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Initial insight into why physical activity may help prevent adolescent smoking uptake

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Abstract

Introduction—Whereas research supports the importance of regular physical activity to decrease the likelihood of smoking uptake, the mechanisms accounting for this relationship are poorly understood. We sought to determine whether the enjoyment or reward derived from physical activity is one mechanism underlying the relationship between smoking and physical activity.

Methods—The sample was composed of 1,374 adolescents participating in a prospective longitudinal survey study of health behaviors. Variables were measured via self-report every six months for eight waves of data spanning four years.

Results—An associative processes latent growth curve model revealed a significant and negative indirect effect of baseline physical activity on baseline smoking through baseline physical activity reward ($b_{\text{indirect}} = -.18$, $z = -3.11$, $p = .002$; 95% CI = $-.29$, $-.07$). Similarly, there was a significant and negative indirect effect of physical activity trend on smoking trend through physical activity reward trend ($b_{\text{indirect}} = -.16$, $z = -2.09$, $p = .04$; 95% CI = $-.30$, $-.01$). The effect of physical activity on smoking at baseline and across time was completely mediated by physical activity reward. There was less support for the idea that smoking progression was associated with reduced physical activity reward and subsequent declines in physical activity.

Conclusions—This study provides the first evidence implicating physical activity reward as one mechanism by which physical activity reduces the likelihood of adolescent smoking uptake. Smoking prevention interventions that promote physical activity and target physical activity enjoyment may have an important impact on adolescent smoking initiation and progression.

Keywords

adolescents; physical activity; physical activity enjoyment; smoking; prevention

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Contributors

Dr. Audrain-McGovern conceived of the study, wrote the introduction and discussion, oversaw analyses and the interpretation of the results, and edited the entire manuscript. Dr. Rodriguez undertook the statistical analysis and wrote the first draft of the results section. Ms. Cuevas collected and entered data, offered summaries of previous work, drafted the methods section, managed the references, and provided comments for the revision of the manuscript. Mr. Sass collected and entered data, managed the literature searches and provided feedback on the manuscript. All authors contributed to and have approved the final manuscript.

Conflict of Interest

Dr. Audrain-McGovern has consulted for Pfizer within the past three years. However, this consultancy was unrelated to the current manuscript. All other authors declare that they have no conflicts of interest.

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1. INTRODUCTION

Cigarette smoking and physical inactivity are the leading preventable causes of morbidity and mortality in the U.S., accounting for almost 30% of all deaths (Mokdad et al., 2004). Adolescence is a critical period for the development of these health risk behaviors (Chassin et al., 1996; Raitakari et al., 1994; SAMHSA, 2008; Telama and Yang, 2000). Physical activity significantly decline across adolescence (Aaron et al., 2002; Boreham et al., 1999; Dovey et al., 1998; Kimm et al., 2002; Raitakari et al., 1994; Sallis et al., 2000; Stubbe et al., 2005; Telama and Yang, 2000; van der Aa et al., 2010; van Mechelen et al., 2000), while the prevalence of cigarette smoking almost doubles (13% to 25%; CDC, 2012). Currently, about 20% of adolescents in the United States regularly smoke cigarettes (CDC, 2012) and only 29% achieve the recommended 60 minutes of physical activity every day (CDC, 2012).

Research indicates that physical activity is protective against smoking uptake. Higher levels of physical activity across mid to late adolescence have been shown to reduce the odds of smoking initiation and progression by almost 50% (Audrain-McGovern et al., 2003). Consistently sedentary adolescents are more likely to initiate regular smoking compared to consistently active adolescents (30% versus 2%; Raitakari et al., 1994) and are five times more likely to become regular smokers (Kujala et al., 2007). In addition, adolescents with decreasing or erratic team sport participation during mid adolescence are almost three times more likely to regularly smoke by late adolescence, compared to those who are consistently involved in team sports (Rodriguez and Audrain-McGovern, 2004).

The mechanisms by which physical activity protects adolescents from smoking have yet to be formally evaluated. Researchers have speculated that individual, environmental, and biological factors may account for the relationship (Audrain-McGovern et al., 2012). One possible mechanism that may help explain the link between adolescent physical activity and smoking is physical activity enjoyment or the subjective reward derived from engaging in physical activity. Physical activity enjoyment represents an hedonic or rewarding rating associated with physical activity (Roemmich et al., 2008). Studies have shown that participation in physical activity is associated with greater physical activity enjoyment (Davison et al., 2007; Deforche et al., 2006; Dishman et al., 2005; Garcia Bengoechea et al., 2010). If an adolescent derives pleasure from physical activity, they may be less likely to seek alternative sources of reward, such as smoking. In addition, physical activity may create neuroadaptations that influence the likelihood that an adolescent will find smoking rewarding and escalate in use. Accumulating evidence indicates that physical activity influences many of the same neurotransmitters, intracellular signaling molecules, and neuroanatomical structures that mediate the positive reinforcing effects of drugs (Audrain-McGovern et al., 2006; Smith and Lynch, 2012).

The present study sought to provide initial evidence for physical activity reward as a potential mechanism underlying the relationship between smoking and physical activity. We hypothesized that higher levels of physical activity would be associated with greater physical activity reward, which in turn, would decrease the odds of adolescent smoking uptake. We also evaluated whether the relationship among these variables was reciprocal, such that smoking contributed to declines in physical activity because smoking makes physical activity less rewarding. Identifying evidence-based treatment targets will be important to inform smoking prevention and intervention efforts that incorporate physical activity as a treatment component.

2. METHODS

2.1. Participants and procedures

Participants were high school students (51% female and 73% White) taking part in a longitudinal study of the relation between adolescent physical activity and smoking adoption. Participants were enrolled in one of four public high schools in suburban Philadelphia, PA. This cohort was drawn from the 1,517 students identified through class rosters at the beginning of ninth grade. Students were ineligible to participate in this study if they had a special classroom placement (e.g., severe learning disability) or if they did not speak fluent English. Based on the selection criteria, a total of 1,487 (98%) students were eligible to participate. Parents were mailed a study information letter (active information) with a telephone number to call to obtain answers to any questions and to decline consent for their adolescent to participate. Of these 1,487 eligible teens, 1,478 (99%) had a parent's passive consent to participate. Thirty adolescents were absent on the assent/survey days and 19 did not provide assent due to lack of interest in the study. Thus, 1,429 of 1,478 teens with parental consent (97%) provided their assent to participate and completed a baseline survey. Adolescents who declined assent or who were absent on the baseline survey day did not differ on race and gender from those who provided assent and completed the baseline survey.

The adolescent cohort was formed in the 9th grade and followed until the end of 12th grade. Each adolescent was assigned a study identification number at baseline. The identification number appeared on their survey at each survey time point. A survey face page with the participants name on it was removed when the self-report survey was handed to the student, ensuring that the adolescent received a survey with their unique identification number at each wave. A self-report 40-minute survey was administered every six months (fall and spring semesters) on-site during compulsory classes each year of high school for a total of eight surveys. The sample size was the $n = 1,374$ participants with complete data for the covariates in the model. University Institutional Review Board approval of the study was obtained.

2.2. Measures

2.2.1. Smoking—Smoking progression was derived from evaluating smoking practices with a series of standard epidemiological questions regarding smoking such as, “Have you ever tried or experimented with cigarette smoking, even a few puffs?”, and “Have you smoked a cigarette in the past 30 days?” (Audrain-McGovern et al., 2009; Eaton et al., 2006). The 7-category ordered categorical smoking variable was coded as 0 = never smoked, 1 = puffed but did not smoke a whole cigarette, 2 = smoked a whole cigarette but not in the past month, 3 = smoked in the last month, 4 = smokes weekly, 5 = smokes 10 cigarettes daily, and 6 = smokes > 10 cigarettes daily. Smoking was measured all eight waves.

2.2.2. Physical activity—Physical activity was assessed with the 7-day Physical Activity Recall (PAR; Sallis et al., 1985, 1997; Sallis and Owen, 1999; Sallis et al., 1999). The PAR has excellent test-retest reliability ($r = 0.81$) and validity ($r = 0.72$ against heart rate monitors) in adolescents (Sallis et al., 1993). It is a widely used measure of habitual activity in observational studies (Gordon-Larsen et al., 2000; Sallis et al., 1985; Young et al., 1993). As in previous large-scale studies, adolescents self-administered the PAR (Dishman et al., 2005; Gordon-Larsen et al., 2000; Harris et al., 2006; McMurray et al., 2004; Motl et al., 2001; Raudsepp and Viira, 2008; Sallis et al., 2000). This required adolescents to report the number of days in the past seven days and the amount of time that they participated in 34 commonly reported activities of moderate to vigorous intensity. Activities were grouped into broad categories (e.g., sports and dance, exercise, general) with spaces to add activities that

were not listed. Physical activity was defined as minutes of moderate and vigorous physical activity (MVPA) over the past seven days. Physical activity was measured all eight waves.

2.2.3. Physical activity reward—The 16-item Physical Activity Enjoyment Scale (PACES) was used to assess physical activity reward (Heesch et al., 2006; Motl et al., 2001). Items such as “When I am active.....I enjoy it”...I get something out of it“....it feels good” are rated on a 5-point bipolar scale (Motl et al., 2001) (“1 = Disagree a lot” and “5 = Agree a lot”) with scores ranging from 16-80 (Dishman et al., 2005; Kendzierski and DeCarlo, 1991; Motl et al., 2001; Wilson et al., 2005). Internal and cross-structure analyses support the single factor structure of the PACES, and its reliability ($\alpha = .88-.94$) and discriminant validity (Davison et al., 2007; Kendzierski and DeCarlo, 1991; Motl et al., 2001; Neumark-Sztainer et al., 2003; Wilson et al., 2005). Negatively worded items are reverse coded (e.g., “I dislike it”) and scores across items were summated to provide a single summed score of physical activity enjoyment. Physical activity enjoyment was measured all eight waves.

2.3. Covariates

We controlled for gender (1 = female), race (1 = white, 0 = else), and parental education (0 = both parents have greater than a high school education, 1 = at least one parent has a high school education or less, 2 = both parents have a high school education or less). Peer and household smoking exposure was controlled for using a single exposure variable (0 = no exposure to peer or household smoking, 1 = exposure to either peer and/or household smoking) (Audrain-McGovern et al., 2004; Choi et al., 1997; Tercyak et al., 2002). Also, we controlled for impulsivity using the impulsivity subscale of the Temperament and Character Inventory (TCI) (5 True/False items KR-20 = .70) (Cloninger et al., 1994a, b), and the availability and access to physical activity in an adolescent's neighborhood using three subscales of the Neighborhood Environment Walkability Scale (crime, traffic and infrastructure for walking, biking, etc.) (Saelens et al., 2003). Test-retest reliabilities for these subscales have ranged from .60-.80 (Saelens et al., 2003; Sallis et al., 1997).

2.4. Data Analysis

Univariate statistics were generated to describe the study population in terms of demographics, smoking, physical activity, and physical activity enjoyment. Univariate estimates were generated with SAS 9.1.3 software.

2.4.1. Latent curve growth modeling (LGCM)—Two separate associated-processes LGCM's were conducted to assess the longitudinal, bi-directional relation of repeated measures of physical activity, physical activity enjoyment, and smoking. LGCM is a Structural Equation Modeling method that models repeated observed measures (measured variables) on factors (latent variables) representing random effects (s) (Duncan and Duncan, 1995). A level factor is used to represent baseline level and trend factors are used to represent rate of change across time (i.e., each unit change in time is associated with a change in a given process). Latent variables define the form of the rate of change across time (e.g., linear, quadratic, cubic). Factor loadings (i.e., correlations between the observed and latent variables) are fixed to define baseline or level (factor loadings are restricted to equal 1 from the level/intercept factor to each observed measure) and trend. For a linear trend, the factor loadings are set so they increase uniformly with each unit increase in time (six months in the present study). In the present model, the factor loading from the linear trend factor to the first observed measure was constrained to equal zero as the first observed measure is the baseline level. The second factor loading is constrained to equal one, indicating a unit increase in the rate of change in each process (i.e., physical activity, physical activity reward, and smoking) for a unit increase in time. The remaining factor loadings for the

linear trend factor were constrained similarly to define a linear growth form (i.e., 2, 3, 4, 5 and 6, for waves 3 through 8, respectively).

In the present analysis, we conducted associated processes mediation LGCMs. Associated processes LGCM is a multivariate method that allows testing paths among random effects (i.e., levels [0] and trends [1,2,...]) from two or more LGCMs (Duncan et al., 1999). One associated processes model was run in the present study to assess the impact of repeated observed measures of physical activity (continuous variables) on smoking (ordered categorical variable) through physical activity reward (continuous variable). This model evaluated whether physical activity reduces the odds of smoking uptake because physical activity is rewarding. A second model assessed the impact of smoking on physical activity through physical activity reward (i.e., the reciprocal model). This model evaluated whether smoking contributes to declines in physical activity because smoking makes physical activity less rewarding.

As smoking is a categorical variable, we estimated model parameters with a Weighted Least Squares estimation technique (WLSMV) in which the diagonal weight matrix uses robust standard errors, and the chi-square test statistic is Mean and Variance adjusted (Muthén, 1998-2004b). This permitted us to attain statistics to assess model fit. Suggested criteria for model fit are non-significant model chi-square, CFI above .95, RMSEA below .05 –.08, and a WRMR value below .9 (Loehlin, 2004; Muthén, 2001). However, we present our results using bootstrapped standard errors (1000 repetitions) as our primary interest was testing a mediation model (Shrout and Bolger, 2002). LGCM were conducted using *Mplus* version 6.0 software.

2.4.2. Missing data—To account for missing data, multivariate modeling used all available data. *Mplus* allows modeling with missing data using maximum likelihood estimation of the mean, variance, and covariance parameters, when requested, employing the Expectation Maximization (EM) algorithm, assuming data are missing at random (Muthén, 1998-2004a, b). However, this only accounts for missing data on the repeated measure of smoking, physical activity, and physical activity enjoyment (our dependent variables), not the covariates (gender, race, parental education, impulsivity, smoking exposure, and neighborhood physical activity access). Thus, cases with missing data on these variables were not included in the analysis. As such, the analyses were based on 1374 participants after excluding those participants with missing data on the covariates.

3. RESULTS

3.1. Descriptive Statistics

Table 1 presents the frequency distributions for all categorical variables, and the means and standard deviations for the continuous variables. Twenty-one percent of adolescents progressed along the smoking uptake continuum across four years. By contrast, minutes of moderate to vigorous physical activity decreased significantly over the same time period from an average of 952.30 (SD = 627.96) minutes a week at baseline to 654.30 (SD=555.87) at last follow up, $t\text{-test}_{(1080)} = 13.76, p < .0001$. Physical activity enjoyment, however, increased significantly from baseline (M = 64.95, SD = 10.34) to last follow up (M = 67.19, SD = 10.54), $t\text{-test}_{(1081)} = -5.88, p < .0001$.

3.2. Multivariate Models: Direct Effects on Smoking, Physical Activity, and Physical Activity Reward

An associative processes model with three processes (physical activity, smoking, physical activity reward) was fit to the data; $\chi^2_{(412, 1374)} = 750.09, p < .0001$, CFI = .99, RMSEA = .

02, WRMR = 1.06. Figure 1 presents the associated processes LGCM with standardized path coefficients for the significant path effects only.

3.2.1. Smoking—Baseline physical activity reward had a negative effect on baseline smoking (OR = .97, 95% CI = .95, .99). For every half standard deviation increase in physical activity reward, the odds of smoking at baseline decreased 14%. Exposure to peer and household smoking was associated with a greater than three-fold increase (OR = 3.20, 95% CI = 2.66, 3.85) in the odds of baseline smoking. Each level decrease in parental education from having two parents with greater than a high school education to both parents having a high school education or less was associated with a 14% decrease (OR = 1.14, 95% CI = 1.05, 1.25) in the odds of smoking at baseline. Further, a standard deviation (SD = 1.42) increase in impulsivity was associated with a 13% increase (OR = 1.13, 95% CI = 1.04, 1.21) in the odds of baseline smoking.

Physical activity reward trend was associated with decreased likelihood of smoking progression (OR = .95, 95% CI = .91, .99). For every half standard deviation increase in physical activity reward, the odds of smoking progression decreased 23%. Further, being White was associated with an increased likelihood of smoking progression (OR = 1.05, 95% CI = 1.01, 1.10).

3.2.2. Physical activity reward—Baseline physical activity was positively associated with baseline physical activity reward ($b = 5.34$, $z = 22.09$, $p < .0001$). Being female ($b = -1.60$, $z = -3.00$, $p = .003$) and having parents with a high school education or less ($b = -.91$, $z = -2.56$, $p = .01$) were associated with lower levels of physical activity reward. In contrast, access to physical activity in an adolescent's neighborhood was associated with greater levels of physical activity enjoyment at baseline ($b = .63$, $z = 7.10$, $p < .0001$).

Baseline physical activity was associated with a decreasing rate of change in physical activity reward ($b = -.21$, $z = -4.24$, $p < .0001$). However, physical activity trend was associated with an increased rate of change in physical activity reward ($b = 3.14$, $z = 8.41$, $p < .0001$). Baseline smoking was also associated with an increased rate of change in physical activity enjoyment over time ($b = 3.14$, $z = 8.41$, $p < .0001$). Being female was associated with an increased rate of change in physical activity reward ($b = .28$, $z = 2.67$, $p = .01$).

3.2.3. Physical activity—Being White was associated with greater baseline physical activity ($b = .19$, $z = 2.39$, $p = .02$). Baseline physical activity enjoyment was associated with a decreasing rate of change in physical activity over time ($b = -.01$, $z = -8.65$, $p < .0001$). Being female and higher levels of impulsivity was associated with a decrease in physical activity over time ($b = -.05$, $z = -2.91$, $p = .004$ and $b = -.01$, $z = -2.15$, $p = .03$, respectively).

3.3. Indirect Effects of Physical Activity on Smoking through Physical Activity Reward

The primary purpose of this study was to assess whether the effects of physical activity on smoking are explained, in part by the effects that physical activity has on physical activity reward. All model parameters were estimated with bootstrapped standard errors (1000 runs) to correct for deviations from normality when calculating standard errors for the indirect effects (Shrout and Bolger, 2002).

With respect to baseline effects, there was a significant and negative indirect effect of baseline physical activity on baseline smoking through baseline physical activity reward ($b_{\text{indirect}} = -.18$, $z = -3.11$, $p = .002$; 95% CI = $-.29$, $-.07$). The direct effect of baseline physical activity on baseline smoking was not significant ($b = .17$, $z = 1.64$, $p = .10$; 95% CI = $-.03$, $.38$), suggesting that the effect of baseline physical activity on baseline smoking is

completely mediated by baseline physical activity reward. That is, greater baseline physical activity was associated with greater physical activity reward, which, in turn, predicted decreased odds of smoking at baseline.

With respect to effects across time, there was a significant and negative indirect effect of physical activity trend on smoking trend through physical activity reward trend ($b_{\text{indirect}} = -.16$, $z = -2.09$, $p = .04$; 95% CI = $-.30, -.01$). The direct effect of physical activity trend on smoking trend was not significant ($b = .30$, $z = 1.57$, $p = .12$; 95% CI = $-.08, .68$), suggesting that the effect of physical activity trend on smoking trend was completely mediated by physical activity reward trend. That is, greater physical activity across time predicted higher levels of physical activity enjoyment, which, in turn, predicted a decreased likelihood of smoking progression across time.

3.4. Indirect Effects of Smoking on Physical Activity through Physical Activity Reward

The reciprocal model with standardized path coefficients for the significant paths is presented in Figure 2. This model fit the data fairly well, $\chi^2_{(412, 1374)} = 760.02$, $p < .0001$, CFI = .99, RMSEA = .02, WRMR = 1.07. Baseline smoking had a significant negative indirect effect on baseline physical activity ($b = -.13$, $z = -3.77$, $p < .0001$; 95% CI = $-.19, -.06$), suggesting that the negative effects of smoking were mediated by physical activity enjoyment. Thus, higher levels of smoking at baseline were associated with lower physical activity reward, which in turn, was associated with less baseline physical activity. The direct path from baseline smoking to baseline physical activity was not significant, indicating total mediation. The mediated path from smoking trend to physical activity trend through physical activity reward trend was not significant ($b = -.13$, $z = -1.79$, $p = .07$; 95% CI = $-.28, .01$).

4. DISCUSSION

The present study provides the first evidence towards understanding the link between adolescent physical activity and adolescent smoking uptake. We hypothesized that higher levels of physical activity would predict greater physical activity reward, which in turn, would predict decreased odds of smoking progression. Indeed, the findings indicated that adolescents with higher levels of physical activity reported greater physical activity reward and were 14% less likely to be smoking at age 14 years and 23% less likely to progress along the smoking uptake continuum across the subsequent four years. While smoking at age 14 years old was associated with less physical activity via lower physical activity reward, this reciprocal relationship was not significant across time. Smoking prevention interventions that promote physical activity and target physical activity enjoyment may have an important impact on adolescent smoking initiation and progression.

This study extends the epidemiological research showing a protective effect of physical activity on adolescent smoking uptake by highlighting physical activity reward as one pathway by which physical activity affects adolescent smoking susceptibility. While a growing body of evidence provides a strong case for clinical trials to evaluate whether physical activity interventions prevent adolescent smoking initiation and progression (Aveyard and Ussher, 2007), the variables that should be targeted to optimize the impact of a physical activity intervention on smoking behavior have not been previously defined. Physical activity reward is one mechanism. Behavioral theories suggest that the pleasure or reward obtained from one behavior (e.g., physical activity) can alter the choice and reinforcing value of another behavior (e.g., smoking) (Comer et al., 1998; Green and Fisher, 2000; Green and Freed, 1993; Madden, 2000). Here, we show that the subjective reward derived from physical activity is associated with a reduced likelihood of adolescent smoking.

Given that almost 20% of adolescents are regular smokers (CDC, 2012) and less than one-third achieve the recommended 60 minutes of physical activity every day (CDC, 2012), targeting physical activity and its associated enjoyment has the potential to impact both smoking and physical activity. Physical activity research has shown that physical activity enjoyment is associated with physical activity, but there has been insufficient attention to strategies that foster the growth of adolescents' enjoyment of physical activity (Schneider and Cooper, 2011). To maintain regular exercise, the rewarding effects need to outweigh the aversive effects. If reward declines, tipping the balance toward displeasure, physical activity will decline. To promote enjoyment, interventions should not strive to promote one type of activity, but rather help adolescents identify and engage in the type or types of activity that are most rewarding. Adolescents may need to seek out activities that they feel they are good at and therefore, more likely to enjoy (Rodriguez et al., 2008). A recent study showed that increasing physical activity enjoyment through choice, variety and modification for lower levels of fitness increased enjoyment and engagement in vigorous physical activity (Schneider and Cooper, 2011).

It is plausible that physical activity reward predicts physical activity and if an adolescent does not find physical activity enjoyable then s/he will be less active. Differences in subjective reward and reinforcing value of physical activity may reflect biologically-based individual differences in the response to physical activity (Epstein et al., 1999; Reiss and Haverkamp, 1996; Saelens and Epstein, 1999) that drive the choice to engage in physical activity over alternative activities (Epstein et al., 1999; Saelens and Epstein, 1999). Whereas our models show some evidence for bidirectional influences for physical activity and physical activity reward, the results indicate that physical activity reward is an important target to support smoking behavior change.

Research has shown that smoking in mid-adolescence predicts declines in physical activity by late adolescence (Audrain-McGovern et al., 2003; Kimm et al., 2002). It seems intuitive that cigarette smoking could make physical activity less rewarding and possibly aversive, contributing to declines in physical activity. In our assessment of reciprocal effects, a higher level of smoking at age 14 years was associated with less physical activity reward, which in turn, was associated with less physical activity at age 14. Early onset regular smoking may easily produce negative physical effects on an adolescent's body altering the enjoyment of physical activity and thus the performance of physical activity in mid adolescence. Quitting smoking may make physical activity more enjoyable and facilitate continued abstinence. Recent research suggests that physical activity can aid adolescent smokers to quit smoking (Horn et al., 2011). However, the impact of smoking progression on the rate of decline in physical activity was not explained by changes in physical activity enjoyment, but it did approach significance ($p=.07$). It is not clear why the longitudinal relationship only approached significance, but it is possible that smoking duration, smoking level, and/or type of physical activity play a role across adolescence.

Considering the role of physical activity in quitting smoking, emerging evidence questions the efficacy and utility of physical activity interventions for smoking cessation in adults (Ussher et al., 2008), although there is limited information on the use of such interventions in adolescents (Horn et al., 2011). Rather than conclude that physical activity is a weak or ineffective treatment for smoking cessation, it may be important for research to attend to the role of physical activity choice (versus one type of activity for all smokers) and the reward derived from physical activity selection. Adults and adolescent smokers may benefit more by choosing the types of physical activity that they want to engage in and therefore find most rewarding.

As the first study to examine the indirect effects of adolescent physical activity on smoking, the study has several strengths. These strengths include a large sample of adolescents, eight measurement waves across four years, and the inclusion of important covariates. One potential limitation is that, we relied on self-reports of smoking. Biochemical verification of smoking status are not typically implemented in epidemiological studies as adolescent self-reports have been determined to be valid and sufficient, especially when confidentiality is assured (Velicer et al., 1992; Wills and Cleary, 1997). Further, the standard cotinine cutoff of 15 ng/ml cannot validate cotinine levels consistent with definitions of being an adolescent current smoker (e.g., 1 cigarette in the past 30 days) (Dolcini et al., 2003). Also, as in previous epidemiological investigations of physical activity [e.g., (Kahn et al., 2008)], the outcome variable of physical activity was based on self-report. Assessing physical activity using objective measures such as accelerometry would have been difficult given the large sample size. The current public health recommendations for physical activity are based on decades of research linking self-reported physical activity with health outcomes (Haskell, 2012; USDHHS, 1996). The predictive validity of accelerometry data has not been similarly established. Finally, the levels of physical activity reported in the present study are comparable to (Aaron et al., 2002) or greater than (Nader et al., 2008) previous studies that have reported minutes of MVPA. Nonetheless, our data are consistent with the epidemiological literature showing that, on average, adolescent physical activity declined across time.

In summary, the present study provides initial support for physical activity reward as one mechanism by which physical activity reduces the likelihood of adolescent smoking uptake. The protective effect of physical activity on smoking via physical activity reward was present at age 14 and persisted through late adolescence. Smoking prevention interventions that promote physical activity and target physical activity enjoyment may have an important impact on adolescent smoking initiation and progression. Physical activity enjoyment is only one mechanism accounting for the relationship between physical activity and smoking uptake. Further research is warranted to identify other mechanisms underlying this relationship to provide evidence-based smoking prevention treatment targets.

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Figure 1.

Associated processes LGCM of the indirect effects of physical activity on smoking through physical activity reward.

Note: standardized path coefficients for significant model paths only

Figure 2.

Reciprocal model examining the impact of smoking on physical activity through physical activity reward.

Note: standardized path coefficients for significant model paths only

Table 1
Descriptive statistics

Variable	Level	N	%
Gender	Male	679	49
	Female	695	51
Race	Black	367	27
	White	1007	73
Smoking exposure	No peer or household smoking	501	36
	Either peer or household smoking	529	39
	Peer and household smoking	344	25
Parental education	Both parents > High school education	813	59
	1 parent High school education	327	24
	Both parents High school education	234	17
Smoking (baseline)	Never smoked	974	72
	Smoked but not a whole cigarette	141	10
	Smoked but not in the past month	109	8
	Smoked in the past month	43	3
	Smokes weekly	33	2
	Smokes daily, 10 cigarettes	54	4
	Smokes daily, > 10 cigarettes	8	1
Smoking (wave 8)	Never smoked	675	63
	Smoked but not a whole cigarette	118	11
	Smoked but not in the past month	119	11
	Smoked in the past month	34	3
	Smokes weekly	21	2
	Smokes daily, 10 cigarettes	89	8
	Smokes daily, > 10 cigarettes	19	2
Smoking progression	Progressed along continuum	283	21
		Mean	SD
PA access		16.73	2.79
Impulsivity		8.00	1.42
PA enjoyment wave 1		64.95	10.34
PA enjoyment wave 8		67.19	10.54
MVPA wave 1		952.30	627.96
MVPA wave 8		654.30	555.87

Table 2
Non-standardized parameter estimates, standard errors, z test statistics, and p-values for the longitudinal relation between smoking, physical activity and physical activity enjoyment

Smoking									
	Baseline level				Linear trend				
	b	SE	Z value	p-value	b	SE	Z value	p-value	
Baseline PA enjoyment	-0.03	0.01	-3.23	0.001	0.00	0.00	0.80	0.42	
PA enjoyment trend					-0.05	0.02	-2.56	0.01	
Baseline PA	0.17	0.10	1.64	0.10	-0.02	0.03	-0.88	0.38	
PA trend					0.30	0.19	1.56	0.12	
Female	0.01	0.07	0.21	0.84	0.02	0.02	0.97	0.33	
White	0.10	0.08	1.33	0.18	0.05	0.02	2.49	0.01	
Smoking exposure	1.16	0.09	12.90	<0.0001	0.01	0.02	0.23	0.82	
PA access	-0.02	0.01	-1.65	0.10	-0.01	0.00	-1.77	0.08	
Parental education	0.13	0.05	2.88	0.004	0.00	0.01	-0.20	0.84	
Impulsivity	0.08	0.03	3.37	0.001	0.00	0.01	0.54	0.59	
PA Enjoyment									
	Baseline level				Linear trend				
	b	SE	Z value	p-value	b	SE	Z value	p-value	
Baseline smoking					0.21	0.10	2.17	0.03	
Baseline PA	5.64	0.40	14.12	<0.0001	-0.21	0.08	-2.55	0.01	
PA trend					3.14	0.67	4.72	<0.0001	
Female	-1.60	0.53	-3.01	0.003	0.28	0.11	2.52	0.01	
White	0.02	0.63	0.03	0.98	-0.23	0.13	-1.78	0.08	
Smoking exposure	-0.77	0.53	-1.45	0.15	-0.16	0.16	-1.01	0.32	
PA access	0.63	0.10	6.64	<0.0001	-0.03	0.02	-1.58	0.11	
Parental education	-0.91	0.37	-2.47	0.01	-0.05	0.07	-0.77	0.44	
Impulsivity	-0.11	0.20	-0.53	0.59	0.03	0.04	0.79	0.43	
Physical Activity									
	Baseline level				Linear trend				
	b	SE	Z value	p-value	b	SE	Z value	p-value	

	Smoking							
	Baseline level				Linear trend			
	b	SE	Z value	p-value	b	SE	Z value	p-value
	b	SE	Z value	p-value	b	SE	Z value	p-value
Baseline smoking					-0.02	0.02	-1.27	0.20
Baseline PA enjoyment					-0.01	0.00	-5.93	<0.0001
Female	-0.14	0.07	-1.95	0.05	-0.05	0.02	-2.87	0.004
White	0.19	0.09	2.22	0.03	-0.02	0.02	-0.89	0.38
Smoking exposure	-0.06	0.07	-0.83	0.41	0.00	0.02	-0.15	0.88
PA access	0.02	0.01	1.45	0.15	0.00	0.00	0.97	0.33
Parental education	0.04	0.05	0.86	0.39	-0.01	0.01	-0.57	0.57
Impulsivity	0.02	0.03	0.87	0.38	-0.01	0.01	-2.15	0.03

* Bootstrapped standard errors.