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Acute Aerobic Exercise and Affect

Current Status, Problems and Prospects Regarding Dose-Response

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Abstract

One of the assumptions underlying recent physical activity recommendations is that lower doses of activity (i.e. intensity and duration) are more enjoyable for the average person, thus leading to higher involvement and adherence rates. However, the veracity of this hypothesis can be questioned, since little is actually known regarding the association between activity doses and affective responses. The few preliminary attempts at the conceptual delineation of the dose-response relationship, all centred around an 'inverted-U' notion, are reviewed and criticised as lacking empirical foundation. Available meta-analyses, as well as the empirical literature on the role of exercise intensity and duration, are examined.

Increased intensity appears to be associated with reduced positivity of affect during and immediately following an exercise bout. Intensity effects appear to be attenuated during recovery. Fitness and training status appear to become significant mediators of the exercise-affect relationship only at high intensities. With intensity being kept constant, different exercise bout durations have not been shown to have a differential impact on pre- to post-exercise affective changes. Recommendations for future research include: (i) a shift from categorical to dimensional conceptualisations and operationalisations of affect; (ii) the examination of psychological theories on the association between activation and affect (e.g. extraversion-introversion, sensation seeking, type A behaviour pattern and related self-evaluative tendencies, reversal theory, optimal stimulation theory, multidimensional activation theory and self-efficacy); (iii) the systematic and theory-based examination of in-task and post-exercise affective responses; (iv) the incorporation of the parameter of fitness and/or activity status in research designs; and (v) the re-evaluation of methods for selecting exercise intensity levels.

Recent consensus statements and public health recommendations regarding the application of physical activity and exercise as preventive health practices call for moderate doses of activity (i.e. intensity of 3 to 6 METs, for at least 30 minutes, which can be distributed across short intermittent bouts during the day).[1-3] This position represents a departure from the credo that fitness enhancement is a prerequisite for health improvement and a transition to the notion that a more ‘active lifestyle’ (i.e. one that entails increased energy expenditure, including both occupational and leisure activities) may be effective at conferring significant health benefits.[4-8]

These proclamations have stirred controversy among exercise scientists. On the basis of scientific evidence, the effectiveness of the recommended doses of activity remains questionable.[9-11] Consequently, the new recommendations are regarded as being influenced, at least in part, by the need for a public health policy that can be successful in reducing the portion of the population that remains sedentary. This need is highlighted by the limited progress towards the initial Healthy People 2000 targets concerning physical activity.[12]

The expectation that the new recommendations will fare better than the more stringent previous ones in getting more people active is based, at least in part, on the assumption that lower doses of physical activity are more tolerable and perhaps more enjoyable than higher doses, and may, therefore, be more easily accepted by a larger segment of the population. A higher degree of enjoyment is, in turn, expected to lead to higher adherence rates.[1,13-19] While there is, in fact, some evidence that supports this assumption,[20-22] other findings are in conflict,[23,24] leading some authors to warn that a secure empirical base is still lacking.[25-27]

In general, experience has shown that assumptions regarding the predictability of complex psychological outcomes of physical activity, such as enjoyment and affect, and associated behaviours, such as adherence, are of limited generalisability. The present review will focus specifically on affective changes associated with acute bouts of aerobic exercise of varying dose characteristics, with one of its primary intended functions being to underscore the important distinction between assumptions, even intuitively appealing ones, and reliably documented scientific observations.

Despite rapidly accumulating evidence of affective benefits associated with acute aerobic exercise, operationalised as decreases in anxiety,[28-30] depression[31-33] and negative moods,[34-37] as well as improvements in general psychological well-being,[34,35,38-40] information regarding dose-response effects remains scarce. Morgan[41] first noted in 1973 that 'there is simply a lack of information concerning the intensity and duration at which exercise should be performed when attempting to improve psychological states such as anxiety, depression and aggression'. In 1986, Dishman[42] speculated that 'it seems unlikely that all types, volumes and settings of exercise will affect all aspects of mental health for all people'. Today, dose-response issues still remain unresolved.[43]

The study of the relationship between exercise doses and affective responses has significant implications for theory and application alike. From a theoretical perspective, determining whether a dose-response relationship exists between aerobic exercise and changes in affective variables constitutes a fundamental step in establishing causality.[44] From an applied stance, as previously noted, identifying the dose of exercise that is likely to optimise the conditions for positive affective change in a given individual is expected to lead to increased participation in and adherence to health-oriented exercise programmes.[44]

The purpose of the present review is 3-fold: (i) to critique some currently popular assumptions regarding the form of the dose-response relationship; (ii) to summarise the relevant empirical literature; and (iii) perhaps most importantly, to make recommendations for future research. This analysis is guided by the principle that the relationship between varying doses of acute aerobic exercise and affective responses is complex. Affective responses to exercise have been shown to be affected by biological and psychological individual difference variables, the physical and social environment, and the objective and perceived attributes of the exercise stimulus, as well as by several psychological states. Given the multitude of influences and the complexity of the possible interactions among them, assuming a mechanistic model, whereby all people should respond similarly to a given dose of exercise, would be simplistic and ultimately ineffective.[43]

The biological reality (i.e. the metabolic requirements of the exercise stimulus in conjunction with the individual's physical capacity) sets some rather inflexible, but also quite broad, boundaries. Within these boundaries, substantial variability in affective responses, both inter- and intra-individual, is likely to occur as a result of the complex interactions mentioned above.[45] This variability has been traditionally treated as error in studies examining the effects of exercise on affect. A central theme of the present analysis is that future research should, instead, strive to dissect this variability by systematically studying the role of theoretically relevant mediators. Such an investigative approach is likely to afford a much greater degree of insight and scientific accuracy compared with efforts that rely on nomothetic assumptions.

1. Assumptions and Attempts at Conceptual Formulations

This section includes a review of the few preliminary attempts towards the delineation of the dose-response relationship between exercise and affective change. These include: (i) 2 intuitively-derived assumptions; (ii) a preliminary taxonomy of the types and volumes of exercise for optimal affective benefits; and (iii) 2 hypothetical dose-response curves. The review of these formulations is followed by a critique.

1.1 Intuitively-Derived Assumptions

The following 2 assumptions, based on intuitive reasoning and some preliminary data regarding dose-response and affective outcomes, have had a widespread impact on practice and theorising in exercise psychology. The first assumption was originally proposed in reference to state anxiety, but is often presented as applicable to a broader range of affective variables. It states that there is a threshold level of exercise intensity and duration which is necessary for significant reductions in state anxiety to occur. Morgan[46-48] and associates[42,49,50] have cited earlier studies employing physical activities performed at low to moderate intensity and/or for a short duration, which produced null results,[51,52] as a basis for the assertion that light exercise does not modify state anxiety. This has led some researchers to speculate what the threshold levels of intensity and duration would be. Specifically, Dishman[42] proposed that intensity must be at least 70% of maximal oxygen uptake ($\dot{V}O_{2max}$) or age-adjusted maximum heart rate (HR_{max}) and the duration must be at least 20 minutes. Raglin and Morgan[50] contended that the intensity needs to be at least 60% of maximal aerobic power.

The second assumption is that high doses of exercise are associated with negative affective responses. This assumption stems from studies that reported null or even adverse effects following high intensity or long duration exercise (i.e. 80 to 90% HR_{max} or a marathon) on mood.[53-55]

1.2 A Proposed Taxonomy to Maximise the Benefits

Berger and associates[53,56,57] have proposed an 'exercise taxonomy to maximise the benefits in terms of positive mood changes. This position implies that there are identifiable attributes of the exercise stimulus that can maximise its efficiency for conferring affective benefits across individuals. With respect to the dose of exercise, this taxonomy recommends exercising at moderate intensity for at least 20 to 30 minutes and with a frequency that allows exercise to be regularly included in a weekly schedule. These specific suggestions were made in spite of the fact that Berger[56] has acknowledged that the current knowledge base on dose-response issues is limited and the few existing studies have yielded equivocal results.

1.3 Hypothetical Dose-Response Curves

Dishman and Landy[58] proposed a dose-response curve for 'integrated biobehavioural responses' to exercise, which has possible implications for affective outcomes. According to this model, biobehavioural 'benefit' interacts with 'cost' and this relationship is mediated by motivation. The authors also noted that 'a progressively greater stress gives a progressively smaller yield'. Motivation was proposed to set the limiting boundaries for adaptation. Sometimes, 'the need for behavioural strain exceeds the incentives and reinforcers available to provide it. There is also reason to believe that, in some instances, motivation to adapt can impose behavioural strain that exceeds the physiological ability to adapt'. The concept of a progressively smaller yield and the incorporation of motivation as a key mediator are intriguing features of Dishman and Landy's suggestions. However, the authors did not elaborate further on their ideas and did not cite any literature supporting their formulation.

A second attempt at describing a dose-response curve was undertaken by Ojanen,[59] based on a statement by Kirkcaldy and Shephard[60] that 'there is some evidence that any response to exercise is nonlinear; a threshold dose must be passed in order to yield an effect, while an excessive dose has adverse physical and psychological consequences'. Thus, Ojanen[59] proposed that the relationship between the dose of exercise and its effectiveness as a psychotherapeutic modality could be described by an inverted-U curve. Consistent with the aforementioned assumptions, the author contended that 'minimal exercise and sometimes even non-aerobic exercise does not seem to produce any effect on psychological variables', and, thus, 'there seems to be a threshold of effective exercise'. On the other hand, 'very intensive exercise probably is disadvantageous as a therapy'. Therefore, it was concluded that any effectiveness of exercise as a psychotherapeutic modality is associated with moderate doses. Ojanen's[59] main purpose was to discuss the possibility of achieving a 'placebo' exercise intervention, as a means of increasing the degree of methodological constraint in studies examining the psychological effects of exercise. Consequently, dose-response issues were only discussed in a tangential fashion and no further elaboration on this idea was provided.

1.4 Critique

All of the aforementioned formulations centre around the intuitively appealing notion that the psychologically optimal level of stimulation is moderate[61] (but see Neiss[62]). Essentially, the common theme underlying each of these assumptions is that 'too little' exercise is unlikely to have a significant impact on affect, whereas 'too much' exercise is likely to be aversive. Consequently, it is assumed that one should exercise at 'moderate' levels of exercise intensity and duration in order to optimise the conditions for positive affective change.

These assumptions suffer from a number of limitations. Firstly, they all implicitly claim nomothetic generalisability. Thus, by failing to take into account the role of individual differences, mediator variables and interactions, these formulations make mechanistic and, ultimately, simplistic and non-generalisable predictions. Secondly, none of the formulations was linked to a theory of emotion, arousal or motivation and, at the same time, none was based on empirical evidence. Thus, having neither an inductive nor a deductive foundation, these preliminary formulations have relied heavily on intuition and a few, conveniently selected, studies.

In fact, the extant literature contains considerable evidence against the generalisability of these models. For instance, contrary to the assumption that exercise intensity and duration must exceed a certain threshold for affective benefits to arise, a meta-analytic review of the anxiety literature showed no difference in effect sizes between studies employing protocols of different intensities or durations.[29] Exercise performed at intensities as low as 30, 35 or 40% of $\dot{V}O_{2max}$ has been shown to effectively reduce state anxiety[63,64] and improve mood.[65] Treadmill running at a moderate level of perceived exertion for as little as 10 minutes has also been shown to reduce state anxiety.[66,67]

Similarly, studies by Thayer and associates,[68-70] as well as others,[71] using the Activation-Deactivation Adjective Checklist (AD ACL),[72] have shown that 4- to 10-minute moderate walks are effective in reducing tension and increasing perceived energy. Even proponents of the threshold assumption[50] have noted that mediator variables might play a critical role in altering or neutralising the presumed threshold: 'It seems tenable to propose that an anxiety reduction would occur if the exercise were performed in a more distracting or pleasant environment and/or if walking represented the appropriate or preferred exercise intensity for an individual'.

The assumption of the negative affective impact of high exercise doses is also questionable. It is not uncommon for very demanding bouts of exercise (i.e. intensity of 80% $\dot{V}O_{2max}$, maximal exercise testing or even an ultraendurance race) to bring about significant affective benefits, particularly in some individuals.[73-78] Similar criticism can be directed towards Berger's[56] taxonomy (also see Landers[79]) and the 2 proposed dose-response curves.

It is important to recognise that the models described above are speculative, with very limited or no empirical support. This critical caveat is often overlooked, creating the false impression that these propositions constitute established scientific facts. The impact of the confusion is becoming apparent as these assumptions progressively permeate the field of exercise psychology, as well as other exercise science subdisciplines. For instance, according to the position statement of the International Society of Sport Psychology on physical activity and psychological benefits,[80] it is only 'moderate to high-intensity aerobic exercise' that has supposedly been shown to reduce state anxiety, whereas 'low-intensity and short-duration exercise has not been shown to reduce state anxiety'. Similarly, discussing the issue of exercise prescription during pregnancy, Wolfe and associates[81,82] recommended moderate exercise, on the grounds that, among other reasons, it is moderate exercise that supposedly optimises the conditions for psychological benefits to occur. Given the growing interest in dose-response issues from exercise scientists and the general public alike, it is critical for researchers in the field of exercise psychology to clarify the distinction between speculative propositions and reliably documented scientific observations.

2. Review of Studies

Reviewing the dose-response literature both within single studies and across multiple studies is challenging.[36] Multiple levels of exercise intensity and duration have rarely been contrasted within single studies. In these few studies, methodological differences, mainly related to the choice of exercise doses and the operationalisation of affect, hinder direct comparisons. Similarly, comparisons across studies (i.e. at a meta-analytic level) are either precarious due to marked methodological differences or altogether impossible because of missing vital information regarding the dose characteristics of the employed exercise stimuli.

2.1 Across Studies (Meta-Analyses)

The published meta-analyses have failed to produce much useful information regarding dose-response issues. In fact, the review by Petruzzello et al.[29] on the effects of acute exercise on state anxiety was the only meta-analytic investigation to yield relevant information. It showed no difference between studies employing different exercise intensities. On the other hand, the duration of the exercise bout was originally shown to be a significant mediator, with exercise protocols of short duration (0 to 20 minutes) eliciting a smaller average effect size (d = 0.04) compared with exercise lasting for more than 20 minutes (d = 0.41). However, the authors warned that the type of control group employed might have confounded these findings. When studies employing known anxiety-reducing treatments (such as relaxation, meditation, etc.) as control conditions were removed, the difference in effect sizes among exercise protocols of different duration was eliminated.

The other 2 meta-analyses on the effects of exercise on anxiety failed to provide any information of relevance to dose-response issues.[83,84] In the meta-analysis by North et al.[32] on the effect of exercise on depression, acute and chronic effects were not analysed separately. With acute and chronic effects combined, the effect of exercise session duration was not significant. The effect of exercise intensity was not examined due to insufficient data.

2.2 Within Single Studies

Four types of studies were sought via computerised searches and extensive cross-referencing. The first category included studies examining the effects of multiple levels of aerobic exercise intensity. This category was further subdivided into a main group including studies using a variety of self-report measures to assess affective responses during exercise and pre- to post-exercise affective changes, and a smaller group examining affective responses during exercise using the single-item Feeling Scale (FS).[85] The second category included studies focusing on affective responses to short, moderate walks. The third category included studies examining affective responses to maximal exercise tests. Finally, the fourth category consisted of studies examining the effects of different exercise bout durations. The search was limited to studies of aerobic exercise with non-clinical samples, studies involving self-report measures of affective variables, and to reports published in the English language. Due to the limited total number of dose-response studies, published abstracts were included in the review, but several had to be eventually excluded because of the absence of critical information (e.g.[86-89]).

Finally, dose-response studies in which the dose of exercise was not accurately quantified (for example, if participants were simply instructed to 'go easy' or 'go as fast as you can') were also excluded (e.g.[90]), because their protocol cannot be replicated on the basis of the information provided.

2.2.1 Exercise Intensity

A total of 31 usable studies were identified that belong in this category. Seventeen of those examined pre- to post-exercise affective changes, 3 employed post-test-only designs, 6 included assessments of both pre- to post-exercise changes and in-task responses, and 5 examined only in-task affective changes (table I).

Twenty-six of these studies, examining the effects of multiple levels of acute aerobic exercise intensity on affective responses during exercise[102,103,106] and pre- to post-exercise changes in affect, are summarised in table I. A total of 945 individuals took part (493 men and 452 women), or an average of 36 participants per study. In 16 studies, each individual participated in more than 1 exercise intensity condition (within-participants designs). With the exception of 120 professors in the study by Morgan et al.,[51] the community sample of 72 sedentary adults in Gauvin et al.[95] and 22 women in Pronk et al.,[100] the participants were typically young adults aged 30 years or younger. Sixteen of the studies included some type of assessment of aerobic capacity and 21 used relative exercise intensities (11 of them based on oxygen consumption). However, only 5 studies used fitness and/or training status as an independent variable in a factorial design. With the exception of 3 studies[97,51] that used post-test only designs, all other studies used either within-participant designs or random assignment of individuals to intensity conditions.

With 3 exceptions,[91,96,109] all experiments took place in the laboratory using a treadmill (7 studies), a cycle ergometer (15 studies) or both (1 study). Ten studies used durations between 8 and 20 minutes, 8 involved durations between 25 and 30 minutes and 2 involved longer durations. Four studies used either variable durations or shorter durations for higher intensities. In one study,[100] participants exercised until a fixed number of kilocalories had been expended. It is interesting to note that, despite the popular assumption of an inverted-U relationship between exercise intensity and affect, almost half of the studies examined only 2 levels of intensity, thus prohibiting the detection of curvilinear trends. The intensities used differed by as little as 10 beats/min,[51] 4% HR_{max} [4] or 10% $\dot{V}O_{2max}$ [75] to 30% HR_{max} reserve (HRR).[92,65,101]

The majority of the studies employed extensively used and validated self-report measures of affective variables. Among them, the Profile of Mood States (POMS)[110] was used in 13 studies and the state anxiety subscale of the State-Trait Anxiety Inventory (STAI)[111,112] was used in 6 studies. The majority of the studies (22 of 25) included an assessment of the affective variables of interest either 'immediately' or within 5 minutes after exercise.

In 14 of the 26 studies (54%) there were no reliable dose-response effects.[113] There are a number of potential explanations for these findings. Firstly, it is possible that the studies did not have sufficient statistical power to detect significant differences as a function of the relatively small sample sizes and the inter-individual variability in affective responses. Secondly, the failure to control for individual differences, primarily fitness or habitual activity levels, might have been critical in obfuscating any effects. Thirdly, the measures of affective variables that were used might have been insensitive or might not have tapped those affective variables that reflected dose-response effects. Fourthly, given that most of these studies involved the examination of only pre- to post-exercise changes, it is possible that any dose-response effects might have dissipated by the time the post-exercise assessments were made. Finally, it is also possible that the exercise intensities examined in these studies do not, in fact, have a differential impact on affective changes.

The search for consistencies among the studies that did show dose-response effects is hindered by the methodological differences among them. From studies involving assessments made during exercise, as well as immediately or shortly after exercise, there is evidence that tension (measured by the Tension scale of POMS or a rating scale) and state anxiety (measured by the STAI) were sensitive to intensity effects, with higher intensities leading to increases and lower intensities producing no change or decreases.[64,102-104] It is important to point out that the increases in STAI scores might in fact reflect increases in tension, rather than state anxiety per se. Although STAI scores have been shown to increase significantly during moderate exercise (e.g. 55% $\dot{V}O_{2max}$),[106] responses to a visual analogue scale with anchors referring directly to anxiety ('not at all anxious' versus 'the most anxious I have ever felt'), were attenuated during a bout of cycle ergometry at 25W.[103]

Evidence for dose-response effects was also found in some studies for the Fatigue scale of the POMS and the Physical Exhaustion scale of the Exercise-Induced Feeling Inventory (EFI).[114] Increases have been shown following high intensity exercise, whereas low or moderate intensity exercise has been shown to produce no change or even decreases.[95,98,103,104,107,109] Increases in fatigue may be more accentuated among participants having lower levels of aerobic fitness.[104]

Table I. Dose-response studies examining pre- to post-exercise affective changes and during-exercise affective responses

Study and sample (gender, age, fitness characteristics e.g. $\dot{V}O_{2max}$)	Design and factors	Intensities, exercise mode, and duration	Self-report measures	Administration time points	Findings
Berger & Owen[91] (32 M, 35 F, active, college age)	Within participants, separate control group	55, 75 and 79% HR_{max}; walk/jog; 20 min	POMS	Before, after	The multivariate intensity by time (pre-post) interaction was not significant
Blanchard et al.[92] (12 recreationally fit, 12 very fit F, college age)	Within participants	50 and 80% HRR, cycle ergometer; 30 min	EFI	Before, after	Only main effects of time for positive engagement, physical exhaustion. No intensity by time interaction
Boutcher et al.[93] (13 M trained, 20.6 ± 0.8y, 14 M untrained, 20 ± 0.5y)	Within participants	Light: RPE ≈ 10, HR < 115 beats/min; moderate: RPE ≈ 13, HR < 145 beats/min; high: RPE ≈ 16, HR < 175 beats/min; treadmill running; 10-min consecutive stages	PANAS	Upon arrival, 10 min before, 5 min before, fifth and tenth min of each 10-min intensity stage, 5 min after, 10 min after	Change scores calculated from average pre-exercise scores. PA showed significant group × intensity period interaction. Compared with baseline, PA increased in the trained group at moderate and hard intensity. In untrained, post-exercise PA was lower than pre-exercise. NA showed significant main effect for group. For trained, NA did not change. For untrained, NA was lower during and after exercise, compared with baseline
Farrell et al.[94] (5 M, 1 F, 30 ± 8.3y, 68.8 ± 5.2 ml/min/kg for M, 25.4 ml/min/kg for F)	Within participants, including control group	60 and 80% $\dot{V}O_{2max}$, self-selected (75.3% $\dot{V}O_{2max}$); treadmill running; 30 min	POMS (TMD), RPE	15 min before, within 5 to 10 min after	RPEs for self-selected intensity intermediate to 60 and 80%. TMD decreased 15 and 16 units following the 60 and 80% conditions, respectively, but only 4 units following self-selected intensity. Differences not statistically significant due to variability in mood responses and small sample size
Farrell et al.[73] (7 M, 27.4 ± 6.8y, 61.1 ± 3.9 ml/min/kg)		40% $\dot{V}O_{2max}$ for 80 min, 60% $\dot{V}O_{2max}$ for 80 min, 80% $\dot{V}O_{2max}$ for 40 min; treadmill running	POMS (tension subscale), RPE	Before instrumentation, after deinstrumentation	For RPE, main effects of intensity and time were significant, but not the interaction. Reduction in tension significant only following 60% and 80% conditions, with no difference between them
Felts and Vaccaro[65] (24 F; 18 to 23y; above average: 41.31 ± 3.95 ml/min/kg; average: 30.1 ± 1.1 ml/min/kg; below average: 24.2 ± 2.4 ml/min/kg)	Mixed plot; between (fitness group, 3 levels), within (condition, low and high intensity exercise, placebo relaxation), within (time)	30% HR_{max} reserve, 60% HR_{max} reserve; cycle ergometer; 25 min	STAI (state anxiety subscale)	Upon arrival, immediately after exercise, 45 min after exercise	Treatment, time of administration and their interaction significant. No fitness effects. Significant anxiety reduction in 30% condition from before to 45 min after exercise. Anxiety at 45 min after exercise significantly lower than both previous assessments in 60% condition. Treatment × time interaction only due to difference between 60% exercise and placebo immediately after treatment
Gauvin et al.[95] (36 sedentary M 35.7 ± 6.4y, 36 sedentary F 37.7 ± 5.7y; 32.4 ± 1.2 ml/min/kg)	Mixed plot: between (intensity), within (condition: control, experimental), within (time)	30, 50 and 70% HR_{max} reserve; cycle ergometer; 30 min	EFI, RPE, FS	EFI: before, 10 min after exercise. RPE, FS: last min of exercise	Exercise intensity only mediated responses to EXH subscale of EFI. 30% condition did not influence post-treatment EXH compared with control, regardless of pre-treatment values. 50% condition led to decreased EXH for those with very high pre-exercise EXH. Those with very low initial EXH showed EXH increases with exercise. 70% condition led to increases in EXH compared with control, regardless of pre-treatment values
Hatfield et al.[75] (12 M; 27.1y)	Within participants	60, 70 and 80% $\dot{V}O_{2max}$; cycle ergometer; 30 min	STAI, POMS, MAACL	Before, 5 min after exercise, 20 min after exercise	Intensity not related to mood change. STAI and anxiety, hostility scales of MAACL decreased from before to 20 min after exercise. Increase in vigor significant only 20 min into recovery
Kennedy and Newton[96] (6 M, 36 F; n = 20 in low intensity condition, 42.0 ± 11.7y; n = 22 in high intensity condition, 36.5 ± 11.8y)	Between participants	61.4% ± 12.87 HR_{max}, 79.5% ± 9.05 HR_{max}; step aerobics; 10 min warm-up, 30 min bench-stepping, 10 min cool-down	30 item short POMS	Before, immediately following the cool-down	Intensity effect but no intensity × time interaction found for anger and fatigue. High intensity group showed less anger and fatigue than low intensity group. Overall, decreases in tension, depression, anger and fatigue, and increase in vigor from before to after exercise

McGowan et al.[97] (12 M; 21 to 29y; 47 ± 4.3 ml/min/kg)	Within participants post-test only, including attentional control	40, 55 and 70% PWC; cycle ergometer; 15 min	ARCI (euphoria and tranquility subscales)	At the end of each experimental session (following exercise recovery and a mental stress test)	No difference in mood state responses across the 4 conditions
Morgan et al.[51] (experiment 1; 120 M professors)	Between participants: mode (cycle ergometer, treadmill), intensity; post-test only design	Terminal heart rates of 150, 160, 170 and 180 beats/min; variable duration	DACL	5 min after exercise	No intensity effect on depression. Cycle ergometry up to 150 and 160 beats/min resulted in higher depression than treadmill exercise up to 160 beats/min
Morgan et al.[51] (experiment 2; 18 M, 18 F students)	Between participants, including a resting control group, post-test only design	0% grade (126 beats/min in M, 111 beats/min in F), 5% grade (144 beats/min in M, 125 beats/min in F) at 3.5 mph; treadmill walking; 17 min	IPAT, DACL	Immediately after exercise	No significant anxiety differences between treatments. Depression of males exercising at 5% grade lower than group that exercised at 0% grade. No gender differences
Motl et al.[98] (11 M collegiate cyclists)	Within participants	Moderate intensity recovery training (69% HR_{max}), high intensity interval training (90% HR_{max}), graded exercise test (95% HR_{max}); cycling; duration not reported	POMS	Before, after	Moderate intensity cycling led to decreases in depression (D), anger (A), fatigue (F) and confusion (C), increase in vigor (V). High intensity cycling led to increases in F and V. Graded exercise test led to increases in D, A, F and C
Nelson and Morgan[99] [6 depressed F (scoring above 15 on BDI), 5 nondepressed F (scoring below 15 on BDI); college students]	Within participants	40, 60, 80% $\dot{V}O_{2max}$; cycle ergometer; duration not reported	POMS [depression (D) and TMD]	Before, 0 to 5 min after, 15 to 20 min after exercise	No significant intensity effects. D and TMD decreased in the depressed, but not in the nondepressed. In depressed group, D and TMD 0 to 5 and 15 to 20 min after exercise both lower than pretest
Porcari et al.[63] (17 M, 19 F; 37.4 ± 5.2y)	Within participants, including a no exercise control group	35, 50, 65% $\dot{V}O_{2max}$, self-chosen pace; treadmill walking; 40 min	STAI (state anxiety)	Before, immediately after, after shower, 120 min after exercise	No intensity effect. Pooled responses across conditions showed anxiety gradually decreased from pre-exercise to immediately after exercise to after shower. Anxiety remained below pre-exercise levels 2 hours after exercise
Pronk et al.[100] (11 premenopausal F; 35.1 ± 1.4y; 2.4 ± 0.1 L/min; 11 postmenopausal F; 54.9 ± 2.2y; 2.0 ± 0.1 L/min)	Two separate samples. Within participants	50, 70% $\dot{V}O_{2max}$; treadmill walking; until 350kcal expended (70.7 and 53.6 min for 50 and 70%, respectively)	Abbreviated POMS, self-esteem scale	Prior to, immediately after exercise	Results analysed separately for each group. For premenopausal, fatigue increased, confusion decreased, but no intensity effect or intensity × time interaction. For postmenopausal, fatigue and self-esteem increased, but no intensity effect or intensity × time interaction
Raglin & Wilson[64] (10 M, 5 F; 23.9 ± 4.4y; 53.7 ± 4.4 ml/min/kg for M, 40.5 ± 6.7 ml/min/kg for F)	Within participants	40, 60, 70% $\dot{V}O_{2max}$; cycle ergometer; 20 min	STAI (state anxiety)	10 min before each exercise session, within 5 min of completion of exercise, 60 and 120 min after exercise	No gender differences. Intensity × time interaction significant. In 40 and 60% conditions, STAI decreased below baseline at all post-exercise assessments. In 70% condition, STAI above baseline 5 min after exercise, but below baseline 60 and 120 min after exercise. Reduction in STAI at 60 and 120 min after exercise did not differ between intensity conditions. Transient STAI increase immediately following 70% condition due only to participants with lowest baseline scores

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Table I. Contd

Study and sample (gender, age, fitness characteristics e.g. $\dot{V}O_{2max}$)	Design and factors	Intensities, exercise mode, and duration	Self-report measures	Administration time points	Findings
Rejeski et al.[101] (12 M; 30.6 ± 1.5y; 58.8 ± 1.6 ml/min/kg)	Within participants, including attention control	50% $\dot{V}O_{2max}$ for 30 min, 80% $\dot{V}O_{2max}$ for 60 min; cycle ergometer	POMS	Upon arrival, 30 min after exercise (after instructions for a mental stress test), 5 min after stress	No intensity effects (alpha set at 0.01)
Roy & Steptoe[102] (30 M; 21.0y)	Between participants, including no exercise control group	25W, 100W; cycle ergometer; 20 min	Single-item, 8-point, bipolar rating scales: relaxed-tense, invigorated-exhausted, confident-worried, in control-under pressure, sad-happy	Baseline, 5, 13, 20 min during, 5, 20 min after exercise	Group × trial interaction for relaxed-tense scale. All 3 ratings during 100W exercise higher than those in either recovery trials. Third assessment during exercise also higher than baseline. Only the third rating during 25W exercise higher than those during recovery. Only trial main effects for the invigorated-exhausted, in control-under pressure and confident-worried scales. Significant group × trial interaction mentioned for confident-worried scale, but no follow-up tests or descriptive statistics reported
Steptoe & Bolton[103] (40 F; 18 to 22y; 3.9 ± 0.8 L/min)	Mixed plot: between (fitness group: high, moderate), between (exercise intensity), within (time)	25W, 100W; cycle ergometer; 15 min	Abbreviated POMS (no confusion scale), exhilaration items, anxiety visual analogue scale, RPE	POMS: before, 1, 5, 15 min after exercise; anxiety: before, 6, 12 min during exercise; RPE: immediately after exercise	RPEs higher in moderately fit *vs* highly fit and following 100W *vs* 25W exercise. Anxiety did not change in 100W condition. In 25W condition, anxiety at 6th and 12th min lower than before exercise. Fitness unrelated to anxiety changes. Tension increased immediately following 100W condition, but reduced below pre-exercise 15 min into recovery. In 25W condition, tension unchanged immediately after exercise, reduced below pre-exercise 15 min after exercise. Fitness unrelated to tension changes. Fatigue increased immediately after 100W exercise, followed by return to pre-exercise levels. In 25W condition, fatigue stable. Vigor showed 3-way interaction: immediately after 100W condition, increased in highly fit, but decreased in moderately fit. Responses then converged towards baseline levels. Exhilaration also showed 3-way interaction. Overall, fit participants had higher Exhilaration. Exhilaration increased immediately after exercise, followed by decline by the 15th min of recovery, except for the moderately fit in 100W condition. Heart rate increases correlated positively with increases in Tension and Fatigue from before to immediately after exercise, anxiety during exercise, negatively with Vigor and Exhilaration. Depression did not change. Anger progressively reduced, no intensity or fitness effects
Steptoe and Cox[104] (32 F; 20 ± 1.1y; 2.6 L/min)	Mixed plot: between (fitness: fit, unfit), within (intensity), within (music, metronome), within (time)	25W, 100W; cycle ergometer; 8 min	Abbreviated POMS (no depression, anger scales), exhilaration items, RPE	Before, immediately after exercise	Intensity × time interaction for tension: increased following 100W exercise, decreased nonsignificantly in 25W condition. Reverse pattern for vigor and exhilaration: increased following 25W condition, decreased to nonsignificant degree in 100W condition. Fitness and sound effects and interactions not significant for any of these mood states. Fatigue increased in both fitness groups following 100W exercise; increase higher in the unfit. Fatigue decreased following 25W exercise. No effects for confusion. RPEs similar following 25W exercise for the 2 fitness groups. Following 100W exercise, unfit had higher RPEs *vs* the fit. RPEs also higher in metronome *vs* music trials

Steptoe et al.[105] [session 2; 72 M; 20 to 35y; 44.2 ml/min/kg ('sportsmen': 51.0 ± 4.6 ml/min/kg;'inactive men': 37.4 ± 5.4 ml/min/kg)]	Mixed plot: between (activity: sportsmen, inactive men), between (intensity, including light exercise control group), within (time)	50, 70% $\dot{V}O_{2max}$; cycle ergometer; 20 min	Abbreviated POMS (tension, vigor, depression), exhilaration items, RPE	POMS: before, 2, 30 min after exercise; RPE: 5, 10, 20 min during exercise	RPEs not different between sportsmen and inactive men in either intensity. Tension did not change from pre- to post-exercise, but decreased compared with pre-exercise by 30th min of recovery, with no group or intensity effects. Vigor increased pre- to post-exercise; regressed to pre-exercise levels during recovery, again with no group or intensity effects. Exhilaration increased after exercise and remained elevated during recovery, also with no group or intensity effects. 70% condition more effective in increasing vigor among low cognitive trait anxious, 50% condition more effective among high cognitive trait anxious
Tate and Petruzzello[106] (15 M, 5 F; 22.6 ± 3.3y; 47.8 ± 8.6 ml/min/kg)	Within participants, including no exercise control group	55, 70% $\dot{V}O_{2max}$, cycle ergometer, 30 min	AD-ACL, 10-item STAI (state anxiety)	Before, 5, 15, 25 min during, 0, 5, 10, 20, 30 min after exercise	Condition × time interaction for STAI: increased in both intensity conditions from pre-exercise to all points during exercise and decreased from all points during exercise to all points after exercise. In 70% condition, increase from 5th to 25th min during exercise, decrease from before exercise to 30th min after exercise. No significant pre-post exercise changes for 55% condition. Condition × time interaction for energetic arousal: increased from before exercise to all points during and after exercise in both intensity conditions, decreases from all points during to all points after exercise. Only time effect for tense arousal, accounted for by decreases from all points during to 5, 10, 20 and 30 min after treatment, collapsed across conditions
Treasure and Newbery[107] (18 M; 23.2 ± 10.5y; 42 F; 22.5 ± 4.7y; sedentary)	Between participants (14 F and 6 M per group), including no exercise control group	45 to 50, 70 to 75% HRR, cycle ergometer, 15 min	EFI	Before, last 30 sec, 15 min after exercise	From before to last 30 sec of exercise, moderate intensity increased revitalization (R), high intensity increased physical exhaustion (EXH) and decreased in R and tranquility (T). From end of exercise to 15 min after, moderate intensity decreased EXH and T, high intensity increased positive engagement (PE) and R, decreased EXH and T. From before to 15 min after, moderate intensity increased PE, R, T, high intensity increased EXH
Tuson et al.[108] (33 M, 32 F; 23.8 ± 2.7y; 42.9 ± 8.5 ml/min/kg)	Between participants, including resting control group	25, 50, 75% $\dot{V}O_{2max}$; treadmill running; 30 min	Positive affect (PA) scale of MAACL-R, RPE	Before, 30th min of exercise, 30 min after exercise	Conducted 2 sets of analyses. For set 1, classification in intensity conditions based on RPE. In participants with high initial PA, pre- and post-exercise PA scores did not differ between those in perceived light and those in perceived moderate intensity conditions. Post-exercise PA lower than pre-exercise in perceived intense condition. For those with low initial PA, post-exercise PA higher than pre-exercise only in the perceived moderate condition. For set 2, classification in intensity conditions based on % $\dot{V}O_{2max}$. No reliable affect changes in any condition using this grouping criterion
Zervas et al.[109] (70 F; 21 to 23y; also see table II)	Between participants	40, 60, 80% HR_{max} reserve, self-selected intensity (approximately 80% HR_{max} reserve); aerobics; 30 min	Abbreviated POMS, exhilaration items, STAI (state anxiety), PACES	POMS, STAI: before, immediately after exercise; PACES: immediately after exercise	Vigor and exhilaration increased following 60%, 80% and self-selected intensity conditions. Fatigue increased in high and self-selected intensity conditions. Enjoyment (PACES) lower after the 40% condition, compared with all other conditions. Highest enjoyment in self-selected intensity group

AD-ACL = activation deactivation adjective checklist; **ARCI** = addiction research center inventory; **BDI** = Beck depression inventory; **DACL** = depression adjective checklist; **EFI** = exercise-induced feeling inventory; **EXH** = physical exhaustion; **F** = female; **FS** = feeling scale; **HR_{max}** = maximal heart rate; **HRR** = HR_{max} reserve; **IPAT** = institute for personality and ability testing; **M** = male; **MAACL** = multiple affect adjective checklist; **NA** = negative affect; **PA** = positive affect; **PACES** = physical activity enjoyment scale; **PANAS** = positive and negative affect schedule; **POMS** = profile of mood states; **PWC** = physical work capacity; **RPE** = rating of perceived exertion; **STAI** = state trait anxiety inventory; **TMD** = total mood disturbance; **$\dot{V}O_{2max}$** = maximal oxygen uptake.

Conversely, increases have been documented in affective states related to positively valenced activation, such as vigor, exhilaration, revitalisation and positive affect either following moderate intensity (but not high intensity), exercise, or following high intensity exercise, but only among fit participants.[93,98,103,104,107-109] One study involving young and fit volunteers also showed that, compared with 55% $\dot{V}O_{2max}$, exercising at 70% $\dot{V}O_{2max}$ led to longer lasting increases in energetic arousal post-exercise.[106]

The findings regarding the effectiveness of low-intensity exercise for producing significant changes in affect are equivocal. Of the studies that employed intensities up to 40%, some showed significant reductions in state anxiety.[63-65] However, studies focusing on other affective variables have produced null results.[73,93,108,109]

Two studies examined self-selected intensities,[94,109] but cannot be directly compared. Farrell et al.[94] reported results that referred only to the Total Mood Disturbance (TMD) score of POMS. TMD was reduced to a lesser extent in the self-selected intensity condition, compared with the 60 and 80% $\dot{V}O_{2max}$ conditions, but the difference was not statistically significant. In the study by Zervas et al.,[109] both the 80% HRR and the self-selected intensity groups exhibited increases in exhilaration and fatigue, compared with pre-exercise values.

Among the possible mediators of the dose-response relationship, the only variable examined in more than 1 study was aerobic fitness (or training status). Of the 5 studies that included fitness as an independent variable in factorial designs, 2 used relative exercise intensities up to 70% $\dot{V}O_{2max}$.[65,105] In these studies, fitness did not appear to have a significant effect. Two other studies using absolute exercise intensities,[103,104] and a third study using consecutive 10-minute bouts of running at increasing intensities,[93] showed that fitness became a significant mediator of affective responses at higher intensities. For example, only the highly fit showed increases in vigor and exhilaration following a 100W cycling bout.[103] Conversely, unfit participants reported more fatigue and higher ratings of perceived exertion (RPE)[115] compared with their more fit counterparts.[104] During running rated as 'moderate' and 'hard', only trained participants exhibited increases in positive affect.[93]

Table II summarises the findings from the 7 dose-response studies that examined affective responses during exercise using the FS.[85] Three additional known dose-response studies have used the FS during exercise, but dose-response effects were obscured by the effects of other independent variables, such as type A/B behaviour patterns[121] or music.[122,123] Nevertheless, a consistent finding that emerged from these studies was that FS responses became significantly less positive as exercise intensity increased. An examination of the studies in table II leads to the same conclusion. Contrary to pre- to post-exercise changes, affective responses during exercise seem to be quite sensitive to intensity effects. Furthermore, there is evidence that affect during exercise is negatively correlated with physiological indices of metabolic strain, such as heart rate, blood lactate levels, respiratory rate and oxygen consumption.[85,117]

Furthermore, the correlation between RPE and FS has been shown to become increasingly more negative as exercise intensity increases.[85,109,116] Zervas and associates,[109] using a between-participant design with random assignment to intensity conditions, showed that in their 40, 60 and 80% HRR intensity groups, the correlations between RPE and FS were –0.00, –0.56 and –0.84, respectively, and the correlations between heart rate and FS were –0.03, –0.26 and –0.43, respectively. However, that study also included a self-selected intensity group, which exhibited a markedly divergent pattern of responses. Despite the fact that the individuals in the self-selected intensity group chose to exercise on average at the same intensity as the high intensity group (i.e. approximately 78% HRR), the correlations between RPE and FS, and heart rate and FS in the self-selected intensity group were slightly positive ($r = 0.27$ and 0.29, respectively). These findings are consistent with findings by Dishman et al.[124] regarding RPE responses to exercise of self-selected intensity. These researchers noted that 'RPE at preferred intensities of exercise can uncouple from indicators of relative metabolic intensity typically linked with RPE'. The further study of the distinction between imposed and self-selected exercise intensity appears warranted (also see Berger and McInman[57] and Morgan[125]).

It is interesting to note that the variability in FS responses has been shown to increase as a function of increased exercise intensity.[85,117,119] Although it has gone unnoticed, this is a finding with considerable theoretical implications. As exercise intensity increases (at least within the range of intensities employed in the studies reviewed herein), affective responses become more variable. In other words, what some people perceive as distressing, other people tend to perceive as pleasant.[126-128] In a similar vein, perceived exertion has been shown to mediate post-exercise affect or pre- to post-exercise affective changes in some studies,[108,109,129] but not in others.[130] These findings are consistent with the notion that participants respond affectively to exercise loads in an active rather than a passive fashion.[43]

The role of fitness as a mediator of in-task affective responses was examined in a series of studies by Parfitt and co-workers.[118-120] Although groups having different fitness levels did not differ in their FS responses at 60% $\dot{V}O_{2max}$, significant differences emerged at 90% $\dot{V}O_{2max}$. The inactive (and less fit) participants exhibited a drop in the positivity of reported affect from the second to the fourth minute of a short exercise bout, as well as from the 60 to the 90% $\dot{V}O_{2max}$ condition. The more active (and more fit) participants, on the other hand, did not exhibit such drops.

In concluding the review of intensity-specific dose-response studies, one additional observation seems in order. Of the 31 dose-response studies reviewed herein, spanning nearly a quarter of a century, only 2 studies[106,108] set forth to test specific theory-informed hypotheses. Hopefully, this is an indication of an evolving trend towards more theory-testing research. In order to facilitate this development, some relevant psychological theories are reviewed in section 3.2.

2.2.2 Moderate Walking

The affective outcomes associated with 'minimal' exercise stimuli are of particular interest in light of the recent public health recommendations calling for activities characterised by relatively low intensity and short duration.[1-3] Moderate walking is being promoted as one such activity that is familiar and generally safe for most segments of the population. Walking is already the most popular mode of health-oriented physical activity among adults.[3] Yet, researchers in public health recognise that 'there may be unique challenges . . . for those involved with the effective dissemination and interpretation of the guidelines'.[8] According to the National Institutes of Health development panel on physical activity and cardiovascular health, 'many people . . . fail to appreciate walking as 'exercise' or to recognise the substantial benefits of short bouts (at least 10 minutes) of moderate level activity'.[1]

Specifically with respect to affective outcomes, the lack of appreciation for the potential benefits associated with walking seems to be pervasive among researchers. This can be attributed to 2 factors: (i) the long preoccupation with the idea that certain vigorous 'thresholds' of intensity and duration must be exceeded for exercise to have a significant impact on affect (see section 1.1); and (ii) the absence of methodologically sound studies examining low intensity and short duration exercise stimuli.

In 1971, Morgan et al.[51] randomly assigned 36 students to a group that walked for 17 minutes at 3 miles/h and 0% grade, a group that walked for 17 minutes at 3 miles/h and 5% grade, and a group that rested in a supine position for 17 minutes. Post-test only assessments of anxiety and depression showed no difference between the 3 groups. From the design of this experiment, it is not possible to infer whether walking produced any affective changes. The effect of walking on state anxiety using the STAI has been examined in 2 studies. Sime[52] used a 10-minute bout of treadmill exercise followed by a 5-minute recovery period (heart rate 100 to 110 beats/min). This treatment led to nonsignificant decreases in state anxiety scores. On the other hand,

Table II. Dose-response studies examining in-task affective changes using the Feeling Scale (FS)

Study (sample characteristics, gender, age, fitness e.g. $\dot{V}O_{2max}$)	Design and factors	Intensities, exercise mode, duration	Administrations	Findings
Hardy & Rejeski[85] (experiment 3; 30 M; 19.5 ± 2.1y; 45.2 ± 5.6 ml/min/kg)	Within participants	30, 60, 90% $\dot{V}O_{2max}$; cycle ergometer; successive 4 min trials	Near completion of each stage	RPE increased, FS decreased with increasing intensity. Correlations between RPE, FS: –0.33, –0.45, –0.55 for the 30, 60 and 90% $\dot{V}O_{2max}$ stage, respectively. RPE had significant positive and FS had significant negative correlations with heart rate (0.85 and –0.70), ventilation (0.77 and –0.65), respiratory rate (0.73 and –0.62), and oxygen consumption (0.82 and –0.69, respectively)
Boutcher et al.[93] (13 M trained, 20.6 ± 0.8y, 14 M untrained, 20 ± 0.5y; also see table I)	Within participants in same session	Light: RPE approximately 10, HR < 115 beats/min; moderate: RPE approximately 13, HR < 145 beats/min; high: RPE approximately 16, HR < 175 beats/min; treadmill running; 10 min each stage	Upon arrival, 10 min before, 5 min before, 5th and 10th min of each 10-min intensity stage, 5 min after, 10 min after	Main effect of intensity, but no group effect or group × intensity interactions. There was a trend for trained participants to show higher FS during all intensity periods
Zervas et al.[109] (70 F; 21 to 23y; also see table I)	Between participants	40, 60, 80% HR_{max} reserve, self-selected intensity (approximately 80% HR_{max} reserve); aerobics; 30 min	10, 20, 30 min (last) of exercise	RPEs highest for high intensity group, lowest for the low intensity group, with moderate and self-selected intensity in between. FS highest for low intensity group. FS of moderate and high intensity groups comparable. FS for self-selected intensity group comparable to low intensity group. At 20th minute, correlations between RPE and FS: –0.00, –0.56 and –0.84 for the 40, 60 and 80% group, respectively; r = 0.27 for self-selected intensity group. Correlations between heart rate and FS: –0.03, –0.26, –0.43 and 0.29, respectively
Acevedo et al.[116] (8 distance runners; 67.0 ± 7.9 ml/min/kg)	Within participants, in same session	VO_2 10% below 4 mmol/L lactate (RV1), VO_2 at 4 mmol/L (RV2), VO_2 10% above 4 mmol/L (RV3); treadmill running; 5 min each velocity	During each run	FS increased nonsignificantly (0.13 ± 2.59 units) from RV1 to RV2, decreased significantly (–0.2.00 ± 2.56 units) from RV2 to RV3. RPE increased significantly from RV1 to RV3. RPE and FS significantly related at RV3 (r = –0.68)
Acevedo et al.[117] (7 M; 20.7 ± 0.4y; 76.8 ± 4.4 ml/min/kg; 9 F; 19.7 ± 0.5y; 59.6 ± 6.4 ml/min/kg)	Within participants, in same session	Running speeds based on 60, 70, 80, 90 and 95% of each participant's personal record in the mile run (consecutive runs with 4 min recovery between runs); running in 200m indoor track; 1400m for M, 1200m for F (variable durations)	Immediately after each run	Running speed: RPE relationship explained by positive linear function. Running speed: FS relationship best explained by a negative linear function, but quadratic function also significant. Correlations between RPE and FS across the 5 running speeds: r_s = –0.80, –0.58, –0.23, –0.16 and –0.59, respectively. Across all workloads, RPE correlated with heart rate (r = 0.75) and lactate (r = 0.55). FS correlated with heart rate (r = –0.63) and lactate (r = –0.42)
Parfitt et al.[118] (30 F; 15 active: 27.2 ± 7.0y; 3.0 ± 0.4 L/min, 15 inactive: 25.6 ± 10.0y; 2.3 ± 0.5 L/min)	Mixed plot: between (activity status), within (intensity condition), within (time)	RPE 9: 31.3% $\dot{V}O_{2max}$, RPE 13: 57.9% $\dot{V}O_{2max}$, RPE 17: 79.7% $\dot{V}O_{2max}$; cycle ergometer, successive 5-min trials (15-min rest between trials)	In the last 20 sec of each trial, 5 min after each trial	Activity group × intensity and intensity × time interactions. Low active felt less positive at RPE 17 than at RPE 9 and less positive than the high active at RPE 9, 13, and 17. All participants felt more positive 5 min after exercise than the last 20 sec of exercise at RPE 13 and 17

TABLE II HERE

Porcari et al.[63] used 40-minute bouts of walking at 35, 50 and 65% $\dot{V}O_{2max}$ and a self-chosen pace, and showed significant decreases in state anxiety scores, regardless of intensity. The effect of walking on mood states using the POMS has been examined in 2 studies,[100,131] but in both cases the intensity was relatively vigorous (i.e. 121 to 126 beats/min,[131] 50 and 70% $\dot{V}O_{2max}$ [100]) and the duration was long (i.e. 1 hour,[131] from 41 to 71 minutes[100]). Therefore, these studies fall outside the scope of this section.

Thayer and associates have conducted a series of field studies examining the effects of short bouts of walking (i.e. 4 to 10 minutes) on mood assessed by the AD ACL. These studies have consistently shown that walking is associated with increases in perceived energy.[68-70] Furthermore, decreases in tension and tiredness have also been found.[69,70] An increase in energy and a decrease in tension following 4- to 10-minute walks have also been reported by Saklofske et al.[71] A limitation of this work is that the intensity of exercise was not quantified.

This problem was addressed in a series of studies by Van Landuyt et al.[132] and Ekkekakis et al.[133] In these studies, the pace was selected by the participants and the intensity ranged from 14 to 22% of age-predicted HRR. Affective responses were examined within a dimensional framework (see section 3.1). A consistent finding was that walking for 10 to 15 minutes was associated with shifts towards activated pleasant affect and recovery from walking was associated with a return towards deactivated pleasant affect. These findings were robust across 4 studies, robust across different measures of affective dimensions, robust across ecological settings (outdoors in social environment and in the laboratory in solitary conditions) and robust within individuals across time.

In summary, short bouts of moderate walking were shown to induce significant affective changes in those cases in which affect was examined from a broad perspective (i.e. in terms of affective dimensions rather than specific affective states). More specifically, it appears that walking has an energising

Parfitt et al.[119] and Parfitt and Eston[120] (20 active M: 23.9 ± 3.5y; 4.3 ± 0.6 L/min; 20 inactive M: 22.9 ± 5.7y; 2.8 ± 0.4 L/min; 20 active F: 24.3 ± 5.8y; 3.2 ± 0.3 L/min; 20 inactive F: 26.6 ± 8.2y; 2.0 ± 0.2 L/min)	Mixed plot: between (gender), between (activity status), within (intensity), within (time)	60, 90% $\dot{V}O_{2max}$; cycle ergometer; 4 min (on separate days)	RPE: 2, 4 min during exercise; FS: 2, 4 min during exercise, 5 min after exercise	Parfitt and Eston[120] reported data during exercise. No fitness effect for RPE. RPEs higher for women *vs* men and during 90 *vs* 60% condition. Intensity × time interaction significant due to a disproportional RPE increase between 2nd and 4th min in 90 *vs* 60% condition. FS more positive at 60 *vs* 90% condition, higher for active *vs* inactive participants. Also, FS higher during 60 *vs* 90% condition. FS decreased from 2nd to 4th min at 90% condition, but no such drop in 60%. Inactive participants had lower FS at 4th than 2nd min, active participants did not change significantly. Inactive participants also had lower FS in 90 *vs* 60% condition, no such difference in the active participants. Active participants showed more positive affect *vs* inactive during 90% condition, no difference between activity groups at 60%. Parfitt et al.[119] reported data collected on the 4ht min of exercise and 5 min after exercise. Overall, active participants reported more positive affect *vs* inactive ones. FS higher 5 min after exercise *vs* last minute of exercise and at 60 *vs* 90% condition. Group × intensity and intensity × time interactions, as in the Parfitt and Eston study (see above). Active showed more positive affect *vs* inactive in 90% condition, no such difference in 60%. FS lower in the last min of 90% condition than any other time or condition

F = female; **M** = male; **RPE** = rating of perceived exertion; **RV** = running velocity; $\dot{V}O_{2max}$ = maximal oxygen uptake.

effect, while recovery from walking has a calming effect. However, based on evidence from the few available studies it seems that these effects are short-lived. Given the increasing interest in the effects of short, moderate intensity physical activities, further attention to the affective changes associated with moderate walking is warranted.

2.2.3 Maximal Exercise

Studies on the affective responses to maximal exercise provide an interesting and potentially instructive experimental paradigm with respect to dose-response issues. Firstly, maximal exercise constitutes a relatively standard exercise load, a fact which facilitates cross-study comparisons. Secondly, such studies permit a test of the popular notion that highly strenuous exercise has a negative impact on affect. To date, only a few studies have examined the affective responses that accompany maximal exercise. Some of these studies examined state anxiety responses using the state anxiety subscale of the STAI. As mentioned above and explained in more detail in section 3.1, these data should be examined with caution, because scores on the STAI might reflect perceived activation and effort-related tension, rather than state anxiety per se (i.e. an emotional response elicited following the cognitive appraisal of the situation as threatening).

In a series of early experiments, Morgan and co-workers[49] used a 4-item version of the state anxiety subscale of STAI to study the responses of individuals exercising to voluntary exhaustion. In the first experiment, STAI responses were assessed before and immediately after 2 maximal treadmill tests, the first involving walking and the second involving running. STAI scores increased significantly in response to both tests, with no difference between the 2 exercise modalities. In a second experiment, the same protocol was repeated with the addition of a third STAI assessment 3 to 5 minutes after exercise. While STAI scores were again significantly elevated immediately following both exercise bouts, a decrease was noted by the fifth minute after exercise. In a third experiment, participants walked and on a separate day ran at 80% of $\dot{V}O_{2max}$ to the point of volitional exhaustion. STAI responses were assessed before, at 4 points during, and 2 times after exercise. STAI responses increased in an almost linear fashion during the first half of both tests, reached a plateau, remained stable for the second half of the exercise and were again reduced following the tests. The same pattern of responses was also obtained with a less fit sample.

In addition to the previously noted validity concerns surrounding the use of the STAI in conjunction with acute bouts of vigorous exercise, these studies can also be criticised for the use of a version of STAI that included only 4 items. Spielberger has noted that STAI scales with less than 10 items are not recommended because of questionable stability and validity.[111]

STAI-defined state anxiety responses associated with maximal exercise tests were also examined in 3 studies by O'Connor and co-workers.[76] The first study involved a group of 12 highly trained male distance runners who participated in a total of 4 maximal treadmill tests. All maximal tests led to nonsignificant reductions in STAI scores. The second study examined males of moderate aerobic capacity (mean $\dot{V}O_{2max}$ = 54.7 ml/min/kg). STAI scores were reduced at both post-exercise assessments, compared with pre-exercise, with no difference between 2 and 10 minutes post-exercise. The third study involved an initial assessment of a group of low-level fitness individuals, who were later assigned to either an 8-week endurance training programme (n = 17) or a pre-test–post-test control condition (n = 15). Following the training programme, the aerobic capacity of the experimental group was increased by 13%. STAI responses were assessed before, as well as 5 and 15 minutes following each test. The effects of group, trial and group by trial interaction were not significant. For both trials and both groups, STAI scores 5 minutes after exercise were significantly higher than the corresponding values before exercise or 15 minutes after exercise, with no difference between those 2 assessments.

Another study, presented in 2 reports,[134,135] compared anxiety, depression and hostility responses of 9 young (mean age = 26.1 years; mean $\dot{V}O_{2max}$ = 40.9 ml/min/kg) and 7 elderly (mean age = 66.0

years; mean $\dot{V}O_{2max}$ = 23.9 ml/min/kg) untrained men to a graded exercise test, as measured by the Multiple Affect Adjective Checklist (MAACL).[136] The study failed to demonstrate any dramatic changes in affect. The MAACL was administered before and 5 minutes after the tests. The 2 groups completed the test having similar RPEs. Anxiety and depression scores remained unchanged in the younger group and only showed a nonsignificant tendency to decrease in the elderly. In hostility scores, there was a significant interaction produced by a 15% drop in the elderly group compared with a 20% rise in the younger group. The possible insensitivity of the MAACL was discussed as an explanation for the inability to detect more pronounced changes in affect.

McAuley and associates[137] examined the responses of 80 older adults (mean age 66 years) to the Subjective Exercise Experiences Scale (SEES).[138] These researchers reported an ‘overwhelming negative response’, involving significant increases in psychological distress and fatigue and decreases in positive well-being. Pronk and co-workers,[78] subjected 22 women volunteers (45 ± 2.5 years) to 2 maximal exercise tests using a modified Balke walking protocol. The 2 tests were separated by approximately 1 month and resulted in similar values of $\dot{V}O_{2max}$ (2.24 ± 2.7, and 2.21 ± 0.09 L/min, respectively), HR_{max} and terminal RPEs. An abbreviated version of the POMS and 5 additional items measuring esteem-related affect were administered prior to and within 5 minutes of the termination of each test. The results showed significant increases in fatigue and esteem-related affect and decreases in tension and vigor. Furthermore, intraclass correlations indicated that these effects occurred relatively reliably across the 2 tests.

The affective impact of a maximal cycle ergometer test, in conjunction with the participants’ aerobic capacity, was examined using a cross-sectional design by Steptoe and associates.[105] ‘Sportsmen’ averaged 51.0 ml/min/kg, while inactive men averaged 37.4 ml/min/kg (a 36% difference). An adaptation of the POMS, including items measuring exhilaration, was administered immediately before and 5 minutes after the test. Exhilaration was increased in both groups, but a decrease in tension was found only for the highly active group. The highly active participants also reported generally higher vigor and exhilaration overall.

A similar study by Motl et al.[139] compared the POMS ratings of 11 collegiate cyclists (mean $\dot{V}O_{2max}$ = 62.5 ml/min/kg) to those of 8 college students (mean $\dot{V}O_{2max}$ = 41.6 ml/min/kg) in response to 3 graded exercise tests to exhaustion. No difference was found between the 2 groups. Both cyclists and students showed increases in depression, fatigue and confusion, and decreases in vigor.

Furthermore, 3 studies have examined the effect of training on affective responses to maximal exercise tests. In a study by Noble and associates,[140] 45 adult women participated in 3 maximal exercise tests (running, racewalking, stepping) before and after a 6-month aerobic exercise programme. An examination of FS ratings during the first 10 minutes of the tests showed more positive responses following the training period than before (no modality effects). Furthermore, the magnitude of the negative correlation between RPE and FS was decreased following training. Similar findings were reported by Acevedo and co-workers.[141] Following an 8-week aerobic training programme, 11 obese women showed a 14% increase in aerobic capacity and significantly improved FS responses across all stages of a graded treadmill test to exhaustion. Finally, Peña and co-workers[142] reported that a 6-month programme of walking or toning in a sample of 152 older adults (mean age 67 years) resulted in an attenuation of the negative affective impact of maximal exercise (evidenced by increases in the psychological distress and fatigue scales and decreases in the positive well-being scale of the EFI).

Given the conflicting findings, the diverse operationalisations of affect and the aforementioned interpretive concerns, there is hardly a sufficient basis for generalised conclusions. This, however, can be seen as an instructive observation in itself. The fact that maximal exercise can lead to affective responses that run the gamut of possible outcomes, in conjunction with observations of intra-study, inter-individual variability,[76] provides a strong argument against the notion of a unitary dose-response model. Moreover, 2 factors have emerged from these studies as potentially significant mediators of affective responses: aerobic fitness and the post-exercise time point of affect assessment. As will be discussed again later (in sections 3.3 and 3.4), both of these factors must be taken into consideration in designing and interpreting dose-response studies.

2.2.4 Exercise Bout Duration

As with the traditional assumptions regarding the effects of exercise intensity, the long-held belief regarding the role of the duration of the exercise bout has been that it must exceed a relatively demanding 'threshold' in order for the exercise bout to produce significant affective benefits. For a significant decrease in state anxiety, Dishman[42] speculated that one must exercise for at least 20 minutes. Likewise, for a significant mood improvement, Berger[53,56,57] speculated that one must exercise for at least 20 to 30 minutes. Although the number of studies that were specifically designed to examine the effects of exercise bout duration remains small, there has been no evidence that the 'threshold' assumption has some basis in fact.

Two studies used within-participant designs. Petruzzello and Landers[143] examined the effects of treadmill running at 75% $\dot{V}O_{2max}$ for 15 or 30 minutes on the state anxiety subscale of the STAI and the scales of the Positive and Negative Affect Schedule (PANAS).[144] Rudolph et al.[67] examined the effects of treadmill running at a 'moderate' level of perceived exertion for either 10 or 20 minutes on the state anxiety subscale of the STAI. Although Petruzzello and Landers found significant main effects of time of assessment for STAI and negative affect, and Rudolph et al. found significant reductions in STAI scores, neither study found a significant interaction between duration condition and time of affect assessment.

Three studies used between-participant designs with random assignment to duration groups. Rejeski et al.[145] compared the effects of cycle ergometer exercise at 70% HRR for 10, 25 or 40 minutes, using the PANAS and the EFI. Significant main effects of time of assessment were found for almost all dependent measures (except physical exhaustion), but there was no significant interaction between duration group and time of assessment. Rudolph and Butki[66,146] compared the effects of treadmill running at an RPE of 13 ('somewhat hard') for 10, 15 and 20 minutes, using the SEES and the state anxiety subscale of the STAI. Positive well-being was significantly increased and psychological distress and STAI scores were significantly decreased post-exercise, compared with pre-exercise, but there was no duration group main effect or duration group by time interaction. Blanchard and Rogers[147] compared the effects of running on an indoor track at 70% HRR for either 25 or 40 minutes, using the EFI. Affective responses improved regardless of duration, with the only exception being that the 25-minute condition led to significantly more positive engagement, compared with the 40-minute condition.

Two additional studies, focusing primarily on exercise duration effects on psychophysiological stress responses, included assessments of self-reported affect, but procedural or analytical features preclude any safe inferences.[148,149] In neither study did the duration of the exercise bout have a significant effect on affective responses.

By failing to show a clear pattern of differential influence of exercise bout duration on pre- to post-exercise affective changes, these findings seem to refute the assumption of a 'threshold' duration required for exercise-associated affective changes to occur. However, this conclusion may be premature. In most studies, post-exercise assessments of affect were made several minutes following the termination of the exercise bout: 5 minutes when exercise was rated as 'somewhat hard',[66,67,146] 20 minutes when the intensity was 70% HRR,[145] or as long as it took for heart rate to return to near-baseline levels.[147] Waiting for such relatively long recovery periods before conducting the post-exercise assessment might have allowed any duration effects to dissipate. In the only relevant study to include an assessment of affect immediately post-exercise, the participants were fit and the exercise stimulus was relatively mild.[143]

As was shown in the review of intensity effects, it is possible that attempting to assess dose-response effects by examining only changes from before to various time points after exercise is problematic, because it disregards the dynamic nature of affective change. A different approach at examining the effects of exercise duration is to assess affective responses at multiple time points during the exercise bout. An example is a study of distance runners by Acevedo and associates,[150] in which FS ratings were obtained every 30 minutes during a 2-hour run, while running intensity was maintained between 70 and 75% $\dot{V}O_{2max}$. Heart rate and lactate and glucose levels were also assessed. In spite of the stable intensity, RPE responses increased over time and FS responses progressively declined. Furthermore, as RPE and physiological indices increased, the magnitude of their negative relationship to FS progressively increased, as did the magnitude of the positive relationship between RPE and physiological variables.

Such findings indicate that, as is the case with the investigation of intensity effects, assessing affective change from pre- to post-exercise can provide a limited and potentially misleading perspective on the true effects of different exercise bout durations. Because the Acevedo et al.[150] study involved a highly fit sample and a much longer than average exercise duration, it would be inappropriate to attempt to generalise its findings to the population at large. This study was instrumental, however, in showing that: (i) affective responses may exhibit a systematic, intensity-independent, pattern of change as exercise duration progresses; and (ii) both affect and exertion ratings develop progressively stronger links to physiological indices of metabolic strain. This area of investigation is in urgent need of more information, particularly regarding the dynamics of affective change during exercise.

3. Problems and Recommendations for Future Research

From the present review, it becomes apparent that the current knowledge base regarding the dose-response relationship between acute aerobic exercise and affect is limited. This is not only a function of the small number of relevant studies that have appeared to date, but may also partly be a reflection of commonly criticised methodological problems, such as the lack of placebo plots, the use of small samples and the lack of control for volunteerism and expectancy effects.[125,151-157] However, it could be argued that perhaps the greatest problem is the lack of theoretical sophistication in the majority of published research. Most studies continue to be purely descriptive and to consider theoretical explanations only in an ex post facto manner. In the following sections, we identify 5 aspects of dose-response research that were shown in the preceding analysis to pose rather vexing problems, and propose theory-based routes for resolving them in future research.

3.1 Psychometrics of Affect

The conceptualisation and operationalisation of affect poses one of the greatest challenges for the future study of the exercise-affect relationship. The commonly used self-report measures of affect have been heavily criticised in recent years[45,158-160] and some critical problems have been documented repeatedly.[101,161,162] Nevertheless, the growing disenchantment with traditionally used instruments has not yet materialised into a systematic, theory-based overhaul of concepts and methods. By continuing to employ measures without scrutinising their relevance, theoretical foundation and psychometric merit in the particular context of acute exercise, this area of investigation runs the risk of becoming bound to, dependent upon and eventually captive to the measures. In this light, we have chosen to examine some of the most important aspects of the affect measurement conundrum and conclude this analysis by proposing a possible solution.

Firstly, little attention has been paid to the substantive theoretical distinctions between affective constructs. It is not uncommon in exercise psychology to see the terms emotion, mood and affect being used interchangeably. As a prominent example, state anxiety, an emotion that is elicited following the cognitive appraisal of a situation as personally threatening, is often equated with tension. However, tension describes the subjective experience of being in an activated unpleasant state but does not entail a specific requisite pattern of cognitive antecedents. To illustrate the importance of this distinction, in a study using a visual analogue scale to assess anxiety during exercise (with anchors referring explicitly to 'anxiety') and the tension scale of POMS to assess pre- to post-exercise changes in tension, Steptoe and Bolton[103] found that 15 minutes of 100W cycle ergometer exercise led to an increase in tension scores immediately after exercise (perhaps associated with effort) but did not have a significant effect on reports of anxiety.

As noted earlier, the issue of the distinction between tension, which may or may not have a cognitive basis, and state anxiety, which by definition is dependent upon a specific pattern of cognitive appraisals, has also been shown to affect one of the most popular measures in exercise psychology, the state anxiety subscale of STAI. Rejeski and coworkers[101] demonstrated that when the scale was used during strenuous exercise, some items related to perceived activation and the absence of tension, such as 'calm' and 'relaxed', showed increases (participants felt less calm and relaxed, which are scored and interpreted as increases in state anxiety), whereas others referring to cognitive antecedents of state anxiety showed decreases. Moreover, the internal consistency of the scale was reduced. Thus, the total score was confounded, raising serious interpretability concerns. The problem lies in the fact that, in the development of the STAI, any increases in activation were assumed to be anxiety-induced or anxiety-related.[161] However, vigorous exercise presents a special case where activation is increased in response to increased metabolic activity, independently of anxiety-related cognitions. Indeed, because the source of the increased activation is so evident, it is highly unlikely that exercisers will misattribute it or in any way relate it to anxiety.[163]

Feeling less 'calm' or 'relaxed' during or immediately following a bout of strenuous exercise does not necessarily mean that one is more anxious. Similarly, following the termination of the exercise stimulus, certain perceptually salient physiological indices, such as blood pressure and muscle tension, have been shown to drop to below pre-exercise values.[164-167] Again, it is theoretically inappropriate to equate the perception of such changes with decreases in anxiety.[101,161] This issue is highly relevant to research on dose-response issues. For example, several researchers have argued that intense exercise leads to increases in state anxiety.[49,50] It is likely that these 'increases' were mainly due to increases only in items pertaining to perceived activation.[101,161,162]

To summarise this first point, from the prevailing cognitive perspective, the generation of a certain emotional state is causally linked to a specific antecedent pattern of situational appraisals. Therefore, emotions require a degree of cognitive involvement, such as the use of memory and the representation of the meaning of the situation and the goals of the individual. Furthermore, emotions are thought to have a clear focus, a relatively short duration, and a close temporal relationship to an eliciting stimulus.[168] On the other hand, mood states are also thought to have a cognitive basis, but typically lack a distinct focus, are temporally and situationally removed from their eliciting stimulus, and have a longer duration, compared with emotions.[168] Finally, affect is a more general term which refers to the quality of the subjective experience that characterises all valenced responses, including, but not limited to, emotions and moods.[168]

From a broad theoretical standpoint, one could conceptualise emotions, moods and affect as lying on a continuum of evolutionary complexity, with emotions requiring the most and basic affect requiring the least amount of cognitive involvement. What is important to recognise is that exercise could conceivably induce changes at all levels of this continuum, from the generic aversion of strain and exhaustion to the intricacies of socio-culturally framed social physique anxiety. These are distinct constructs which cannot be effectively studied through a unitary perspective. Instead, a more reasonable approach seems to be to recognise their substantive differences and proceed systematically from the general (i.e. affect) to the specific (i.e. emotions).

The second aspect of the affect measurement conundrum in exercise psychology deals with the fact that the phenomenological nature of the affective changes associated with exercise remains unknown.[45,169] What is generically referred to as the exercise-associated 'feel-better' phenomenon has been traditionally operationalised as decreases in anxiety or depression, or changes in various mood states. However, a theoretical rationale for focusing on these variables to the exclusion of other potentially relevant variables has never been presented. Instead, it seems that the process of selecting operationalisations of affect has centred around the measures rather than the constructs themselves. It is not surprising that the most popular measures in this line of research, such as the STAI and the POMS, were developed and were gaining popularity in the late 1960s and early 1970s, when the study of the exercise-related 'feel-better' phenomenon was getting under way.

Although those early efforts were undoubtedly instrumental in sensitising the scientific community and the public about the affective benefits of exercise, this battery of measures has outlived its utility. Among other problems, these measures focus on few and distinct negative affective states, thus providing a limited and biased view of the affective changes associated with exercise. Furthermore, when these measures are used with young and healthy samples of undergraduate student volunteers and when the negative affective states they were developed to assess are not induced experimentally, baseline scores typically tend to fall very close to the minimum of the possible range, thus minimising variability and obscuring any exercise effects (called a 'floor effect').[45] For the systematic examination of the elusive nature of the 'feel-better' phenomenon to begin, it seems that the development of a widely accepted, theory-based template or 'map' of affective space would be desirable. The basic requirements of such a conceptual model are its breadth and balance; this 'map' must be as broadly encompassing and unbiased as possible, in order to enable the detection of affective changes in any conceivable direction.

In response to escalating frustration with the traditionally employed measures, 2 scales were developed specifically for use in the exercise context: the EFI[114] and the SEES.[138] Despite their growing popularity, these scales have not undergone any critical scrutiny to date, so a discussion of certain key conceptual and technical issues seems in order.

The EFI[114] was based on the fundamental assumption that 'the stimulus properties of physical activity are capable of producing several distinct feeling states'. Specifically, the EFI includes scales for the assessment of revitalisation, tranquility, positive engagement and physical exhaustion. However, as previously noted, there is presently no evidence that would allow one to focus on certain affective states as being uniquely relevant to the exercise experience to the exclusion of other affective states. Therefore, there is no evidence that the EFI can capture the most phenomenologically salient affective changes associated with exercise. For instance, with the exception of the physical exhaustion scale (which might or might not be negatively valenced), the EFI can provide no information on possible negative affective responses to exercise. Furthermore, from a technical psychometric standpoint, a close inspection of the structural analyses reported by Gauvin and Rejeski[114] reveals that the EFI lacks simple structure; the revitalisation and positive engagement factors are almost perfectly redundant, with no statistical or conceptual support for their distinction. After correcting for their unreliability, scores on the revitalisation and positive engagement scales are correlated ($r = 0.90$) and the associated latent factors were shown to be correlated ($r = 0.86$). Therefore, both the content domain and the structure of the instrument must be called into question.

On the other hand, the SEES[138] was developed as a measure of more general or superordinate structural aspects of exercise-associated affect, compared with the EFI. However, the conceptual assumptions underlying the development of the instrument appear to be flawed. The SEES includes 3 scales:

Psychological Well-Being (PWB), Psychological Distress (PD) and fatigue. The PWB and PD scales were presented as conceptual equivalents of the 'Positive Affect' (PA) and 'Negative Affect' (NA) dimensions, respectively, as described by Watson, Tellegen and associates.[170-172] PA and NA are theorised to be 2 orthogonal and bipolar dimensions that define global affective space. Specifically, high PA is characterised by adjectives denoting pleasantness and high activation (e.g. 'elated'), whereas its bipolar opposite, low PA, is represented by adjectives characteristic of unpleasantness and low activation (e.g. 'drowsy'). Conversely, high NA represents a composite of high activation and unpleasantness (e.g. 'distressed'), whereas low NA describes a state of pleasant low activation (e.g. 'calm').

While the actual statistical and conceptual underpinnings of the PA-NA model are widely accepted, the selection of the labels 'Positive Affect' and 'Negative Affect' has been criticised as being misleading.[72,173] This is because these terms denote unipolar states, not bipolar dimensions. Consequently, some authors have erroneously equated PA with generic pleasure and NA with generic displeasure, thus being led to believe that 'positive affect' (referring not to PA, but rather to generic pleasure) and 'negative affect' (referring not to NA, but rather to generic displeasure) are orthogonal. However, an examination of the empirical evidence presented by Watson, Tellegen and associates[170-172] clearly shows that this statement is false; in fact, pleasure (e.g. 'happy') and displeasure (e.g. 'sad') were shown in the structural analyses reported by Watson, Tellegen and associates[170-172] to be bipolar opposites on a dimension labelled 'pleasantness-unpleasantness'. Echoing similarly misguided statements, McAuley and Courneya[138] declared that 'from a conceptual standpoint, we concur with the broader social psychological literature that suggests emotional and affective responses vary along two (positive and negative) . . . dimensions'. The fallacy of this position is manifested in the significant (–0.52) correlation found between PWB and PD scores.[138] It must be emphasised that this correlation refers to raw scores; as studies have shown, the magnitude of negative correlations between pleasure and displeasure scores is increased dramatically when scores are corrected for random and nonrandom measurement error.[174-176]

The foregoing analysis demonstrates that there are serious issues related to the measurement of affective responses in the context of exercise which remain unresolved. Given the cardinal role of measurement for any scientific endeavour, it seems imperative that these issues be given immediate attention as exercise psychology researchers venture into the study of dose-response issues. From the points raised herein, the following conclusions can be drawn as a basis for a resolution: (i) measurement efforts should initially target general affect, with the long term goal of systematically narrowing the investigative scope and eventually focusing on the most relevant specific affective states and, possibly, emotions; (ii) the operationalisation of affective space must be broad and balanced between affective positivity and negativity; (iii) the model should be able to account for fluctuations in perceived activation and distinguish between positively and negatively laden activation; and (iv) the model should have a clearly delineated and widely accepted theoretical foundation, in order to allow the development of measures following a deductive approach, that is, to proceed from a clearly defined set of theoretical precepts to the development of items and scales.

Considering these requisites, the most appropriate solution at this point appears to be the transition to a dimensional model of affect. As opposed to categorical approaches which consider affective states as discrete entities, dimensional approaches seek to identify a structural model or a cohesive conceptual representation of the systematic relationships among affective states. The relative advantage of a dimensional approach in the context of exercise is the breadth of scope that it affords. Given our current lack of understanding of the nature of the affective changes associated with exercise, it is preferable to maintain a broad perspective instead of following a categorical approach, which 'at the outset, limits the focus of investigation to specific

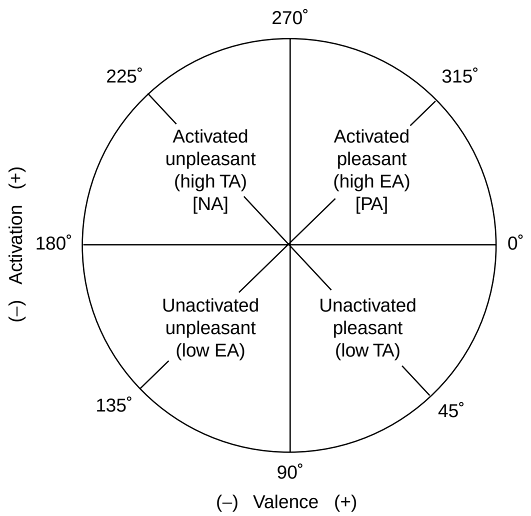

Fig. 1. The circumplex model of affect. **EA** = energetic arousal; **NA** = negative affect; **PA** = positive affect; **TA** = tense arousal.

emotions'.[45] Among the various dimensional models, perhaps the highest degree of parsimony is afforded by the 2-dimensional circumplex model and its rotational variants (see fig. 1).[177-179] According to this conceptualisation, affective states are systematically interrelated, such that they can be thought of as located along the perimeter of a circle which is defined by 2 orthogonal and bipolar dimensions: one is characterised by pleasure-displeasure and the other refers to the degree of activation. The resultant 4 quadrants of the affective space are characterised by tension or distress (high activation and displeasure), excitement or enthusiasm (high activation and pleasure), calmness or relaxation (low activation and pleasure) and boredom, fatigue or depression (low activation and displeasure).

The circumplex model of affect is recognised as having great heuristic value, providing a simple yet powerful way to organise facts about affect.[173] Its application in the context of exercise seems to have the potential to address all the issues identified in the preceding analysis: it can provide a global representation of the affective space, it is balanced between positive and negative affectivity, it is based on the distinction between activation and affective valence and, because it targets elemental dimensions of affect, a circumplex-based operationalisation should maintain its psychometric integrity in the context of acute exercise. Yet, despite these potential advantages, 'the circumplex model of affect has been virtually ignored by researchers in exercise psychology'.[45] We propose that it is time exercise psychology researchers examined the merits of the circumplex model.[180]

3.2 Theoretical Models of the Association Between Activation and Affect

One of the fundamental theoretical premises of the present review, as presented from the outset, is that the issue of dose-response effects is unlikely to be resolved in a nomothetic manner. Instead, we suggested that a more effective avenue to pursue would be the systematic dissection of inter- and intra-individual variability by examining the role of mediator variables. Indeed, psychological theory offers a number of potentially relevant hypotheses, from a variety of sources, which are worthy of investigation. The theories to be presented here by no means constitute a complete list. Priority was given to formulations which have evolved mainly from human research, that have direct implications for exercise dose-response research, and for which standardised self-report measures of the key variables are currently available. For each of the 7 models presented below, the discussion of possible applications for the context of exercise and the review of any relevant empirical literature are preceded by a short introduction to the basic premises of the theory.

3.2.1 Extraversion

Within Eysenck's[181] dimensional theory of personality, there is strong evidence that extraversion-introversion is a powerful modulator of mood and mood variability.[182,183] More specifically, extraversion has been shown to be closely linked with positive affect.[184-186] Eysenck hypothesised that, in general, the relationship between sensory stimulation and hedonic tone can be described as an 'inverted-U'; that is, too little (i.e. sensory deprivation) or too much stimulation (i.e. pain) is equally disliked, with intermediate levels being preferred.

However, he postulated that extraverts and introverts depart from this general curve in opposite directions (for reviews and graphical illustrations, see Eysenck[187] and Eysenck et al.[188]). Introverts, because of their hypothesised high level of basal arousal, augment incoming stimulation, whereas extraverts, because of their low level of basal arousal, reduce the intensity of incoming stimulation. Thus, there is a point at the low end of the sensory stimulation continuum where introverts are hypothesised to experience positive hedonic tone, whereas extraverts are hypothesised to experience negative hedonic tone. Conversely, there is a point at the high end of the sensory stimulation continuum where extraverts are hypothesised to experience positive hedonic tone and introverts negative hedonic tone. In other words, Eysenck's theory predicts that 'the optimal (preferred) level of stimulation of introverts is to the left of the general population, that of extraverts is to the right'.[188] Consequently, extraverts are expected to seek out strong sensory stimulation, whereas introverts would seek to avoid it.

Applying this model in the context of exercise, extraverts would be predicted to prefer larger doses of activity (higher intensity, longer duration) compared with introverts. However, despite its simplicity and strong conceptual underpinnings this hypothesis has not been examined systematically (for a review, see Morgan[189]). A preliminary study cited by Morgan[190] indicated that extraversion was associated with a higher preferred level of intensity and lower RPE scores in cycle ergometer exercise, particularly at higher absolute intensity levels. However, a study of adolescent boys failed to replicate this finding.[191] Shiomi[192] showed that extraverts tend to persist longer while exercising against a constant load across a number of trials. This may be facilitated by more efficient energy substrate mobilisation found among extraverts.[193] On the other hand, extraversion was found to be unrelated to levels of glucose or lactate following exercise.[194] Finally, studies have shown that extraversion is associated with involvement in more physically active recreation.[195,196]

Researchers should be aware that relatively brief standardised measures of the basic constructs of the theory are available,[197] as is a large empirical literature documenting the relevance of the theory to research examining the interplay between the intensity of sensory stimulation and affect.

3.2.2 Sensation Seeking

A conceptual relative of the Eysenckian dimension of extraversion-introversion,[198-200] sensation seeking is described as a genetically determined[201] and biologically based[200,202] trait. It is defined by 'the need for varied, novel, and complex sensations and experiences and the willingness to take physical and social risks for the sake of such experience'.[203] The dimensions of sensation seeking, as measured by the Sensation Seeking Scale (SSS),[203] are: (i) thrill and adventure seeking; (ii) experience seeking; (iii) disinhibition; and (iv) boredom susceptibility.[203,204] Sensation seeking can be conceptualised as the result of natural variation in approach and withdrawal mechanisms which form the basis for individual differences in reactivity to intense and novel stimulation.[202,205] In the contemporary formulation of the theory,[128,200,202] the brain catecholamine systems are considered the source of hedonic tone. These systems are known to respond to physiological stimulation and arousal. The predictions of the theory regarding the interaction between the degree of arousal (and the associated activation of the brain catecholamine systems) and hedonic tone is based on a variation of the optimal level of arousal theory.[200] According to this notion, there is a level of activity of the catecholamine systems which is optimal for positive hedonic tone.

Extremely low catecholamine system activity (CSA) is associated with depression, withdrawal, and inhibition of activity. Extremely high activity in these systems, on the other hand, is associated with dysphoria, primarily anxiety. Thus, the optimal level of CSA is theorised to be moderate. A high sensation seeker is hypothesised to have low tonic CSA. Therefore, intense stimulation would be required in order to increase CSA to the optimal level for positive hedonic tone. Conversely, the low sensation seeker is hypothesised to have high tonic CSA, and additional stimulation may result in anxiety or panic. A high sensation seeker is also characterised by a 'strong nervous system', which manifests itself as an insensitivity to weak stimulation and high tolerance for high levels of stimulation (e.g. high pain thresholds). In the case of high intensity stimuli, the high sensation seeker is prepared to endure, while the nervous system of the low sensation seeker is set to shut down in anticipation of overload.[202]

Zuckerman[206] has argued that 'sensation seeking is a general trait that is not restricted to any one sensory modality'. Given the tendency of high sensation seekers to prefer higher levels of sensory stimulation, it could be hypothesised that sensation seeking would be associated with a preference for larger doses of exercise. However, this idea remains unexamined. In the only exercise-related studies, Babbitt et al.[207,208] found that participants in group-based, regimented and structured aerobic exercise classes scored below the population average on the SSS, and that SSS scores were negatively correlated with a measure of the tendency for regimentation.

Research on the association between sensation seeking and preferences for exercise doses might have been hindered by the apparent lack of relevance of the SSS items and factors to the common motives for participating in aerobic exercise. However, it must be noted that sensation seeking can also manifest itself as a state. According to Zuckerman,[206] 'like many traits, sensation seeking may rest on a biological foundation and yet may depend for its particular expression on a range of environmental possibilities'. Thus, situation-nonspecific self-report measures of state sensation seeking were developed.[203,209,210] These measures might prove to be much more relevant to exercise psychology and might help boost research interest towards the concept of sensation seeking.

3.2.3 Type A Behaviour Pattern and Self-Evaluative Tendencies

Despite the declining popularity of the Type A Behaviour Pattern (TABP) as a predictor of cardiovascular morbidity and mortality, there has been significant progress in the development of social-cognitive models for TABP which focus on self-evaluative processes.[211-213] These models may provide insight to the role of individual differences in self-evaluative tendencies in shaping affective responses to exercise performed in social contexts.

TABP has been associated with a tendency towards involvement in intense and competitive exercise.[214-218] This might be associated with the lower adherence rates found among type A individuals, compared with type B individuals,[219,220] as well as with the increased prevalence of exercise-related injuries in type A individuals.[221,222] TABP is also associated with a particular pattern of responses during exercise. Type A individuals tend to exert more effort, resulting in higher physiological activation during exercise, but they either underestimate or under-report sensations of exertion and discomfort, at least at low to moderate levels of exercise intensity.[223-225] At higher intensities, they tend to react with more negative affect, compared with type B individuals,[121] and have more pronounced psychoneuroendocrine stress responses.[226] The role of TABP as a mediator of perceptual and affective responses to exercise has not been confirmed in all studies,[227-230] suggesting an important role for situational factors (e.g. perceived social evaluation). In the unobtrusive observational study of Worringham and Messick,[231] perceived social evaluation was shown to be associated with the selection of faster running speeds.

3.2.4 Theory of Psychological Reversals

A fundamental tenet of the theory of psychological reversals, or 'reversal theory',[232,233] is that optimal hedonic tone is not necessarily linked to a certain (i.e. moderate) level of arousal.[234,235] Instead, according to reversal theory, it is the individual's state of mind (or 'meta-motivational state') that determines the experiential quality of arousal. The pair of metamotivational states that is most relevant in the context of exercise and affect is the 'telic-paratelic' pair. According to Apter,[232] the 'telic' state is defined as the phenomenological state in which the individual is primarily oriented towards, or feels the need to be primarily oriented towards, some essential goal. The 'paratelic' state, on the other hand, is defined as a state in which the individual is primarily oriented towards his or her ongoing behaviour and the immediate sensations associated with it. A person may exhibit reversals from one state (e.g. telic) to the other (e.g. paratelic) over time, in response to various reversal-inducing stimuli. Furthermore, a person may exhibit a tendency to spend relatively more time in one state than the other. This predisposition is termed telic or paratelic 'dominance'.

Telic and paratelic states are theorised to impact the linkage between arousal and affect in opposite directions. The telic state is characterised by a tendency to lower the intensity of experience, whereas in the paratelic state there is a tendency to heighten it. Therefore, in the telic state, the preferred level of intensity is low (characterised by 'anxiety-avoidance'), whereas in the paratelic state the preferred level of intensity is high (characterised by 'excitement-seeking').[127,233,236-238] Thus, the relationship between arousal and hedonic tone can be described by 2 dose-response curves: one for the telic and the other for the paratelic state.

These ideas are applicable to the context of exercise. For instance, exercising while being preoccupied with the expected outcomes of the activity, such as weight loss or fitness enhancement, or exercising under social, familial or ego-related pressures, would put one in a telic state. The same would presumably occur when a research participant, complying with the instructions of the experimenter, exercises at an imposed level of exercise intensity. In these situations, reversal theory would predict that lower levels of stimulation would be preferred and that higher levels would be experienced as aversive.

Conversely, exercising for the sake of the experience, without allowing the ultimate goal of exercise participation to overshadow the experience of the immediate sensations, would place someone in a paratelic state. The same would also be likely to occur if a study participant was allowed to select the mode and the dose of the experimental exercise stimulus. In paratelic states, reversal theory would predict that higher levels of stimulation would be preferred. However, it should also be kept in mind that, according to Apter,[232,233,235] numerous stimuli might induce reversals from one state to the other at any time. For instance, the exerciser might be presented with an externally-imposed goal (e.g. 'let's finish this mile'); might experience pain or intense exertional symptoms (signifying physical danger); might perceive the situation as competitive (ego-threat); might be frustrated with not being able to reach excitement; or might simply feel that he or she had had enough after some time of enjoyable exercise.

One of the most intriguing implications of the theory is that a directly opposite pattern of responses is predicted when the dose of exercise (i.e. intensity, duration) is self-selected versus imposed. Preliminary data by Dishman et al.[124] regarding RPE responses, and Zervas et al.[109] regarding the relationship of heart rate and RPE to FS during exercise of self-selected intensity seem to support the predictions of reversal theory. This presents some potentially fruitful avenues for future research.

The potential applications of reversal theory for the study of exercise-associated affective changes have been discussed by some authors,[239-241] but systematic research is still lacking. A preliminary study by Kerr and Vlaswinkel[242] examined changes in reversal theory variables in runners exercising in natural conditions. The results showed that preferred arousal progressively increased during the run, while the discrepancy between perceived and preferred arousal progressively decreased. Furthermore, faster runners had higher preferred levels of arousal than slower runners and experienced smaller discrepancies between perceived and preferred arousal. However, the mediating role of telic and paratelic states in the relationship between exercise dose and affective response has not been examined. Researchers interested in this topic should be aware that both dispositional[243] and state[244,245] measures of reversal theory constructs are available.

3.2.5 Optimal Stimulation Theory

The optimal stimulation theory emerged from Csikszentmihalyi's writings on enjoyment and the experience of flow states.[246-251] 'Flow' is defined as 'a subjective state that people report when they are completely involved in something to the point of forgetting time, fatigue, and everything else but the activity itself'.[251] One of the most common characteristics of activities associated with flow experiences is that they involve a perceived balance between the challenges they present and one's level of ability. Therefore, a person feels that he or she can act upon them without feeling either bored or worried. Initially, the theory predicted that this condition applied to the whole gamut of levels of skill and challenge. However, Massimini and Carli[252] later proposed that optimal experience is defined by the perceived matching of an above average challenge with an above average skill.

Applied to the context of exercise, optimal stimulation theory would predict that 'optimal experiences', presumably associated with positive affective responses, are more likely to occur among highly trained or fit individuals engaged in exercise of such intensity that would be perceived as challenging, but not exceeding, their ability. This hypothesis has not been tested. In a study based on optimal stimulation theory, Tuson et al.[108] examined the hypothesis that exercise perceived to be of moderate intensity would be associated with more positive affective responses compared with exercise perceived to be too light or too strenuous. The results showed that for participants with both high and low initial levels of positive affect, exercise perceived to be of moderate intensity was the most effective in increasing positive affect. On the other hand, exercise intensity defined as a percentage of estimated maximal aerobic capacity was unrelated to changes in affect.

The notion that the conditions for positive affective change are optimised when perceived demand and perceived capacity are matched and the postulate that both demand and capacity must be 'above average' warrant further study. However, testing the optimal stimulation theory is hindered by the conceptual and methodological difficulties associated with operationalising the rather abstract constructs of 'optimal experience' and 'flow'.[250-253]

3.2.6 Thayer's Multidimensional Activation Theory

In response to problems associated with the notion of a unitary activation continuum, Thayer[72,254,255] developed a theory which incorporates 2 bipolar activation dimensions: one characterised by energy-sleep and one characterised by tension-placidity. The first activation dimension, termed 'Energetic Arousal' (EA), refers to feelings ranging from energy, vigor and liveliness to feelings of fatigue and tiredness. This dimension is hypothesised to follow a circadian rhythm and to reflect changes in gross physical activity. The second dimension, termed 'Tense Arousal' (TA), ranges from subjective tension to placidity, quietness and stillness. Thayer[72] proposed that the relationship between the 2 dimensions varies as a function of energy expenditure, such that they are positively correlated from low to moderate levels of energy expenditure, and negatively correlated from moderate to high levels.

Applied to the context of exercise, this model would predict that EA and TA would be positively correlated during exercise of low to moderate intensity and negatively correlated during exercise of high intensity. However, the actual levels of energy expenditure that correspond to the labels 'low', 'moderate' and 'high' have not been specified. Thayer and associates have repeatedly demonstrated that walking increases subjective energy and reduces tension.[68-70] Thayer considers walking as an exercise of 'moderate' intensity, but emphasises that it is not clear what amount of exercise is sufficient to increase energetic arousal, nor is it clear what level of exercise will result in fatigue instead of increased energy.[72] Furthermore, he hypothesises that 'a given amount of exercise may result in an initial period of fatigue followed by increased energy feelings a short while later'.[72] In addition to energy expenditure, 2 more variables are assumed to mediate the relationship between EA and TA: the individual's overall physical condition and his or her 'state' at the time of the exercise.

It is worth pointing out that the theory also makes a rather unique prediction regarding affective responses at low levels of energy expenditure. At such levels, it is theorised that increases in EA would be associated with increases in TA. Therefore, exercise of low intensity would increase rather than decrease negative affectivity. To substantiate this position, Thayer[72] cited a study of psychiatric patients by Dodson and Mullens,[256] in which jogging resulted in reduced tension and increased alertness, whereas light exercise resulted in increased anxiety.

To date, only 1 dose-response study[106] has examined the predictions of the multidimensional activation theory. Volunteers participated in 3 randomly ordered, 30-minute long conditions: 55 and 70% $\dot{V}O_{2max}$ cycle ergometer exercise conditions, and a control condition. EA and TA, measured using Thayer's AD ACL,[72] were assessed before, at 5, 15 and 25 minutes during each treatment, and at 0, 5, 10, 20 and 30 minutes into recovery. A clear dose-response pattern did not emerge. TA was reduced from all points during and immediately following exercise to all assessments made during recovery. On the other hand, EA was increased during exercise and remained elevated after exercise compared with baseline, but was significantly lower compared with assessments made during exercise. The only dose-response effect was that the elevated levels of EA were maintained longer following the 70% $\dot{V}O_{2max}$ exercise condition. The failure to detect differential dose-response effects might have been a result of the small difference between the 2 employed intensities, which would both be characterised as 'moderate' by current exercise prescription standards.[257]

3.2.7 Self-Efficacy

According to Bandura,[258] 'perceived self-efficacy refers to beliefs in one's capabilities to mobilize the motivation, cognitive resources, and courses of action needed to meet situational demands'. Efficacy cognitions are theorised to be important determinants of behaviour, thought patterns and affective reactions in situations perceived as challenging. In such situations, highly efficacious individuals tend to approach more challenging tasks, exert more effort and persist longer. In the context of acute exercise, there is considerable evidence that self-efficacy is, in fact, associated with affective responses and ratings of perceived exertion.[259-264] Based on the idea that the salience of self-efficacy as a mediator of affective responses is maximised in the face of challenging (i.e. aversive) stimuli, McAuley and Courneya[261] proposed that the association between physical self-efficacy and affect should become stronger when exercise intensity reaches a level where exertional symptoms become unequivocally aversive (tentatively specified as above 70% HR_{max}). At such an intensity level, a highly efficacious person is expected to exhibit more positive affect and lower perceived exertion compared with a less efficacious one.

The 2 dose-response studies that have examined this hypothesis have yielded conflicting results. Treasure and Newbery[107] showed that self-efficacy ratings obtained at the fifth minute of an exercise bout predicted reports of physical exhaustion assessed by the EFI at the fifteenth (final) minute of exercise when the intensity was 70 to 75% HRR, but not when it was 45 to 50% HRR. Conversely, Tate et al.[265] showed that pre-exercise efficacy was a significant predictor of tense arousal during exercise performed at 55% $\dot{V}O_{2max}$, but not at 70% $\dot{V}O_{2max}$. Pre-exercise efficacy was also a significant predictor of energetic arousal 30 minutes following exercise at 55% $\dot{V}O_{2max}$ and of tense arousal 5 minutes following exercise at 70% $\dot{V}O_{2max}$. Differences in the participants' fitness levels and the exercise intensities involved might account for the conflicting results. Future research on this topic is warranted, provided that the problem of accurately operationalising a 'challenging' exercise dose is adequately addressed.

3.3 Exercise and Post-Exercise Time Points

The review of studies examining in-task affect showed that during exercise of moderate and high intensity the positivity of self-reported affect is typically reduced[85,109,117,119,120] and tension is increased.[102] However, shortly following the termination of the exercise bout, a rapidly evolving pattern of affective improvement seems to arise, evidenced by almost all the self-report measures.[65,75,103,105,106,119] The same pattern of temporal changes had been observed in the earlier studies on state anxiety by Morgan and associates.[49,266,267] The consistency of this pattern across measures, protocols and laboratories is remarkable.

This pattern fits the predictions of the opponent-process theory of motivation.[268-271] This theory suggests that the initial affective reaction to strenuous exercise is driven by the so-called ‘a-process’, resulting in aversion and discomfort. However, this process always arouses an opponent process, the so-called ‘b-process’, which is characterised by the opposite affective quality (i.e. positive hedonic tone). The teleological purpose of the b-process is to return the organism to a state of hedonic neutrality. The interaction of these processes over time controls the intensity and the quality of the resultant affect. The b-process is hypothesised to be of longer latency relative to the a-process, and of slow build-up and slow decay. Thus, its effects persist after the termination of the exercise bout and are responsible for the feelings of lowered tension and exhilaration experienced post-exercise. Solomon[270] speculated that a ‘critical intensity’ of the a-process might need to be reached for the opponent process to be initiated. Therefore, some stimuli might arouse affect, but might not be of sufficient intensity to evoke an opponent process. For more detailed discussions of the opponent-process theory as it applies to exercise, the reader is referred to Boutcher[272] and Dishman and Landy.[58]

Given the consistent replication of the previously described pattern of affective changes during and following exercise of moderate and high intensity, it is suggested that the concept of opponent process be more closely examined. Methodologically, this entails the more consistent examination of in-task and post-exercise affective responses.

3.4 Aerobic Fitness and Activity Levels

Reviewers in the past have concluded that fitness is not a significant mediator of exercise-associated affective changes.[36] However, when dose-response studies are examined, this conclusion appears to misrepresent the data. There is evidence that the effects of fitness and activity levels are, in fact, intensity-dependent and are unveiled only at high, even relative, exercise doses.[76,103,105,273] Differences in affective responses to exercise between high- and low-active or high- and low-fit individuals have been demonstrated when the employed exercise stimuli were demanding (i.e. 80 to 85% of age-adjusted HR_{max} for 20 minutes;[273] 100W for 15 minutes;[103] a maximal exercise test[76,105]), but not when they were moderate.[274] Also, during exercise of high (90% $\dot{V}O_{2max}$), but not moderate (60% $\dot{V}O_{2max}$), relative intensity, high-active individuals showed lower perceived exertion and more positive affect, compared with low-active ones.[119,120]

Therefore, it appears that the dismissal of fitness and/or activity levels as being unrelated to exercise-associated affective changes cannot be justified on the basis of findings from dose-response studies. Consequently, the incorporation of this variable in factorial designs is strongly recommended, particularly for dose-response studies that include high exercise intensities and/or long durations.

3.5 Selection of Exercise Intensity Levels

Some of the studies examined in this review employed absolute levels of exercise intensity (i.e. fixed workloads[51,102-104] or fixed heart rate levels[51]), whereas most used relative levels (i.e. percentages of $\dot{V}O_{2max}$, HR_{max} or HRR). In other cases, exercise intensity was determined on the basis of individual perceptions of effort (i.e. ratings on the RPE scale).[93,162] In general, ‘relative’ methods are considered preferable over ‘absolute’ methods, because they are thought to take into account individual variability in physical capacity. For example, a workload of 100W may represent a metabolically different stimulus for a trained versus an untrained individual, whereas 70% $\dot{V}O_{2max}$ is assumed to represent a metabolically equivalent stimulus across individuals. In most cases, however, this assumption is false, since 70% $\dot{V}O_{2max}$ may represent aerobic effort in one individual, but require a substantial anaerobic component in another, even if they are of the same gender and have similar maximal aerobic capacity, age and health characteristics.[275] Therefore, to present a metabolically standard stimulus across individuals, one must take into account important individually determined metabolic landmarks.

In this respect, the typology of exercise intensity presented by Gaesser and Poole[276] may be used as a guide. Based on the commonalities in underlying physiology, these researchers postulated 3 distinct exercise intensity domains: (i) the domain of ‘moderate exercise’ includes all workloads below the lactate threshold; (ii) the domain of ‘heavy exercise’ extends from the lactate threshold to the work load that corresponds to the power-time asymptote (i.e. the highest workload at which lactate appearance and removal rates can be balanced and a lactate steady state maintained); and (iii) the domain of ‘severe exercise’ extends from the power-time asymptote to $\dot{V}O_{2max}$.

These metabolic landmarks have great adaptational value for the organism, so it would make good adaptational sense if they were linked to ‘alarming’ affective responses. In the RPE literature, there is evidence that the lactate and gas exchange thresholds act as ‘anchor points’, corresponding to stable ratings of exertion, unaffected by gender, training or exercise modality.[277-280] Furthermore, there is evidence that the correlation between RPE and physiological indices,[281] and FS and physiological indices,[282,283] particularly with ventilatory variables, is strengthened considerably at workloads at and above the lactate and gas exchange thresholds. In the only dose-response study to date to focus on affective responses and define exercise intensity relative to the onset of blood lactate accumulation (OBLA; i.e. 4 mmol/L), Acevedo and coworkers[116] found that FS increased nonsignificantly from a running velocity which corresponded to approximately 10% below OBLA to the velocity associated with OBLA, but decreased significantly (2 ± 2.6 points) from OBLA to a running velocity approximately 10% above OBLA. At this latter speed, RPE and FS were negatively related ($r = -0.68$) and RPE and VO_2 were positively related ($r = 0.61$).

In summary, the practice of defining exercise intensity in terms of arbitrarily selected percentage levels of $\dot{V}O_{2max}$, HR_{max} or HRR should not be considered an effective method of standardising exercise loads. Theoretical reasoning based on adaptational considerations, as well as preliminary evidence from the RPE and FS literatures, suggest that a more scientifically sound method would be to define exercise intensity in terms of adaptationally significant metabolic landmarks, such as the lactate and gas exchange thresholds and the power-time asymptote.

4. Conclusions

The study of the dose-response relationship between acute aerobic exercise and affect is still at an early stage. Given the relatively small number of studies and taking into account their methodological differences and limitations, characterising any conclusions as definitive would be imprudent. In this context, the cardinal function of the present review was to identify the main inadequacies in the extant literature, point out possible dead-ends, and recommend avenues for future research.

The review of studies examining pre- to post-exercise affective changes failed to reveal a consistent pattern of dose-response effects. Immediately following the termination of the exercise stimulus, there appears to be a ubiquitous trend towards improved affectivity, which manifests itself across a variety of self-report measures. Due to its almost instantaneous onset, this trend largely neutralises any dose-response effects. On the other hand, the few studies that have examined affective responses during exercise have painted a more diverse picture. Affective responses during exercise appear to be sensitive to dose effects, with increasing intensity and progressing duration being generally associated with reduced affective positivity. These findings suggest that research protocols limited to pre- to post-exercise assessments of affect offer a restrictive and possibly misleading representation of dose-response effects. Instead, experimental protocols should be geared towards tracking the dynamics of affective change across time, both during exercise and into recovery. It also appears that fitness and activity status become significant mediators of the exercise-affect relationship at larger exercise doses. Therefore, the examination of aerobic fitness or activity levels in future dose-response studies should be promoted.

However, it must be emphasised that even patterns that appear consistent when examined at a group level might subsume psychologically important individual variation. As noted from the beginning of this review, seeking a unitary and generalisable dose-response relationship underestimates the complexity of the issue. To aid future studies aimed at dissecting the variability in affective responses, 7 theoretical models were reviewed and their relevance to dose-response research was highlighted.

In terms of methodological attributes, future dose-response studies should not include less than 3 levels of intensity and/or duration in order to allow the detection of curvilinear trends, as hypothesised by most of the existing relevant theoretical models (see section 3.2). It is also appropriate to reconsider the way that levels of exercise intensity are determined. The practice of selecting arbitrary levels of $\dot{V}O_{2max}$ or HR_{max} has outlived its utility. 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.[276] The durations should preferably span a wide range, from 10 to 60 minutes, in order to cover most possible prescriptions. Because of the inextricable contributions of intensity and duration in determining an exercise ‘dose’, future research should strive to co-examine intensity and duration in factorial designs.[87,88]

Two of the assumptions underlying the typical laboratory paradigm require further investigation. Firstly, there seems to be sufficient theoretical justification to recommend the systematic study of the distinction between ‘self-selected’ or ‘preferred’ versus imposed exercise doses.[56,125] Secondly, the validity of extrapolating findings from laboratory studies to non-laboratory contexts should be reconsidered.[162,284] For instance, the effectiveness of a short, moderate intensity walk for conferring positive affective changes might be dramatically increased when the walk is incorporated in a stressful daily schedule. Similarly, a bout of intense exercise performed in the laboratory and an equally intense bout performed in a more pleasant or stimulating physical or social environment might have different affective outcomes.

The issue of measurement of affect arose as perhaps the most critical in this review. For a number of reasons outlined in section 3.1, addressing this issue should take priority. A shift from the categorical to a dimensional conceptualisation of affect was suggested here as an appropriate avenue. Dimensional models of affect, such as the circumplex, are characterised by unparalleled parsimony and thus appear to be ideal templates for charting the most phenomenologically salient affective changes associated with exercise.

The study of the dose-response relationship between acute aerobic exercise and affective responses has profound implications for theory and practice alike. To accelerate the much-needed progress in this area, exercise psychology researchers have to face the challenge of questioning several long-held beliefs and practices and replacing them with critical thought, methodological rigor and theoretical sophistication.

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