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Reinforcing value of smoking relative to physical activity and the effects of physical activity on smoking abstinence symptoms among young adults

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Abstract

This study sought to evaluate whether individual differences in the reinforcing value of smoking relative to physical activity (RRVS) moderated the effects of physical activity on smoking abstinence symptoms in young adult smokers. The repeated measures within-subjects design included daily smokers (n=79) 18–26 years old. RRVS was measured with a validated behavioral choice task. On two subsequent visits, participants completed self-report measures of craving, withdrawal, mood, and affective valence before and after they engaged in passive sitting or a bout of physical activity. RRVS did not moderate any effects of physical activity (p's > .05). Physical activity compared to passive sitting predicted decreased withdrawal symptoms (β=−5.23, CI= −6.93, −3.52; p<0.001), negative mood (β=−2.92, CI= −4.13, −1.72; p<0.001), and urge to smoke (β=−7.13, CI= −9.39, −4.86; p<0.001). Also, physical activity compared to passive sitting predicted increased positive affect (β=3.08, CI= 1.87, 4.28; p<0.001) and pleasurable feelings (β=1.07, CI= 0.58, 1.55; p<0.001), and greater time to first cigarette during the ad-libitum smoking period (β=211.76, CI= 32.54, 390.98; p=0.02). RRVS predicted higher levels of pleasurable feelings (β=0.22, CI= 0.01 – 0.43, p=0.045), increased odds of smoking versus remaining abstinent during the ad-libitum smoking period (β=0.04, CI= 0.01, 0.08; p=0.02), and reduced time to first cigarette (β=−163.00, CI = −323.50, −2.49; p=0.047). Regardless of the RRVS, physical activity produces effects that may aid smoking cessation in young adult smokers. However, young adult smokers who have a higher RRVS will be less likely to choose to engage physical activity, especially when smoking is an alternative.

Keywords

Smoking; physical activity; young adults; mood; affect; reinforcing value

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INTRODUCTION

Young adults 18 – 24 years of age have the highest smoking prevalence of any adult age group (CDC, 2014), and they are less likely to succeed at quitting smoking even though they are more likely to attempt to quit (Curry, Sporer, Pugach, Campbell, & Emery, 2007; Rigotti, Lee, & Wechsler, 2000; Solberg, Asche, Boyle, McCarty, & Thoele, 2007). Less is known about what approaches may help this population quit smoking (Backinger, Fagan, Matthews, & Grana, 2003; Husten, 2007; Lantz, 2003). Physical activity may be a helpful smoking cessation aid for young adults, as their smoking histories are shorter and physical activity may be more accessible than for older, more chronic smokers.

The negative reinforcing effects of physical activity (lower cravings, withdrawal symptoms, and negative mood) have been well documented among smokers in the laboratory (Ussher, Taylor, & Faulkner, 2014). However, exercise-based smoking cessation interventions have not consistently produced greater quit rates in clinical trials (Ussher et al., 2014). As such, the efficacy of physical activity as a treatment for smoking cessation remains unresolved (Ussher et al., 2014).

Identifying individual differences in the response to physical activity may highlight smokers who benefit most from physical activity as a smoking cessation aid, and those that benefit least. According to behavioral economic theory, variability in the impact of a bout of physical activity may be explained, in part, by the reinforcing value of smoking relative to physical activity (Correia, 2005; Vuchinich & Tucker, 1988). Smokers who have a higher reinforcing value of smoking relative to physical activity may experience fewer reinforcing effects of physical activity, making physical activity an unlikely choice as an alternative reinforcer to smoking (Green & Fisher, 2000; Green & Freed, 1993; Madden, 2000). In contrast, smokers who derive comparable reinforcing value from physical activity and smoking may be more likely to substitute physical activity for smoking, making physical activity a viable option as a smoking cessation aid for these smokers.

This relative reinforcing value is likely the result of the positive reinforcing effects of physical activity (e.g., increases in pleasure, positive mood) in addition to the negative reinforcing effects; yet there has been little investigation of the positive reinforcing effects of physical activity in the context of smoking behavior (Bock, Marcus, King, Borrelli, & Roberts, 1999; Everson, Daley, & Ussher, 2008; Kinnunen et al., 2008; Taylor, Katomeri, & Ussher, 2006). These positive effects may be critical to the substitutability of physical activity for smoking, and to the long-term changes in smoking behavior (Williams et al., 2008). Likewise, in order for physical activity to serve as an alternative reinforcer and promote smoking cessation, it should decrease smoking behavior. The variability in latency to smoke after a bout of moderate physical activity (8–57 minutes) provides indirect evidence that physical activity impacts smoking behavior for some smokers, although not for others (Taylor & Katomeri, 2007; Thayer, Peters, Takahashi, & Birkheadflight, 1993).

The present study sought to evaluate whether individual differences in the reinforcing value of smoking relative to physical activity (RRVS) moderated the effects of physical activity (versus rest) on the primary outcomes of craving, withdrawal, negative and positive mood,

affective valence, and smoking reinforcement in young adults. Individual differences in the RRVS may render physical activity an effective smoking cessation treatment for some smokers, but not at all effective for others. Most of the intervention research in this area has focused on smokers who are relatively sedentary (Ussher et al., 2014). Low levels of physical activity may indicate that they do not engage in physical activity because their experience with physical activity in the past has not been particularly rewarding. Therefore, they may be unlikely to experience enough reward from exercise to find it a useful cessation tool. Identifying individual differences in the response to physical activity among smokers is an important step in the direction of personalizing smoking cessation interventions to increase their efficacy.

METHODS

Participants

Young adult cigarette smokers (n=79) were recruited from the community through print advertisements. Eligible smokers were between the ages of 18–26 years old, and who currently smoked ≥ 5 cigarettes a day for at least one year.

Participants provided written informed consent to a protocol approved by the University of Pennsylvania's Institutional Review Board. Participants then provided a carbon monoxide (CO) breath sample to verify smoking status and a urine sample for a drug screen (Instant Technologies, Inc. Norfolk, VA) and pregnancy test. Smokers who had a CO < 10 ppm, a positive urine drug screen for illicit drugs or psychotropic medication, or who were pregnant were excluded. Smokers were also excluded from participation if they currently used nicotine products other than cigarettes, reported a psychiatric disorder (excluding nicotine dependence), met the threshold for moderate or higher risk stratifications for exercise prescription as outlined by the American College of Sports Medicine, and had physical problems precluding moderate intensity physical activity. Table 1 provides a summary of the characteristics of the sample (n=79).

Procedures

Eligible participants completed a baseline assessment (e.g., demographics, smoking history, physical activity-related variables) and were scheduled for three morning laboratory sessions. Participants received instructions to prepare for these sessions (e.g., no nicotine for 9 hours prior to the session, avoid moderate to vigorous exercise for the prior 48 hours, wear exercise clothing and sneakers). All laboratory visits occurred after overnight smoking abstinence (9 hours), which was confirmed via a carbon monoxide (CO) reading < 8 ppm or 50% of the CO value at Intake. Assessments were made after over-night abstinence from smoking and 48-hours of physical activity to ensure motivation to respond in a behavioral choice task (relative reinforcing value). To promote participation and retention, participants received $50 compensation for each laboratory visit.

Laboratory Session 1—Participants arrived at the laboratory at 9 a.m. and provided a CO sample to verify overnight abstinence. In preparation for the assessment of the reinforcing value of smoking relative to physical activity (RRVS), participants received an

introduction to a behavioral choice paradigm. Participants were introduced to and briefly practiced the "apple picker" computer task (described below) whereby they had the chance to earn points for cigarette puffs or for minutes of physical activity (Barkley, Epstein, & Roemmich, 2009; Roemmich et al., 2008; Saelens & Epstein, 1999). The physical activities included brisk walking on a treadmill or riding on a stationary bicycle (Vision Fitness, Cottage Grove, WI). Participants sampled each of the physical activities for two minutes. The goal was to determine the general motivation to be active or to smoke rather than to quantify the reinforcing value of specific activities or smoking (Barkley et al., 2009; Epstein, Leddy, Temple, & Faith, 2007; Roemmich et al., 2008; Saelens & Epstein, 1999). Two activities were included as the choice to earn points for physical activity may be affected by the type of activity available. We opted to offer two aerobic choices rather than one aerobic activity and one strength training activity to limit variability in the findings attributable to aerobic versus anaerobic activity.

The RRVS was assessed by asking the participants to perform work, in the form of moving the computer mouse to hit targets, to earn access to either physical activity or smoking. Participants had the option to work on one screen to earn points towards physical activity or a second screen to earn points toward smoking. The screens were connected to the same computer, so participants did not have to move from a seated position to switch between working for physical activity or working for cigarette puffs. Using a concurrent schedule (Perkins, Epstein, Grobe, & Fonte, 1994; Perkins, Jacobs, Sanders, & Caggiula, 2002), participants could switch from working on one screen to the other as often as they wished. Adapted from the "Applepicker" software program (Norman & Jongerius, 1985), participants were instructed to move the computer mouse to have the cursor hit the targets (either a sneaker or cigarette). Consistent with an assessment of substitutability via choice paradigms, the reinforcement schedule in the physical activity-earning screen remained constant at a fixed ratio FR-25 (25 targets need to be achieved to earn a point) while the reinforcement schedule for smoking increased with a progressive ratio schedule of PR-25x over 10 trials, such that 25, 50, 75, 100, 125, 150, 175, 200, 225, and 250 targets had to be achieved to earn a point (Bickel, Marsch, & Carroll, 2000; Epstein et al., 2007).

The computer task was performed until a participant completed 10 trials and accumulated a total of 10 points from which they earned either 1 minute of physical activity for each point (i.e., up to 10 minutes of physical activity) or one puff of a cigarette for each point (i.e., up to 10 puffs of a cigarette). Puffs were smoked at the end of the procedure to prevent satiation from the cigarette puffs influencing responding in subsequent trials. To ensure that responding in the choice task was based on reinforcer preference rather than departure from the laboratory, the choice procedure was followed by a one-hour wait in the laboratory. RRVS was defined by the breakpoint (maximum responding) for physical activity versus smoking (Barkley et al., 2009; Bickel et al., 2000; Epstein et al., 2007). The breakpoint reflected the highest trial in which the participant earned points for cigarette puffs versus physical activity. Lower breakpoints would suggest a lower reinforcing value of smoking relative to physical activity and higher breakpoints would reflect a higher reinforcing value of smoking relative to physical activity.

Laboratory Sessions 2 and 3—Participants arrived at 09:00 for each visit, provided a CO sample to verify overnight abstinence, and completed self-report measures of craving, withdrawal, mood, and affective valence. Participants then engaged in passive waiting or a bout of physical activity depending on their assignment. The order of these conditions was randomly determined without replacement and counterbalanced to minimize bias due to order effects.

The 20-minute physical activity condition began with a 2-minute warm-up on the activity that the participant selected at the initial visit (i.e., walking, biking). The same activity was offered to decrease intra-individual variability due to changes in physical activity type across sessions. Participants were instructed in a moderate pace (e.g., walk briskly as if to catch a bus or pedal as if late for an appointment, but not to the point of breathlessness) (Janse Van Rensburg & Taylor, 2008; Janse Van Rensburg, Taylor, Hodgson, & Benattayallah, 2009; Taylor, Katomeri, & Ussher, 2005; Taylor et al., 2006; Ussher et al., 2014). To assess exercise effort, participants provided an oral Rating of Perceived Exertion using the 0–10 Borg scale (Borg, 1998; Chen, Fan, & Moe, 2002). A POLAR heart rate monitor was worn throughout the activity to assess relative exercise intensity (Janse Van Rensburg et al., 2009). The activity was followed by a 2-minute cool-down. Passive waiting condition involved sitting quietly in a private reception area. We chose to compare a bout of physical activity to passive waiting based on the literature showing that 20 minutes of passive waiting did not have a significant impact craving, withdrawal, or mood (Daniel, Cropley, Ussher, & West, 2004; Everson et al., 2008; Janse Van Rensburg & Taylor, 2008; Taylor et al., 2005; Taylor, Ussher, & Faulkner, 2007). Five minutes after the physical activity or rest bout ended (9:45), craving, withdrawal symptoms, mood and affect were measured to provide a post-bout measure of change (Everson et al., 2008; Janse Van Rensburg et al., 2009; Taylor et al., 2005; Taylor et al., 2006; Ussher, West, Doshi, & Sampuran, 2006).

At 9:50 a.m., participants were taken to a specially ventilated smoking research room equipped with a sofa, a stool, a television monitor, and magazines. Participants were told that they had a 60-minute laboratory waiting session where they would periodically complete questionnaires. Participants were given the opportunity to smoke their preferred brand of cigarettes if they chose. Participants were told that the 60-minute laboratory session would be followed by a 30-minute period of enforced abstinence from smoking (Mueller et al., 2009). Cigarettes of the participant's preferred brand, a lighter and an ashtray were placed on a stool next to the couch, but out of direct sight. A clock was placed on the table showing minutes elapsed from 60 minutes.

Latency to the first cigarette puff was the outcome variable. Participants were observed by a research assistant who monitored the latency (in minutes/seconds) to their first cigarette puff (Cousins, Stamat, & de Wit, 2001). The session was also videotaped and scored by independent raters. Thus, we measured smoking latency in a validated ad-libitum laboratory paradigm that simulated events in the natural environment of abstinent cigarette smokers (e.g., the impact of a bout of physical activity on the choice to smoke or remain abstinent) (Dallery & Raiff, 2007; McKee, Krishnan-Sarin, Shi, Mase, & O'Malley, 2006; Mueller et al., 2009). These experimental sessions required about 2.5 hours.

Measures

Outcome Variables

Craving: Craving was measured with the Questionnaire on Smoking Urges Brief (QSU). The QSU is a 10-item Likert-format self-report instrument (Tiffany & Drobes, 1991) with established reliability and validity (Cappelleri et al., 2007; Cox, Tiffany, & Christen, 2001; Janse Van Rensburg & Taylor, 2008; Taylor et al., 2006; Toll, Katulak, & McKee, 2006).

Withdrawal Symptoms: Withdrawal symptoms were measured with the 9-item Mood and Physical Symptoms Scale, the most frequently used measure of smoking withdrawal symptoms in the studies of acute bouts of physical activity on smoking (α=.84) (Everson et al., 2008; Ussher et al., 2014; West & Hajek, 2004).

Negative Mood: Negative mood was measured by the well-validated short form of the Profile of Mood States Tension-Anxiety (6 items) scale (α= .87) (Backhouse, Ekkekakis, Bidle, Foskett, & Williams, 2007; Baker, Denniston, Zabora, Polland, & Dudley, 2002; McNair, Lorr, & Droppleman, 1992; Shacham, 1983). Tension is a common measure of negative affect used to evaluate the impact of physical activity on smoking outcomes (Taylor et al., 2006).

Positive Mood: Positive mood was measured by the four item Positive Well-Being subscale of the Subjective Exercise Experiences Scale (SEES) (McAuley, Courneya, Rudolph, & Lox, 1994). The SEES is valid and reliable (α=.85), and has been used to assess the effects of exercise on mood in nonsmokers and smokers (Everson et al., 2008; Lox & Rudolph, 1994; Parfitt, Markland, & Holmes, 1994).

Affective Valence: Affective valence dimension of pleasure-displeasure was assessed with the Feeling Scale (FS). The FS is an 11-point, single-item, bipolar rating scale commonly used for the assessment of affective valence associated with physical activity (Ekkekakis, 2003; Ekkekakis & Lind, 2006; Lind, Ekkekakis, & Vazou, 2008; Lind, Joens-Matre, & Ekkekakis, 2005; Rejeski, Best, Griffith, & Kenney, 1987; Taylor et al., 2006; Williams et al., 2008). Present feelings were ranked on an 11-point, very bad (−5) to very good (+5) scale. The FS correlates with other self-report measures of pleasure and physical activity (Hall, Ekkekakis, & Petruzzello, 2002).

Smoking Latency: Smoking latency was the time to first smoking puff from 0 – 60 minutes in a 60-minute ad-lib smoking period. Greater latency to smoke after a bout of physical activity (versus rest) is indicative of a reduced smoking reinforcement (Cousins et al., 2001; Mueller et al., 2009).

Predictor Variables—Demographics and smoking history were measured at baseline. Nicotine dependence was measured with the Fagerstrom Test for Nicotine Dependence, a 6-item, self-report measure (Heatherton, Kozlowski, Frecker, & Fagerstrom, 1991) with satisfactory internal consistency (α=.64) and high test-retest reliability (r=.88) (Pomerleau, Carton, Lutzke, Flessland, & Pomerleau, 1994). Current physical activity was measured via the valid and reliable 7-day Physical Activity Recall (Sallis, 1997; Sallis, Buono, Roby,

Micale, & Nelson, 1993), an established measure of habitual activity (Young, Haskell, Jatulis, & Fortmann, 1993). Physical activity liking was measured via the valid and reliable 16-item Physical Activity Enjoyment Scale (PACES) (Heesch, Masse, & Dunn, 2006; Kendzierski & DeCarlo, 1991; Motl et al., 2001) with response options ranging from 1=disagree a lot to 5= agree a lot.

RRVS was assessed by a validated choice paradigm, evaluating the preference for smoking over physical activity (Lussier, Higgins, & Badger, 2005; Perkins et al., 1994; Yoon, Higgins, Bradstreet, Badger, & Thomas, 2009). This task yields an output maximum or breakpoint (maximum amount of responding trials 1–10) for smoking versus physical activity. Lower breakpoints reflect lesser reinforcing value of smoking relative to physical activity. Higher breakpoints reflect greater reinforcing value of smoking relative to physical activity (Bickel et al., 2000). The breakpoint is the preferred measure of relative reinforcer efficacy (Barkley et al., 2009; Bickel et al., 2000; Epstein et al., 2007).

Data Analyses

Univariate statistics were generated to describe the study population in terms of demographics and smoking characteristics. Smoking latency was tested in a mixed models regression. For measures that were taken before and after the bout of physical activity/rest (i.e., craving, withdrawal symptoms, negative mood, positive mood and affective valence), we generated difference scores. Pre-post differences were tested in a mixed models regression framework with subject specific random effects (random intercepts). The hypotheses involved evaluating condition by RRVS interactions (within-between interaction effects). As a precaution against unnecessary testing, only predictors with a bivariate association of $p < .25$ with the outcome were entered into the model. We also tested for order effects. Order effects were assessed via condition by order interactions and were found to be non-significant. All analyses were conducted within Stata (Stata Corporation, College Station, TX, USA).

RESULTS

Descriptive Statistics

Table 1 describes the study population in terms of demographic, smoking, and physical activity variables at baseline. The average intensity of the physical activity bout was 68.14% of maximum heart rate (SD=9.38). The average score of 65.09 (SD=9.64) on the PACES revealed a relatively high level of physical activity enjoyment among the participants (possible range 16 – 80). Variability in habitual levels of physical activity is highlighted by the average number of minutes of physical activity a week across quartiles. Activities that participants engaged in included soccer, skiing, dancing, basketball, baseball, softball, and racquet and board sports (e.g., snowboarding, skateboarding) Table 2 summarizes the values on the outcome variables before and after a bout of physical activity and a bout of passive sitting.

Multivariate Models

Interaction Models—We hypothesized that among smokers with lower RRVS, a bout of physical activity (vs. rest) would reduce cigarette craving, withdrawal symptoms, and negative mood and increase positive mood, affective valence, and latency to smoke. These condition by RRVS interactions were tested in a series of mixed models regressions. All such interactions proved non-significant and were excluded from the analysis. This within-subjects design, with a sample of 79, had 80% power to detect within-between interactions, Bonferroni corrected for 6 outcomes (alpha=.008). We proposed and observed within-subject correlations for our outcomes from 0.5 to 0.9, yielding correlations adjusted effect sizes of 0.8 to 1.2, with estimated power from 82% to 97%. Our analysis revealed smaller effects than we had anticipated once values were differenced. We report these results in supplementary data.

Main Effects Models—Covariates were tested for entry as main effects, and admitted to the model with a preliminary p-value of 0.25. In the case of highly correlated covariates, the overall strongest of the group was retained. Three variables were retained in the models including session (physical activity versus passive sitting), RRVS, and self-reported habitual physical activity through sports. As noted in Table 3, physical activity compared to passive sitting predicted decreased withdrawal symptoms ($p<0.001$), negative mood ($p<0.001$), and urge to smoke ($p<0.001$). In addition, physical activity compared to passive sitting predicted increased positive affect ($p<0.001$) and pleasure ($p<0.001$). Physical activity also resulted in greater time to first cigarette in ad-lib smoking ($p=0.02$). RRVS predicted higher levels of pleasure ($p=0.045$). Also, higher RRVS predicted increased odds of smoking versus remaining abstinent during the ad-libitum smoking period ($p=0.02$), and reduced time to first cigarette ($p=0.047$).

DISCUSSION

We sought to identify which young adults may benefit most from physical activity as a smoking cessation aid by examining whether individual differences in the reinforcing value of smoking relative to physical activity (RRVS) moderated the effects of physical activity on psychological and smoking outcomes. Among young adult smokers, the RRVS did not moderate any effects of physical activity. Compared to rest, an acute bout of physical activity decreased withdrawal, craving, and negative mood. In addition, physical activity increased positive mood, pleasure and smoking latency. These findings suggest that regardless of the RRVS, physical activity produces effects that may aid smoking cessation in young adult smokers.

In spite of these beneficial effects, young adult smokers who have a higher RRVS will be less likely to choose to engage physical activity, especially when smoking is an alternative. Greater RRVS predicted increased odds of smoking (versus remaining abstinent) and decreased smoking latency during the ad-libitum smoking period. These findings may explain why the reinforcing effects of physical activity observed in the laboratory do not translate to greater smoking cessation rates in clinical trials. Physical activity is not a choice in the laboratory, but smokers do choose whether they want to engage in physical activity

outside the laboratory. Lower relative reinforcer efficacy of physical activity may explain suboptimal exercise adherence (i.e., < 70%) (Kinnunen et al., 2008; Marcus et al., 1999; Marcus et al., 2005; Prapavessis et al., 2007), attendance, retention (Borrelli et al., 2002; M. Ussher, West, McEwen, Taylor, & Steptoe, 2003) and smoking abstinence (Madden, 2000; Marcus et al., 2005) in clinical trials of physical activity for smoking cessation. In order to bridge the gap between the smoking cessation-related benefits of physical activity and the motivation to engage in physical activity, research needs to focus on increasing the relative reinforcer efficacy of physical activity among smokers.

Consistent with a growing body of laboratory-based research, we observed reductions in craving, withdrawal, and negative mood after a bout of physical activity (Ussher et al., 2014). These effects have been observed up to 30 minutes post-exercise in smokers who have abstained from 30 minutes to over 17 hours (Taylor et al., 2007; Ussher et al., 2014). Compared to rest, physical activity decreased withdrawal symptoms by 21%, craving by 15%, and negative affect by 44%. As such, physical activity decreases the displeasure associated with smoking abstinence. While these effects are typically diminished by the use of smoking cessation medications, 73% of young adults do not use any pharmacological assistance upon quitting smoking (Solberg et al., 2007). Thus, physical activity could be an effective strategy to mitigate withdrawal, craving and negative mood that accompany smoking cessation in this population.

The positive reinforcing effects of physical activity in smokers, such as increased positive mood and pleasure have received far less attention. Compared to rest, physical activity increased positive affect by 26% and feelings of pleasure by 80%. The few studies that have evaluated the impact of an acute bout of physical activity on positive affect have found increases in positive affect measured soon after a bout of physical activity (Elibero, Janse Van Rensburg, & Drobes, 2011; Everson et al., 2008). Increasing pleasure may be more important to the choice to engage in physical activity after smoking cessation than decreasing displeasure. Individuals who find physical activity reinforcing are more likely to be regularly active and to choose physical activity over alternative activities (Epstein, Kilanowski, Consalvi, & Paluch, 1999; Saelens & Epstein, 1999). These effects reflect more than an hedonic rating or level of liking associated with a physical activity (Roemmich et al., 2008), as simply liking physical activity was not predictive of any effects in the present study and is not predictive of the amount of time a young adult will spend engaged in that activity (Saelens & Epstein, 1999).

Physical activity also delayed ad libitum smoking as observed in previous studies (Kurti & Dallery, 2014; Taylor & Katomeri, 2007; Thayer et al., 1993). Participants began the ad libitum smoking session eight minutes after the physical activity or rest bout ended. After a bout of physical activity, participants waited, on average, an additional nine minutes to smoke (range 12 seconds to 54 minutes), while 6% chose not to smoke at all. After a bout of rest, participants waited almost six minutes to smoke (range 0 seconds to 41 minutes). While the latency may seem short, it is enough time to mitigate a smoking lapse in individuals attempting to quit smoking. However, the variability in smoking latency suggests that physical activity may not impact the choice to smoke for all smokers (Taylor & Katomeri, 2007; Thayer et al., 1993).

As one of the first studies to examine individual differences in the effects of physical activity on smoking and psychological variables, the study has several strengths. It focused on young adult smokers, a group with the highest smoking prevalence, less quitting success, and less research to inform effective treatment. The study was built on a strong empirical and theoretical framework. It utilized rigorous experimental procedures to reconcile discrepant findings and to address an important science gap regarding individual variation in the effects of physical activity on smoking.

The potential limitations of the study are also important to acknowledge. We investigated the effects of moderate intensity physical activity, but the effects of physical activity may vary by intensity. We chose the intensity, duration and types of physical activity that have been shown to impact the proposed outcomes, and were easily accessible inside and outside the laboratory, facilitating translation to clinical intervention. It is true that some participants may have found neither of the aerobic activities appealing, which may have reduced the capacity to find a positive effect. In addition, this study was not designed to evaluate the impact of chronic bouts of physical activity. However, our participants had varied levels of habitual physical activity, which was accounted for in our statistical models. It is important to note that the sample was composed of a relatively high percentage of males, although smoking is more prevalent among male young adults than females (57% vs 43%) (Curry, Sporer, Pugach, Campbell & Emery, 2007). Exercise-based smoking cessation studies have historically focused more on females than males. Also, the sample had a relatively low level of nicotine dependence (FTND = 4.1). As such, this sample may not be representative of young adults or other adults who present for smoking cessation treatment.

Finally, participants were not seeking smoking cessation treatment, which may have impacted the range of values for the RRVS. The average breakpoint was 7.66 (SD=3.00; Range 0–10), indicating that many participants were more motivated “to work for” cigarette puffs than physical activity after overnight abstinence. The range of RRVS scores was restricted. About 85% of the sample had a breakpoint greater than five, indicating greater reinforcing value of smoking relative to physical activity. The restricted range of RRVS scores may have made it difficult to detect relationships between RRVS and the other outcome measures. The clinical value of the RRVS will need to be evaluated in young adult smokers who are motivated to quit smoking. The reinforcing value of smoking relative to physical activity may indeed change over time and upon smoking cessation.

In conclusion, young adult smokers experience mood and smoking related benefits of physical activity, which may help facilitate smoking abstinence. However, young adults with higher RRVS may be less likely to engage in physical activity. These findings emphasize the need to identify ways to increase the reinforcer efficacy of physical activity relative to smoking to ensure that more smokers consistently engage in physical activity and receive the smoking cessation-related benefits. Decreasing the behavioral cost and increasing the accessibility of physical activity may also increase the choice of physical activity to offset smoking abstinence symptoms. A bout of physical activity may need to be brief and accessible across a variety of contexts (e.g., college lecture hall, workplace). Five minutes of isometric exercises have shown beneficial effect on craving and withdrawal symptoms (Ussher, West, Doshi & Sampuran, 2006). Further research will lead to a better

understanding of the role of physical activity in smoking cessation treatment, and how to optimize the substitutability of physical activity for cigarette smoking.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1

Characteristics of the sample (n=79).

Variable	Count (%)
Sex	Female 23 (29%)
	Male 56 (71%)
Race	White 55 (70%)
	Black 17 (22%)
	Other 7 (8%)
Education (High School, HS)	≤ HS 23 (29%)
	> HS 56 (71%)
	Mean (SD)
Age	21.6 (2.17)
FTND	4.10 (2.10)
Cigs Per/Day	12.33 (5.05)
PA Enjoyment	65.09 (9.64)
RRVS	7.66 (3.00)
Physical Activity	Quartiles (min/week)
	18.6
	64.7
	137.9
	441.7

Note. RRVS, Reinforcing Value of Smoking Relative to Physical Activity. PA, Physical Activity. FTND, Fagerstrom Test for Nicotine Dependence.

Table 2

Changes in outcome variables across and between conditions (n=79).

	Physical Activity		Passive Sitting	
Variable	**Pre**	**Post**	**Pre**	**Post**
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Craving	42.19 (14.21)	36.49 (15.81)	41.28 (13.95)	42.71 (14.68)
Withdrawal	25.52 (10.03)	21.13 (9.15)	26.06 (10.50)	26.89 (11.46)
Negative Mood	5.57 (5.45)	3.72 (4.73)	5.54 (5.74)	6.62 (6.39)
Positive Mood	12.30 (6.15)	14.71 (5.51)	12.48 (5.50)	11.72 (6.34)
Pleasure	1.43 (2.03)	2.24 (1.85)	1.51 (1.94)	1.25 (2.08)
Smoking Latency (seconds)		553.95 (956.24)		349.19 (738.82)

Table 3

Main Effects Models

Outcome	Predictor								
	Physical Activity (vs Sitting)			Reinforcing Value (RRVS)			Physical Activity		
	β	Confidence Interval	p value	β	Confidence Interval	p value	β	Confidence Interval	p value
Craving	−7.13	−9.39, −4.86	<.001	.47	−.61, 1.56	.39	.35	−.73, 1.43	.53
Withdrawal	−5.23	−6.93, −3.52	<.001	−.58	−1.60, .44	.26	.45	−.57, 1.47	.39
Negative Mood	−2.92	−4.13, −1.72	<.001	−.32	−.82, .184	.22	.21	−.29, .71	.40
Positive Mood	3.08	1.87, 4.28	<.001	.44	−.08, .96	.09	.02	−.50, .54	.95
Pleasure	1.07	.58, 1.55	<.001	.22	.01, .43	.045	−.12	−.33, .09	.29
Smoking vs Abstained	−.04	−.09, .02	.18	.04	.01, .08	.02	.02	−.01, .06	.19
Smoking Latency (sec)	211.76	32.54, 390.98	.02	−163.00	−323.50, −2.49	.04	−55.23	−215.74, 105.28	.50

Note. Physical activity condition is binary, coded 0/1. Reinforcing value of smoking relative to physical activity (RRVS) and self-reported habitual physical activity through sports are standardized continuous variables, and coefficients represent one standard deviation change in predictor value.