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Self-Regulating Smoking and Snacking Through Physical Activity

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Objective: Emotional snacking contributes to weight gain after smoking cessation. Exercise acutely reduces cravings for cigarettes and snack food. This study examined if different exercise intensities acutely reduces snack and cigarette cravings and attentional bias (AB) to video clips of snacks and cigarettes among abstinent smokers. ***Methods:*** Abstinent smokers (and snackers; $N = 23$) randomly did 15 mins of moderate and vigorous cycling and a passive control in a cross-over design. Visual initial AB (IAB) and maintained AB (MAB) were assessed pre- and after treatment while watching paired snacking/neutral or smoking/neutral video clips. Desire to snack and smoke were assessed throughout. ***Results:*** ANOVAs revealed significant condition × time interactions for initial and maintained AB for smoking [IAB: $F(1.58, 34.75) = 3.58$, MAB: $F(2, 44) = 4.52$, $p < .05$] and snacking [IAB: $F(2, 44) = 8.13$, MAB: $F(2, 44) = 5.08$, $p < .01$]. IAB for both smoking and snacking were lower after moderate and vigorous exercise than the control. MAB was lower only after vigorous exercise. Fully repeated ANOVAs revealed a condition × time interaction for desire to smoke, $F(3.31, 72.75) = 12.62$, and snack $F(4.34, 95.52) = 9.51$, $p < .001$. Cravings were lower after moderate and vigorous exercise, compared with control. ***Conclusions:*** Exercise acutely reduces both AB and cravings for cigarettes and snacks and may help self-regulation of smoking and snacking. Vigorous exercise was only more advantageous for reducing MAB.

AQ: 2

Keywords: exercise, food craving, self-regulation, inhibition, cigarette cravings

On average, smokers experience almost 5 kg of weight gain in the year after quitting, with 41% and 7% gaining at least 5 kg and 10 kg, respectively (Pisinger & Jorgensen, 2007) and 9 kg over 8 years (Lycett, Munafò, Johnstone, Murphy, & Aveyard, 2011), with associated increased health risks (Yeh, Duncan, Schmidt, Wang, & Brancati, 2010). Fear of such changes may prevent quitting or causes relapse (Perkins, 1993). Weight gain may be due to a slower metabolism and increased hedonic food snacking (Spring, Pagoto, McChargue, Hedeker, & Werth, 2003). As Donny, Caggiula, Weaver, Levin, and Sved (2011) note, "Abstinence from nicotine in regular smokers also appears to enhance the incentive and relative reinforcing property of food" (p. 145).

The Incentive-Sensitization Theory (Robinson & Berridge, 2001) helps to explain how nicotine deprivation produces a reward deficiency state that increases motivational salience of accessible rewards. Indeed, West et al. (2010) reported that glucose tablets can help to control cravings for cigarettes. Also, brain imaging studies suggest that similar areas of interest are activated when viewing images of cigarettes and snack food, when these substances are associated with reward (Avena, Gold, Kroll, & Gold, 2012; Schroeder, Binzak, & Kelley, 2001; Tang, Fellows, Small, & Dagher, 2012). Cravings for one substance during abstinence may be replaced by cravings for another rewarding substance, thereby challenging self-regulation of smoking and snacking to avoid weight gain.

Exercise may be a useful smoking cessation aid (Ussher, Taylor, & Faulkner, 2012), but the literature is limited by the quality of the study design and the predominant focus on the effects of a few weekly sessions of structured exercise. However, exercise can prevent weight gain (Farley, Hajek, Lycett, & Aveyard, 2012) and, during temporary abstinence, acutely reduces self-reported cravings and withdrawal symptoms (Haasova et al., 2013; Taylor, Ussher, & Faulkner, 2007). Exercise can also modulate cue-elicited brain activation (Janse Van Rensburg, Taylor, Benattayallah, & Hodgson, 2012), reduce visual attentional bias (AB) to still smoking images (Janse Van Rensburg, Taylor, & Hodgson, 2009), and attenuate cue reactivity and delay smoking (Taylor & Katomeri, 2007).

Most acute studies have focused on short bouts of moderate intensity physical activity, but Scerbo, Faulkner, Taylor, and Thomas (2010) reported greater reductions in cravings after running versus walking, albeit with inconsistencies across outcome measures. Also, Everson, Daley, and Ussher (2008) reported no difference in effects on strength of desire to smoke between moderate and vigorous intensity exercise. It is important to know if exercise intensity is important to shed light on any possible mechanisms, and to provide guidance for smokers and cessation professionals. No study has compared the effects of different exercise intensities on AB with smoking images.

Exercise has also been shown to acutely reduce appetite and hunger (Tsofliou, Pitsiladis, Malkova, Wallace, & Lean, 2003), and reduce chocolate cravings (Taylor & Oliver, 2009), ad libitum snacking (Oh & Taylor, 2012), and AB to chocolate images (Taylor, Oliver, & Janse Van Rensburg, 2009; Oh, 2012) among

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regular snackers who were abstinent from chocolate. However, no study has examined whether exercise of different intensities reduces snack food cravings and AB among smokers who regularly snack, during smoking abstinence.

AB, defined as selective attention to personally relevant information over neutral information, has been associated with level of use of and cravings for various substances (Field, Mogg, & Bradley, 2005; Field, Mogg, Zetteler, & Bradley, 2004b; Field, Munafo, & Franken, 2009) and with relapse to substance use (Garland, Franken, & Howard, 2012). Eye tracking technology offers the most direct approach to assess AB (Field, Mogg, & Bradley, 2004a) and video clips may offer greater external validity than still images. Initial AB (IAB) is concerned with an implicit association and maintained AB (MAB) with a subsequent cognitive bias (Field et al., 2009).

Three studies have reported the effects of exercise on AB to substance-related images. Janse Van Rensburg, Taylor, and Hodgson (2009) found that 15 mins of moderate intensity exercise (compared with rest) reduced the percentage of initial fixations and duration of time spent looking at still smoking images (vs. neutral cues) during temporary abstinence. Taylor, Oliver, and Janse Van Rensburg (2009) reported that a 15 min brisk walk reduced AB to still chocolate images, using eye tracking technology, among abstinent regular chocolate eaters. Also, Oh (2012) reported that a 15 min brisk walk (compared with rest) reduced AB (using a dot probe task) to still chocolate images (compared with neutral images).

How exercise reduces AB to salient cues is not understood. The transient hypofrontality hypothesis suggests that areas of the frontal lobe (involved in higher cognitive functions) are disrupted particularly during vigorous exercise (Dietrich, 2003, 2006), and there is some support for this idea (Del Giorno, Hall, O'Leary, Bixby, & Miller, 2010), but this has not been directly tested among smokers (or snackers). Support for this hypothesis may be strengthened if AB to smoking (and snacking) cues is reduced more after vigorous, compared with moderate intensity exercise.

Greater AB to food cues has recently been associated with negative affect (Hepworth, Mogg, Brignell, & Bradley, 2010) and induced chocolate cravings (Kemps & Tiggemann, 2009) and further research is needed to explore the relationship between mood, cravings, and AB for food and smoking cues. There is strong evidence that exercise reduces cigarette withdrawal symptoms and enhances mood and affect (Taylor et al., 2007). By improving mood, there may be less visual attention to cues normally associated with reward and pleasure.

But the relationship between exercise intensity and affect is more complex when affect is considered in two-dimensional space along the axes of affective activation (felt arousal) and affective valence (pleasurable feeling). Vigorous exercise (above the ventilatory threshold; VT) tends to acutely reduce affective valence during but not afterward, and moderate intensity (sub-VT) increases affective valence, for most people, during and afterward (Ekkekakis, Hall, Van Landuyt, & Petruzzello, 2000; Ekkekakis, Parfitt, & Petruzzello, 2011). In contrast both moderate and vigorous exercise increase affective activation both during and after exercise. In summary, after completing both moderate and vigorous exercise there are improvements in both affective valence and activation, compared with before exercise.

If the urge for cigarettes is driven by a need to increase activation and valence (see Schachter, 1973) then vigorous exercise, which reduces affective valence, may result in no reduction in cravings during exercise, but a reduction in cravings afterward. In contrast if an urge is driven by an implicit need to enhance activation then both moderate and vigorous exercise may result in reduced cravings. Although assessing concurrent changes in affect during and after exercise may not provide a clear causal mechanism for how exercise impacts on substance-related variables, it may be valuable to guide future research.

Therefore, the main aim of this study was to assess if a 15-min bout of moderate or vigorous exercise, compared with rest, reduces AB to smoking and snack food video clips, and also cravings for cigarettes and snack food, among temporarily abstinent smokers. We hypothesized that vigorous exercise would decrease AB more than moderate intensity exercise because of the greater disruptive effect on cognitive functions. Second, we expected similar reductions in self-reported cravings (for cigarettes and snacks), from baseline to after moderate and vigorous intensity exercise. Finally, we wished to explore if changes in affective valence and activation, from baseline to after exercise, were associated with change in substance-related variables (i.e., cravings and AB).

Method

Participants

Following institutional ethical approval, participants were recruited through public advertisements and were screened by telephone. Participants were required to be 18–45 years of age, smoke ≥ 10 cigarettes daily, eat ≥ 1 chocolate bar and other snacks (e.g., at least a 25 g bag of potato chips, or at least one large cookie) per day, and have no contraindications to exercise at vigorous intensity, using a Physical Activity Readiness Questionnaire and Cardiovascular disease (CVD) risk factor assessment (ACSM, 2009).

Two previous studies informed our sample size calculations. First, Janse Van Rensburg et al. (2009) reported that mean (*SD*) AB (using % dwell time) to still smoking images, after 15 mins being sedentary and moderate intensity cycling, was 53.5% (12.3) and 44.2% (8.5; i.e., ES = 0.84), respectively. We estimated that for a within-subject design, with a power of 0.95, and alpha of 0.05, a sample size of 21 participants was needed to detect differences in AB to smoking images. Second, among non-smokers, Taylor et al. (2009) reported that mean (*SD*) AB (using total dwell time across trials) to still snacking images, after 15 mins being sedentary and moderate intensity cycling, was 4.9 (1.2) seconds and 4.0 (0.8) seconds (i.e., ES = 0.88), respectively. We estimated that for a within-subject design, with a power of 0.95, and alpha of 0.05, a sample size of 19 was needed to detect differences in AB to snacking images. Given the occasional difficulties in using data recorded from eye tracking technology, we aimed to recruit at least 21 participants.

Eighty-three potential participants responded to public advertisements (posted on walls and digital media) or in response to a flyer handed out in public places. Fifty-three participants were excluded based on the above criteria. Five additional people were excluded due to difficulties in data capture due to eye color, leaving a final sample of 23 participants who provide complete data.

Procedures

Prior to arrival, participants were asked not to eat, drink (except water), or exercise for 2 hours and abstain from smoking for 15 hours before the testing session, to elevate cigarette cravings and withdrawal symptoms. Participants were requested not wear eye-makeup or oil based facial products that could interfere with the detection of eye movements. Participants were asked to engage in three treatment conditions, on separate days at about the same time of day, in a randomized cross-over design as follows: (a) low-moderate intensity exercise, (b) vigorous intensity exercise, and (c) passive control.

At the beginning of each session, expired carbon monoxide (CO) levels were recorded using a Bedfont Smokerlyzer (Bedfont Scientific Ltd, Kent, England) to confirm cigarette abstinence (i.e., at CO < 10 *ppm*). Participants were then shown packets of high energy snack food (e.g., chocolate, cookies/biscuits, potato chips/crisps) for 10 secs but not allowed to eat them, to elicit food cravings. We aimed to maximize the potential of observing any effects of exercise but also to simulate real world scenarios where such food is often readily available. A heart rate monitor was fitted and worn throughout the session to assess exercise intensity, with data being recorded over 15 sec epochs.

At baseline and within 5 mins after treatment in each session, the participants were seated at a desk approximately 95 cm in front of a computer screen and eye tracking camera (Pan/Tilt optics system, Model 504, Applied Science Laboratories (ASL), Bedford, England). The camera (60 Hz output) was placed 69 cm from the participant and was linked to the eye tracking system (Model 5000 control unit, Eyeline II Eye-tracking System, ASL), which processed the eye image and recorded visual AB to smoking and snacking images. Cigarette and food cravings, and affect, were assessed at (a) baseline, (b) midtreatment, (c) immediately after treatment, and (d) 10 mins after treatment (i.e., after second AB task).

Exercise treatment. The exercise session consisted of a 2 min warm-up, followed by a 15 min cycle ergometer session during which participants were instructed to maintain at either moderate intensity at 40%–50% heart rate reserve (HRR) and 11–13 on a rating of perceived exertion (RPE; using a 6–20 Borg Scale, Borg, 1998; i.e., fairly light-somewhat hard) or vigorous intensity at 70%–75% HRR and 15–17 on the RPE scale (i.e., hard–very hard; ACSM, 2009), followed by a 2 min cool down.

Passive treatment. Participants sat passively and quietly at a desk for 17 mins. Such a control condition has been shown to have no effect on substance-related cravings (Haasova et al., 2013).

Other descriptive measures. At the end of the final session (to avoid reactivity to the assessments), participants completed the Power of Food Scale (PFS, Lowe et al., 2009) which has 15-items and measures trait hedonic hunger with three subscales: food available, food present, and food tasted. The authors note that it is sensitive to capturing an individual's perception of the hedonic aspects of the food environment, not only in terms of overeating (i.e., energy intake beyond energy needs) but also in the activation of food-related thoughts, feelings, and motivations. We also administered the Fagerstrom Test for Nicotine Dependence (FTND, Heatherton, Kozlowski, Frecker, & Fagerström, 1991) to assess levels of nicotine dependence.

After the final testing session, participants received a £20 payment for their participation.

Outcome Measures

Attentional bias (AB). Video clips were filmed using digital technology (Sony Digital Camera, Dsc-T77, Tokyo, Japan). Close-up views of various snack foods (e.g., milk chocolate biscuits, potato chips/crisps, chocolate cream cookies/biscuits, sweets, white and milk chocolate cake, milk chocolate, Jaffa cakes, and chocolate seashells), that were considered to hold hedonic properties, were videoed. Neutral video clips involved common household or outdoor objects (e.g., paperclips, shells, tea bag, leaves). Smoking video clips involved close-up views of someone blowing smoke, lighting a cigarette, and offering a cigarette from a pack. Contrasting neutral video clips involved blowing seeds off a dandelion, lighting a candle, and offering a pen from a pack. Each pair of video clips (snacking/neutral and smoking/neutral) was matched closely for movement, contrast, luminescence, size, shape, and color.

Each separate video clip was imported into film editing software (Microsoft Windows Movie Maker, Version 5.1) and trimmed to 7,000 ms, with the first 1,000 ms frame of the video clip used as a still image. Previous research has used still images rather than video to measure AB, so the aim was to assess IAB using a still image, then MAB using a video clip. The still image (adjusted to 1,200 ms) and video clip (7,000 ms) was transferred to a video production timeline, with a total duration of 8,200 ms for each sequence. Finally, at the start of each sequence a cross on the screen was displayed for 2,000 ms at the center of the screen in the gap where subsequent image sequences appeared.

The presentation of the paired video was formed using Microsoft Office PowerPoint, 2003 with the following constraints: (a) the video compilations were resized to 9.5 cm height and 11 cm width, with a 3.4 cm gap between the inner edges of each video (1° visual angle); (b) both videos were adjusted to play simultaneously, and the order of images, and whether salient or neutral images appeared to the left or right of the screen, were randomly presented (www.random.org/sequences); and (c) the total 16 pairs of video clips (eight pairs of snacking/neutral and eight pairs of smoking/neutral video clips with a cross displayed at the center of the screen for 2,000 ms between each sequence) lasted approximately 2 min 43 secs. The smoking/neutral video clips were played in a block followed by snacking/neutral video clips. Participants did not watch the same sequence of videos across the different sessions.

To measure AB, a close-up telephoto image of each participant's eye was initially obtained and vertical and horizontal displacement between pupil center and the corneal reflection were measured by the eye tracking system described above. A 9-point calibration screen (using a 3 × 3 array of small circles) was displayed on the participant's computer monitor to check camera direction, zoom, and illumination. After initial calibration, the Eye-Trac 6000 Data Analysis Program (Eyenal, version V2 32, Applied Science Group, 2001–2004) captured the direction of the participant's gaze with data sampling set at every 17 ms. A fixation was defined when the subjects' eyes were stabilized on a particular position (within a 1° visual angle) for 100 ms or more (Mogg, Bradley, Field, & De Houwer, 2003). Fixations on either the snacking/smoking or neutral image were identified if visual gaze was at least ± 1° wide of the central cross position on the horizontal plane (Bradley, Garner, Hudson, & Mogg, 2007; Mogg, Field, & Bradley, 2005). Thus, fixations were excluded if data points fell within this horizontal angle of the central cross and if the duration of fixation was ≤ 99ms in line with previous research (Field et al., 2004a).

Self-reported measures. Strength of desire to smoke (SoD) was assessed using an item: "How strong are your smoking urges just now?" (West & Hajek, 2004) on an adapted 6-point scale (0 = *no urges* to 5 = *extremely strong*), as used in a number of previous studies (see Haasova et al., 2013). Desire to snack was assessed using the following items (modified from the Food Craving Questionnaire–State version, FCQ-S; Cepeda-Benito, Gleaves, Williams, & Erath, 2000): "I have an intense desire to eat a snack," "I am craving a snack," "I have an urge for snacking" on a 5-point scale (1 = *strongly disagree* to 5 = *strongly agree*). The sum of these three items provided a total score for desire to snack (range 3–15). The Feeling Scale (FS; Hardy & Rejeski, 1989) was administered by asking participants to indicate on an 11-point scale how they felt from −5 = *very bad* to 0 = *neutral* to +5 = *very good*. It has been widely used as a measure of affective valence or pleasure (Ekkekakis et al., 2011), particularly in the context of exercise and affect studies. The Felt Arousal Scale (FAS; Svebak & Murgatroyd, 1985) was administered by asking participants to indicate on a 6-point scale how aroused they felt from 1 = low arousal to 6 = high arousal. It has been widely used as an indicator of affective activation or arousal, particularly in the context of exercise and affect studies (Ekkekakis & Acevedo, 2006).

Data analysis. To determine IAB we initially identified the first eye fixation within the area of interest on either the smoking (or food) or neutral images which occurred at least 100 ms after the image onset (Bradley et al., 2007; Mogg et al., 2005). A direction bias score (i.e., IAB) was then determined for each participant by calculating the number of trials when the initial eye fixation was directed toward the smoking (or food) related images as a percentage of overall critical trials. Scores > 50% reflect a bias toward smoking (or food) images compared with neutral images (Mogg et al., 2005). To determine MAB we first calculated the total amount of time (from the sum of fixations lasting at least 100 ms) that gaze was fixated on either smoking (or snacking) or neutral image over the video presentation. Thus, the percentage dwell time (i.e., MAB) on smoking (or snacking) video clips was calculated by dividing the total fixation time on smoking (or snacking) video clips by total fixation time (all fixations: smoking (or snacking) + neutral video clips) as previously reported (Janse Van Rensburg et al., 2009). The calculation of IAB and MAB followed previous studies on AB and took into account gaze on both substance and neutral images.

SPSS (version 18) was used for data analysis. Data was initially checked for normality (using the Shapiro-Wilk test), skewness, and kurtosis. Descriptive data for participant's demographic and background variables were reported. Baseline AB and self-reported outcome measures were compared using one-way repeated measures ANOVA with identify differences. Three-way ANOVAs (condition × time × order) were conducted to identify any order effects. With AB data, repeated measures ANOVAs were conducted to examine the interaction and main effects of time (baseline, after treatment) and condition (rest, moderate, and vigorous exercise). For self-reported cravings and affect data, repeated measures ANOVAs were conducted to examine the interaction and main effects of time (baseline, mid, immediately after, and 10 mins after treatment) and condition. One-way repeated measures ANOVAs were planned to explore condition effects at each time point after baseline, with post hoc *t* tests to determine between condition differences. For non-normally distributed data we used a Friedman test to identify an effect of condition at each time point, with "post hoc" Wilcoxon's Ranked tests for related samples to compare conditions. With insufficient statistical power to conduct mediation analysis (Fritz & MacKinnon, 2007) we determined correlations between changes in affect and substance-related variables (AB and cravings) in the exercise conditions. All statistical tests were assessed using $p < .05$ and Bonferroni corrections applied as appropriate. Cohen's *d* was calculated for effect sizes.

Results

Twenty-three participants (15 males and eight females), of Caucasian background, had a mean (*SD*) age of 23.96 (4.83) years, BMI of 23.47 (2.98) kg/m^2, FTND of 2.78 (1.78), and PFS score of 42.48 (11.93). There were no significant baseline differences between each of the three conditions (passive control, and moderate and vigorous exercise condition) for any of the main outcome variables.

Manipulation Checks

Mean (*SD*) HRR (%) and RPE during moderate and vigorous exercise were 45.82 (10.28) and 12.79 (0.45), and 75.46 (9.38) and 16.70 (0.69), respectively, thereby confirming target ACSM (2009) intensities. In the passive condition resting HR was 69.48 (9.04) beats per min.

Effects of Condition Order on Outcome Values

A three-way mixed ANOVA, 6 (order) × 3 (condition) × 4 (time: baseline, mid, immediately after, and 10 mins after treatment) for subjective outcome measures, and with time (baseline and after treatment) for AB, revealed that condition order did not interact with the main effects of condition and time or condition × time effects, for any outcome.

Effects of Exercise on Smoking and Snacking Related Outcomes

Means and SDs are shown for each condition over time in Table 1, and Figure 1 and 2 show changes scores from baseline to various follow-up points, by condition. T1,F1-F2

Smoking Outcomes

IAB. There was a significant main effect of condition, $F(2, 44) = 12.02$, $p < .001$ and time, $F(1, 22) = 11.86$, $p < .01$, and interaction for condition and time, $F(1.58, 34.75) = 3.58$, $p < .05$. After treatment, a one-way ANOVA showed a significant effect of condition, $F(2, 44) = 13.35$, $p < .001$. IAB was significantly lower after moderate, $t(22) = 5.42$, $p < .001$; 95% CI [16.59, 37.12], $d = 1.28$, and vigorous exercise, $t(22) = 4.17$, $p <$ AQ: 3 $.001$; 95% CI [12.20, 36.31], $d = 0.99$, compared with the control. *T* tests revealed reductions from baseline to after treatment in the moderate, $t(22) = 3.45$, $p < .01$; 95% CI [8.59, 34.58], $d = 0.99$,

Table 1
Mean (SD) for Measures of Attentional Bias and Cravings for Smoking and Snacking

	Condition		
Variable (Time)	Passive	Moderate	Vigorous
Smoking-IAB (%)			
Baseline	70.70 (17.96)	64.31 (23.35)	63.25 (17.06)
After treatment	69.58 (21.89)$_{ab}$	42.73 (20.09)$_{a}$	45.33 (26.44)$_{b}$
Smoking-MAB (%)			
Baseline	65.45 (17.06)	62.40 (16.66)	65.35 (13.23)
After treatment	67.24 (20.82)$_{b}$	58.62 (20.60)	52.77 (19.14)$_{b}$
Strength of desire to smoke			
Baseline	2.48 (1.28)	2.61 (1.12)	2.35 (1.27)
Midtreatment	2.65 (1.23)$_{ab}$	0.96 (0.98)$_{a}$	0.65 (1.34)$_{b}$
Immediately after treatment	2.57 (1.38)$_{ab}$	0.87 (1.06)$_{a}$	0.61 (0.99)$_{b}$
10 mins after treatment	2.91 (1.44)$_{ab}$	2.0 (1.17)$_{ac}$	1.17 (1.15)$_{bc}$
Snacking-IAB (%)			
Baseline	70.07 (24.49)	72.60 (22.42)	67.71 (25.00)
After treatment	78.94 (14.39)$_{ab}$	51.59 (30.29)$_{a}$	51.80 (21.67)$_{b}$
Snacking-MAB (%)			
Baseline	62.00 (17.60)	64.90 (14.15)	64.84 (15.66)
After treatment	67.53 (16.46)$_{b}$	59.41 (22.59)	54.86 (22.48)$_{b}$
Desire to snack			
Baseline	9.78 (3.72)	10.65 (3.21)	10.70 (2.57)
Midtreatment	9.91 (3.84)$_{ab}$	7.96 (3.48)$_{ac}$	5.83 (3.19)$_{bc}$
Immediately after treatment	10.39 (3.76)$_{ab}$	8.83 (3.73)$_{ac}$	6.35 (3.39)$_{bc}$
10 mins after treatment	10.65 (3.43)$_{b}$	10.00 (3.59)$_{c}$	8.09 (3.29)$_{bc}$

Note. a, b, c = significant differences (with Bonferroni correction, $p < .01$).
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

and vigorous exercise condition, $t(22) = 2.59$, $p < .05$; 95% CI [3.55, 32.29], $d = 0.77$.

MAB. There was a significant main effect of condition, $F(2, 44) = 3.58$, $p < .05$ and time, $F(1, 22) = 5.05$, $p < .05$, and interaction for condition and time, $F(2, 44) = 4.52$, $p < .05$. After treatment, a one-way ANOVA showed a significant effect of condition, $F(2, 44) = 4.93$, $p < .05$. After treatment, MAB was significantly lower after vigorous exercise compared with the control, $t(22) = 3.58$, $p < .01$; 95% CI [6.10, 22.86], $d = 0.72$, and *t* tests only revealed reductions from baseline to after treatment only in the vigorous condition, $t(22) = 2.95$, $p < .01$; 95% CI [3.73, 21.44], $d = 0.74$.

SoD. There was a significant main effect of condition, $F(1.14, 30.99) = 33.47$, $p < .001$ and time, $F(1.95, 42.89) = 28.06$, $p < .001$, and interaction for condition and time, $F(3.31, 72.75) = 12.62$, $p < .001$. A one-way ANOVA showed a significant effect of condition at midtreatment, $F(1.43, 31.40) = 29.95$, $p < .001$, immediately after treatment, $F(1.19, 26.10) = 30.52$, $p < .001$, and 10 mins after treatment, $F(1.54, 33.93) = 21.76$, $p < .001$. At midtreatment, SoD was significantly lower after vigorous, $t(22) = 5.62$, $p < .001$; 95% CI [1.26, 2.74], $d = 1.56$, and moderate exercise, $t(22) = 7.65$, $p < .001$; 95% CI [1.23, 2.16], $d = 1.50$, than after the control condition. Immediately after treatment, SoD was significantly lower after vigorous, $t(22) = 6.05$, $p < .001$; 95% CI [1.29, 2.63], $d = 1.59$, and moderate exercise, $t(22) = 5.25$, $p < .001$; 95% CI [1.03, 2.37], $d = 1.37$, than in the control. At 10 mins after treatment, SoD was significantly lower after vigorous, $t(22) = 5.40$, $p < .001$; 95% CI [1.07, 2.41], $d = 1.32$, and moderate exercise, $t(22) = 3.53$, $p = .002$; 95% CI [0.38, 1.45], $d = 0.69$, than in the control. Only at 10 mins after treatment there was a significant difference between moderate and vigorous exercise, $t(22) = 4.23$, $p < .001$; 95% CI [0.42, 1.23], $d = 0.71$. Data for SoD at midrest (control), mid-, and immediately after moderate exercise, and at mid-, immediately after, and 10 mins after vigorous exercise were not normally distributed, according to the Shapiro-Wilk test. A Friedman test confirmed the significant effect of condition at mid-, immediately after, and 10 mins after treatment. Wilcoxon's Ranked tests for related samples also confirmed the between condition differences at each time point as reported above.

Snacking Outcomes

IAB. There was a significant main effect of condition, $F(1.55, 34.08) = 7.81$, $p < .01$ and time, $F(1, 22) = 5.13$, $p < .05$, and interaction for condition and time, $F(2, 44) = 8.13$, $p < .01$. After treatment, a one-way ANOVA showed a significant effect of condition, $F(2, 44) = 19.17$, $p < .001$. IAB on snacking was lower in the moderate exercise, $t(22) = 5.29$, $p < .001$; 95% CI [16.63, 38.08], $d = 1.04$, and the vigorous exercise, $t(22) = 6.29$, $p < .001$; 95% CI [18.20, 36.09], $d = 1.42$, compared with the passive condition. Post hoc *t* tests revealed that there was a significant reduction for IAB on snacking video clips from baseline to after treatment in the moderate exercise, $t(22) = 3.04$, $p < .01$; 95% CI [6.67, 35.37], $d = 0.77$, and the vigorous exercise condition, $t(22) = 2.62$, $p < .05$; 95% CI [3.32, 28.49], $d = 0.68$.

MAB. There was a significant condition × time interaction effect, $F(2, 44) = 5.08$, $p < .01$. After treatment, a one-way ANOVA showed a significant effect of condition, $F(2, 44) = 5.65$, $p < .01$. After treatment, MAB was significantly lower after vigorous exercise compared with the control, $t(22) = 3.34$, $p < .01$; 95% CI [4.79, 20.54], $d = 0.63$. Post hoc *t* tests revealed

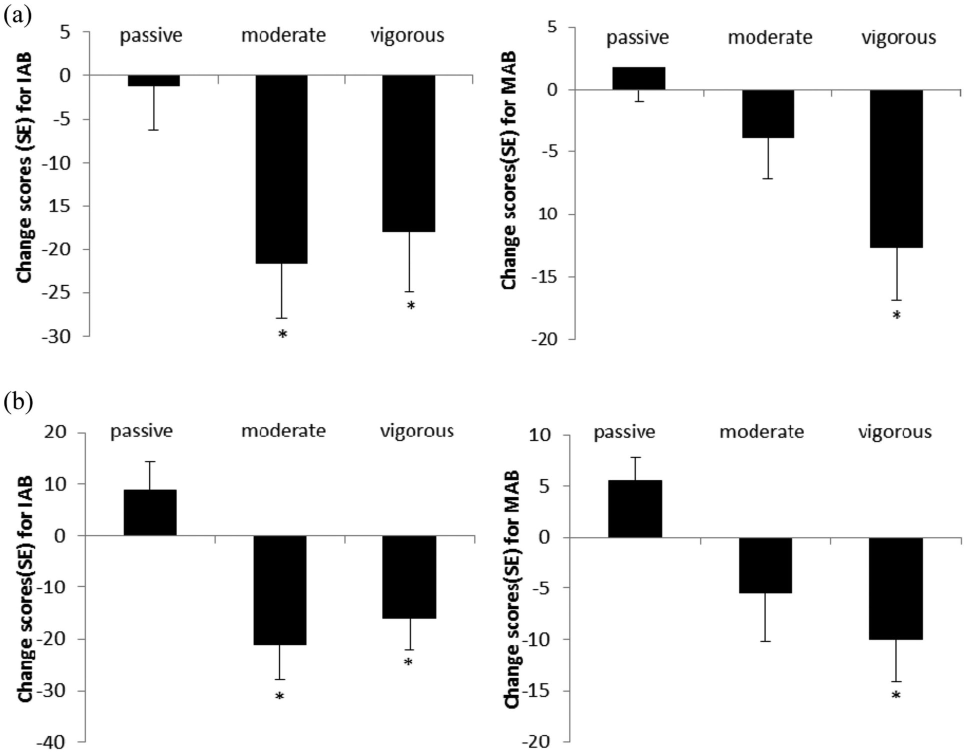

Figure 1. The effects of a passive, moderate exercise, and vigorous exercise condition on initial (IAB) and maintained (MAB) attentional bias towards smoking (a) and snacking (b) video clips.

reductions from baseline to after treatment only vigorous condition, *t*(22) = 2.44, $p < .05$; 95% CI [1.49, 18.48], *d* = 0.50.

Desire to snack. There was a significant main effect of condition, *F*(2, 44) = 10.94, $p < .001$, and time, *F*(3, 66) = 16.69, $p < .001$, and interaction for condition and time, *F*(4.34, 95.52) = 9.51, $p < .001$. A one-way ANOVA revealed a significant effect of condition at midtreatment, *F*(2, 44) = 13.98, $p < .001$, immediately after treatment, *F*(1.53, 33.56) = 15.61, $p < .001$, and 10 mins after treatment, *F*(2, 44) = 9.08, $p < .001$. At midtreatment, desire to snack was significantly lower in the vigorous, *t*(22) = 5.39, $p < .001$; 95% CI [2.43, 5.38], *d* = 1.16, and moderate exercise, *t*(22) = 2.46, $p < .05$; 95% CI [0.31, 3.60], *d* = 0.53, than in the control. At immediately after treatment, desire to snack was significantly lower after vigorous, *t*(22) = 4.44, $p < .001$; 95% CI [2.16, 5.93], *d* = 1.11, and moderate exercise, *t*(22) = 2.44, $p < .05$; 95% CI [0.24, 2.89], *d* = 0.42, than after the control condition. At 10 mins after treatment, desire to snack was lower only after vigorous exercise, *t*(22) = 3.43, $p < .01$; 95% CI [1.01,

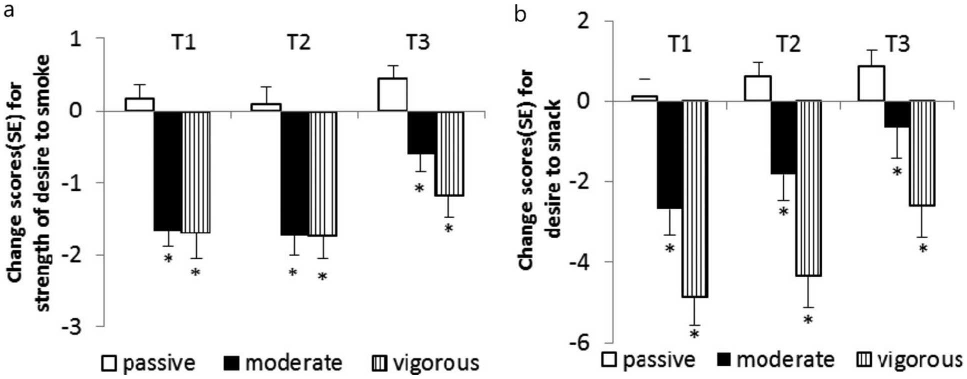

Figure 2. The effects of a passive, moderate exercise, and vigorous exercise conditions on strength of desire to smoke (a) and desire to snack (b). *Note:* T1 = the change score from baseline to midtreatment; T2 = the change score from baseline to immediately after treatment; T3 = the change score from baseline to 10 mins after treatment. * $p < 0.01$.

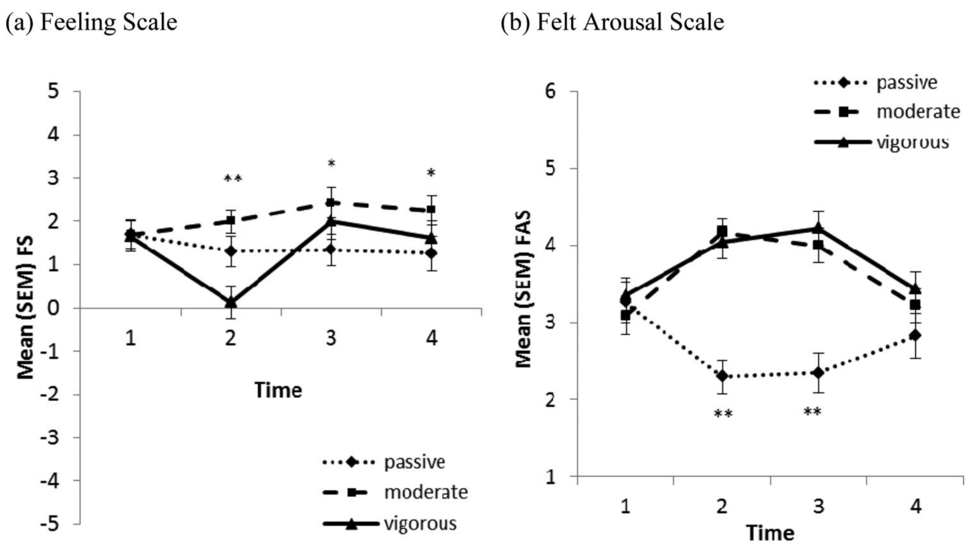

Figure 3. The effects of a passive, moderate exercise, and vigorous exercise condition on Feelings Scale (FS) (a), and Felt Arousal Scale (FAS) (b). (a) Feeling Scale (b) Felt Arousal Scale. *Note:* T1 = baseline; T2 = midtreatment; T3 = immediately after treatment; T4 = 10 mins after treatment. * $p < 0.05$. ** $p < 0.001$.

4.12], $d = 0.78$, compared with the control. There were differences between moderate and vigorous exercise at midtreatment, $t(22) = 3.03$, $p < 0.01$; 95% CI [0.67, 3.59], $d = 0.64$, immediately after treatment, $t(22) = 4.14$, $p < .001$; 95% CI [1.24, 3.72], $d = 0.69$, and 10 mins after treatment, $t(22) = 3.47$, $p < .01$; 95% CI [0.77, 3.06], $d = 0.55$, $p < .01$. Data for desire to snack at mid- and immediately after vigorous exercise were not normally distributed, according to the Shapiro-Wilk test. A Friedman test confirmed the significant effect of condition at mid-, immediately after, and 10 mins after treatment. Wilcoxon's Ranked Tests for related samples also confirmed the between condition differences at each time point as reported above.

Affect Outcomes

FS. There was a significant main effect of condition, $F(2, 44) = 5.38$, $p < .01$ and cubic effect of time, $F(1, 22) = 30.65$, $p < .001$, and interaction for condition and time, $F(6, 132) = 7.73$, $p < .001$. As shown in Figure 3 there were significant effects of condition at mid-, immediately after, and 10 mins after treatment.

At midtreatment FS was lower after vigorous exercise than in the control, $t(22) = 2.93$, $p < .01$; 95% CI [0.34, 2.01], $d = 0.69$, and moderate exercise, $t(22) = 4.52$, $p < .001$; 95% CI [1.01, 2.73], $d = 1.18$, conditions. The moderate exercise condition showed higher FS than the control immediately after, $t(22) = -3.27$, $p < .01$; 95% CI [−1.78, −0.40], $d = 0.63$, and 10 mins after treatment, $t(22) = -2.90$, $p < .01$; 95% CI [−1.71, −0.29], $d = 0.42$. There were no differences in FS between vigorous exercise and the other conditions immediately and 10 mins after treatment. Data for FS at mid- and 10 mins after moderate exercise, and at 10 mins after vigorous exercise were not normally distributed according to the Shapiro-Wilk test. A Friedman test confirmed the significant effect of condition at mid-, immediately after, and 10 mins after treatment. Wilcoxon's Ranked Tests for related samples also confirmed the between condition differences at each time point as reported above.

FAS. There was a significant main effect of condition, $F(2, 44) = 18.77$, $p < .001$ and quadratic interaction for condition and time, $F(1, 22) = 44.06$, $p < .001$. As shown in Figure 3 there were significant effects of condition at mid- and immediately after treatment. At midtreatment FAS was higher after vigorous, $t(22) = -5.30$, $p < .001$; 95% CI [−2.42, −1.06], $d = 1.67$, and moderate exercise, $t(22) = -6.77$, $p < .001$; 95% CI [−2.44, −1.29], $d = 1.93$, than in the control condition. Immediately after treatment, FAS was higher in the vigorous, $t(22) = -5.00$, $p < .001$; 95% CI [−2.64, −1.09], $d = 1.61$, and moderate exercise, $t(22) = -6.88$, $p < .001$; 95% CI [−2.15, −1.15], $d = 1.42$, than in the control. There were no differences in FAS between the moderate and vigorous exercise at any time point. Data for FAS at immediately after rest (control), mid-, and 10 mins after moderate, and 10 mins after vigorous exercise were not normally distributed according to the Shapiro-Wilk test. A Friedman test confirmed the significant effect of condition at mid- and immediately after treatment. Wilcoxon's Ranked Tests for related samples also confirmed the between condition differences at each time point as reported above.

Correlations between change in affect and smoking and snacking related variables. Changes (from baseline to immediately after vigorous exercise) in FS were negatively correlated with changes in MAB ($r = -0.42$, $p < .05$) for snack food images, and changes in FAS were negatively correlated with changes in IAB ($r = -0.43$, $p < .05$) and MAB ($r = -0.44$, $p < .05$). In other words, greater increases in affect were associated with smaller decreases in AB. There were no significant correlations between change in affect and change in AB for smoking images. There were also no significant correlations between change in measures of affect and changes in self-reported smoking and snacking cravings.

Discussion

This is the first study to show that exercise can acutely reduce both visual AB and self-reported cravings for cigarettes and snack foods among temporarily abstinent smokers who regularly snack. Previous studies have independently shown an acute benefit of physical activity for both cravings and AB (with still images) to cigarettes (Janse Van Rensburg et al., 2009) and snack food (Oh, 2012; Taylor & Oliver, 2009). The present study suggests that brief bouts of moderate and vigorous intensity physical activity can enhance self-control or self-regulatory capacity while challenged with nicotine abstinence and the presence of snack food cues.

A main aim of the study was to examine if level of intensity moderated any effects of exercise on AB to smoking and snacking images. Both moderate and vigorous exercise significantly reduced IAB for both smoking and snacking images, suggesting that the ability of such images to grab attention was reduced. In contrast, only vigorous intensity exercise reduced MAB suggesting that moderate intensity exercise may be insufficient to keep gaze and interest from drifting toward the salient images of cigarettes and snack food. The latter finding is in line with the transient hypofrontality hypothesis with vigorous, but not moderate intensity exercise disrupting cognitive function. This is the first study to directly contrast different exercise intensities: Although after moderate and vigorous exercise AB was no different there is evidence that changes, compared with the passive control condition, only occurred in response to vigorous activity, for both smoking and snacking related images. These findings appear to be in contrast with those reported by Janse Van Rensburg et al. (2009) who found that MAB (time spent gazing or dwell time) toward still smoking images (presented alongside neutral images) decreased following a 15 minute bout of moderate intensity exercise. However, the present study involved less dependent smokers and lower baseline self-reported cravings than in Janse Van Rensburg's study. It may be that only when smokers find it particularly challenging to avoid thoughts about smoking does moderate intensity exercise reduce AB: When thoughts about smoking are less dominant, only vigorous intensity exercise causes shifts in AB away from smoking related images.

Taylor et al. (2009) also reported that a 15 min brisk walk (at moderate intensity) reduced MAB (but not IAB) to still images of chocolate, using eye tracking technology, among regular chocolate eaters who were abstinent. Also, Oh (2012) reported that a 15 min brisk walk (compared with a passive condition) reduced IAB (using a dot probe task) to chocolate still images (compared with neutral images), but not MAB, again among regular chocolate eaters who were abstinent. Using still and video images may capture different aspects of AB so comparisons between the respective studies may be premature, but the present study adds to existing research that suggests exercise may have an influence on how we process images of substances we crave.

In related work, Oh and Taylor (2012) reported that 15 mins of brisk walking reduced ad libitum chocolate consumption by almost half among regular chocolate eaters. Further research is needed to assess AB to actual chocolate in naturalistic ad libitum situations to determine if AB precedes consumption, as one may expect, and if exercise reduces AB and consumption.

In terms of self-reported cravings, only at 10 mins after exercise was strength of desire to smoke lower after vigorous compared with moderate intensity exercise. Scerbo et al. (2010) reported similar differences for desire to smoke at 20 mins after exercise (but not before or up to 30 mins after exercise). In contrast, Everson et al. (2008) reported no differences between intensities for desire to smoke during or after exercise, albeit with a lower intensity of vigorous exercise.

In contrast, at all assessments during and after exercise, vigorous intensity led to a lower desire to snack, compared with moderate exercise. This is the first study to report any differential effect across exercise intensities on food cravings. Within a broader body of literature on energy expenditure and compensatory energy intake (Blundell, Stubbs, Hughes, Whybrow, & King, 2003; Martins, Morgan, & Truby, 2008) a few studies have considered the effects of exercise intensity (e.g., Pomerleau, Imbeault, Parker, & Doucet, 2004; Moore, Dodd, Welsman, & Armstrong, 2004) but not among participants who were vulnerable to failure in self-regulation of snacking.

In animal studies, exercise reduces self-administered use of substances (e.g., Kanarek, Marks-Kaufman, D'Anci, & Przypek, 1995) and ethanol (Ehringer, Hoft, & Zunhammer, 2009) possibly by decreasing the positive-reinforcing effects of these substances and providing a hedonic substitution. Certainly, in humans there is consistency that a single bout of exercise can reduce the desire to consume a range of substances that are associated with positive reinforcement. If neurobiological changes in dopamine and serotonin, for example, mediate the effects of exercise on affect then one may expect to see an association between changes in affect, and cravings and AB.

We hypothesized that during vigorous exercise affective valence (FS) would be reduced but would increase, relative to baseline, after exercise. There was indeed a reduction in valence during vigorous exercise but cravings were also reduced. This would imply that other mechanisms are involved, such as distraction, or substance thought suppression during vigorous exercise. As expected, both moderate and vigorous exercise induced increases in affective valence (FS) and activation (FAS) from baseline to after exercise, and these changes visually paralleled those in self-reported cravings. However, there were only weak correlations between changes (from pre- to immediately after different exercise intensities) in affect valence and activation. In contrast, there were significant correlations between changes in MAB for snack food and both changes in FS and FAS, and changes in IAB and FAS. In each case greater increases in affect were associated with smaller reductions in AB, surprisingly. The absence of other significant correlations between changes in smoking AB and affective outcomes, provides little support for the idea that exercise induced affect is implicated in changes in substance-related measures. Larger studies are needed to fully explore the mediating effects of affect.

The present study had several limitations. First, the exercise conditions were only compared with a passive resting control condition, and not a distraction task. In the smoking literature several studies (e.g., Ussher, Nunziata, Cropley, & West, 2001) have involved an attention control (e.g., video watching, completing a task) and each has shown that exercise reduces cravings above and beyond any distracting control condition. Second, we captured AB from the presentation of relatively few film clips which may not have captured the types of snack food of salience to all participants. Certainly, the findings suggest that exercise was able to reduce AB using this novel and perhaps more externally valid approach. Third, the eye tracking technology required calibration prior to each assessment, leading to 2–3 min variations between completing exercise and collecting AB data, and any effect of exercise may have dissipated. Other ways of collecting AB data using dot probe tasks, for example, could be explored. Fourth, laboratory-based exercise helped to control for confounding variables, but further research could be conducted in more natural exercise settings. Fifth, the study followed previous protocols to manipulate temporary nicotine and snacking abstinence, to create a situation of self-regulatory challenge. Smoking cessation was confirmed using CO testing but we relied on self-reported abstinence from snacking at each visit to the laboratory. In a previous study (Taylor & Oliver, 2009) a diary of chocolate snacking was kept for 3 days followed by a request for participants to restrain from snacking for two days. Both procedures resulted in similarly high baseline scores on the FCQ-S. Future research could involve smokers who have actually quit and fear weight gain. Finally, the participants were fairly young and less dependent on nicotine than some exercise studies and replication is needed with older and heavier smokers. However, ongoing exploration of moderators of the large acute effects of exercise on self-reported cravings by M. Haasova, (personal communication, October 1, 2012) suggests that the effects are larger for people who smoke more and who are older. This may mean that the present study under estimated the effects of exercise. Also, participants in the present study were all Caucasians, and future studies should examine the generalizability of these findings among other ethnic groups.

It is worth considering how the present findings could be translated into the development of new interventions to build self-regulatory capacity. Oaten and Cheng (2006) reported how exercise chronically helped participants to improve self-regulatory capacity behaviorally (e.g., reduce smoking, alcohol etc.) and cognitively (i.e., using an attentional control task) over time, though a number of threats to internal validity were evident in their study (e.g., exercise was poorly defined). Providing dietary advice may not be sufficient to prevent weight gain in those attempting smoking cessation (Leslie et al., 2012), and dietary restriction may increase hunger, causing increased cigarette cravings and potential for relapse, so further research is needed to explore the effectiveness of promoting short bouts of exercise for smoking cessation and preventing weight gain (Taylor, Everson-Hock, & Ussher, 2010). Although there are fears that trying to change multiple behaviors may result in cognitive overload and failure to quit smoking (McEwen, Hajek, McRobbie, & West, 2006), promoting short bouts of physical activity may have synergistic effects on smoking cessation and preventing weight gain (Everson-Hock, Taylor, Ussher, & Faulkner, 2010; Marcus, Hampl, & Fisher, 2004).

The sample in the present study had a mean total PFS score of 42.48 which was higher than in a previous study (i.e., 36.42; Forman et al., 2007). Interestingly in their prospective study, 30% of participants who had scores ≥ 42 went on and actually consumed chocolate, compared with none among those with lower PFS scores, who received no intervention. Although it may not be possible at this stage to explicitly identify the clinical significance of the present findings, among those who are challenged in self-regulating both smoking and snacking the replacement of sedentary behavior with brief bouts of physical activity may implicitly facilitate self-control.

Conclusion

A brief bout of physical activity reduces cravings and AB for snacking and smoking cues during temporary abstinence. Both vigorous and moderate intensity reduced IAB but only vigorous exercise reduced MAB to smoking and snacking cues. Both moderate and vigorous intensity exercise reduced strength of desire to smoke and desire to snack during and up to 10 mins after exercise, but the reduction was greater in response to vigorous exercise for snacking. Further research is needed to explore how exercise appears to have shared acute effects on substance-related cravings and AB. The clinical significance of the present findings are hard to estimate but repeated short bouts of a physical activity (i.e., up to 100 kcals each) and possibly reduced energy intake may help smokers who quit to limit weight gain, which has been shown to increase health risk (Yeh et al., 2010). At present, dietary and pharmacological interventions appear to have little effect on preventing weight gain (Farley et al., 2012).

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