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REVIEW

The acute effects of physical activity on cigarette cravings: Exploration of potential moderators, mediators and physical activity attributes using individual participant data (IPD) meta-analyses

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Abstract
Rationale The effects of acute bouts of physical activity (PA) on Strength of Desire (SoD) and Desire to Smoke (DtS) using individual participant data (IPD) from 19 acute randomised controlled studies were quantified. However, there is a need to identify factors influencing this relationship.
Objectives To understand who most benefits from PA, whether changes in affect mediate these effects and whether any specific attributes of PA are associated with cigarette cravings.
Methods IPD (n=930) contributed to one-stage IPD meta-analyses. Participants engaging in PA were compared against controls, using post-intervention DtS and SoD (when DtS is not available) with baseline adjustments. The craving scales were linearly rescaled to 0–100 % (a mean difference between groups of −10 would indicate that post-intervention cravings were 10 % lower in the PA compared with the control group). Demographic, smoking and other characteristics were examined as predictors and potential moderators, whereas change in affect was considered as a mediator. PA was categorised according to type, duration and intensity, to determine PA attributes associated with cravings reduction.
Results None of the included covariates were shown to moderate or mediate the effects of PA. Intensity of PA was significantly associated with a reduction in cravings; moderate and vigorous intensity PA offered the most benefits. A one-stage IPD meta-analysis yielded effect sizes of −9.22 (−15.24; −3.20) for light, −34.57 (−42.64; −26.50) for moderate and −31.29 (−38.00; −24.57) for vigorous intensity in comparison with controls.
Conclusions Moderate intensity PA could be recommended to all smokers regardless of demographic, smoking and other characteristics.

Keywords Acute exercise · Physical activity · Cigarette cravings · Individual participant data (IPD) · Meta-analysis · Moderation · Mediation · Smoking

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Introduction

The proportion of smokers in England have decreased from 39 % of the population in 1980 to 20 % in 2012, with two-thirds of all current smokers wanting to give up smoking but finding it challenging to curb cigarette cravings in a quit attempt (Eastwood 2012). Systematic reviews (Taylor et al. 2007; Ussher et al. 2012) have demonstrated positive effects of acute bouts of physical activity (PA) in reducing cigarette cravings in abstaining smokers. These effects have been quantified in a meta-analysis using aggregate data (Roberts et al. 2012; n=10 studies) and in a meta-analysis using individual patient data (IPD; Haasova et al. 2013; n=19 studies), both showing a significant reduction in cravings of approximately 30 % for participants engaging in a form of PA, compared with participants in a passive condition. Cigarette cravings were recorded on a scale of 1–7 using self-reported measures of cravings, Desire to Smoke (DtS; Tiffany and Drobes 1991) and Strength of Desire to Smoke (SoD; West and Hajek 2004; West and Russell 1985).

The circumplex model of affect (Russell 1980) proposes that all affective states arise from two dimensions: one related to valence (a pleasure–displeasure continuum), assessed by the Feeling Scale (FS; Hardy and Rejeski 1989), and the other related to arousal, assessed by the Felt Arousal Scale (FAS; Svebak and Murgatroyd 1985). Temporary smoking abstinence leads to a decrease in arousal and an increase in emotional stress, which both return to a normal level after smoking a cigarette (Steptoe and Ussher 2006). The Nesbitt's Paradox, when smoking increases sympathetic arousal, yet smokers report feelings of relaxation and contentment, was explained using evidence that smoking a cigarette has independent effects on arousal and emotional stress (Parrott 1998). A meta-analysis of 158 studies found that a single session of aerobic exercise resulted in moderate increases in affective activation (Cohen's d=0.47, standard deviation=0.37) from pre- to post-treatment (Reed and Ones 2006). Also, another review noted increases in affective valence in response to a single session of exercise with considerable inter-individual variability occurring at high PA intensities (Ekkekakis et al. 2011). It has been suggested that changes in affect, as a result of PA, may mediate effects of cigarette cravings (Taylor et al. 2007). Indeed, eight studies designed to investigate the acute effects of exercise on cravings found changes in affect following PA but have been underpowered to assess the mediating effects on cravings of changes in affect due to PA.

The recent meta-analyses (Haasova et al. 2013; Roberts et al. 2012) raised several further questions, specifically, (1) are there any potential predictors of cigarette cravings or moderators of the effect of PA on cigarette cravings? (2) Is it possible to identify any mediating mechanisms by which PA influences cigarette cravings (e.g. affective activation or valence) and (3) are there any specific features of PA (such as type, intensity or duration) that have differential effects on cigarette cravings?

This information may identify important variables that researchers could usefully consider in future research on PA and smoking cessation. In addition, the findings may help practitioners prescribe PA more effectively to smokers attempting to quit. A survey of 170 Stop Smoking Service advisors in the UK revealed that 56 % reported promoting PA for craving management (Everson et al. 2010). This paper aims to address these issues using IPD meta-analysis methods. Compared with meta-analysis using aggregate data, IPD meta-analysis allows adjustment for participant-level baseline covariates, which may increase the power to detect a treatment effect (Riley et al. 2010); also, the use of IPD is beneficial when exploration of associations between treatments and patient-level characteristics is important (Stewart et al. 2011). If data are available at baseline and post-intervention, IPD meta-analysis also facilitates the investigation of potential mediators of the intervention. In this instance, IPD meta-analysis permits inclusion in the analyses of participant characteristics that can serve as potential predictors of cigarette cravings, as well as enables the investigation of potential moderators and mediators of the effects of PA on cigarette cravings. Furthermore, IPD allows exploration of the relationship between the two measures of cigarettes cravings (DtS and SoD) used across the primary studies included in the meta-analyses.

Methods

The earlier meta-analysis (Haasova et al. 2013) followed PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines for conducting and reporting systematic reviews (Moher et al. 2009). A systematic review of literature was conducted, following the methodology described by Taylor et al (Taylor et al. 2007). All searches were conducted between 1 April and 31 May 2011. Only randomised controlled trials (RCTs) were eligible for inclusion. Trials were eligible if they examined effects of acute PA on cigarette cravings using DtS or SoD with a minimum abstinence period of 2 h prior to baseline craving measurement and included a passive control condition. Studies involving participants taking part in a cessation programme or using nicotine replacement therapy were excluded. Both published and unpublished studies were eligible (Haasova et al. 2013). Nineteen RCTs reported DtS and/or SoD to assess acute cigarette cravings among temporarily abstaining smokers and contributed IPD to the current analyses. The search strategy, inclusion and exclusion criteria, data extraction, and data handling are described in detail elsewhere (Haasova et al. 2013). The MacArthur guidelines (Kraemer et al. 2002) were

followed in analyses of moderators and mediators. All statistical analyses were performed using Stata v. 11.

Craving measures

The two craving measures, DtS and SoD, were reported on a Likert scale of 1–7. All craving measures were taken immediately before the intervention and immediately after (16 studies) or 5 min after the intervention (3 studies). To facilitate the use of linear regression modelling and to assist with interpretation of the results, all responses on the 1–7 scale were linearly rescaled to a range of 0–100 (Lyratzopoulos et al. 2012). Thus, a mean difference between groups of −10 would indicate that post-intervention cravings were 10 percentage points lower in the intervention group compared with the control group. Spearman correlation coefficients were used to investigate the association between the two measures of cravings within individuals who had observations available for both DtS and SoD at the same time point (baseline or post-intervention). If the correlation between the two craving measures was found to be high, it may be justifiable to combine studies using these different outcome variables in the same meta-analysis.

Potential predictors, moderators and mediators

Selection of potential predictors of cigarette cravings, and moderators of the effects of PA on cravings, was of necessity dependent on the availability of participant-level data in the primary studies. Our previous meta-analysis suggested that age and nicotine dependence may moderate the acute effects of PA on cigarette cravings (Haasova et al. 2013); hence, these characteristics were investigated as potential predictors and moderators in the analyses. Exploratory analyses encompassed additional potential predictors and moderators, such as gender, body mass index (BMI), weekly PA levels and resting rate, since there is some evidence that inactive and/or overweight smokers may experience reduced pleasure following exercise (Ekkekakis et al. 2011). Smoking characteristics such as the Fagerström Test of Cigarette Dependence (FTCD; Fagerström 1978; Fagerström 2012), abstinence period, carbon monoxide measures taken prior to the start of the intervention, and number of years the participant had been smoking were also included as potential predictors and/or moderators in the analyses. Participants were categorised as being physically active (≥150 min of moderate or vigorous activity in a week) or inactive (<150 min of moderate or vigorous activity in a week), to explore the effects of participants' baseline PA levels on the effects of acute bouts of PA on cigarette cravings. The Seven-Day Physical Activity Recall Questionnaire (Blair et al. 1985) was used in five studies. The International Physical Activity Questionnaire (Craig et al. 2003) was used in three studies, and one study used a cut-off of 30 min on five or fewer days per week. Changes in affect were suggested to mediate the acute effects of PA on cigarette cravings (Taylor et al. 2007); hence, we included measures of affect (FAS and FS) as potential mediators in our analyses. Similarly to the cravings outcomes, to facilitate interpretation of results and to calculate change scores for affect, both FS (measured on a Likert scale of −5 to +5) and FAS (measured on a Likert scale of 1–6) scores were linearly rescaled to 0–100 (Lyratzopoulos et al. 2012).

Physical activity attributes

The previous review suggested that some aspects of PA, such as intensity of exercise, may influence the effects of acute PA on cigarette cravings (Haasova et al. 2013). We therefore categorised all treatment conditions in terms of intensity, duration and type. In the primary studies, intensity of PA in studies was described using Rating of Perceived Exertion (RPE; Borg 1998), percentage of maximum heart rate, heart rate reserve or combinations of these methods.

Three PA intensity categories were defined: light, moderate and vigorous. Moderate-intensity exercise was investigated in 17 studies, 8 of these investigating the effects of walking and 9 investigating the effects of cycling. Vigorous-intensity exercise was investigated in four studies, two investigating the effects of cycling and two of running. Six studies investigated the effects of light-intensity exercise, one investigating the effects cycling, two of walking, and three of isometric exercise.

There were three PA duration categories: short (PA of 5-min duration), medium (PA of 10-min duration) and long (PA of 15-min duration or longer). Two studies used a PA intervention of 5-min duration, seven studies used a PA intervention of 10 min' duration, and one study used a self-paced 1-mile walk that lasted on average 17 min and 48 s. Also, there were three types of PA: isometric exercise, cycling and walking/running. All control conditions were passive. Table 1 summarises all combinations of PA attributes available in the 19 studies for both DtS and SoD. Online Resource Tables 1 and 2 summarise the PA attributes available in the 19 studies for DtS and SoD separately (see Online Resource details given at the end).

Statistical analyses

Due to the heterogeneity of studies with regard to types of PA intervention and participant characteristics, random effect meta-analysis methods were applied to the data (Riley et al. 2011). IPD enables the use of more complex one-stage models (rather than a traditional two-stage approach). One-stage models have advantages over a two-stage model when investigating participant-level sources of heterogeneity, as participant-level characteristics can be incorporated into the

Table 1 Physical activity attribute combinations investigated in randomised controlled trials

Intensity	Duration	Type	Number of studies	Number of participants
Light	Short	Isometric	1	20
		Cycling	1	28
	Medium	Isometric	2	34
Moderate	Short	Cycling	1	28
	Medium	Walking/Running	2	43
		Cycling	5	105
	Long	Walking/Running	5	127
		Cycling	3	56
Vigorous	Medium	Cycling	1	15
	Long	Walking/Running	2	28
		Cycling	1	23

model (Lambert et al. 2002). One-stage IPD meta-analyses as described in the previous review (Haasova et al. 2013) compared participants engaging in PA with control participants. Mixed linear regression models (Higgins et al. 2001) were used, adjusted for baseline values of the outcome variable (DtS/SoD for cravings analyses and FS/FAS for affect analyses), with a fixed effect on study, random intercept on participant (adjustment for multiple observations within participant for crossover trials) and random effect on treatment (allowing the treatment effect to vary across studies). An approximate 95 % midrange of the effect size across studies (assuming a normal distribution of treatment effects across studies) was derived using the mean difference between the intervention and control groups and the standard deviation for intervention effect across studies (Lyratzopoulos et al. 2012). If the fixed effect is given by a and the standard deviation (SD) of the random effect is given by b, then a 95 % midrange is given by $a-1.96b$ and $a+1.96b$. For 95 % of studies, the true mean difference between the intervention and control groups would lie within this range.

A series of analyses were performed, investigating the effects of the trial interventions (PA and control), with adjustment for individual demographic, psychological and smoking related covariates (described above) on cigarette cravings. In addition, baseline FS and FAS were investigated as potential predictors or moderators of treatment effect. Only variables demonstrating a significant interaction with the intervention were considered to be moderating the effects of acute PA on cigarette cravings (Kraemer et al. 2002). To analyse the potential mediating influence of affect in the relationship between PA and cigarette cravings, FS and FAS were used as outcomes to determine any effect of PA on affect. Should FS or FAS be found to be associated with PA, the change in FS or FAS (post-treatment score−baseline score) would be used to investigate an association between change in affect and cravings. An interaction between treatment and change in affect would also be added to the model, to determine whether the change in affect had a main effect on outcome (as a mediator of change in cravings) or an interactive effect with treatment (Kraemer et al. 2002).

One-stage IPD meta-analyses investigated all the attributes of physical activity individually. For example, all PA intensities, light, moderate and vigorous, were individually compared against controls. Random effects were applied to PA attributes (allowing the effects of individual PA attribute categories to vary across studies) only when the between studies variance appeared to be non-zero and was estimated with reasonable precision. An analysis combining all three PA attributes was then performed, identifying the attributes of PA associated with change in cravings, while adjusting for effects of all other PA attributes.

Results

IPD data were available from 19 studies; of these, 17 reported DtS, while 15 reported SoD; only 2 studies reported SoD only. The number of participants in each study varied from 10 to 84; overall, there were 930 observations in the IPD dataset.

Strength of desire and desire to smoke relationship

The Spearman correlation coefficients (including data from 13 studies where both DtS and SoD were reported) for the relationship between DtS and SoD were high, 0.786 ($p<0.01$) at baseline ($n=703$) and 0.840 ($p<0.01$) post-intervention ($n=704$). However, a variation across the individual studies was found. The Spearman correlation coefficients varied from 0.542 to 0.877 for baseline values and from 0.685 to 0.954 for post-intervention values (Online Resource Table 3; see Online Resource details given at the end). Despite a degree of variability across studies in the correlations between DtS and SoD, the two measures were combined in one craving outcome. For the main analyses, DtS was used as the preferred

outcome measure, with SoD used as a proxy for DtS for the two studies that reported SoD only. As a sensitivity analysis, all analyses were repeated using DtS and SoD as separate outcomes.

One-stage individual participant data meta-analyses of effects of physical activity on cigarette cravings

The analyses of the effects of acute PA on cigarette cravings as published in the recent review (Haasova et al. 2013) were repeated using the 0–100 scale. A one-stage IPD meta-analysis yielded a fixed effect mean difference between groups of −31.56 (−42.14; −20.99) for SoD with an SD on the associated random effect of 14.17; the 95 % midrange of intervention effects across studies was −59.33; −3.80. Similarly, a one-stage IPD meta-analysis yielded a fixed effect mean difference between groups of −33.78 (95 % CI −42.39 to −25.16) for DtS, with an SD on the associated random effect of 12.04; the 95 % midrange of intervention effects across studies was −57.37; −10.18. The new combined cigarette craving measure was also analysed; a one-stage IPD meta-analysis yielded a fixed effect mean difference between groups of −31.71 (−40.01; −23.41) with an SD on the associated random effect of 12.26; the 95 % midrange of intervention effects across studies was −55.74; −7.68. Table 2 enables a comparison of the results using the original 1–7 Likert scale and the linearly rescaled 0–100 scale for SoD, DtS and the combined cigarette craving measure.

Potential predictors and moderators of cigarette cravings

When included as individual covariates with intervention, only age, BMI and number of years of smoking were significantly associated ($p<0.05$) with the post-intervention combined cigarette craving measure. In addition, resting heart rate approached significance ($p=0.062$). Age and number of years of smoking were positively associated with reduced cravings post-intervention, whereas BMI and resting heart rate were positively associated with higher cravings post-intervention. The associations of all individual covariates with cigarette cravings after intervention are reported in Table 3. All models including individual covariates were extended by including interaction effects with intervention and the covariate. However, no significant interaction effects were found. These results suggest that none of the included covariates acted as a moderator of the effects of PA on cigarette cravings.

The influence of the individually significant predictors was investigated further. In a model including all individually significant predictors and resting heart rate, only BMI ($p=0.019$) remained significantly negatively associated with craving reduction; however, only 178 observations were available. Based on the number of observations available and significance of individual predictors, a final model including BMI and age was considered to be the most appropriate model. Ten studies collected both BMI and age data. A one-stage IPD random effect meta-analysis (574 observations) yielded a fixed effect mean difference of −0.27 (95 % CI −0.51; −0.03) for age and a fixed effect mean difference of 1.10 (95 % CI 0.52; 1.68) for BMI (Table 3). Both age and BMI were significantly associated with cravings but did not moderate the effect of PA (no interaction was found between intervention status and age or BMI, with respect to cravings). Separate analyses of the two craving measures (DtS and SoD) showed similar results (Online Resource 4; see Online Resource details given at the end).

Table 2 One-stage meta-analyses of the effects of acute physical activity on the combined cigarette craving measure and measures of affect

Outcome	*n* participants (*n* studies)	0–100 % scale ES (95 % CI)[a]	Original scales ES (95 % CI)[a]
SoD[b]	797 (15)	−31.56 (42.14, −20.99)	−1.89 (−2.53, −1.26)
DtS[b]	837 (17)	−33.78 (−42.39,−25.16)	−2.03 (−2.54, −1.51)
Combined cravings[b,c]	930 (19)	−31.71 (−40.01, −23.41)	−1.90 (−2.40, −1.40)
FS[d,e]	372 (8)	7.30 (2.64, 11.97)	0.73 (0.26, 1.20)
FAS[d,e]	372 (8)	16.43 (7.53, 25.34)	0.82 (0.38, 1.27)
FS[d,e] (moderate-intensity PA only)	318 (8)	8.95 (5.19, 12.70)	0.90 (0.52, 1.27)
FAS[d,e] (moderate-intensity PA only)	319 (8)	17.64 (8.64, 26.64)	0.88 (0.43, 1.33)

CI Confidence Interval, *DtS* desire to smoke, *ES* effect size, the combined cigarette craving measure mean difference, *FAS* felt arousal scale, *FS* feeling scale, *N* number, *SoD* desire to smoke

[a] All ES were significant at $p<0.001$

[b] Negative ES favours intervention, positive ES favours control condition

[c] DtS substituted by SoD where no DtS scores were available

[d] Positive ES favours intervention, negative ES favours control condition

[e] The combined cravings measure consists of DtS only (all studies that included FS/FAS reported DtS)

Table 3 Associations of covariates and the effects of PA on the combined cigarette cravings measure

Covariates	*n* participants	*n* studies	0 to 100-scale ES (95%CI)	*p* value
Gender (male=reference group)	769	14	1.85 (−1.58, 5.28)	0.291
CO (ppm)	485	9	0.31 (−0.18, 0.81)	0.211
PA level (inactive=reference group)	536	9	0.27 (−7.21, 7.76)	0.943
FTCD	869	17	0.23 (−0.57, 1.03)	0.571
Abstinence period (hours)	504	9	0.06 (−0.26, 0.37)	0.732
Baseline FS[a]	378	8	−0.52 (−1.84, 0.81)	0.443
Baseline FAS[a]	378	8	0.72 (−1.35, 2.80)	0.495
Resting heart rate (bpm)	462	9	0.22 (−0.01, 0.45)	0.062
Smoking years	502	10	−0.36 (−0.57, −0.16)	0.001
BMI (kg/m^2)	574	10	0.93 (0.36, 1.49)	0.001
Age (years)	796	15	−0.30 (−0.49, −0.10)	0.003
BMI and age				
BMI	574	10	1.10 (0.52, 1.68)	<0.001
Age			−0.27 (−0.51, −0.03)	0.029

Each covariate is fitted individually with intervention (adjusted for study) in one-stage IPD meta-analyses. The results of the most appropriate model, including age and BMI in the same analysis, are also included

BMI body mass index, *ES* effect size, the combined cigarette craving measure mean difference, *FAS* felt arousal scale, *FS* feeling scale, *FTCD* Fagerström Test of Cigarette Dependence, *n* number of observations

[a] The combined craving measure consists of DtS only (all studies that included FS/FAS reported DtS)

One-stage individual participant data meta-analyses of physical activity on affect

Eight studies provided IPD for FS and FAS data. The effects of acute PA on FS and FAS were quantified using the linearly rescaled 0–100 scale. One-stage IPD analyses of post-intervention FS (372 observations) with random effects on the intervention and a fixed effect on study, and adjusted for baseline FS, yielded a mean difference of 7.30 (95 % CI 2.64; 11.97) between the intervention group and controls, with an SD of 3.78 and 95 % midrange of intervention effects across studies of −0.06; 14.66. Using the same approach, analyses of post-intervention FAS (372 observations) yielded a mean difference of 16.43 (95 % CI 7.53; 25.34), with an SD of 8.16 and 95 % midrange of intervention effects across studies of 0.43; 32.43. Results suggest that acute PA increases both affect measures, FS and FAS, among temporarily abstaining smokers. The results of these analyses are shown in Table 2, with the results on the original FS and FAS scales added. The effects were also quantified using moderate PA only, and similar results were found (Table 2). Table 2 enables comparison of the effects of PA on affect with the effects of PA on cigarette cravings.

Change in affect as a potential mediator of the effects of physical activity on cigarette cravings

The prospective mediating effects of change in FS and FAS on the observed reduction in cravings associated with PA were examined using only DtS as the craving measure, as all studies that collected affect data also used DtS as their craving measure. Analyses of the effect of intervention on post-intervention DtS, with adjustment for baseline DtS, showed no significant association with change in affect when measured using FS or FAS. These findings suggest that neither FS nor FAS mediates the effect of PA on cigarette cravings as measured using DtS (Table 4). Two sensitivity analyses, an analysis of moderate-intensity PA only (Table 4) and an analysis using SoD as the craving measure showed similar results (Online Resource 5; see Online Resource details given at the end).

Physical activity attributes

The available combinations of the PA characteristics are presented in Table 1. Individually, all three attributes of PA, duration, intensity and type were found to be significantly associated with a reduction in cravings (Table 5). Interventions of medium and long duration significantly reduced cigarette cravings in comparison with controls, as did walking/running and cycling interventions. Light-, moderate- and vigorous-intensity interventions all significantly reduced cigarette cravings in comparison with controls. However, in a model including all three PA attributes (duration, intensity and type), only the intensity of PA remained significant. In the final model, the moderate-intensity effect was allowed to vary across studies, while a fixed effect was applied to the light and vigorous-intensity PA categories (due to negligible variation

Table 4 Associations of change in affect (FS/FAS) and the effects of PA on cigarette cravings, using separate one-stage IPD meta-analyses for each covariate

Covariates	Number of observations	Number of studies	0 to100-scale ES (95 %CI)	*p* value
Change in FS	372	8	−0.13 (−0.29, 0.02)	0.091
Change in FAS	372	8	−0.07 (−0.04, 0.18)	0.196
Change in FS (moderate-intensity PA only)	318	8	−0.13 (−0.32, 0.05)	0.165
Change in FAS (moderate-intensity PA only)	319	8	−0.09 (−0.04, 0.21)	0.174

The combined craving measure consists of DtS only in the analyses of affect (all studies that included FS/FAS reported DtS)

DtS desire to smoke, *ES* effect size, mean difference, *FAS* felt arousal scale, *FS* feeling scale, *PA* physical activity

in effect across studies or a very wide 95 % CI on the SD). A one-stage IPD meta-analysis (930 observations) yielded a mean difference in cravings compared with controls of −9.22 (95 % CI −15.24; −3.20) for light intensity, −34.57 (95 % CI −42.64; −26.50) for moderate intensity and −31.29 (95 % CI −38.00; −24.57) for vigorous-intensity PA. Separate analyses for DtS and SoD yielded similar results (Online Resource 6; see Online Resource details given at the end).

Discussion

Possibly, of most clinical importance were the results of the various attributes of PA on cigarette cravings. As suggested in the previous review (Haasova et al. 2013), the intensity characteristics of PA significantly influenced the craving reduction. Moderate- and vigorous-intensity exercise had an effect on cravings of similar magnitude; therefore, from a clinical perspective, there appears to be no additional benefit in terms of decrease in cravings from vigorous exercise compared with moderate exercise. Overall, there is sound evidence to recommend short bouts of moderate-intensity exercise to smokers as a means of reducing cigarette cravings. In addition, moderate-intensity exercise may be easier to adopt and maintain than vigorous exercise for sedentary smokers (Taylor et al. 2007). However, these findings are drawn from a population of acute studies with only temporary smoking abstinence and may therefore have limited clinical applicability for smoking cessation. However, the length of the abstinence period (2–30 h) was not found to influence the self-reported cigarette cravings, perhaps suggesting a wider application of these findings.

The current study is the first to inspect the relationship of two commonly used single-item measures of cigarette cravings, SoD and DtS. DtS is assessed with the statement: 'I have a desire for a cigarette right now' (1=strongly disagree, 4=neither agree or disagree and 7=strongly agree). SoD is assessed with the statement 'How strong is your desire to smoke right now?' (1=not at all, 4=somewhat and 7=extremely). Although the scales are semantically different, both measures were found to be highly correlated. A composite

Table 5 The effects of PA attributes on the combine cigarette craving measure: separate one-stage meta-analyses of the effects of duration, type and intensity

PA characteristics (*n*)	Categories	0–100 % scale: ES (95 %CI)	*p* value
Duration[a] (930)	Short	−12.73 (−35.91, 10.44)	0.282
	Medium	−31.12 (−45.74, −16.51)	>0.001
	Long	−36.54 (−46.28, −26.81)	>0.001
Type[b] (930)	Isometric	−5.89 (−13.06, 1.28)	0.107
	Walking/Running	−34.58 (−47.31, −21.85)	>0.001
	Cycling	−35.53 (−45.81, −25.25)	>0.001
Intensity[c] (930)	Light	−9.22 (−15.24, −3.20)	0.003
	Moderate	−34.57 (−42.64, −26.50)	>0.001
	Vigorous	−31.29 (−38.00, −24.57)	>0.001

One-stage IPD meta-analyses (adjusted for baseline cravings), with a fixed effect on study, random intercept on participant, comparing PA categories against control participants

Negative ES for craving measures favours intervention, and positive ES favours control condition

n number of observations, *ES* effect size, the combined cigarette craving measure mean difference, *IPD* individual participant data

[a] The model had random effects applied on short, medium and long duration categories

[b] The model had random effects applied on walking/running and cycling categories

[c] The model had random effects applied on moderate-intensity categories

measure of cravings was used in the main analyses. Although there was a considerable degree of variation in baseline and in post-intervention correlation coefficients among the individual studies, separate analyses for DtS and SoD yielded similar results and confirmed the findings from the main analyses. In addition, the use of a single cravings measure, instead of two separate outcomes, helped to simplify the interpretation of the results. Similarly to the recent meta-analysis of the two separate outcomes (Haasova et al. 2013), PA of any form (compared with a passive control condition) was found to be associated with a reduction of approximately 30 % in cigarette cravings using the combined measure of cravings.

Importantly, no moderators of the effects of PA on cigarette cravings were identified. Both age and BMI were significantly associated with cravings, but such associations may not be clinically significant, and these factors did not moderate the effect of the PA. In summary, the effects of exercise on craving reduction appear robust across a range of potential demographic and smoking-related covariates. This has implications for both clinical practice and research. In terms of clinical practice, PA could be recommended to all smokers regardless of factors such as age, gender, level of nicotine dependence, or BMI. Most of the primary studies used an overnight smoking abstinence period, three studies required a minimum abstinence period of 3 h, and two studies used a period of 2 h. Length of abstinence did not moderate the effects of PA on cravings, therefore suggesting that shorter abstinence periods could be used to recruit heavy smokers in future studies.

We expected a positive influence of PA on measures of affect and anticipated that these effects could partially explain the effects of PA on cigarette cravings. After short bouts of exercise, positive feelings (FS) and the level of arousal (FAS) were increased. Due to different methodologies and populations, a comparison of our results with the findings from the meta-analyses investigating the effects of aerobic exercise on positive activated affect (Reed and Ones 2006) was not appropriate. However, neither FS nor FAS appeared to mediate the relationship between PA and cigarette cravings. It may be that other dimensions of mood or affect, or other as yet unexplored processes, mediate the effects of exercise on urges to smoke, and further research is warranted.

Conclusion

All intensities of PA were found to be helpful in decreasing acute cigarette cravings and could be used in smoking cessation. Moderate-intensity PA provided increased benefit when compared with light-intensity PA, whereas vigorous-intensity PA did not confer additional benefits compared with moderate PA. There was no evidence to suggest a mediating role of affect (as measured by FS and FAS); none of the demographic, health-related or smoking-related variables investigated here appeared to be moderators of the effects of PA. Moderate-intensity PA (e.g. brisk walking) could be recommended to all smokers attempting to quit. However, the application of the use of PA in smoking cessation and its effectiveness remains to be examined.

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