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The acute effects of exercise on cigarette cravings, withdrawal symptoms, affect and smoking behaviour: a systematic review

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ABSTRACT

Aim To review the effects of a single session of exercise on cigarette cravings, withdrawal symptoms and smoking behaviour. **Methods** A systematic search and critical appraisal of all 14 relevant studies. **Results** All 12 studies that compared a bout of exercise with a passive condition reported a positive effect on cigarette cravings, withdrawal symptoms and smoking behaviour. Two other studies that compared two intensities of exercise revealed no differences in outcomes. Single and multi-item measures of cigarette cravings, withdrawal symptoms and negative affect decreased rapidly during exercise and remained reduced for up to 50 minutes after exercise. Effect sizes for seven studies that assessed 'strength of desire to smoke' showed a mean reduction, 10 minutes after exercise, of 1.1 (SD 0.9). Four studies reported a two- to threefold longer time to the next cigarette following exercise. Cravings and withdrawal symptoms were reduced with an exercise intensity from as high as 60–85% heart rate reserve (HRR) (lasting 30–40 minutes) to as low as 24% HRR (lasting 15 minutes), and also with isometric exercise (for 5 minutes). All but one study involved participants temporarily abstaining for the purposes of the experiment. Distraction was probably not the primary reason for the effects. **Conclusions** Relatively small doses of exercise should be recommended as an aid to managing cigarette cravings and withdrawal symptoms. Further research to understand the mechanisms involved, such as stress reduction or neurobiological mechanisms, could lead to development of more effective and practical methods to reduce withdrawal phenomena.

Keywords Behavioural intervention, cue reactivity, coping, nicotine, physical activity, quitting aids.

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INTRODUCTION

Exercise has been recommended as an aid to smoking cessation (e.g. [1,2]), predominantly through limiting weight gain (and fear of weight gain). Unfortunately, studies designed to evaluate the effects of exercise, with such a focus, have shown mixed effects on smoking cessation [3,4]. Exercise may also play an important role in the acute management of tobacco withdrawal symptoms (e.g. depression, irritability, restlessness, poor concentration) and cravings that predict smoking relapse [5,6]. There has been a recent rapid growth in research on this topic and there is a need to consolidate this work to help guide future recommendations for exercise interventions and research. This paper provides the first systematic review of studies designed to assess the acute effects of a bout of exercise on cigarette cravings and withdrawal symptoms, and related variables, among those attempting to quit smoking and among temporarily abstinent smokers.

METHOD

We conducted a systematic review using online searches of the following electronic databases: Sport Discus (1975–July 2006), MEDLINE (1992–January 2006), PubMed (1966–January 2006), Web of Science (1945–January 2006), EMBASE (1980–January 2006) and PsycINFO (1887–January 2006). We also searched the Cochrane Tobacco Addiction Group specialized register, ETD Digital Library—Network Digital Library of Theses and Dissertations, and Proquest Digital Dissertations up to July 2006. Keywords included smoking, smoking cessation, exercise, physical activity, craving and withdrawal. We also hand-searched reference lists of relevant articles and the 2001–05 annual meeting abstracts of the Society for Research on Nicotine and Tobacco. For further leads, requests for literature were posted on key list-servers (SALIS, OTRU-NET, SRNT and Globalink), and we e-mailed authors of publications on exercise and smoking cessation interventions.

We included all studies assessing the acute effect of exercise on cigarette cravings or withdrawal symptoms, or affect, or smoking behaviour among smokers who were temporarily abstinent or who were attempting to quit. The search revealed 14 studies. Of these, 12 compared an active and a passive condition and the remaining two compared only different intensities of exercise. Also, two studies were not published [7,8] and two were published abstracts [9,10], but are considered in the review due to their unique methodology. Three additional studies were excluded from this review, as the focus was not on smoking-related withdrawal symptoms or cravings [11] or did not examine the effect of single bouts of exercise [12,13].

A wide range of outcome variables was identified in the studies, including single- and multi-item, and uni- and multi-dimensional measures of cigarette cravings (e.g. strength of desire to smoke), smoking-related withdrawal symptoms and non-specific measures of mood and affect (e.g. Profile of Mood States: see Table 1 for full list), and dimensions of smoking topography or behaviour (e.g. time before smoking the next cigarette). The overall findings, in terms of effects of exercise on different outcome measures, will be presented first with a critical appraisal of the methods used. This will be followed by a critical discussion of the possible mechanisms involved, and the implications for research and practice.

RESULTS

All 12 studies comparing an exercise and passive condition reported a positive effect on at least one key outcome variable as shown in Table 1.

Cigarette cravings

Nine of the 10 studies [9,10,14–22] that compared the effects of an active and passive condition on cravings reported a significant reduction during and following exercise. Only Daley and colleagues [23] failed to show an effect, although with moderate effect sizes (ES) of 0.47–0.74 at post-treatment assessments, this was due perhaps to being underpowered.

The findings revealed a moderate to large acute effect of exercise on smoking cravings, when comparing means (SDs) for the exercise and passive conditions at the post-baseline assessments. The calculated ES for seven randomized controlled studies (following temporary smoking abstinence) that assessed 'strength of desire to smoke' [24] peaked either during or soon after exercise. ES ranged from 0.50 to 2.07 for five of the studies. One other study involving 5 minutes of seated isometric exercise had a peak ES of 0.29 [22]. At the other extreme, a self-paced brisk 1-mile walk resulted in a peak ES of 4.6 [19], and the longest post-exercise effects. For the seven studies, the mean ES at 10 minutes post-treatment (i.e. the time-point when data were available from the seven studies) was 1.1 (SD = 0.9).

Three studies compared directly the effects of intensity of exercise on cravings and in only one case [15] were there statistically significant differences. Cycling at 40–60% of heart rate reserve (HRR) for 5 minutes reduced cravings compared with cycling at 10–20% HRR. It is unknown if longer periods of exercise at the respective intensities would have had the same effect. Pomerleau and colleagues [25] and Everson and colleagues [26] reported no significant difference on cravings between cycling at 80% versus 30% of VO_{2max} (for 30 minutes), and between 55% versus 44% of age-predicted maximal heart rate (for 10 minutes), respectively. The Pomerleau study was underpowered with just 10 subjects; a trend towards lower cravings in response to higher intensity exercise was reported. Also, the participants had only 30 minutes of abstinence prior to treatment, suggesting that baseline cravings may not have been particularly high (they were not reported) and a flooring effect may have masked any effects of exercise. The absence of a significant difference in cravings between the two intensities of exercise in the Everson study seems due, probably, to the relatively similar exercise intensities.

Physical activity of very low intensity and duration (e.g. isometric exercise, stretching), compared with a passive condition, has been shown to reduce cravings [22]. Given that cravings can peak relatively quickly, such exercise may be valuable as a temporary coping strategy, particularly in situations where cardiovascular-type exercise is impractical. In contrast, longer periods of low- to moderate-intensity exercise (i.e. a 15-minute brisk walk at 37%, 30% and 24%, of HRR; see [9,10,18,27]) have been shown to reduce cravings significantly for as long as 50 minutes, even during demanding mental challenges and in the presence of a lit cigarette.

Withdrawal symptoms

Eight of the nine studies [9,10,14–17,19,21,22] that compared the effects of an active and passive condition reported a significant reduction in at least two withdrawal

Table 1 Summary of studies on the acute effects of exercise on urges to smoke, withdrawal symptoms and time to smoking the next cigarette.

Study	Subjects characteristics	Abstinence period	Exercise characteristics	Measures	Design	Outcome
Mikhail (1983) (7)	18 m, inactive, low-moderate fitness. Mean age = 26 yrs. Mean time as smoker = 10 yrs. Smoked ≥ 1 pack/day for 3 yrs. Non-quitters	30 mins	All 10 mins. (a) & (b) = +4–5 min cool down) (a) cycle @ 104 bpm (66–69% max hr) (b) cycle @ 120 bpm (82–85% max hr) (c) passive (reading)	60 mins of Surreptitious observation in lab with freedom to smoke/read. Time to 1st puff. Duration of 1st lit cig. & no. of puffs. No. cigs in follow-up 60 mins + 23 hr. (adjusted for wake hrs).	Within subjects. 1 hr in lab post-treatment + 23 hr post-lab.	(a) & (b) less time with 1st lit cig. cf. (c). (a) & (b) not different. (b) No other sig. diffs. *
Reeser (1983) (8)	25 f & 12 m, inactive. Mean age = 24 yrs. Mean cigs = 23 p.d. Mean time as smoker = 8.4 yrs. Smoked ≥ 1 pack/day for 2 yrs. Non-quitters	None prescribed but mean time = 30 mins.	20 mins (a) = 3 min stretch + 13 min ex. + 2 min cool-down + 2 min stretch. (a) cycle @ 140 bpm (60% max HR) (b) stretch & isometrics (c) passive	30 mins of surreptitious observation in lab with freedom to smoke/read. SAI. Time to 1st cig & no. of puffs & time lit. No. who smoked. Time to 1st cig after leaving lab. (self-reported)	Between subjects (matched by age & sex) then randomised. Data presented from 2 lab sessions with same treatment condition.	Data averaged from 2 sessions: (b) < (c) on number of puffs (ES = 0.69). (b) > (c) on time to 1st cig (net diff = 24 mins) (ES = 1.0) (a = 14 min; b = 31 min; c = 7 mins). 28% in (a & b) and 15% (in c) didn't smoke during 30 min observation.
Pomerleau *et al.* (1987) (25)	10 inactive healthy males. Mean age = 24 yrs. Mean cigs = 28 per day.	30 mins	(a) 80% VO_2max vs (b) 30% VO_2max. Both 30 mins cycling.	POMS, SWS	Within subjects. Follow-up to 30 mins post-exercise.	(a) v. (b) NS for all measures *
Thayer *et al.* (1993) (20)	5 m & 11 f, Age = 18–44 years. Smoked 1–2 packs per day	45 mins	(a) brisk walk (b) inactivity 5 mins of either	Short AD-ACL (energy & tension), urge to smoke, time to next cig.	Within subjects. Follow-up immediately post-exercise	(a) reduced Urge to smoke, increased energy & time to next cig. (17 vs. 9 mins delay). *
Bock *et al.* (1999) (14)	Group 1 = 24 f Group 2 = 44 f Both groups inactive. Mean cigs = 20 per day. Mean age = 38 yrs.	During smoking cessation	(a) 30–40 mins 60–85% HRR, aerobic activity (group 1 & 2) (b) Equal contact passive.All grps (a1, a2, & b) were involved in an 11 wk trial.	PANAS, ESR, & cravings.	Within (pre-post exercise/control) subjects.	(a) Group 1 & 2 reduced negative affect, nicotine withdrawal and cigarette cravings, in all weeks (5–10) after quit date. No effect on positive affect. *
Ussher *et al.* (2001) (21)	78 inactive m & f. Mean cigs = 18 per day. Mean age = 36 yrs. Mean FTND = 5.9. Mean baseline SoD = 6.6.	15 hrs	(a) 40–60%HRR, cycling + video; (b) video control; (c) passive control, All for 10 min.	MPSS, plus Tiffany 'desire to smoke item	Between subject (randomly assigned). Assessments Pre (T1), mid (T2), immediately post (T3), 5 (T4) & 10 mins post (T5) treatment.	(a) < (b & c) for desire & SoD to smoke, irritability, restlessness, tension, depression, poor concentration, stress at T2, T3, T4 & T5 (not SoD). ES (a) v (c) for SoD to smoke = 0.54, 0.47, 0.27, & 0.14, at T2, T3, T4 & T5, respectively. Effects of exercise greater for less active.
Daley *et al.* (2004) (23)	16 sedentary m & f. Mean cigs = 12 per day. Mean age = 21 yrs.	c. 17 hrs	(a) 60–65% age predicted HR cycling; (b) passive video on smoking cessation. Both for 30 min.	PANAS & SWS	Between subjects. Pre- (T1), post-(T2), 30 (T3) & 60 mins post (T4) treatment.	(b) increased negative affect cf (a). No other sig. time X group interaction. ES (a) v (b) for cravings = 0.53, 0.47 & 0.74, at T2, T3 & T4 (all non sig at $p < 0.05$).

Daniel *et al.* (2004) (15)	884 inactive m & f. Mean cigs = 17 per day. Mean age = 30 yrs. Mean FTND = 4.0. Mean baseline SoD = 4.1.	11–15 hrs	(a) 40–60% HRR cycling, (b) 10–20% HRR cycling, (c) passive control. All for 5 mins.	5 MPSS items, plus desire & SoD to smoke items.	Between subjects (randomly assigned). Pre, mid (T2), immediately (T3), 5 min (T4) post & 10 mins (T5) post-treatment.	Results presented as change scores from baseline. (a) reduced cf (c) for: desire (at T2 & T3); SoD to smoke (at T2, T3 & T4); irritability, restless & depression (at T3 & T4); tension, (at T4). (b) reduced cf (c) poor concentration (at T3). Condition differences, (a) < (c) ES = 1.16, 0.97, 0.58, 0.24 (at T2, T3, T4 & T5, respectively) for SoD.
Taylor, Katomeri & Ussher (2005; 2006) (18 & 19)	10 male & 5 female, active. Mean cigs = 17 per day. Mean age = 26 yrs. Mean FTND = 4.0. Mean baseline SoD = 5.8	> 15 hrs	(a) Self-paced 1 mile treadmill brisk walk (means = 10.8 RPE; 30% HRR, 17 mins), (b) passive waiting	MPSS, desire & SoD to smoke, 2 factor 32-item QSU. FS & FAS. POMS scales.	Within subjects. Randomly ordered. Assessments at Pre (T1), mid (T2), immediately (T3), 10 mins (T4), 20 mins (T5) post-treatment.	(a) < (b) desire & SoD to smoke at T2, T3, T4, & T5 and both QSU scales at T5. Reduced tension & increased FS at T5 & increased FAS at T3. For desire to smoke, ESs = 3.9, 3.7, 3.7, 3.1; & SoD ESs = 3.8, 4.6, 2.8, 1.6 at T2, T3, T4 & T5, respectively.
Ussher *et al.* (2006) (22)	27 f & 33 m. Mean = 18 cigs per day, age = 32 yrs. Mean FTND = 3.9. Mean baseline SoD = 5.2	Mean = 17.3 hrs	5 mins of: (a) seated isometric exercise, (b) body scan, (c) sitting passively	SoD to smoke, & MPSS items.	Between subjects (randomly assigned). Assessments at Pre (T1), immediately (T2), 5 mins (T3), 10 mins (T4) 15 mins (T5), & 20 mins (T6) post-treatment.	(a) < (c) for SoD to smoke (at T3 & T4), ESs = 0.27, 0.29, respectively), poor concentration (at T3, T4, & T5). No effects at T6. (b) < (a & c) on baseline scores which confounded results.
Taylor & Katomeri (in press), Taylor & Katomeri (2006) (17 & 27)	34 m & 26 f, moderately active. Mean age = 28.5 years, mean cigs = 15 per day. Non-quitters. Mean FTND = 3.5. Mean baseline SoD = 4.1.	2 hrs	(a) 15 mins self-paced treadmill brisk walk (means = RPE = 11, HRR = 24%). (b) passive waiting	Desire & SoD to smoke. MPSS, 2 factor QSU. Time to next cig. after leaving lab. (from phone text). SBP/DBP & HR.	Between subjects (randomly assigned). Measures at baseline, mid- & post-ex. then pre & post 3 tasks: Stroop, speech task, & handled lit cig. Ad lib. smoking.	(a) < (b) for Desire & SoD & 7 MPSS items, at all assessments from mid-ex to post lit cig. ES for desire ranged from 1.04–1.78 with mean = 1.62. ES for SoD ranged from 1.2–2.07 with mean = 1.45. (a) attenuated responses to lit cig. cue for SoD to smoke (ES = 0.42), tension, stress, poor concentration & SBP. (a) also attenuated SBP & DBP responses to Stroop & speech tasks, and restlessness to Stroop. (a) > (b) for time to next cig (84 v 27 min) (ES = 1.20)

Table 1 *Cont.*

Study	Subjects characteristics	Abstinence period	Exercise characteristics	Measures	Design	Outcome
Everson, Daley & Ussher (2006) (26)	19 m & 18 f, less active. Mean age = 17.7 yrs. Mean cigs = 13.6 per day. Non-quitters. Mean dependence = 7.2 (on 0–10 scale of HONC). SoD = 3.4 (estimated from original 0–5 scale).	Mean = 17.2 hrs	(a) (RPE = 12.3, HR = 112 bpm, 55% age-predict HR max). (b) (RPE = 8.3, HR = 89 bpm, 44% age-predicted HR max). Both 10 mins cycle.	SoD to smoke, MPSS, SEES-PWB, SEES-PD, SEES-fatigue.	Between subjects (stratified, by gender, randomly assigned) design. Measures at pre- (T1), mid- (T2), 5 (T3) & 30 min (T4) post-treatment.	No differences between groups at any time point (except higher SEES-PD during (a). ES (a) v (b) for SoD = 0.50, 0.15 & 0.47 at T2, T3 & T4 (all non sig at $p < 0.05$), with lower cravings for (a).
Daniel, Cropley, & Fife-Schaw (2006) (16)	23 m & 17 f, sedentary. Mean age = 23.4 yrs. Mean cigs = 14 per day. Non-quitters. Mean FTND = 3.0. Mean baseline SoD = 4.0	Mean = 13.6 hrs	(a) 10 mins cycle (40–60% HRR). (b) Passive (Cognitive distraction task)	SoD to smoke, MPSS, PANAS	Between subjects (random assigned). Measures at pre- (mean of -10, -5 & 0 mins), during- (mean of mid and end of treatment), & post-treatment (mean of + 5 & + 10 min).	(a) < (b) during and after treatment for desire & SoD, difficulty concentrating and stress. ES (a) v (b) for cravings = 2.0 & 1.0 during and post treatment, for both desire and SoD to smoke. (a) < (b) during treatment for 5 other MPSS items but due to increase during cognitive distraction task rather than reduction during exercise.
Katomeri & Taylor, 2006a & 2006b) (9 & 10)	17 m & 13 f. moderately active. Age = 21.9 yrs, cigs = 13.7 per day. Non-quitters. Mean FTND = 3.5. Mean baseline SoD = 5.2.	2 hrs	(a) 15 mins self-paced treadmill brisk walk (means = RPE – 12.2, HRR – 37.3%). (b) passive waiting	Desire & SoD to smoke. MPSS, FS & FAS, 2 factor 10-item QSU. Time to next cig. after leaving lab. (from phone text).	Within subjects. Randomly ordered. Mid & post-exercise + pre- & post-smoking cue. Ad libitum smoking.	(a) < (b) Both desire & SoD to smoke measures, both QSU & 7 MPSS items during & post-treatment (ES for desire and SoD ranged from 1.5 to 3.1; mean = 2.3). (a) > (b) for change in desire to smoke in response to lit cig. cue. (ES = 0.61). (a) < (b) for time to next cig (66 v. 31 min.) (ES = 0.85)

HR: heart rate; HRR: heart rate reserve; SBP: systolic blood pressure; DBP: diastolic blood pressure; HONC: Hooked on Nicotine Checklist [57]; ESR: Evening Symptom Report [58]; MPSS: Mood and Physical Symptoms Scale [28]; POMS: Profile of Mood States [59]; PANAS: Positive and Negative Affect Scale [60]; AD-ACL: Activation–Deactivation–Adjective Check List [61]; QSU: Questionnaire on Smoking Urges (factor 1: anticipation of smoking as pleasant, enjoyable and satisfying, and factor 2: reduced anticipation of relief from negative affect by smoking) 32-item measure [62]: 10-item QSU [63]; desire to smoke [62]; SoD: strength of desire to smoke [24]; FTND: Fagerstrom Test for Nicotine Dependence [64]; FS: Feelings Scale [65]; FAS: Felt Arousal Scale [66]; SAI: State Anxiety Inventory (67); m = male; f = female; RPE: rating of perceived exertion [68]; SEES: Subjective Exercise Experiences Scale (PWB: positive well-being, PD: psychological distress) [69]; SWS: Shiffman Withdrawal Scale [70]. *Data not available for ES (effect sizes) calculation.

symptoms during and following exercise. A fairly consistent pattern of reductions of all symptoms during and following exercise was reported, with a similar effect to those reported above for measures of cigarette cravings. Only Daley and colleagues [23] showed no beneficial effect, using the Shiffman Withdrawal Scale [67], and that was the only study not to use the Mood and Physical Symptoms Scale (MPSS) [28]. Withdrawal symptoms shown to be reduced by exercise include stress, anxiety, tension, poor concentration, irritability and restlessness.

General mood and affect measures

Reeser [8] reported no reduction in state anxiety following exercise (compared with a passive condition), whereas three other studies [14,19,20] all reported significant enhancement of mood and affect during and following exercise. Bock and colleagues [14] reported reduced negative affect, but no effect on positive affect (using the Positive and Negative Affect Scale; PANAS). Two studies [19,20] reported increased activation and energy in response to exercise, respectively. In contrast, the same two studies [19,20] reported reduced tension up to 20 minutes post-exercise, and no reduction, respectively. Taylor [19] also noted that reduced tension appeared to mediate reductions in desire to smoke.

Smoking topography or behaviour

Four studies [8,10,17,20] reported that exercise significantly increased the time to *ad libitum* smoking, by a net time of 24 (ES = 1.0), 8 (ES data not available), 57 (ES = 1.2) and 35 minutes (ES = 0.85) for the four respective studies. In the Reeser study [8], after treatment the passive control smoked an average of 7 minutes later, and the stretch and isometrics group lasted an average of 31 minutes later. Interestingly, after moderate intensity aerobic exercise the time to smoking was not extended significantly. In the respective studies, in terms of time since the last cigarette smoked, after the passive control condition the first cigarette was smoked on average after 57, 59, 212 and 188 minutes (estimated from the methods reported). The variation across the four studies in net delay to *ad libitum* smoking (as a result of exercise) is not easy to explain, as the four studies involved different designs. The fact that the Reeser study [8] involved heavier smokers (mean cigarettes = 23 per day) and a moderate–vigorous exercise intensity, compared with the Katomeri and Taylor studies [10,17] with 15 and 14 cigarettes smoked per day, respectively, and a low–moderate exercise intensity, may account for a shorter net effect of exercise on smoking behaviour. Vigorous exercise may elicit a stress response (due both to physiological demands and cognitive threat appraisal) that could have less positive effects on smoking behaviour and cravings than less intense exercise.

One possible criticism of 'net time to the next cigarette' as an outcome is that it does not account for compensatory smoking behaviour (e.g. taking more puffs). Only two studies [7,8] reported on other topographic measures relating to this issue. Mikhail [7] reported that two active conditions resulted in less time holding the first cigarette smoked, and Reeser [8] reported that stretching/isometrics resulted in fewer puffs on the first cigarette smoked after exercise.

Responses to cue-elicited cravings

Only two studies have examined the effects of exercise on cue-elicited outcomes. In the first [17,27], exercise attenuated increases in strength of desire to smoke, the MPSS items tension, stress and poor concentration and blood pressure, in response to a lit cigarette, and restlessness in response to the Stroop task. In contrast, in the second study [9,10], there were greater increases in desire to smoke following exercise in response to a lit cigarette, due most probably to a ceiling effect (i.e. the control condition had high pre-cue cravings, thereby leaving less scope for a cue-elicited change). Also, the first study involved a smoking cue following demanding mental challenges but the second did not. The combination of stress and a smoking cue requires further investigation in the context of an acute exercise study.

DISCUSSION

Clearly, a single session of exercise has an acute effect on smoking behaviour, cravings, withdrawal symptoms and affect, particularly in experimental settings. The magnitude of the reduction in cravings is encouraging and comparable with, or in many cases exceeding, the acute response to glucose and oral nicotine replacement therapy (NRT) [30,31]. For example, West and colleagues [30] showed a reduction in ratings of strength of desire to smoke of up to 1.0 point on a sevenpoint scale for glucose versus placebo; whereas, using the same scale, exercise shows a mean reduction in ratings of desire to smoke, compared with control, ranging from 0.7 points for 5 minutes of isometric exercise [22], to 4.6 points for a 1-mile brisk walk [18]. Also, exercise tends to show a more consistent and rapid effect on cravings and withdrawal symptoms when compared with studies of oral NRT [15,31]. For example, in one of the most rigorous studies, effects were not evident until 10 minutes after taking the nicotine gum, relative to a placebo [32].

This section will provide a critical discussion on the methodologies used and the probable mechanisms by which acute exercise may be a useful aid to smoking cessation. The implications for research and practice will be highlighted throughout.

The positive effects of exercise on smoking outcomes have been observed for a range of smoker characteristics, periods of abstinence, exercise characteristics, measures and designs (all involving randomized controlled studies). Only one study involved actual quitters [14], and although it showed an acute effect of exercise on several outcomes the study compared data collected during an 11-week intervention. Each week subjects provided data before and after each session they attended, in either a passive or physically active condition. Because it was group-based, the exercise dose was poorly controlled, with a wide variation in intensity and uncontrolled social elements. All other studies in the review involved the manipulation of temporary abstinence. Although this is a common experimental procedure (e.g. [30]) the severity of symptoms experienced may not correspond entirely to withdrawal symptoms and cravings that are experienced in a more natural environment [33]. The four studies [8,10,17,20] to report the effects of exercise on *ad libitum* smoking behaviour, following temporary abstinence, may extend the generalizability of the findings somewhat. Nevertheless, further research is required to understand the effects of exercise on lapses at different temporal stages in the quit attempt, perhaps using ecological momentary assessment (e.g. using electronic diaries) [6,34], with larger sample sizes.

Only one study involved a researcher who was blinded to the treatment condition (that was conducted by a trained exercise leader in a different room [17,27]). Such a methodological weakness across the studies reviewed has the potential to elevate the strength of effects, but it is encouraging to note that the one study to eliminate this bias also showed the largest ES.

Given the relatively small number of studies and the heterogeneous doses of exercise across those studies, it is probably premature to consider the impact of methodology on the findings. However, it would appear that the effects of exercise are similar following brief or longer periods of abstinence, and for moderate or higher levels of baseline cravings. There is currently insufficient evidence to support a linear or curvilinear relationship between intensity of exercise (i.e. low versus moderate versus high) and effect on cravings. The two studies [25,26] that addressed this issue were not designed adequately, and no conclusion can be drawn from a comparison across studies involving different exercise intensities. Such evidence is required, as it may help us to understand why exercise is effective.

Possible mechanisms

It is important to consider why exercise has beneficial effects. First, if a plausible mechanism can be shown then this adds support for a causal effect. Secondly, by understanding how exercise has an effect on smoking outcomes then more effective interventions and guidance can be developed. A number of mechanisms could account for why acute exercise appears to reduce cravings and withdrawal symptoms, including distraction, stress reduction (deactivation) and activation and neurobiological mechanisms.

Distraction

At a high intensity, above what is termed the 'ventilatory threshold' [35], exercise may induce greater cognitive demand than at lower intensities. There may also be some relatively low-intensity 'mindful' exercise (e.g. yoga, Tai Chi, isometrics, stretching) that demands increased cognitive focus (i.e. distraction from smoking). Ussher and colleagues [22] reported that isometric exercise and a distracting 'body scanning' control condition had similar effects on cravings. However, the isometric exercise (compared with another passive condition) had relatively modest effects and this study requires replication. In other studies, following moderate intensity cycling, there was a greater reduction in cravings and withdrawal symptoms when compared with a distracting task (in a control condition) [16,21]. Finally, one may expect that if exercise reduces cravings and withdrawal symptoms by distraction then the effects should dissipate quite quickly after exercise. This does not appear to be the case, even when other stimuli (e.g. mental challenges and a lit cigarette) are presented [17], with cravings reduced for 50 minutes following exercise, compared with a passive condition. In summary, distraction does not appear to be the main mechanism by which exercise reduces cravings and withdrawal symptoms.

Stress reduction and activation

An urge to smoke can be driven by the need for both stimulation and relaxation. In order to understand this phenomenon, known as Nesbitt's Paradox, Parrott [36] recommended that a multi-dimensional understanding of affect is useful in which changes in activation and valence can occur independently and at the same time. If an alternative to smoking can provide both reduced tension and increased stimulation then it may mimic the effects of tobacco. Taylor and colleagues [19] used the two-dimensional Circumplex model of affect to reveal that reductions in cravings following exercise were mediated by reductions in tension rather than increases in activation. However, further research is needed to induce states of boredom and a desire for stimulation (that may elicit an urge to smoke) to test if the activating property of exercise [34] mediates reductions in cravings.

Stress can increase cravings and withdrawal symptoms [33] and contribute to relapse during attempts to quit [37,38]. Given that exercise can reduce responses (i.e. negative mood and physiological arousal) to a stressor [39,40], one may expect that stress-elicited cravings and withdrawal symptoms may be attenuated by exercise. One study [17,27] reported that a brisk walk did not attenuate stress-induced increases in the subjective responses but did attenuate blood pressure responses to each task. Further research is needed to understand the role of exercise in stress management during smoking abstinence. Other, more potent, experimental and natural stressors could be used that typically trigger cravings to explore the effects of exercise.

The presence of a cigarette during abstinence has been used widely to elicit cravings in experimental studies [33] and may be due to the stress (and negative affect) associated with not being able smoke. One study [17,27] reported that cue-elicited increases (i.e. by handling a lit cigarette) in strength of desire to smoke, stress and tension and systolic blood pressure were attenuated following exercise. Further research is needed to explore the acute effects of exercise on smoking-related cues, including imagining smoking situations and the use of visually presented smoking images (e.g. using virtual reality software or photographs) in order to understand how exercise may serve as an aid to smoking cessation.

In summary, there is some evidence that exercise reduces cravings by its effect on stress (and negative affect), but further research is needed to assess the involvement of other psychological and physiological stress markers (e.g. electromyograph (EMG); heart rate variability; startle reflex, cortisol, eye movement and attentional bias), perhaps involving even more challenging tasks.

Psychobiological mechanisms

Several psychobiological changes, such as increases in β-endorphins, cortisol or opioids, may mediate the link between engaging in exercise and affective responses [41]. In the absence of any research on the neurobiology of exercise in the context of substance misuse treatment [42] it is important to refer briefly to current developments in the treatment of addiction to speculate how exercise may work. It is generally acknowledged that increases in dopamine activity (DA) within the mesolimbic system, originating in the mid-brain, mediates the rewarding effects of most drugs of misuse, including nicotine [43]. Pharmacological treatments for nicotine addiction are effective by attenuating the rewarding effects of cigarette smoking [44] and responses to a subsequent nicotine challenge or cue [33].

Animal research has shown that exercise reduces self-administered amphetamine [45], cocaine [46] and ethanol [47]. Exercise also increases DA release into the striatum of the rat [48,49], and this may be a key mechanism for reducing the appetite for drug administration. However, evidence of changes in regional brain activation in humans that might reflect exercise-related facilitation of DA has not yet been shown [50].

The context of acute exercise and smoking cravings and withdrawal symptoms offers an exciting opportunity to study how exercise enhances mood and possibly mimics the rewarding effects of smoking (and the use of other addictive substances). Research is needed to identify the neurobiological mechanisms involved in the link between exercise and cravings. This could involve examining how exercise moderates DA in response to cue-elicited cravings.

Other ways in which acute exercise can aid smoking cessation

Vigorous exercise can suppress appetite [51], which may be important for smokers trying to avoid weight gain during a quit attempt [52]. In the present review the only study to assess the effect of exercise on self-reported hunger (as a withdrawal symptom) reported no effect [21], due possibly to less than vigorous intensity or a poor experimental control of eating prior to the study. Further research is needed on the possible effects of exercise on hunger, appetite and food cravings, particularly when faced with a more challenging environment for behavioural self-regulation (e.g. stress and food cues following fasting), during temporary smoking abstinence and actual quit attempts.

Approximately 60% of all individuals involved in a quit attempt experience some form of cognitive decline [53]: for example, there is a greater number of non-fatal accidents in the work-place reported on National Non-Smoking day than any other day in the year [54]. There is evidence that a single session of exercise can enhance concentration [55]. In the present review, poor concentration was reduced by exercise in all five studies in which it was assessed [10,15,16,21,22]. Further research is needed to determine if, using more rigorous measures of different aspects of cognitive functioning (e.g. complex decision making tasks, memory), exercise can enhance functioning during smoking abstinence.

CONCLUSIONS

A review of 14 studies suggests that a single session of exercise can be recommended as a smoking cessation aid for regulation of cravings, withdrawal symptoms and negative affect. Bouts of exercise may also be one strategy for reducing cigarette consumption, thereby lowering health risks for those unwilling or unable to quit [29] and reducing the risk of progressing to regular smoking (and other substance misuse) [3]. A relatively small dose of exercise in which most people can conveniently engage appears to be sufficient. This line of research is in its infancy. Further research is needed to determine if exercise is equally effective in natural environments during actual quit attempts, and to enhance our understanding of the mechanisms involved in order to develop better practice in promoting exercise for practitioners and smokers [56].

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