. whether exercise can make people 'feel better' and, thus, help combat such mental health problems as anxiety or depression). In contrast, most recent studies target affect because of its possible implications for exercise adherence.

Third, newer studies paint a fundamentally different picture of the intensity-affect relation than earlier ones. Although Ekkekakis and Petruzzello[22] found that 54% of the studies they reviewed showed no intensity effects, the newer studies, due to a combination of stronger methodologies and more refined hypotheses, have produced evidence of a dose-response pattern. As the reliability of these findings is established through replications by independent laboratories, new prospects arise. A few years after the publication of the first ACSM guidelines for exercise testing and prescription, Dishman recognized the need to find a ''compromise'' between the ''ideal physiological prescription'' and a ''manageable behavioral prescription'' in order to ''allow adherence to be sufficient for desired biological changes to occur''[31,32] (p. 248 and p. 174, respectively). This was a pioneering proposal for a transition to a tripartite model upon which exercise prescription guidelines should be based. Besides ''the dose that induces the greatest health benefit'' and ''the potential risk in a particular population''[23] (p. 133), it is time to also consider which intensity is more likely to increase pleasure and, thus, promote motivation and adherence.

Fourth, in the latest edition of the *Guidelines for Exercise Testing and Prescription*, the ACSM[33] identified the use of ''measures of affective valence'' (i.e. pleasure/displeasure) as a potentially useful adjunct method of self-monitoring exercise intensity besides heart rate (HR) and ratings of perceived exertion (RPE). The ACSM[33] also noted the need for ''further research'' before measures of affective valence can be ''recommended as primary tools for the estimation of exercise intensity'' (p. 157). Thus, an updated review on the relation between exercise intensity and affect seems warranted.

2. Summary of Conclusions and Recommendations of the 1999 Review

According to earlier proposals,[34,35] the relation between exercise intensity and affective responses can be modelled as an inverted-U curve. This implies that mid-range intensities should result in optimal affective changes, whereas intensities that are 'too low' or 'too high' are less effective. Ekkekakis and Petruzzello[22] discussed evidence that the inverted-U is an unsatisfactory model of the intensity-affect relation for at least three reasons.

First, the model does not fit the data well. Low-intensity, short-duration exercise (e.g. self-paced walks) has been found to produce transient but significant increases in pleasure and energy.[36-40] A meta-analysis focusing on the influence of exercise on high-activation pleasant affect (e.g. vigour, energy) concluded that the effect size associated with low intensities (15–39% oxygen uptake [$\dot{V}O_2$] reserve) was almost twice as large ($d=0.57$) as that associated with moderate (40–59% $\dot{V}O_2$ reserve; $d=0.35$) or high intensities (60–85% $\dot{V}O_2$ reserve; $d=0.31$).[41] On the other hand, high-intensity exercise stimuli, such as incremental exercise protocols to volitional exhaustion, in addition to increases in fatigue, have been found to yield some positive changes, such as improvements in self-esteem.[42] Finally, during exercise performed at mid-range intensities (e.g. 60% $\dot{V}O_{2max}$), some individuals report increases but others decreases in pleasure.[43]

Second, the inverted-U model does not take into account inter-individual variability in affective responses. However, variability, even to the same exercise intensity and for individuals of the same sex, age, health and physical fitness, is often pronounced.[43,44] Evidence also shows that the degree of variability changes as a function of exercise intensity.[45] Thus, the phenomenon of variability warrants substantive research attention.[46]

Third, the inverted-U is a descriptive model, not a mechanistic one. Consequently, it does not yield testable hypotheses that could elucidate the underlying causes of the observed affective changes. However, mechanistic explanations are necessary insofar as they form a basis for developing interventions to optimize affective responses.

The review of the 31 studies published up until 1998 revealed two groups of studies with distinct findings. The largest group consisted of 26 studies in which affective variables (e.g. state anxiety, mood states) were assessed, typically with multi-item inventories, only before and after or before, during and after the exercise bouts. Slightly more than half of these studies (14 of 26) did not show significant intensity effects. Of those that did, there was some evidence that (i) when tension or state anxiety were measured during or immediately after a bout, higher intensities were associated with higher scores; and (ii) fatigue tended to be higher and energy or vigour tended to be lower in response to higher exercise intensities, particularly among participants with low cardiorespiratory fitness.

The second group consisted of seven studies (with a two-study overlap with the first group), in which affective responses during exercise were assessed along the dimension of pleasure/displeasure, using the single-item Feeling Scale (FS).[19] The FS is an 11-point rating scale, ranging from (I feel) ‘very good’ (+5) to ‘very bad’ (−5). Six of these seven studies showed that, as the intensity increased, pleasure ratings declined.

2.1 Overhaul of the Methodological Platform

Most earlier investigations of the relationship between exercise intensity and affective responses were based on a methodological platform with several features that were identified by Ekkekakis and Petruzzello[22] as problematic. First, to assess ‘how people feel’, researchers used questionnaires tapping certain distinct states (e.g. anxiety, vigour, fatigue, depression). These variables were chosen because they were the ones measured by the questionnaires that were available for non-clinical use in the 1970s and 1980s. Second, because these questionnaires were relatively long and, therefore, inconvenient to administer during exercise, they were typically completed only before and after exercise. Third, the intensity of the exercise bouts was set as a percentage of HR_{max} or $\dot{V}O_{2max}$, usually without providing a rationale. Thus, one study might have compared 40% to 60% $\dot{V}O_{2max}$ while another compared 50% to 75%. Fourth, analyses of change were based on the general linear model and, thus, individual differences in affective responses to the same intensity were treated as error.

Collectively, these methodological features might have obfuscated intensity effects. Focusing on only a few distinct states left open the possibility that intensity effects occurred not in the states being assessed but in others.[47] Measuring affect only before and after the bout allowed the possibility that intensity effects occurred during exercise but dissipated thereafter.[48,49] Attempting to equate the intensity across individuals by using percentages of maximal capacity cannot standardize the contribution of aerobic and anaerobic metabolic pathways or a multitude of attendant physiological processes.[50-59] This increases variability in affective responses and reduces statistical power to detect intensity effects. Finally, analysing changes only at the level of group averages neglects important individual differences and can conceal divergent patterns among individuals or subgroups.[43-46,48] In the most extreme case, if two groups exhibit equal but opposite changes during the bout, the group average will deceptively indicate that there was no change.[43]

To address these problems, Ekkekakis and Petruzzello[22] proposed certain changes to the methodological platform that are important to revisit, to set the backdrop against which the newer studies can be evaluated. The domain of affect can be conceptualized as defined by a small set of dimensions that account for most of the similarities and differences among affective states. A model called the circumplex includes the bipolar and orthogonal dimensions of affective valence (pleasure/displeasure) and perceived activation.[60] The full trajectory of the affective response to an exercise bout can be tracked with repeated administrations of two single-item rating scales, one for each dimension.[22] It should be noted that, because responses depend on a single rating that could be swayed by random error (e.g. respondent carelessness), single-item scales are considered less reliable than multi-item ones. On the other hand, due to their brevity, they are minimally intrusive, thus allowing assessments with even minute-by-minute frequency. The intensity of exercise should be set in relation to a physiological marker that reflects the contributions of aerobic and anaerobic metabolic processes, such as the VT or the lactate threshold (LT).[58,59] Finally, exercise-induced changes in affect should be examined not only at the level of group averages, but also at the level of individuals and subgroups.[43,48]

3. Updated Review

Articles were located by a combination of (i) monitoring the tables of contents of journals in exercise science, exercise psychology, health psychology, preventive medicine and behavioural medicine for the last decade; (ii) performing literature searches using scientific databases (PubMed, PsycINFO, Web of Knowledge, Scopus); and (iii) conducting extensive cross-referencing. Forty-one articles were identified, published between January 1999 and December 2009. Of these, eight were excluded for the following reasons: (i) exercise intensity was set solely on the basis of RPE;[61] (ii) different intensities were prescribed verbally but the actual intensities were not monitored;[62] (iii) the effect of different intensities was not analysed;[63] (iv) the effects of intensity could not be disentangled from the effects of another independent variable (music);[64] or (v) the effects of intensity were confounded with the effects of perceived autonomy.[65-68]

Of the 33 remaining publications, three pairs referred to the same three studies (see Cox et al.[69] and Cox et al.;[70] Katula et al.[71] and McAuley et al.;[72] and Lochbaum et al.[73] and Lochbaum[74]), so there were 30 unique studies. Because the publications within each pair dealt with different dependent variables, all were retained. The 33 publications were organized into three groups. First, in 15 publications describing 12 studies, the levels of exercise intensity being compared represented different percentages of maximal capacity (see table I). Second, in ten publications, the levels of exercise intensity being compared were defined in relation to the VT, the LT or the onset of blood lactate accumulation (OBLA) [see table II]. Third, eight publications described affective responses to graded exercise tests (see table III).

A total of 1007 individuals participated (491 males, 516 females). This number corresponds to an average sample size of 34, which, interestingly, is the number required to detect a difference between two dependent means, assuming a medium effect size ($d=0.5$), alpha of 0.05, power of 0.80, and a two-tailed test. There was a noteworthy improvement in the diversity of samples compared with previous decades. The age range was extended in both directions, with studies now covering children and adolescents,[96,97,106] and older adults.[71,72,81] The average age was 26 years but the range extended from 12.5 years[106] to 68.2 years.[71] Likewise, about one-third of the studies either

Table I. Studies examining the relationship between exercise intensity (operationally defined as different percentages of maximal exercise capacity) and affective responses

Study	No. of subjects, sex and fitness level (age[a] and $\dot{V}O_{2max}$)	Design and factors	Intensity, mode and duration	Measures and administration timepoints	Findings
Blanchard et al.[75]	12 F fit (23.4 y, 53.8 mL/kg/min) 12 F unfit (24.8 y, 33.0 mL/kg/min)	Mixed, fitness status (between) by intensity (within) by time	Low (50% HRR), high (85% HRR), stationary cycling, 30 min	SEES; upon arrival and when HRs returned to ± 10 beats/min of when entered lab	Positive Well-being: no effect of fitness. Higher in the 50% than the 80% condition. Psychological Distress: in low intensity, no change for either fit or unfit. In high intensity, no change for fit but significant increase for the unfit. Fatigue: no changes
Blanchard et al.[76]	60 F physically active, (~22 y) 12 per group	Mixed, intensity/duration combination or control (between) by time	Low (50% HRR), high (85% HRR), stationary cycling, 15 or 30 min	EFI; upon arrival, at 7.5 min for 15 min bout and at 15 min for 30 min bout, when HRs returned to ± 10 beats/min of entering the lab	No main effects of duration, so data from the two durations were collapsed. Tranquility: no change. Positive Engagement and Revitalization: increased significantly from pre to post, with no differences between intensities. Physical Exhaustion: decreased significantly in the 50%, no change in the 85% condition
Cox et al.[69]	24 F, active, 12 younger (18.6 y, 42.3 mL/kg/min) 12 older (40.2 y, 36.2 mL/kg/min)	Mixed, age (between) by intensity (within) by time	60% $\dot{V}O_{2max}$, 80% $\dot{V}O_{2max}$, control, treadmill exercise, 33 min (2 min walk, 8 min ramp, 20 min steady, 3 min walk)	SAI; upon arrival, ~5 min later, 30, 60, 90 min after	No differences in state anxiety between conditions at baseline or 5 min post. At 30 and 60 min post, 80% was lower than control. At 90 min post, all conditions were different, with control showing the highest and 80% the lowest scores. SAI was lower than baseline in the control condition at post min 5, 30, 60. At 60%, all post-exercise timepoints were lower than baseline. At 80%, SAI was not below baseline at post min 5 but was lower at min 30, 60, 90
Cox et al.[70]	24 F, active, 12 younger (18.6 y, 42.3 mL/kg/min) 12 older (40.2 y, 36.2 mL/kg/min)	Mixed, age (between) by intensity (within) by time	60% $\dot{V}O_{2max}$, 80% $\dot{V}O_{2max}$, control, treadmill exercise, 33 min (2 min walk, 8 min ramp, 20 min steady, 3 min walk)	SEES; upon arrival, ~5 min after, 30, 60, 90 min after	Fatigue: only time main effect (lower at 90 min post than baseline). Psychological Distress: main effect of time (lower throughout recovery than baseline) and an intensity by age interaction (but none of the follow-ups were significant). Positive Well-being: triple interaction. For younger, intensity effect (higher for 80% $\dot{V}O_{2max}$) but no time effect or intensity by time interaction. For older, intensity effect and intensity by time interaction. Throughout recovery, 60% and 80% $\dot{V}O_{2max}$ higher than control. Increase from baseline only for 80% $\dot{V}O_{2max}$ at 30 min post

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Table I. Contd

Study	No. of subjects, sex and fitness level (age[a] and $\dot{V}O_{2max}$)	Design and factors	Intensity, mode and duration	Measures and administration timepoints	Findings
Daley and Huffen[77]	30 active adults, 16 M, 14 F, (31.7 y)	Within-subject	40% HR_{max}, 70% HR_{max}, stationary cycling, 20 min	SEES; before, 10 min during, 5 min after	Positive Well-being: no significant changes in the 40% condition but significant increase post-exercise in the 70% condition. Fatigue: no significant changes in the 40% condition, but an increase over time in the 70% condition. Psychological Distress: no significant changes
Daley and Welch[78]	16 F, 8 active (20.1 y, 3.01 L/min) 8 inactive (20.1 y, 2.13 L/min)	Mixed, activity status (between) by intensity (within) by time	50–55% age-predicted HR_{max}, 80–85% age-predicted HR_{max}, treadmill exercise, 20 min	SEES; before, 10 min during, 5 min after	Active and inactive participants did not differ. Positive Well-being: during exercise, increase in the low-intensity condition but not the high-intensity condition. In high-intensity condition, scores increased only after exercise and were higher than after the low-intensity condition. Psychological Distress: no intensity effect. Scores significantly reduced during and after exercise compared with before. Fatigue: no significant changes
Dunn and McAuley[79]	42 F low active (20 y, 32.5 mL/kg/min)	Within-subject	60% $\dot{V}O_{2peak}$, 80% $\dot{V}O_{2peak}$, treadmill walking or jogging, 20 min	SEES, EFI; immediately prior, midpoint, immediately following, 20 min post	Positive Well-being: increased in both conditions, with no significant differences. Psychological Distress: significant decreases in 60% from pre to 20 min post and in 80% from immediately post to 20 min post. Fatigue: for 60%, decreases from pre to all remaining points. For 80%, decrease from immediately post to 20 min post. Exhaustion: reductions only in 60%, from pre to all remaining times. Positive Engagement: in 60%, increase from pre to immediately post and 20 min post. In 80%, increase from pre to 20 min post. Revitalization: in 60%, increases from pre to all remaining points. In 80%, increases from pre to immediately post and 20 min post. Tranquility: in 60%, increases from during and immediately post to 20 min post. In 80%, non-significant decrease during and immediately post, followed by a significant improvement over pre at 20 min post

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Table I. Contd

Study	No. of subjects, sex and fitness level (age[a] and $\dot{V}O_{2max}$)	Design and factors	Intensity, mode and duration	Measures and administration timepoints	Findings
Katula et al.[71]	80 sedentary older adults, 17 M (62.68 y, 23.35 mL/kg/min) 63 F (68.24 y, 19.34 mL/kg/min)	Within-subject	Light (walking or stretching and toning, 29% HRR); moderate (1-mile indoor walking test, 49% HRR), maximal (maximal graded treadmill test, 96% HRR)	SAI (10 item); before and after	Significant decrease following light, non-significant decrease following moderate and a significant increase following maximal
McAuley et al.[72]	80 sedentary older adults, 17 M (66.58 y, 23.90 mL/kg/min) 63 F (67.50 y, 19.78 mL/kg/min)	Within-subject	Light (walking or stretching and toning), 28% HRR, 29.77 min, moderate (1-mile indoor walking test), 46%, 17.36 min, maximal (maximal graded treadmill test, 96% HRR, 11.42 min)	SEES; before and after	Positive Well-being: with exercise intensity and duration as covariates, significant increase after light, non-significant decrease after moderate and significant decrease after maximal. Psychological Distress: with exercise intensity and duration as covariates, decrease in Psychological Distress after light, a non-significant increase after moderate and a significant increase after maximal. Fatigue: with exercise intensity and duration as covariates, no change after light and significant increases after moderate and maximal
Kilpatrick et al.[80]	29 undergraduate students, 15 M, 14 F, (20.8 y, 35.1 mL/kg/min)	Within-subject	10 min warm-up and 20 min at 60% $\dot{V}O_{2max}$ (stationary cycling), followed by (i) additional time at 60% (3.9 min), (ii) cool-down (10 min) or (iii) sprint (2.7 min) [equated work]	SEES; immediately after each exercise protocol and after 15 min quiet rest	Fatigue: higher following the sprint compared to the cool-down, both at 0 and 15 min post. However, there was a significant decrease from 0 to 15 min post. Psychological Distress: trial by time interaction approached but did not reach significance. Distress elevated following the sprint at 0 min post and reduced thereafter. Positive Well-being: no significant effects
Lochbaum et al.[73]	53 university students, 28 active: 15 M, 13 F (24.4 y, 49.9 mL/kg/min) 25 inactive: 13 M, 12 F, (23.4 y, 39.3 mL/kg/min)	Mixed, activity status (between) by intensity (within) by time	50–55% $\dot{V}O_{2max}$, 70–75% $\dot{V}O_{2max}$, treadmill exercise, 30 min	AD ACL; immediately prior, min 5, 15, 25 during, immediately after, min 10 and 20 after	‘Affective balance’ score was calculated (EA minus TA) from the AD ACL. Greater positive affect found during the 55% condition compared with the 70% condition, with the significant differences being during exercise and not during recovery. This was more pronounced among the inactive, who showed a significant decline during the 70% condition (mean positive affect balance score at min 25 of exercise of 0.0) but no change during the 55% condition

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Table I. Contd

Study	No. of subjects, sex and fitness level (age[a] and $\dot{V}O_{2max}$)	Design and factors	Intensity, mode and duration	Measures and administration timepoints	Findings
Lochbaum[74]	53 university students, 28 active: 15 M, 13 F (24.4 y, 49.9 mL/kg/min) 25 inactive: 13 M, 12 F (23.4 y, 39.3 mL/kg/min)	Mixed, activity status (between) by time (intensity not treated as a factor)	50–55% $\dot{V}O_{2max}$, 70–75% $\dot{V}O_{2max}$, treadmill exercise, 30 min	AD ACL, SAI, immediately prior, min 5, 10, 25 during, immediately after, min 10 and 20 after	The three measurement timepoints during and after exercise were averaged. For 55%, EA and TA were elevated from baseline both during and after exercise. The inactive group showed increases in TA and SAI over time, whereas the active showed no change in TA and a decrease in SAI from pre to post. No group by time interaction for EA. For 70%, EA and TA increased from baseline during and after exercise. SAI increased only during exercise. TA was higher for the inactive throughout and showed a larger increase during and after than in the active. EA showed a significant group by time interaction but no significant follow-ups. No group by time interaction for SAI
Oweis and Spinks[81]	21 F, (55.5 y, 22.0 mL/kg/min)	Within-subject	Light (45% $\dot{V}O_{2max}$), moderate (60% $\dot{V}O_{2max}$), high (75% $\dot{V}O_{2max}$), control (zero resistance), stationary cycling, 10 min plus 2 min warm-up and 2 min cool-down	AD ACL, FS; 'directly following each physical activity bout'	EA: lower after light than control, higher after high than light. TA: lower after high than control and light. FS: lower after high than light and moderate
Smith et al.[82]	26 F college students (22 y, 39.2)	Within-subject	40% $\dot{V}O_{2peak}$, 70% $\dot{V}O_{2peak}$, quiet rest; stationary cycling, 25 min plus 5 min warm-up	SAI (10 item), SAM; SAI: upon arrival, immediately before and 20 min after. SAM: min 15 and 25 during	SAI: No intensity effects. Scores decreased post compared with pre-preparation and pre-exercise. SAM: valence was higher (more positive or pleasant) during cycling at 40% than 70%. Likewise, dominance was higher during 40% than 70%
Tieman et al.[83]	26 M adults, (24.5 y) 13 high active (53.8 mL/kg/min) 13 low active (43.0 mL/kg/min)	Mixed, activity status (between) by intensity (within) by time	40% $\dot{V}O_{2peak}$, 75% $\dot{V}O_{2peak}$, quiet reading; stationary cycling, 20 min	SAI; upon arrival, 20 and 5 min prior to, 5 and 25 min after	Among low active, SAI was lower after light cycling compared with quiet rest and hard cycling. Among high active, SAI was unchanged. Additional analyses examined SAI responses to a maximal cycling test. SAI was assessed 60 and 5 min prior to and 5 min after the test. Among low active, SAI increased 5 min post compared with 60 and 5 min pre. Among high-active, scores were unchanged

a Age and $\dot{V}O_{2max}$ are presented as sample means.

AD ACL = Activation Deactivation Adjective Check List[84]; **EFI** = Exercise-induced Feeling Inventory[85]; **EA** = energetic arousal; **F** = female; **FS** = Feeling Scale[19]; **HR_{max}** = maximal heart rate; **HRR** = heart rate reserve; **HRs** = heart rates; **lab.** = laboratory; **M** = male; **SAI** = State Anxiety portion of the State-Trait Anxiety Inventory[86]; **SAM** = Self-Assessment Manikin[87]; **SEES** = Subjective Exercise Experiences Scale[88]; **TA** = tense arousal; **$\dot{V}O_{2max}$** = maximal oxygen uptake; **$\dot{V}O_{2peak}$** = peak oxygen uptake; ~ indicates approximately.

Table II. Studies examining the relationship between exercise intensity (operationally defined in relation to the ventilatory threshold [VT], lactate threshold [LT] or the onset of blood lactate accumulation) and affective responses

Study	No. of subjects, sex and fitness level (age[a] and $\dot{V}O_{2max}$)	Design and factors	Intensity, mode and duration	Measures and administration timepoints	Findings
Bixby and Lochbaum[89]	7 M, 8 F, high-fit (23.53 y, 48.99 mL/kg/min) 5 M, 12 F, low-fit (23.52 y, 34.74 mL/kg/min)	Mixed, fitness level (between) by intensity (within) by time	Low (75% of HR at VT), high ('just below' [3 beats/min] HR at VT), recumbent cycling, 30 min	AD ACL; 5 min into baseline, start of exercise, 10, 20, 30 min of exercise, 10, 20, 30 min of recovery	'Affective balance' score was calculated from AD ACL (EA minus TA). Significant intensity by time interaction, with more positive affect during the low-intensity condition (no differences during recovery). Fitness group main effect significant (fit showed more positive affect overall) but no interaction with time or with three-way (group by intensity by time)
Bixby et al.[49]	27 college students, 14 F (23.1 y, 37.1 mL/kg/min) 13 M (23.6 y, 40.9 mL/kg/min)	Within-subject	Low (75% of HR at VT), high ('just below' HR at VT), stationary cycling, 30 min	VAMS at 15, 10 and 5 min before, 10, 20, 30 min during and 10, 20, 30 min after; PANAS 5 min before, 20 min during, 20 min after	VAMS: No differences at baseline or recovery. During low intensity, no change at min 10, but significant improvement at min 20 and 30. During recovery, scores still higher than baseline until min 30. During high intensity, scores lower than baseline throughout the bout. During recovery, scores better than all exercise timepoints and the last baseline time point. No differences between intensities during recovery. PANAS: Positive Affect was higher during exercise than during baseline and recovery (no intensity effects). During low-intensity exercise, Negative Affect lower than baseline during exercise and recovery. During high intensity, Negative Affect not reduced during but only after. The two intensity conditions were different during exercise but not during baseline and recovery
Blanchard et al.[90]	44 community residents, 35 F, 9 M (41.5 y, 30.1 mL/kg/min)	Between-subject	High-intensity short duration (second VT, 70.3% $\dot{V}O_{2peak}$, 19.5 min), low-intensity long duration (first VT, 49.8% $\dot{V}O_{2peak}$, 35.25 min), volume of work equated, stationary cycling	SEES; pre, 5 min post	Participants were enrolled in a 12 wk programme and data were drawn from exercise bouts #9 (wk 3), #18 (wk 6) and #27 (wk 9). Positive Well-being: increased for bouts #9 and #18. Psychological Distress: decreased for bouts #9 and #18. Fatigue: increased for bout #18. Exercise condition did not influence changes in Positive Well-being and Psychological Distress. In the high-intensity short-duration condition, Fatigue showed larger increase than low-intensity long-duration condition. Fitness did not influence the changes in any variable
Ekkekakis et al.[91]	14 F (21.2 y, 47.7 mL/kg/min) 16 M (21.5 y, 56.6 mL/kg/min)	Within-subject	20% $\dot{V}O_{2max}$ $<$VT, @VT; 10% $\dot{V}O_{2max}$ $>$VT, treadmill, 15 min	FS, AD ACL; pre-, post-cool-down, 10, 20 min post; FS also every 3 min during	Regardless of intensity, FS improved from pre- to all-times post-exercise. During exercise, FS declined significantly in the $>$VT condition, whereas decreases during $<$VT and @VT were smaller and

Continued next page

Table II. Contd

Study	No. of subjects, sex and fitness level (age[a] and $\dot{V}O_{2max}$)	Design and factors	Intensity, mode and duration	Measures and administration timepoints	Findings
					not significant. Regardless of intensity, EA increased from pre- to post-cool-down, then decreased by 10 min post. Regardless of intensity, TA at 10 and 20 min post was lower than post-cool-down
Kilpatrick et al.[92]	20 adults; 12 M, 8 F (23.4 y, 34.2 mL/kg/min)	Within-subject	85% of VT for 30 min, 105% of VT for ~24 min, total work equated, treadmill exercise	AD ACL, PANAS; post-exercise only	No differences between intensities
Kilpatrick et al.[93]	37 college students (23.9 y); 20 M, (37.3 mL/kg/min) 17 F (32.1 mL/kg/min)	Within-subject	85% of VT (64.7% $\dot{V}O_{2max}$) for 30 min, 105% of VT (50.1% $\dot{V}O_{2max}$) for 24.2 min, total work equated, stationary cycling	FS, immediately before exercise, every 6 min (85% VT) or every 5 min (105% VT), after cool-down, 15 min post	No FS differences between intensities before or after exercise but a significant intensity by time interaction during exercise. No significant changes at 85% VT but a significant decrease from baseline throughout 105% VT
Parfitt et al.[94]	12 M sedentary (36.5 y, 34.1 mL/kg/min)	Within-subject	Below OBLA (39.8% $\dot{V}O_{2max}$), above OBLA (72.6% $\dot{V}O_{2max}$), self-selected (54.1% $\dot{V}O_{2max}$), treadmill exercise, 20 min	FS; pre, last 45 sec of each 5 min period during, last 45 sec of each 10 min period following up to 30 min	During exercise, FS became less positive and ultimately negative above threshold but remained positive and stable in the other two conditions. The levels were more positive during self-selected and below threshold than above threshold, with no difference between below threshold and self-selected. FS was more positive at all timepoints post compared with pre, with no differences between intensities
Rose and Parfitt[95]	19 F, sedentary (39.37 y, 36.1 mL/kg/min)	Within-subject	<LT (67.04% $\dot{V}O_{2max}$), @LT (75.79% $\dot{V}O_{2max}$), >LT (85.27% $\dot{V}O_{2max}$), self-selected (60.20% $\dot{V}O_{2max}$), treadmill exercise, 20 min	FS; last 45 sec of each 5 min period during, after cool-down, at 10, 20 min post	FS less positive >LT than <LT, @LT, and self-selected. Self-selected more positive than @LT. No differences between <LT and @LT or between self-selected and <LT. In >LT, FS was less positive post than pre (but more positive by 10 min post). For all other conditions, no difference between pre and post
Schneider and Graham[96]	146 adolescents (14.79 y); 82 M, (44.02 mL/kg/min) 64 F, (33.47 mL/kg/min)	Mixed, low-high behavioural activation (between) by low-high behavioural inhibition (between) by intensity (within) by time	Moderate (80% of the Watts @VT), hard (Watts at 50% of the difference between VT and $\dot{V}O_{2max}$), stationary cycling, 30 min	FS, AD ACL; FS at 0, 10, 20, 30 min during, 10 min post, AD ACL at 0, 30, and 10 min post	Adolescents with high behavioural inhibition or low behavioural activation showed lower FS regardless of intensity. Significant intensity by time interaction, with hard leading to decreases in FS during exercise. For EA, those with high behavioural activation scored higher in the moderate condition but not in the hard condition post-exercise. No main effects or interactions for TA

Continued next page

Table II. Contd

Study	No. of subjects, sex and fitness level (age[a] and $\dot{V}O_{2max}$)	Design and factors	Intensity, mode and duration	Measures and administration timepoints	Findings
Sheppard and Parfitt[97]	22 adolescents (13.3 y); 11 M, (48.2 mL/kg/min) 11 F, (38.4 mL/kg/min)	Within-subject	Low (80% of power output @VT), high (130% of power output @VT), self-selected, stationary cycling, 15 min (3 min warm-up)	FS; 5 min pre, immediately before the start, last 45 sec of each 5 min period during, 5, 10, 15, 30 min post	No difference in FS between the low and self-selected intensity. FS became less positive during exercise in the high-intensity condition but not in the low- or self-selected intensity condition. In pre-to-post analyses, FS was found to be lower immediately post and 5 min post in the high-intensity condition. There was also an increase in FS from 5 min pre to 30 min post in the self-selected condition

a Age and $\dot{V}O_{2max}$ are presented as sample means.

AD ACL = Activation Deactivation Adjective Check List[84]; **EA** = energetic arousal; **F** = female; **FS** = Feeling Scale[19]; **HR** = heart rate; **@LT** = at the LT; **<LT** = below the LT; **>LT** = above the LT; **M** = male; **OBLA** = onset of blood lactate accumulation; **PANAS** = Positive and Negative Affect Schedule[98]; **SEES** = Subjective Exercise Experiences Scale[88]; **TA** = tense arousal; **@VT** = at the VT; **<VT** = below the VT; **>VT** = above the VT; $\dot{V}O_{2max}$ = maximal oxygen uptake; **EA** = energetic arousal; **VAMS** = Visual Analogue Mood Scale[99]; $\dot{V}O_{2peak}$ = peak oxygen uptake; ~ indicates approximately; # indicates number.

targeted physically inactive individuals or examined physical activity and/or physical fitness as a moderator. Tests of aerobic capacity were conducted in 27 of 29 studies. $\dot{V}O_{2max}$ averaged 39 mL/kg/min but ranged from 19.3 mL/kg/min (63 older women)[71] to 67.7 mL/kg/min (11 male distance runners).[100]

As was the case in the earlier review, nearly all studies took place in a laboratory. The treadmill (walking or running) was used in 14 studies and stationary cycling was used in the remaining 16 studies. With the exception of studies investigating affective responses to graded exercise tests, the duration of exercise bouts generally ranged between 15 and 30 minutes. In a noteworthy new development, some studies addressed the problem of confounding the effects of intensity with those of larger amounts of work (when bouts of lower and higher intensities are performed for the same duration) by varying the duration to produce isocaloric bouts.[80,90,92,93]

Perhaps responding to the call for tracking of affective changes during the bouts,[22] two-thirds of the studies included at least one assessment of affect during exercise, whereas pre- to post-exercise or post-test-only assessment protocols were reported in one-third (ten of 33) of the publications. Consistent with this trend, the single-item FS[19] was used in 12 studies, followed by the 20-item Activation Deactivation Adjective Check List[84] in nine and the 12-item Subjective Exercise Experiences Scale[88] in eight.

Of the 22 studies comparing the effects of distinct bouts performed at different intensities, 14 compared two levels of intensity, precluding the detection of curvilinear dose-response patterns. Interestingly, a series of studies compared bouts performed at different *imposed* levels of intensity to a bout performed at self-selected intensity.[94,95,97] Given their theoretical and practical interest, these studies were reviewed in detail elsewhere.[109]

The assessment of fitness and close monitoring of intensity levels, the examination of diverse samples and the frequent sampling of affect are all signs of improved methodologies. On the other hand, some methodological problems persisted, including confounds with the ecological and social setting,[71,72] imprecise standardization

Table III. Studies examining the relationship between exercise intensity (operationally defined as different stages of graded exercise tests) and affective responses

Study	No. of subjects, sex and fitness level (age[a] and $\dot{V}O_{2max}$)	Design and factors	Intensity, mode and duration	Measures and administration timepoints	Findings
Acevedo et al.[100]	11 competitive distance runners, (22.6 y, 67.7 mL/kg/min)	Within-subject	$\dot{V}O_2$ 10% below OBLA, $\dot{V}O_2$ at OBLA, $\dot{V}O_2$ 10% above OBLA, consecutive runs; treadmill running (a minimum of 5 min) per intensity	FS during the fifth (final) min of each intensity run	Significant decline in FS over time, but follow-up analyses showed that the decline was only significant from OBLA to 10% above OBLA (where FS ratings were below zero). No significant relationships between FS and other variables below and at OBLA. Above OBLA, FS was related to RPE (–0.67), HR (–0.43), and ventilation (–0.41)
Acevedo et al.[101]	7 M well-trained runners 18–39 y (28.71 y, 61.01 mL/kg/min)	Within-subject	60% $\dot{V}O_{2max}$ (10 min), 75% $\dot{V}O_{2max}$ (10 min), 90% $\dot{V}O_{2max}$ (5 min), 100% $\dot{V}O_{2max}$ (2 min), 4 min walks in-between; treadmill running	VAS from 'excitement' to 'apprehension' at the end of each	Affect 'relatively unchanged' from 60% to 75% $\dot{V}O_{2max}$ but a significant change toward 'apprehension' from 75% to 90% $\dot{V}O_{2max}$, followed again by a plateau from 90% to 100% $\dot{V}O_{2max}$
Ekkekakis et al.[102]	Group A: 13 F (22.8 y, 46.9 mL/kg/min); 17 M (24.4 y, 51.5 mL/kg/min) Group B: 14 F (21.2 y, 47.7 mL/kg/min) 16 M (21.5 y, 56.6 mL/kg/min)	Within-subject (the two groups were analysed separately)	Eight timepoints during max. test: first 2 min, min before, min of, 2 min after the VT, last 2 min; treadmill exercise, 11.3 min (group A), 12.1 min (group B)	FS; every min during	Quadratic decline patterns in FS across both protocols. Follow-up analyses showed that the only three-point segments for which quadratic decline was significant were those starting with the VT
Ekkekakis et al.[103]	9 F normal-weight (43.7 y, 25.9 mL/kg/min) 8 F overweight (39.1 y, 24.0 mL/kg/min) 7 F obese (44.7 y, 17.5 mL/kg/min)	Mixed, weight group (between) by time	Six timepoints during max. test (rest, warm-up, 1 min before VT, min of VT, min after VT, final min) plus cool-down and 20 min seated recovery; treadmill exercise	FS, AD ACL; AD ACL before, immediately after, after cool-down, min 10 and 20 post, FS during	FS declined gradually during the test and was lower overall for the obese women compared with the other two groups. Energy increased post-exercise in normal-weight and overweight but not in obese, then returned to baseline by min 10 of recovery. Tiredness decreased post-exercise regardless of group. Tension decreased compared with baseline, regardless of group, during first 10 min of recovery. Calmness decreased immediately post-exercise but returned to baseline after cool-down
Hall et al.[104]	30 college students, 13 F, 17 M (23.9 y, 49.6 mL/kg/min)	Within-subject	Eight timepoints during max. test: first 2 min, min before, min of, 2 min after the VT, last 2 min; treadmill exercise, 11.3 min	FS, AD ACL; AD ACL before, immediately after cool-down, min 10 and 20 post; FS also every min during	During the test, FS gradually declined. Every min-to-min change starting with 1 min after the VT and until test termination was significant. From pre to immediately post, increase in EA, decreases in TA from pre to min 10 and 20 post. FS improved from pre to all timepoints post

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Table III. Contd

Study	No. of subjects, sex and fitness level (age[a] and $\dot{V}O_{2max}$)	Design and factors	Intensity, mode and duration	Measures and administration timepoints	Findings
Hall et al.[105]	12 M college students, (24 y, 40.4 mL/kg/min)	Within-subject	Four timepoints during max. test: stage 1 (50 Watts), stage 2 (before VT), stage 3 (VT), stage 4 (last); recumbent cycling	FS, every 2 min during, 10 min post	FS stable for stages 1 and 2 but declined sharply during stages 3 and 4. There was a rebound 10 min post
Sheppard and Parfitt[106]	23 M, sedentary: 13 men (35.3 y), 10 boys (12.5 y)	Mixed, age (between) by time	Five timepoints during max. test: second min, min before VT, min of VT, second min after VT, last min; stationary cycling, 18.9 min for men, 14.0 min for boys	FS; every 2 min during	Age group did not show main effect or interaction with time. Significant declines in FS after the VT (quadratic declines in FS from VT to final min in both men and boys)
Welch et al.[107]	20 F, inactive (23.2 y, 33.6 mL/kg/min)	Within-subject	Six timepoints during max. test: first min, min before VT, min of VT, min after VT, second min after VT, last min; stationary cycling, 10.43 min	FS; before exercise, every min during, 0, 5, 10, 20 min post	FS declined continuously during the test (compared with min 1, all subsequent timepoints were lower). However, declines were larger from the min after the VT to the end. No change in FS from pre- to post-0 or post-5 but increases from pre- to post-10 and post-20

a Age and $\dot{V}O_{2max}$ are presented as sample means.

AD ACL = Activation Deactivation Adjective Check List[84]; **EA** = energetic arousal; **F** = female; **FS** = Feeling Scale[19]; **M** = male; **max.** = maximum; **OBLA** = onset of blood lactate accumulation; **RPE** = Rating of Perceived Exertion[108]; **TA** = tense arousal; **VAS** = Visual Analogue Scale; $\dot{V}O_2$ = oxygen uptake; $\dot{V}O_{2max}$ = maximal $\dot{V}O_2$; **VT** = ventilatory threshold.

of intensity,[61,62] variable periods before the post-activity assessment[75,76] and post-test-only designs.[80,81]

What is remarkable about the new crop of studies is the consistency of their findings. Unlike the earlier review, in which a slight majority of the studies (54%) indicated a lack of intensity effects,[22] all but one of the studies examined in this review showed a significant intensity effect for at least one of the dependent variables. The general conclusion that emerges is that there is an inverse relationship between exercise intensity and affective responses, a phenomenon that appears stronger among those studies that included assessments during exercise. In the only exception,[92] in which no significant intensity effects were reported, the study was probably underpowered (n = 20) and the dependent variables were only assessed post-exercise. In the following sections we examine the most significant trends more closely.

3.1 The Importance of Physiological Landmarks

In their conclusions, Ekkekakis and Petruzzello[22] had noted that "a more appropriate avenue for future research would be to define exercise intensity in terms of metabolic landmarks with biological significance for the organism, such as the gas exchange or the lactate threshold, or the power-time asymptote" (p. 357). Consistent with this recommendation, in half of the new studies, the intensity was set in relation to the VT,[49,89,90,92,93,96,97,102-107] the LT[95] or OBLA (4 mmol/L).[94,100]

The experimental protocols varied, with some studies involving incremental exercise tests on the treadmill or cycle ergometer,[91,102-107] some involving a series of consecutively performed short bouts[100] and some involving steady-workload bouts performed on different days.[49,89,91,93-95,97] Furthermore, studies involved diverse samples, including adolescents,[96,97,106] inactive young or middle-aged adults,[94,95,103,106,107] regularly active college students[49,89,91,93,102,104,105] and trained athletes.[100]

Despite their differences, these studies produced the first reliable evidence of a dose-response pattern, a finding that represents a major advance in this line of research. These studies have shown that exercise intensities below the VT, LT or OBLA typically do not have a negative impact on during-exercise affective states when analyses of change are performed at the level of groups. In fact, such intensities may improve affect during exercise either at the level of entire groups[49] or at least within subgroups.[91,94,95] In contrast, when the intensity exceeds these physiological landmarks, there is a decline in the positivity of affect (see figure 1). Studies of incremental exercise tests have shown that, as intensity increases and approaches maximal capacity, declines are reported by an increasing percentage of participants. Finally, when the intensity reaches maximal capacity, a decline is reported by all or nearly all participants.[45,102,104] At that point, the average rating is not only significantly less positive compared with baseline but it also crosses into affective negativity (worse than 'neutral' on the FS).

It should be noted that the VT and LT may be driven by partly dissociable mechanisms and cannot be assumed to represent the same underlying phenomenon. Nevertheless, "while it is possible to dissociate the [LT] from the [VT] by using a variety of manipulations of protocol and dietary status owing to the complexity of both lactate accumulation and ventilatory control, in most situations the [LT] and [VT] are coincident"[110] (p. 241). This claim is supported by a meta-analysis.[111] On the other hand, the relation of these thresholds to the OBLA is less clear.[112] Although the concept of the OBLA guarantees objectivity (since it is based on a 'fixed' accumulation of 4 mmol/L), the problem is that it "takes no account of inter-individual differences in the rate of blood lactate accumulation"[110] (p. 245), although such differences can be large. Furthermore, a level of blood lactate accumulation of 4 mmol/L, which is the value commonly designated as OBLA,[94,100] is "reached at a significantly higher exercise intensity than the [LT]"[110] (p. 245) and typically exceeds the maximum lactate steady state. Therefore, unlike intensities proximal to the VT or LT, which can be maintained for a long time without a severe homeostatic perturbation, an intensity corresponding to the OBLA makes

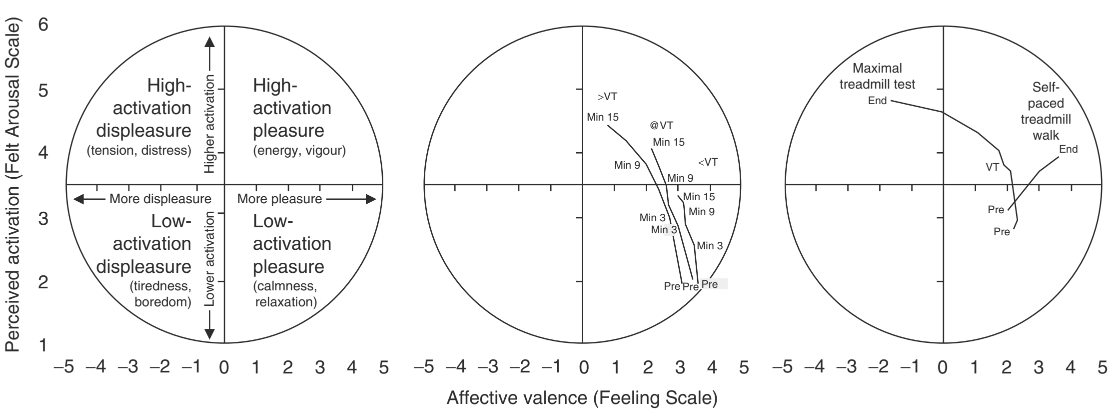

Fig. 1. Left circle: the circumplex model of affect, which can be used as a template (or two-dimensional 'map') for plotting affective responses to exercise of different intensities. The horizontal dimension represents 'affective valence' (pleasure/displeasure) and the vertical dimension represents perceived activation. This 'affective space' is divided into four quadrants: (i) high-activation displeasure (e.g. tension, distress, nervousness, jitteriness); (ii) high-activation pleasure (e.g. energy, vigour, excitement, revitalization); (iii) low-activation displeasure (e.g. tiredness, boredom, fatigue, lethargy); and (iv) low-activation pleasure (e.g. calmness, relaxation, tranquility, serenity). Middle circle: affective responses to 15 min bouts of treadmill exercise performed at intensities (i) 20% $\dot{V}O_{2max}$ <VT; (ii) @VT; and (iii) 10% $\dot{V}O_{2max}$ >VT. The decreases in pleasure during the <VT and @VT conditions were non-significant (effect sizes of $d = -0.51$ and $d = -0.76$, respectively). However, in the >VT condition, the decrease reached statistical significance as early as min 6 ($d = -0.53$) and grew increasingly larger through min 15 ($d = -1.22$). Data from Ekkekakis et al.[91] Right circle: for comparison, affective responses to a 15 min self-paced treadmill walk (showing an increase in pleasure, with effect size $d = 1.18$) and a graded treadmill test to exhaustion with average duration of 11.3 min (showing a decrease in pleasure, with effect size $d = -2.08$). Data from Ekkekakis et al.[38] and Hall et al.[104] **$\dot{V}O_{2max}$** = maximal oxygen uptake; **VT** = ventilatory threshold; **@VT** = at the VT; **>VT** = above the VT; **<VT** = below the VT.

the maintenance of a physiological steady state impossible. For example, in the study by Parfitt et al.,[94] a 20-minute bout of treadmill exercise at an intensity that initially corresponded to 4 mmol/L culminated in an average accumulation of 7.17 mmol/L. These facts should be kept in mind when comparing the studies summarized here.

Group-level declines in pleasure beyond the VT, LT and OBLA have been found both in studies that used incremental protocols and in those that compared steady-workload bouts performed at intensities below and above these thresholds. The former have shown that declines only begin when the intensity exceeds the VT.[102,104,105] Similarly, the latter have shown that declines only occur when the intensity is initially set at or above the VT,[49,89,91,93,97] the LT[95] or OBLA.[94]

The only exceptions have been two studies in which affective variables were not assessed during exercise but rather only several minutes post-exercise.[90,92] In these studies, there were no differences in affective states after bouts performed below or above the VT. This, however, is not surprising, since research has established that dose-response effects that occur during exercise tend to dissipate rather rapidly once the bouts are terminated, especially among young and healthy participants.[49,91,93]

In studies that examined the affective responses of physically inactive college women,[107] physically inactive boys and men[106] or physically inactive and obese middle-aged women[103] to incremental tests to exhaustion, a decrease in FS scores started from the beginning of the test rather than only after VT. However, the rate of decline was larger above the VT than below (e.g. with $d=0.62$, 0.54, 0.72 from the beginning to the VT and 1.56, 1.72, 1.54 from the VT to the end in Welch et al.[107] and the boy and men samples of Sheppard and Parfitt,[106] respectively). In these studies, the combination of the physically inactive and/or obese status of the participants and the intimidating nature of the exercise tests possibly accounted for the earlier onset of the decline in pleasure.

A question that arises from these data is: is it possible that the effect of intensity is confounded by the effect of total work, since most of these studies compared bouts of higher-versus-lower intensity but of the same duration? To address this issue, Kilpatrick et al.[93] adjusted the duration to produce bouts of different intensities but equal caloric expenditure. Thus, they compared 30 minutes of cycling at 85% of $\dot{V}O_2$ at VT and 24 minutes (on average) at 105% of $\dot{V}O_2$ at VT. The results showed that the sub-VT bout did not produce a decline in pleasure during exercise but the supra-VT bout did. Thus, the affective decline can be specifically attributed to the supra-threshold intensity rather than differences in total energy expenditure.

3.2 The Phenomenon of Individual Variability

Making the case for the need to evaluate the magnitude and causes of inter-individual differences in affective responses, Ekkekakis and Petruzzello[22] had noted that "even patterns that appear consistent when examined at a group level might subsume psychologically important individual variation" (p. 367). Several studies have since focused on this issue.[43,45,48,94,95,107] This is highlighted here because the elevation of variability from being treated as error to becoming a *bona fide* topic of investigation represents a significant paradigm shift.

From a theoretical perspective, the study of variability is important because it is reasonable to assume that part of it does not reflect random error (including errors in the determination of the VT or LT) but may rather reflect systematic sources of variance, at least some of which may be psychological (e.g. differences in personality, temperament or situational appraisals). From a practical standpoint, if the factors that contribute to variability in affective responses are identified, this could spur the development of individually tailored interventions, thus optimizing the exercise experience.

Recently, de Geus and de Moor[113] presented a conceptual model, according to which adherence to exercise may be influenced by immediate affective responses and long-term effects of exercise on self-esteem. In turn, genetically determined individual differences can influence both of these mechanisms by making some individuals more and others less likely to experience improved affect and self-esteem. Based on this model, de Geus and de Moor[113] advocated the customization of exercise prescriptions: "We should not close our eyes to human genetic variation. Some individuals may require a different exercise programme which emphasizes the appetitive aspects for an individual and reduces the aversive aspects. The exact strategy to optimize this balance requires a furthering of our understanding of genetic differences in the psychological responses to exercise. In some cases, obtaining increased adherence can be as simple as reducing exercise intensity" (p. 58).

Acknowledging this variability is crucial. It should be noted that one of the reasons that delayed the investigation of the affect-adherence link was the belief that nearly all individuals find exercise pleasant. For example, Morgan and O'Connor[114] had argued that investigating this link might seem "intuitively defensible" but is actually "simplistic" and "probably not necessary." The reason was that "roughly 80–90% of individuals" report that they "feel better" when they exercise but "50% drop out" (p. 116). The newer data challenge the notion of a nearly-universal 'feel-better' exercise effect (see figure 2). The key was the shift from examining only pre- to post-exercise changes to tracking the trajectory of affective change during and after the exercise bout.

A conceptual framework to facilitate the interpretation of these findings was proposed by Ekkekakis et al.[45] Based on evolutionary principles, it was argued that a homogeneous response indicates high adaptational significance (i.e. strong implications for optimizing Darwinian fitness). This is because responses closely tied to either the promotion or the endangerment of adaptation tend to spread throughout the population. Thus, a homogeneously positive affective response indicates approach towards a useful stimulus, whereas a homogeneously negative affective response indicates avoidance of a dangerous stimulus. On the other hand, variable responses (e.g. some individuals responding with increases and others with decreases in pleasure) indicate either a lack of adaptational significance or a trade-off between benefits and risks. For example, individual differences in pain sensitivity or tolerance can be explained by the fact that those possessing these traits may benefit in some circumstances (e.g. being able to withstand an injury during a fight, thus gaining a

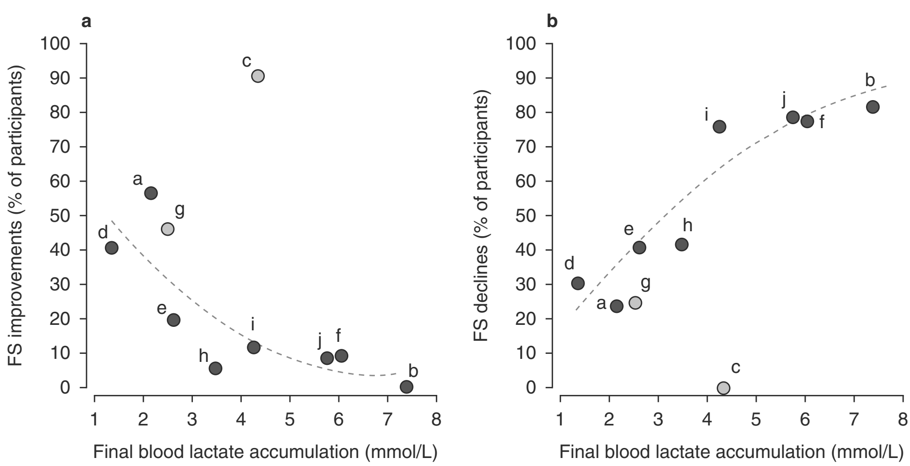

Fig. 2. Scatter plots of the relation between blood lactate accumulation at the end of the exercise bout and the percentage of participants reporting increases (**a**) or decreases (**b**) in Feeling Scale (FS) scores during the bout. Each marker represents the results from one bout from several different studies. Data points (c) and (g) are marked in light grey because they represent bouts performed at self-selected intensities. A second-degree polynomial has been fitted to the data to illustrate the trend. Data from Parfitt et al.:[94] below the lactate threshold (LT) [point a], above the LT (point b) and self-selected intensity (point c); Rose and Parfitt:[95] below the LT (point d), at the LT (point e), above the LT (point f) and self-selected intensity (point g); Ekkekakis et al.:[91] below the ventilatory threshold (VT) [point h], at the VT (point i) and above the VT (point j).

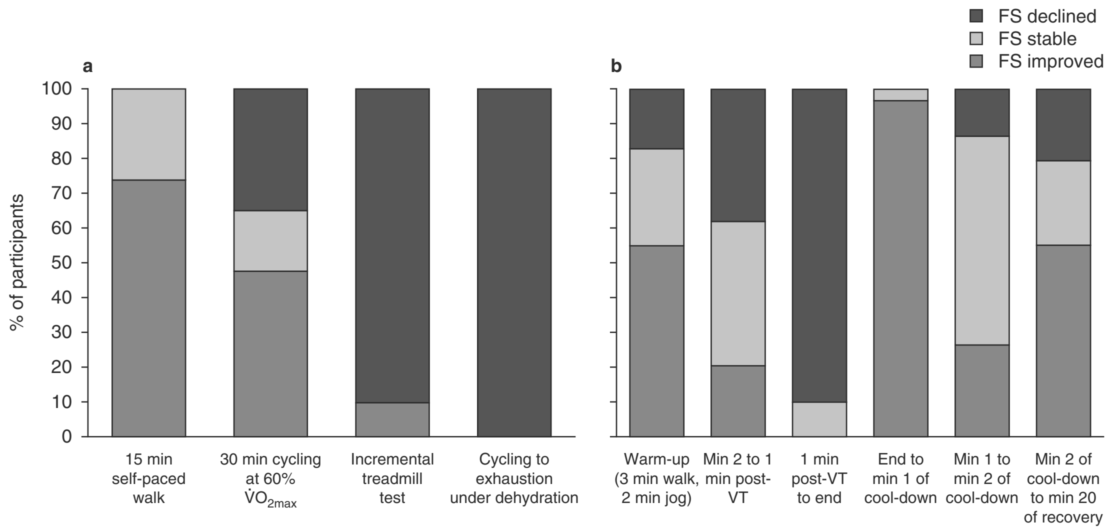

Fig. 3. (**a**) Percentages of participants reporting increases, no change and decreases in Feeling Scale (FS) scores during exercise bouts with different demand characteristics. The data show generally positive changes at low intensities, generally negative changes at high intensities and heterogeneity at mid-range intensities. Data from Ekkekakis et al.[45] (**b**) Percentages of participants reporting increases, no change and decreases in FS scores across different stages of a graded treadmill test to exhaustion and subsequent recovery. The data show mostly positive changes with light intensities (below the ventilatory threshold [VT]), heterogeneity close to the VT and homogeneously negative changes above the VT. The termination of the test is followed by a rapid and homogeneously positive 'rebound' during the cool-down and, progressively, the re-emergence of heterogeneous changes during the 20 min recovery. Data from Ekkekakis et al.[45] $\dot{\mathbf{V}}\mathbf{O}_{2\mathbf{max}}$ = maximal oxygen uptake.

critical advantage, or tolerating hard physical labour, thus accumulating more resources) but risk their safety in others (e.g. bringing themselves closer to biological limits, thus risking injuries, exhaustion or death).

The data in figure 2 suggest that the range of variable affective responses (i.e. approximately 20–60% reporting improvements and 20–45% reporting declines) is below a blood lactate accumulation of 3.5–4.0 mmol/L. Conversely, beyond this intensity, the percentage of those reporting increases in pleasure drops to 10–15%, whereas the percentage of those reporting decreases in pleasure rises to 75–80%.

The data in figure 2 also suggest that, when the intensity is submaximal, it is possible for relevant traits or situational appraisals to produce deviations from this general trend. Despite a lactate accumulation of 4.34 mmol/L, the self-selected intensity condition in the study by Parfitt et al.[94] resulted in 92% of the participants (sedentary men, mean age 36.5 years) reporting improvements in pleasure. The perception of autonomy that the self-selection of intensity entailed was the likely reason for the markedly different response compared with the other conditions (also see next section).

Figure 3 illustrates two additional noteworthy phenomena. First, the positive affective responses to self-paced walking seem to be shared by most participants. In a re-analysis of data that included affective responses to short self-paced walks, Ekkekakis et al.[45] noted improved FS scores in 74–77% of individuals. Second, homogeneously positive affective responses also appear after the cessation of strenuous exercise. This 'affective rebound' is shared by nearly all (>95%) participants.

Having established that affective responses to exercise can vary between individuals, the next step is to investigate the sources of this variability. Based on evidence of variability in the intensity of activity that individuals choose and can tolerate when forced, Ekkekakis et al.[46] proposed the constructs of intensity preference and intensity tolerance. Intensity preference was defined as "a predisposition to select a particular level of exercise intensity when given the opportunity (e.g. when engaging in self-selected or unsupervised exercise).'' Intensity tolerance was defined as ''a trait that influences one's ability to continue exercising at an imposed level of intensity even when the activity becomes uncomfortable or unpleasant'' (p. 354). The measure that was developed to assess these two constructs was the Preference for and Tolerance of the Intensity of Exercise Questionnaire (PRETIE-Q).[46,115]

At the core of the conceptualization of intensity preference and intensity tolerance was the idea that what determines whether an exercise intensity is preferred or can be tolerated, is the pleasure or displeasure that is experienced. Consistent with this notion, both the preference and the tolerance scales of the PRETIE-Q predicted FS scores during exercise at the VT (16–18% and 16–21% of the variance, respectively).[46] Neither scale was a significant predictor during exercise below the VT and only the tolerance scale was a significant predictor above the VT (16–29% of the variance).[46] Furthermore, the preference (but not the tolerance) scale accounted for significant portions of the variance in self-selected intensity (percentage of $\dot{V}O_2$ at VT), contributing 18–19% beyond the variance accounted for by age, body mass index and $\dot{V}O_{2max}$.[116] Conversely, the tolerance scale accounted for significant portions of the variance in the amount of time individuals persevered during incremental treadmill tests after reaching their VT, contributing 14–20% beyond the variance accounted for by age, body mass index, physical activity habits and even $\dot{V}O_{2max}$.[117]

In a study based on the theory of psychological reversals, Legrand et al.[118] tested whether the individual-difference variable of telic dominance could moderate affective responses during bouts of treadmill running at an intensity that was maintained near a respiratory exchange ratio (RER) of 1.0 for 10 minutes. A telic-dominant person tends to avoid high levels of arousal (experiencing them as tension or anxiety) whereas a paratelic-dominant person tends to seek out high levels of arousal (experiencing them as excitement). Participants who scored high on telic dominance reported significantly less pleasure than those who scored low at minute 6 and 9, after controlling for $\dot{V}O_{2max}$.

Finally, Schneider and Graham[96] investigated the role of the individual-difference variables of behavioural activation and behavioural inhibition. The behavioural-activation trait refers to high sensitivity to reward, approach motivation and propensity for positive affective responses. Conversely, the behavioural-inhibition trait refers to high sensitivity to punishment, withdrawal motivation and propensity for negative affective responses. Behavioural activation and inhibition did not interact with exercise intensity (below or above VT) or time but both had main effects on affective responses. Adolescents scoring highly on behavioural activation reported significantly higher and those scoring highly on behavioural inhibition reported significantly lower levels of pleasure before, during and after exercise.

3.3 Affective Responses and the Self-Selection of Intensity

Ekkekakis and Petruzzello[22] had noted that ''there seems to be sufficient theoretical justification to recommend the systematic study of the distinction between 'self-selected' or 'preferred' versus imposed exercise doses'' (p. 367). They reviewed results from earlier research showing that, although the correlation between FS scores and HR or RPE became more negative as exercise intensity increased, the correlation was positive when the intensity was self-selected. This was consistent with an observation by Dishman et al.[119] that ''[RPE] at preferred intensities of exercise can uncouple from indicators of relative metabolic intensity typically linked with [RPE]'' (p. 787). A possible reason for this intriguing 'uncoupling' is that the self-selection of intensity creates a sense of autonomy and control, allowing exercisers to cognitively 'reframe' the exercise experience (i.e. it is not something I *must* do, it is something I *choose* to do). As shown in figure 2, the 'uncoupling' phenomenon also applies to FS scores. Eleven of the 12 sedentary men studied by Parfitt et al.,[94] despite an average lactate accumulation of 4.34 mmol/L, reported feeling better when asked to self-select the intensity, yielding the most positive pattern of responses (compared with imposed intensities at 2.5 and 4.0 mmol/L of lactate accumulation).

For detailed discussions of the implications of self-selected exercise intensity for affective responses, readers are referred to recent reviews.[109,120] Nevertheless, a mention of this issue was deemed necessary due to its significance for the intensity-affect link. It has been suggested that what guides people in the selection of an exercise intensity is the pleasure or displeasure they experience. In other words, in this case as in many others, people seek to maximize pleasure and/or minimize displeasure.[121] Acevedo et al.,[100] commenting on their finding of a drop in FS scores above the OBLA, argued that this apparently perceptible event could be used by exercisers as a guide in regulating their intensity. Specifically, they wrote that "the documented nonlinear drop in [FS scores] following [the OBLA] *versus* the linear increase demonstrated by [RPE] may be clearly identified by exercisers" (p. 272). Working on the same idea but focusing on the VT, Ekkekakis et al.[102] found quadratic declines in pleasure at intensities above the VT and suggested that these declines "could be valuable as a practical marker" of the VT, such that "exercisers could … monitor when they begin to feel substantially worse than they felt before, and regulate their pace accordingly" (p. 157). This finding was the basis for the recent recommendation by the ACSM[33] that ratings of affective valence could be used as an adjunct method of self-monitoring exercise intensity.

If people self-regulate their exercise intensity by using the maximization of pleasure and/or the minimization of displeasure as guides, this implies that most individuals would spontaneously choose intensities near the VT or LT, since further increases in intensity would reduce pleasure (see section 3.1). This phenomenon has also been observed with endurance athletes.[122,123] Indeed, Lind et al.[124] showed that a group of sedentary middle-aged women selected intensities not significantly different from their VT (92% and 97% of $\dot{V}O_2$ at VT) at the fifteenth and twentieth minute of a 20-minute bout of treadmill exercise; consistent with predictions, pleasure ratings remained stable.

In a follow-up study, Lind et al.[67] examined the fragility of this phenomenon, simulating what would happen if a treadmill speed just 10% higher than the self-selected was imposed (e.g. by a personal trainer). They found that $\dot{V}O_2$ reached 115% of the level at VT and pleasure declined significantly. However, besides the added intensity, the loss of perceived autonomy[125] inherent in an externally imposed intensity prescription might have also lowered pleasure. Indeed, Vazou-Ekkekakis and Ekkekakis[126] found that, when participants exercised at an intensity that was identical to one they had previously self-selected but were told that the intensity was controlled by the experimenters, they reported not only less autonomy but also attenuated levels of enjoyment and energy.

A study by Rose and Parfitt[127] examined the intensity that sedentary women (mean age 44.8 years) selected when instructed to choose a treadmill speed and gradient that would result in them feeling 'good' (+3 on FS) or 'fairly good' (+1 on FS) during four 30-minute workouts in each condition. The women selected intensities that allowed them to maintain a physiological steady state. For the 'feel good' condition, the average intensity was just 6% higher than the $\dot{V}O_2$ at VT (95% CI included the VT during all four workouts). In fact, the average intensity was just 2–4% above the VT during the first workout (it rose to 6–10% during the three subsequent workouts, in parallel with increases in self-efficacy). To reduce their pleasure to 'feel fairly good', the women slightly increased their intensity (8% higher than $\dot{V}O_2$ at VT). Across the four trials within each condition, the selected intensities were remarkably consistent (intraclass correlations for %$\dot{V}O_2$ at VT of 0.98–0.99). Rose and Parfitt[127] cautioned that "even a very subtle increase in intensity can be enough to make the individual feel less positive" (p. 1857).

These studies have far-reaching implications. Exercising while having the freedom to regulate one's intensity apparently 'rewrites the rules' to some extent, enabling some participants to experience affective responses that can remain positive over a larger portion of the exercise-intensity range than one would have predicted based on studies following the imposed-intensity paradigm. In most cases, the average self-selected levels of exercise intensity fall within the range recommended by the ACSM[33] for the development and maintenance of cardiorespiratory fitness.[109] However, there is considerable inter-individual variability. In the study by Lind et al.,[124] although the peak of the self-selected intensity distribution was centred near 100% of $\dot{V}O_2$ at VT, individual values ranged from 62% to 160% at the end of the 20-minute bout. Thus, although these findings support a paradigmatic shift from a prescription-based to a preference-based model of exercise promotion,[109,120] they also underscore the need to provide customized exercise options to participants.

3.4 Emergence of Theory and Theory-Testing Studies

Ekkekakis and Petruzzello[22] foresaw ‘‘an evolving trend towards more theory-testing research’’ (p. 349). In the last decade, there were indeed signs of change on this issue. Several researchers identified theories as the basis of their hypotheses and offered theory-grounded rationales for methodological decisions. The theories that were examined include reversal theory,[62] opponent-process theory,[73,89] multidimensional arousal theory[81] and the dual-mode theory.[91,93-97,106,107] Reversal theory, the opponent-process theory and the multidimensional arousal theory were reviewed by Ekkekakis and Petruzzello.[22] The dual-mode theory is outlined in this section.

In the framework of the dual-mode theory,[45,128-130] affective responses to exercise are examined from an evolutionary perspective and are, thus, considered adaptive responses that were shaped through natural selection to promote adaptation in the specific context of exercise. The theory postulates that affective responses to exercise are determined by the continuous interplay between two factors, namely cognitive parameters (e.g. physical self-efficacy, self-presentational concerns) and interoceptive cues (e.g. signals from chemoreceptors, baroreceptors, thermoreceptors and visceroceptors). The relative importance of these two factors is theorized to change systematically as a function of exercise intensity. Specifically, cognitive factors are expected to be the dominant determinants of affect at intensities below and (mainly) near the VT/LT, as the intensity begins to pose a challenge. On the other hand, interoceptive cues will gain salience at intensities that exceed the VT/LT and a physiological steady state becomes difficult or impossible to maintain. Thus, the theory predicts that (i) at intensities below the VT/LT, affect will be mainly positive, (ii) at intensities proximal to the VT/LT, affective responses will differ considerably between individuals, with some reporting increases and others decreases in pleasure; and (iii) at intensities above the VT/LT, most individuals will report reduced pleasure. Finally, the theory predicts that exercise that induces a decline in pleasure during the bout will be followed by a positive affective rebound after the bout.

Until now, there is reasonable support for those tenets of the dual-mode theory that have been investigated. Specifically, as noted in section 3.1, several studies have shown that the intensity that exceeds the VT or LT acts a ‘turning point’ toward reduced pleasure during exercise. Furthermore, as summarized in section 3.2 and figures 2 and 3, it seems that there is a predominantly pleasant response below the VT/LT, marked variability proximal to the VT/LT and a homogeneous reduction in pleasure above the VT/LT.

The aspect of the theory that has not been tested rigorously yet is the mechanistic basis, involving intensity-dependent shifts in the relative contribution of cognitive and interoceptive influences. Preliminary data consist of correlations of cognitive (e.g. self-efficacy) and peripheral physiological variables (e.g. HR, $\dot{V}O_2$, RER, blood lactate) with FS scores across different exercise intensities,[103,128] correlations between associative-dissociative thoughts and FS scores,[107] and post-exercise interviews based on such questions as ‘‘Can you describe how you felt while you were exercising on the treadmill?’’ and ‘‘Can you explain why you felt that way?’’[95] The evidence seems consistent with theoretical predictions. For example, Ekkekakis[128] reported that, as participants progressed through the stages of a treadmill test, self-efficacy contributed nearly all (80–100%) of the accounted variance in FS scores (R^2 of 12–23%) while the intensity was below the VT.

On the other hand, from the VT to $\dot{V}O_{2max}$, the RER contributed most (65–80%) of the accounted variance (R^2 of 34–55%). Welch et al.[107] found that, in their sample of physically inactive women undergoing an exercise test, ''attentional focus was largely dissociative at the beginning of exercise (min 1) and became progressively more associative as intensity increased'' (p. 412), possibly indicating the strengthening of afferent cues. Consistent with this finding, Rose and Parfitt[95] noted that, during exercise performed at or above the LT, most participants reported not being able to focus on anything other than the exercise itself and the discomfort it caused.

Although these findings appear to support the tenets of the dual-mode theory, the limitations of the descriptive methods preclude strong inferences. Since participants can be taught techniques to control their cognitions but have limited capacity to attenuate their physiological responses unless the intensity is lowered or exercise is stopped, the relative influence of cognitive and interoceptive factors on affective responses has profound practical implications. According to theoretical predictions and preliminary evidence, the ability of most participants to cognitively control the negative affect that is elicited at intensities exceeding the VT/LT may be diminished. It should be kept in mind that the VT is estimated to occur between 50% and 58% $\dot{V}O_{2max}$ in healthy but sedentary adults.[131]

4. Future Directions

As demonstrated in this review, in the last decade, this line of research has not only seen an increase in the rate of accumulation of new data but also improved methodologies and more systematic hypothesis testing, resulting in meaningful new information. In the following sections, we identify directions for future growth based on what we see as key voids in current knowledge.

4.1 Further Investigation of Individual Differences

Several recent studies have established that individuals differ in their affective responses to the same exercise intensity. Dissecting the sources of this variability will be perhaps the greatest challenge for researchers in the years ahead. The pursuit of this goal could help elucidate what de Geus and de Moor[113] characterized as two of the ''most vexing questions in exercise interventions,'' namely ''why exercisers exercise, and why non-exercisers do not'' (p. 57).

We envision that research will follow two major paths. One will deal with situational appraisals, such as self-efficacy for exercise tasks,[132,133] self-conscious apprehension about one's physical appearance and capabilities,[66,103,134,135] or perceptions of autonomy.[94,126,136] The other will focus on dispositional factors, such as individual differences in somatosensory modulation,[46] behavioural approach versus inhibition[96,118] or approach versus withdrawal motivation.[74,137,138] Furthermore, researchers have called for studies on genetic polymorphisms, a topic that remains unexplored.[113,139]

4.2 Study of the Mechanistic Bases of Affective Responses at Different Intensities

Although more studies tested theory-based hypotheses, no experimental studies focused on the mechanisms underlying affective responses to exercise. The findings summarized in this review make it clear that the exercise-affect relationship comprises multiple phenomena.[128] Consequently, mechanisms must account for this complexity.[48,130] An expansion of the methodological toolbox, from qualitative approaches to neuroscientific methods (including both basic neuroanatomy and neurophysiology with animal models and human neuroimaging studies) could prove very fruitful in the coming years.

As noted in section 3.4, the dual-mode theory[128] offers a framework from which testable hypotheses about the mechanisms underlying the pattern of affective responses observed in recent studies can be derived. However, the postulated mechanisms, particularly the neural mechanisms,[130] have not been examined. For example, one outstanding question refers to the mechanisms responsible for the robust improvements in affect observed with low-intensity and self-paced exercise, such as short walks.[36-41] According to the dual-mode theory, at intensities below the VT/LT, there is ‘low to moderate’ influence of cognitive factors.[45,128] So far, studies have shown very weak or null correlations between affective responses and cognitive factors (e.g. self-efficacy) at low intensities.[128] The correlations with peripheral physiological parameters are also near zero. This begs the question of what accounts for the positive responses within this intensity domain. Mixed methods, combining quantitative and qualitative approaches,[95] might be an appropriate avenue to tackle this question.

At the high end of the intensity range, the dual-mode theory predicts a unified trend toward reduced pleasure, which is attributed to an intensification of afferent homeostatic signals.[128-130] This postulate is based on strong negative correlations between ratings of pleasure and various peripheral physiological variables above the VT/LT.[128] An alternative possibility emerged recently[140] from findings of reduced prefrontal cortical oxygenation (assessed by near-infrared spectroscopy) at high exercise intensities.[141-143] According to the neural basis of the dual-mode theory,[130] at intensities above the VT/LT, affective responses depend increasingly on subcortical, rather than cortically mediated, paths to the amygdala. The postulated function of this switch from a mode of affect induction that relies on cortical input (near VT/LT) to a mode that bypasses the cortex (at higher intensities) is to ensure that a strong negative affective response would be generated, unmitigated by cognitive coping efforts. The oxygenation data suggest that this ‘switch’ might occur not only as a result of the intensification of homeostatic afferents but also as a result of an additional safety mechanism; namely, the reduced activity of the prefrontal cortex. According to Davidson,[144,145] the prefrontal cortex exerts an inhibitory control over the amygdala during exposure to aversive stimuli, thus regulating the negative affective responses that accompany aversive stimuli. Davidson et al.[146] proposed that “in the absence of this normal inhibitory input, the amygdala remains unchecked and continues to remain activated” (p. 898).

From a practical standpoint, this mechanism, if true, implies that cognitive interventions aimed at controlling the displeasure of strenuous exercise (e.g. by attentional dissociation, cognitive reframing or bolstering one’s sense of self-efficacy) would be ineffective at intensities exceeding the VT/LT.[147] Thus, for individuals who have difficulty maintaining a physiological steady state during exercise (e.g. chronically sedentary, overweight or obese), a biofeedback-based intervention aimed at improving the self-monitoring and self-regulation of intensity might prove more effective.[148]

4.3 Examination of Population-Specific Variations

Some of the studies on the exercise-affect relationship that were conducted in the last decade focused on samples selected to be sedentary or overweight/obese. These samples represent better approximations of the ‘average’ adult population than college students and are, therefore, of great public-health interest. Ekkekakis and Lind[149] reported that middle-aged, sedentary, overweight women responded with decreases in pleasure when walking on the treadmill at a speed 10% higher than the one they had self-selected, whereas normal-weight women did not. Welch et al.[107] studied women between the ages of 18 and 35 years who were physically inactive for at least a year. Unlike earlier findings from college students, which showed that decreases in pleasure occurred only when the intensity exceeded the VT,[102,104] Welch et al. observed a continual decrease in pleasure for the duration of a graded test. Similarly, Sheppard and Parfitt[106] found decreases in pleasure before the VT in inactive middle-aged men. Ekkekakis et al.[103] found the same for obese middle-aged women.

These data underscore the need to direct more research attention to individuals who are physically inactive and/or overweight or obese. Although these characteristics are now shared by the majority of adults in industrialized countries, the lack of information about the affective responses in these populations is striking. Preliminary data show that most adults who are sedentary and overweight or obese experience reduced pleasure over most of the range of exercise intensity, making the high dropout and non-participation among overweight and obese adults seem less surprising. There are several possible explanations for this phenomenon. On the one hand, the causes might be physical, such as respiratory difficulties and dyspnoea, a compromised thermoregulatory capacity or intensified muscular and skeletal pain. On the other hand, the culprit might be a diminished sense of efficacy, self-presentational concerns or the fear of intense and unfamiliar physical symptoms. These possibilities warrant systematic investigation in the years ahead.

4.4 Consistency in the System Used to Classify Exercise Intensities

As noted in section 3.1, although many researchers investigated the role of the VT, LT or OBLA in affective responses to exercise, different laboratories focused on different markers or used different procedures to determine these markers. However, as authors in exercise physiology have cautioned,[112,150] such inconsistencies are bound to create confusion.

Given the demonstrated importance of these physiological markers for affective responses, it seems reasonable to predict that they will continue to attract research attention in the following years. Researchers are urged to provide physiologically defensible rationales for choosing to focus on the VT, LT or OBLA. Furthermore, the procedures used for the determination of these markers must be reported in sufficient detail to allow replication by others. Consistent with recently published guidelines, we call for a strong commitment to quality assurance procedures, such as use of multiple graphing options and independent judges.[131,151] We also caution that, at least at the present stage of technological development, exclusive reliance on computer algorithms for the determination of the VT or LT may lead to errors.[152] It is also crucial to ensure that factors known to influence the VT and LT (including the exercise testing protocol, diet or state of sympathetic stimulation) are carefully controlled. Addressing the challenge of employing physiologically defensible methods for defining exercise intensity is a prerequisite for effectively communicating findings from this line of research with practitioners and other researchers within the exercise sciences.

5. Conclusion: Towards a Tripartite Rationale for Exercise Intensity Prescriptions

The model underpinning the exercise prescription guidelines issued by ACSM[33] is based on two considerations, namely the maximization of effectiveness (i.e. improvements in fitness and/or health) and the minimization of risk (i.e. potential for injury). As more evidence linking affect to adherence accumulates, it is becoming clear that this bipartite rationale should be reconsidered. Simply put, a prescription may well be effective and safe but, if very few want to follow it, then its public-health relevance becomes questionable.

The neglect of pleasure in exercise prescription guidelines until now was, arguably, a consequence of the lack of reliable evidence of a dose-response relationship between exercise intensity and affective responses.[22] However, the research reviewed in this article suggests that the 'compromise' between the 'ideal physiological prescription' and a 'manageable behavioural prescription' that Dishman[31,32] envisioned decades ago might be closer to becoming a reality.

There are certainly several remaining stumbling blocks. First, as in other scientific fields, a dualistic rift also exists within exercise science. Citations by health-oriented exercise physiologists to research in health-oriented exercise psychology, or *vice versa*, are rare, as if the two subdisciplines did not share the same goal. Accepting affect as an essential pillar of exercise prescription, alongside effectiveness and safety, requires overcoming some long-held beliefs and 'traditional' divisions.

Second, since their first edition almost 35 years ago, exercise prescription guidelines have been based on a 'recommended range' model. Specifically, recent guidelines[33] specify that the range of effective and safe intensity extends from 40% $\dot{V}O_2$ or HR reserve (64% HR_{max}) to 85% $\dot{V}O_2$ or HR reserve (94% HR_{max}). For most adults, these intensities encompass a very broad range of activities, from a moderately paced walk to a hard run. This range is reportedly 'intentionally broad' to accommodate individuals of very different levels of aerobic fitness. However, in the effort to be as broad as possible, this range has become almost all-encompassing and, thus, potentially confusing. Similarly, the descriptors 'moderate' (i.e. 3–6 metabolic equivalents [METs] or 10.5–21.0 mL/kg/min) and 'vigorous' (i.e. >6 METs or 21.0 mL/kg/min) that are used in physical activity recommendation for health[153] are also, essentially, all-encompassing. The data reviewed in this article suggest that these broad ranges include intensities likely to be pleasant and intensities that will, in most cases, be unpleasant.

An alternative to the range-based model is the threshold-based model that is commonly used in rehabilitation.[131,154-157] The main argument for the threshold-based approach to exercise prescription is that there is a specific level of intensity above which exercise becomes a systemic stressor, as evidenced by a wide range of physiological indices.[158] That level of intensity seems to correspond to the VT/LT. As the data reviewed in this article show, these thresholds demarcate a domain of intensity that, besides being stressful for several physiological systems, is also felt as unpleasant. In a sense, supra-threshold intensities induce an *integrated psychobiological stress response*. Conversely, intensities up to these thresholds can remain safe and effective for improving health and fitness but are also pleasant (or at least tolerable) for most healthy individuals.

An obstacle in the transition from a range-based to a threshold-based model of exercise prescription is the long precedent; a familiar *modus operandi* is always hard to change. Moreover, the concepts of the VT and LT have a controversial history in exercise science.[112,150,151] Some researchers question their significance as physiological indices or even their existence. Many practitioners suggest that both markers require expensive instruments (a metabolic or lactate analysis system), making them impractical for routine exercise testing and prescription.[159] Even if the data can be gathered, the reliable determination of these markers is challenging.[131,151,152]

To overcome these difficulties, researchers have proposed some practical alternatives. These include teaching exercisers to self-regulate their intensity using the non-linear decline in pleasure that accompanies the transition to supra-threshold intensities,[100] a combination of the non-linear decline in pleasure with a RPE of 12–14 on the 6–20 scale[102] or the talk test.[160,161] The accuracy of these methods is still being evaluated. We foresee that this will continue, especially given the recent call by ACSM[33] for "further research" before these methods can be "recommended as primary tools for the estimation of exercise intensity" (p. 157).

Perhaps more importantly, given the inter-individual variability in affective responses near the VT/LT, the precise determination of VT/LT is not an absolute prerequisite for exercise prescription. A more appropriate goal for practitioners is to identify a level of intensity near the VT/LT, at which participants can maintain a constant or improving (but not diminishing) level of pleasure. In some cases, this level might be below the VT/LT and in other cases slightly above. Because increases or decreases of the intensity compared with the self-selected level by the exercise practitioner might incur a psychological cost (by lowering perceived autonomy), such interventions should be rare as long as the deviations are small. However, in some cases, the self-selected intensity might be clearly too low to be effective or too high to be safe.[124] Even in such cases, the exercise practitioner should avoid directly imposing an intensity. Instead, we recommend an educational approach aimed at improving the participants' self-monitoring and self-regulation skills based on the principles of biofeedback[148] and using the participant's sense of pleasure or displeasure as a guide.

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