Smoking Progression and Physical Activity

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Abstract

This study examined the relationship between changes in physical activity and changes in smoking among adolescents. We prospectively examined smoking progression, physical activity, demographic factors, and covariates in 978 high school students participating in a longitudinal cohort study of the predictors of smoking adoption. We used latent growth modeling with the parallel processes smoking progression and physical activity as our method, with smoking progression measured as an ordered categorical variable. Results indicated that higher levels of physical activity reduced the odds of progressing to smoking or a higher level of smoking by nearly 1.5 (1.44; $P < 0.05$). No race differences were found. However, being male increased the odds of smoking progression by 1.32 ($P < 0.05$). Higher levels of physical activity may reduce the risk of smoking during adolescence. Youth smoking prevention initiatives should incorporate strategies to promote physical activity to prevent smoking experimentation and escalation.

Introduction

Cigarette smoking is the leading preventable cause of disease and death in the United States (1). Despite knowledge of its negative health effects, many adolescents experiment with smoking, and others progress from experimentation to a regular smoking habit. Studies have shown that early inception of smoking, even if only occasional, can lead to a rapid increase in smoking, escalating to regular smoking (2–6). Most smokers start smoking before 18 years of age (7), with the critical period for experimentation with tobacco and subsequent development of regular smoking spanning early to late adolescence (4). It is estimated that over 2000 adolescents become regular smokers every day (1). About 29% of adolescents currently smoke, with rates increasing progressively from 24% among 9th graders to 35% among 12th graders (8). As such, smoking progression in adolescence is a significant concern, and the identification of factors that influence progression is critical for smoking prevention and intervention efforts.

Previous research has identified several factors associated with adolescent smoking. However, few studies have focused on how these factors may influence the longitudinal course of smoking. One behavioral factor that may shed light on the smoking adoption process is physical activity. Studies have found a consistent and negative relationship between physical activity and cigarette smoking, suggesting that adolescents who participate in greater levels of physical activity are less likely to smoke or smoke fewer cigarettes (9–16). For instance, one study found that greater student participation in sports during high school was associated with a reduced likelihood of either regular or heavy smoking (10). Another study found that adolescents who had not smoked in the past 30 days were more likely to engage in hard physical activity than adolescents who had smoked in the past 30 days (16). These studies suggest that physical activity may have a protective function against cigarette smoking. However, the extant data on physical activity and smoking in adolescence are inconclusive and mainly cross-sectional in nature (17, 18).

To clarify the relationship between smoking progression and physical activity, we conducted a longitudinal analysis with a sample of adolescents participating in a 4-year prospective study of the social, psychological, and genetic predictors of smoking. We focused specifically on data collected at four waves, beginning in the 9th grade and concluding in the 11th grade. We assessed growth patterns of smoking progression and physical activity using LGM[1] with parallel processes. Effects of gender, race, baseline depression, and participation in freshman PE class were examined. This is the first study that we are aware of to use this methodology to investigate the longitudinal relationship between physical activity and smoking. Based on our review of the literature, we hypothesized that physical activity would protect against smoking progression.

Materials and Methods

Participants

Participants were high school students (52% female) enrolled in five public high schools in northern Virginia comprising a longitudinal cohort to investigate the biobehavioral predictors of adolescent smoking adoption. This cohort was drawn from the 2393 students identified through class rosters at the beginning of 9th grade. Students were ineligible to participate in this study if they had a special classroom placement (*i.e.*, severe learning disability and/or English as a second language). The cohort was formed in the 9th grade and is being followed until the end of the 12th grade.

Based on the selection criteria, a total of 2120 (89%)

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[1] The abbreviations used are: LGM, latent growth modeling; YRBS, Youth Risk Behavior Survey; CES-D, Center for Epidemiological Studies Depression; PE, physical education; CFI, comparative fit index; RMSEA, root mean squared error of approximation; HP2010, Healthy People 2010.

students were eligible to participate. Of the 2120 eligible students, 1533 (72%) parents provided a response. Of these 1533, 1151 (75%) parents consented to their teen's participation in the study, yielding an overall consent rate of 54%. An analysis of differences between students whose parents consented and those whose parents did not consent to participation in the study revealed a race by education interaction. The interaction indicated that the likelihood of consent was over twice as great for Caucasian parents with more than a high school education than for those with a high school education or less (19). Although overall differences were small, some caution in generalization is suggested.

Participation in the study required student assent as well as parental consent. Fifteen students declined participation. An additional 13 students failed to participate in either the baseline administration or the make-up due to absence. The final baseline sample size was 1123 of the 2120 eligible students. University institutional review board approval of the study protocol was obtained.

Procedures

Data were collected on-site, during a classroom common to all students (*e.g.*, health, science, history). A member of the research team distributed the survey. Each student received a survey with a subject identification number. The survey contained a front page with the student's name that was removed when the survey was given to the student. The completed survey only contained an identification number. A member of the research team read aloud a set of instructions, emphasizing confidentiality to promote honest responding, and encouraged questions if survey items were not clear. Surveys took about 30 min to complete. Make up sessions were held in the library for students absent during initial survey administration.

Students were resurveyed in the fall and spring of the 10th grade and in the spring of 11th grade, for a total of four data collection waves. The rates of participation at the three follow-ups from baseline were about 95% (approximately 1070 students surveyed), 96% (approximately 1081 students surveyed), and 93% (approximately 1043 students surveyed) for fall 10th grade, spring 10th grade, and spring 11th grade, respectively. The primary variables of interest were smoking, physical activity, baseline depression, gender, and race. The data presented herein are based on 978 participants with complete responses for the predictor and outcome variables at each time point.

Measures

Smoking Progression. Adolescent smoking practices were summarized in an ordered-categorical variable with five categories representing increasing levels of smoking. The variable was generated from responses to 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?" (20). The five ordered categories are as follows: (*a*) 0, never smoker; (*b*) 1, puffer (not ever having smoked a whole cigarette); (*c*) 2, experimenter (having smoked a whole cigarette but not having smoked within the last 30 days or having smoked a whole cigarette and having smoked within the last 30 days but $\leq$100 cigarettes total in a lifetime); (*d*) 3, current smoker (smoked $<$20 days in the last 30 days and $>$100 cigarettes in a lifetime); and (*d*) 4, frequent smoker ($\geq$20 days smoked in the last 30 days and $>$100 cigarettes in a lifetime). Research supports the reliability of YRBS items assessing smoking practices with κ coefficients in the substantial or higher range [$\kappa \geq$ 61% (21, 22)]. Research also supports the validity of self-report measures of smoking behavior in adolescents, particularly in nontreatment contexts where confidentiality is emphasized (4, 23, 24). Smoking practices were assessed at all four waves.

Physical Activity. Physical activity was assessed with a continuous variable generated by summing four items from the YRBS (20). The first three items asked respondents how many of the past 7 days they participated in (*a*) 20 min of physical activity ". . . . that made you sweat or breathe hard, such as basketball, soccer, running, swimming laps, fast bicycling, fast dancing, or similar aerobic activities. . . ; (*b*) . . . physical activity for at least 30 min that did not make you sweat and breath hard, such as fast walking, slow bicycling, skating, pushing a lawn mower, or mopping floors. . . ; (*c*) . . . exercise to strengthen or tone your muscles, such as push-ups, sit-ups or weight lifting?" These items measured the frequency, duration, and intensity of physical activity, as well as aerobic and anaerobic activity. The fourth item requested the number of teams on which the individual played during the past 12 months, including those run by the ". . . . school or community group." Physical activity was assessed at all four data collection waves. Scores on the physical activity composite ranged from a low of 0, representing no physical activity, to a high of 24, representing high involvement in physical activity. Research supports the reliability of the YRBS items assessing physical activity with κ coefficients in the moderate to substantial range (21, 22). Research also supports the construct validity of self-report measures of physical activity (25). Cronbach coefficient reliability estimates for the physical activity composite used in the present study were 0.63, 0.66, 0.67, and 0.72, for waves 1–4, respectively.

Demographics. Race and gender were included as covariates. Gender was as follows: 0 = male; and 1 = female. Race was classified into two categories: 0 = Caucasian; or 1 = non-Caucasian. Gender and race were included as covariates to control for their effects on smoking and physical activity (8, 15, 18, 26–31).

Depressive Symptoms. Depression was assessed with the CES-D inventory at baseline. The CES-D is a 20-item self-report measure of depressive symptoms (32). Items on the CES-D are rated along a 4-point Likert scale to indicate how frequently in the past week each symptom occurred (0 = rarely or none of the time, 3 = most of the time). Scores range from 0 to 60, and higher scores indicate a greater degree of depressive symptoms. The CES-D has been shown to be a reliable and generally valid measure of adolescent depressive symptoms (33–36). We included baseline depression as a covariate because adolescent depression has been shown to relate negatively to physical activity (37–39) and positively to smoking (35, 40, 41). Cronbach coefficient α reliability estimate for the CES-D in the present study was 0.88.

PE. PE participation was assessed as the sum of two YRBS items. One item asked "In an average week when you are in school, on how many days do you go to PE classes?" Responses ranged from 0 to 6 (0, 1, 2, 2.5, 3, 4, or 5 days). The second item asked "During an average PE class, how many minutes do you spend actually exercising or playing sports?" Responses ranged from 0–3 (0 = "less than 10 min," 1 = "10–20 min," 2 = "21–30 min," and 3 = "more than 30 min"). The final variable in the analysis was dichotomized by a median split, with values of $>$5 representing high PE activity, and values $\leq$5 representing low PE activity. PE was included as a covariate because PE was mandatory for participants at baseline (9th grade). There-

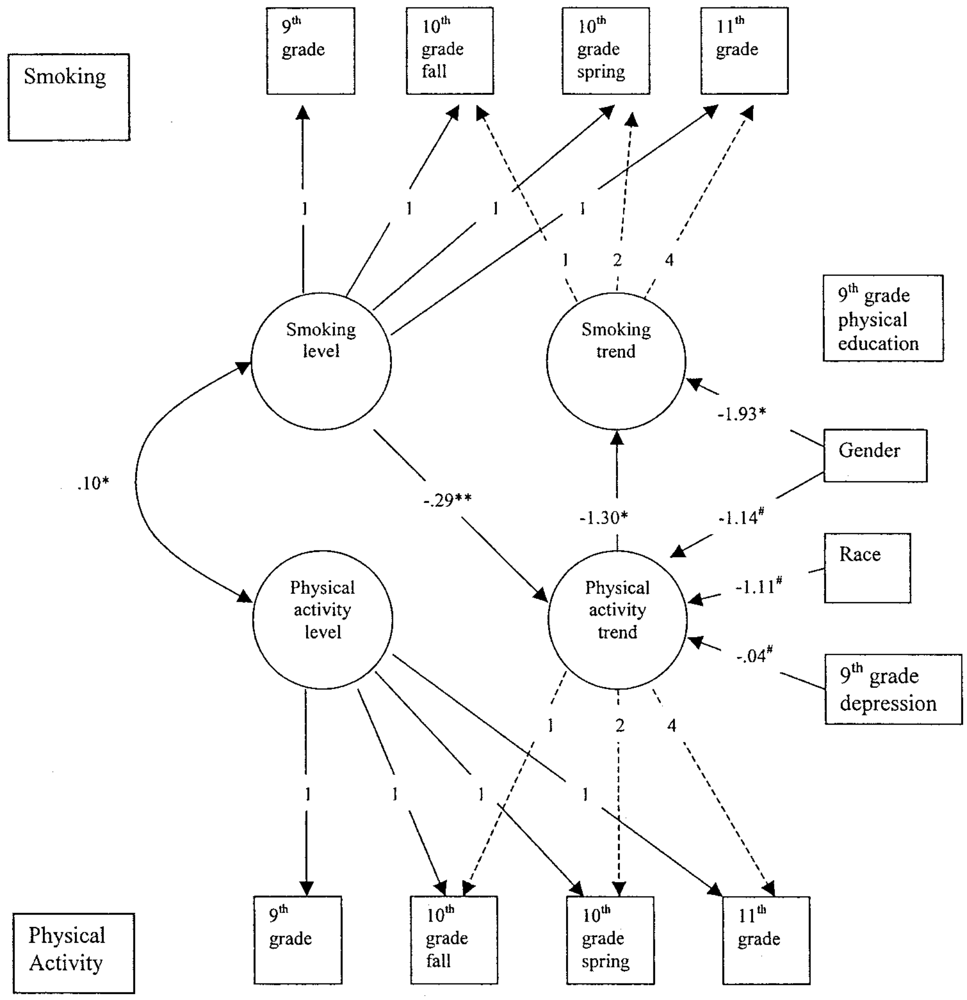

Fig. 1. Latent growth model with smoking progression and physical activity parallel processes and time invariant covariates. Nonsignificant paths are not included in the model.

fore, it is possible that participation in PE may confound the effects of physical activity on smoking progression.

Data Analysis

The analysis was conducted with LGM. LGM is a special form of structural equation modeling. LGM assesses individual growth curves, averaging trends (slopes) and levels (intercepts) to evaluate the fit of general growth patterns to the data (42–45). In LGM, levels and trends are the factors (*i.e.*, latent variables) that are proposed to be responsible for the growth of some observed variable (*e.g.*, smoking level) over time. At the individual level (*i.e.*, within subjects), growth is expressed as $y_{it} = \eta_{0i} + \eta_{1i} x_t + \epsilon_{it}$ (Formula 1), where y = outcome, x = time score, η_0 = baseline level growth factor (intercept), η_1 = trend growth factor (slope), ϵ = within subjects error, i = individual, and t = time point. Subscripts 0 and 1 represent the level and trend growth factors, respectively. The mean (between subjects) baseline level is represented by the formula $\eta_{0i} = \alpha_0 + \gamma_0 w_i + \zeta_{0i}$ (Formula 2), and mean trend is represented by the formula $\eta_{1i} = \alpha_1 + \gamma_1 w_i + \zeta_{1i}$ (Formula 3), where α = mean value, w = time invariant covariate, and ζ = between subjects error. As such, the smoking status of a given individual (y_{it}) at an observed time point (x_t) depends on that individual's smoking status at baseline (η_{0i}), rate of change in smoking practice (η_{1i}), and some unknown factor termed error (ϵ_{it}), for lack of better terms. Further, the individual's level (η_{0i}) and trend (η_{0i}) factors are affected by the average population rate at baseline (α_0) and mean population trend (α_1), as well as any covariates (w_i) included in the model, along with unmeasured sources (ζ_i).

In the present study, we used LGM with parallel processes to analyze longitudinal data collected at four points over three academic years (grades 9 through 11). A parallel processes model is a structural equation model composed of two or more latent growth models and hypothesized paths among the growth factors (*e.g.*, from physical activity trend to smoking trend) and from selected covariates (*e.g.*, from gender to smoking trend). Paths between growth factors are represented by the symbol (β). Paths from the covariates to the growth factors are represented by the symbol (γ). The model tested with standardized coefficients is presented graphically in Fig. 1. The parallel processes in Fig. 1 are represented by inclusion of two separate latent growth models in a structural model, one for physical activity and one for smoking. According to the model, within subject variability is reflected in the observed differences in the measured variables over the four data points (repeated measures). The between-subject model includes the trend and level factors. Because the level (intercept/baseline) value remains constant across time points, factor loadings for the four observed variables with the level factor were set equal to 1. To reflect growth, factor loadings for the observed variables with the trend factor were set equal to 0, 1, 2, and 4 for smoking progression and physical activity, reflecting linear growth for variables measured at unequal time points; the first three waves occurred 6 months apart. Thus, a factor loading 1 represents a 6-month change in time, 1 unit. The fourth wave occurred 1 year after the third wave, a change of 2 time units, reflected in a factor loading increase from 2 at wave 3 to 4 at the wave 4. Setting the wave 1 factor loading to 0 sets the first wave as baseline.

Several covariates were also included that we hypothesized would account for variability in the growth factors (46). For continuous dependent variables (*e.g.,* physical activity), a unit change in a covariate results in an increase or decrease in the growth factors, depending on the size and direction of the β trend. For ordered categorical or dependent variables, a unit change in the covariate results in a negative or positive change (depending on the sign associated with the β value) in the log odds of being in the next *versus* the present category (47). Exponentiation of the log odds converts the log odds to odds, facilitating interpretation (47–49).

Model estimation was conducted with M*plus* software, because M*plus* provides for LGM with categorical dependent variables (47). Models including categorical observed variables are estimated with weighted least square parameter estimates. Models that include only continuous observed variables are estimated by maximum likelihood procedures (47, 49). Therefore, estimation in the present study relied on weighted least square. Model fit was evaluated with χ^2, the CFI, and RMSEA. Suggested values for CFI are CFI $>$ 0.95 (48, 50). Suggested values for RMSEA range from 0.05 to 0.08 (46, 47).

Results

Sample Characteristics. Participants were 978 high school students participating in a longitudinal study of the biobehavioral predictors of adolescent smoking adoption. About half of the sample was female (52%). The racial distribution of the sample was: 63% Caucasian, 12% Hispanic, 11% Asian, 8% African American, and 6% other. The cohort was formed in the 9th grade and is being followed until the end of the 12th grade. Four data collection, waves have been completed: 9th grade, spring of 2000; 10th grade, fall of 2000 and spring of 2001; 11th grade, spring of 2002. The data analyzed in this study included these four waves only.

Prevalence data for smoking indicated a general increase in smoking from grade 9 through grade 11. For instance, the percentage of participants who were never smokers decreased from 61% in 9th grade to 51% in 11th grade, whereas the percentage of adolescents experimenting with cigarette smoking increased from 21% to 26% in the same time period. The percentage of frequent smokers increased from 4% to 7% over the same four waves. Overall, from grade 9 through 11, about 29% of the sample progressed to a higher level of smoking. By contrast, physical activity decreased across the four data waves for each of the five smoking statuses.

Growth Measurement Models. Before assessment of a parallel processes model with covariates, it is recommended that the growth measurement models for each process (*i.e.,* physical activity and smoking progression) be estimated independently (49). A growth measurement model is the LGM for a given repeated measure (*e.g.,* physical activity), with its unique trend (slope) and level (intercept) factors, but without covariates. Growth measurement models assess the fit of a specific growth curve (*e.g.,* linear or quadratic) whether growth actually occurs, and the potential variability of both growth factors' level and trend. The growth measurement model for physical activity fit the data well, χ^2 (4, 1017) = 7.74, CFI = 0.98, RMSEA = 0.030. The mean trend factor (η_1) was significantly different from zero ($\eta_1 = -0.44$, $z = -9.46$, $P < 0.002$), indicating a significant decline in physical activity from baseline over the four time points (baseline level was $\eta_0 = 12.23$). Variances for trend and level factors were both significantly different from zero ($z_{\text{level}} = 14.20$, $P < 0.002$; $z_{\text{trend}} = 2.77$, $P < 0.01$), indicating that there were individual differences in both baseline physical activity and rate of change in physical activity over the four time points.

The growth measurement model for smoking also fit the data well [χ^2 (7, 988) = 44.79, CFI = 1.00, RMSEA = 0.074]. The mean trend was significantly different from zero ($\eta_1 = 0.07$, $z = 7.64$, $P < 0.002$). However, because the smoking construct is an ordered categorical variable, interpretation of the growth process differs from interpretation in the case of a repeated continuous dependent variable. What is being estimated in the case of ordered categorical dependent variables like our smoking level variable is the change in the log odds of being in a higher *versus* a lower category for a unit change in time (47, 49). The mean baseline level is standardized to equal zero ($\alpha_0 = 0$) because thresholds represent the level. Therefore, the intercept factor does not contribute to calculation of the log odds of progression, as it would if the intercept were not standardized to zero. Hence, the log odds of progression to a higher category of smoking is equivalent to the mean trend value (α_1, see Formula 2; note also that the mean of the error terms is zero, and the time invariant covariate term in Formula 2 does not factor into this calculation because covariates are not included in measurement models).

The likelihood of progression from a lower to a higher category depends on the threshold values between categories. The number of thresholds equals the number of categories less one. In the present case, with five categories of smoking, there are (5 – 1) = 4 thresholds. A threshold value of zero represents equal probability of being in the lower *versus* higher category. Lower threshold values indicate easier movement from one category to the next, whereas higher thresholds reflect more difficult transition between categories. In the present study, the threshold between the two categories never smoker and puffer ($\tau = 0.29$) was lower than the threshold between experimenter and current smoker ($\tau = 1.66$) because more individuals tried a cigarette than advanced to current smoking. Therefore, progression from being a never smoker to being a puffer was easier than progression from experimentation to current smoking.

To assess whether time affects threshold values, an indication of the effects of time on the facility of progression, thresholds are constrained equal across time. A significant trend (η_1) value is an indication that the equality of thresholds across time is not a tenable hypothesis, and as such, time affects the likelihood of progression. The finding of a positive smoking trend (η_1) in the present study indicated that the log odds of advancing to a higher smoking category increased by 0.07 (Confidence Interval = 0.05–0.08) for every unit change in time (6 month units from baseline to third follow-up). Therefore, time increased the likelihood of progression, rejecting the hypothesis of threshold invariance over time. To facilitate interpretation, log odds were converted to odds ratios by exponentiation of the log odds value. Exponentiation of the log odds in the present case resulted in a multiplicative change of e^{β} ($e^{0.07} = 1.07$, CI = 1.05–1.09) in the odds of advancing to a higher category for each 6-month increase in time. Therefore,

Table 1 Intercorrelations for adolescent physical activity and smoking, with means and SDs

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1. Gender	1.0											
2. Race	0.01[a]	1.0										
3. PE 9[b]	0.02[a]	−0.14	1.0									
4. CES-D 9	0.14	0.06[c]	−0.10[d]	1.0								
5. PA 9	−0.15	−0.19	0.09[d]	−0.12	1.0							
6. PA 10 F	−0.16	−0.18	0.03[a]	−0.12	0.53	1.0						
7. PA 10 S	−0.13	−0.15	0.05[a]	−0.10[d]	0.51	0.55	1.0					
8. PA 11	−0.20	−0.15	0.06[c]	−0.14	0.49	0.50	0.57	1.0				
9. Smoking 9	−0.06[c]	0.05[a]	−0.08[d]	0.13	0.05[a]	0.02[a]	−0.03[a]	−0.03[a]	1.0			
10. Smoking 10 F	−0.04[a]	0.05[a]	−0.11[d]	0.13	0.05[a]	0.01[a]	−0.03[a]	−0.005[a]	0.79	1.0		
11. Smoking 10 S	−0.06[c]	−0.001[a]	−0.10[d]	0.12	0.07[c]	0.03[a]	−0.02[a]	−0.01[a]	0.75	0.87	1.0	
12. Smoking 11	−0.07[c]	−0.03[a]	−0.06[a]	0.11[d]	0.09[d]	0.06[c]	0.03[a]	0.02[a]	0.70	0.79	0.83	1.0
Mean	0.52	0.37	0.65	13.80	12.07	11.18	11.41	10.43	0.72	0.84	0.91	1.03
SD	0.50	0.48	0.48	9.08	5.61	5.71	5.73	5.96	1.03	1.12	1.17	1.23

[a] $P > 0.05$.
[b] PE 9, 9th grade physical education; CES-D 9, 9th grade depressive symptoms CES-D inventory score; PA, physical activity (vigorous, moderate, flexibility and strength, and team sport participation); PA 9, 9th grade physical activity score; PA 10 F, 10th grade fall physical activity score; PA 10 S 10th grade spring physical activity score; PA 11, 11th grade physical activity score; Smoking 9–11, smoking level for grades 9 through 11 (1, never smoker; 2, puffer; 3, experimenter; 4, current smoker; 5, frequent smoker). All correlations are significant, $P < 0.0001$, except where indicated.
[c] $P < 0.05$.
[d] $P < 0.005$.

the odds of advancing to the next smoking category *versus* remaining in the present category increased by 7% for each 6-month change in time, with a minimum increase of 5% and a maximum increase of 9% in the odds of smoking progression. Furthermore, variances for smoking trend and level were both significantly different from zero ($z_{\text{level}} = 59.64$, $P < 0.002$; $z_{\text{trend}} = 4.88$, $P < 0.002$), indicating that there was individual difference in both baseline smoking status and the odds of progression over time. These findings indicated that it became easier to cross thresholds to higher smoking levels over time, but not for every individual.

Parallel Process Latent Growth Model. The next model assessed was the parallel process LGM with time invariant covariates (measured at one time point only) gender, race, 9th grade PE, and depression. Table 1 presents the intercorrelations for physical activity, smoking, and the time invariant covariates, along with their means and SDs. The parallel process LGM, χ^2 (12, 988) = 153.76 was significant. However, the CFI = 0.99, indicating that the model fit the data well. The RMSEA also was acceptable (RMSEA = 0.074). Inclusion of the time invariant covariates (*i.e.*, 9th grade depression, 9th grade PE, gender, and race) in the model, in addition to regressing smoking trend on physical activity trend and level, and regressing physical activity trend on smoking level, resulted in a nonsignificant smoking trend ($\eta_1 = -0.16$, $z = -1.43$, $P > 0.05$). However, physical activity trend remained significant ($\eta_1 = -0.410$, $z = -3.36$, $P < 0.002$). These findings indicate that the time invariant covariates and the direct paths from physical activity growth factors together resulted in a nonsignificant smoking trend and that physical activity and the covariates accounted for a significant amount of the variance in smoking progression. Inclusion of the covariates and the physical activity parallel process accounted for 48% of the variation in smoking trend. The residual variance in smoking trend was significant ($\zeta = 0.01$, $z = 2.06$, $P < 0.05$).

The path from physical activity baseline level ($\beta = 0.005$, $z = 1.84$, $P > 0.05$) to smoking trend was not significant, indicating that physical activity level at baseline (9th grade) did not directly affect smoking progression. However, the direct path from physical activity trend ($\beta = -0.363$, $z = -1.97$, $P < 0.05$) to smoking trend was significant, indicating that for a 1-unit increase in physical activity trend (η_1 for physical activity), there was a 0.363 decrease in the log odds of smoking (η_1 for smoking). Exponentiation of the log odds changes resulted in a 1.44 decrease in the odds of progressing to the next higher smoking category. There was a significant negative path from baseline smoking status to the physical activity trend ($\beta = -0.17$, $z = -2.82$, $P < 0.005$), indicating that initial smoking status was inversely related to physical activity over time. The correlation between physical activity and smoking levels, centered at 9th grade, was significant ($r = 0.36$, $P < 0.05$), indicating that initial physical activity was positively associated with initial smoking status, with higher levels of baseline physical activity associated with higher levels of baseline smoking.

The path from 9th grade PE to the smoking trend was not significant ($\gamma_1 = -0.01$, $z = -0.25$, $P > 0.05$), indicating that freshman PE did not affect smoking progression and that the significant negative effect of physical activity on smoking progression discussed previously was independent of the effects of 9th grade PE. Depression at 9th grade did not have a significant effect on smoking trend ($\gamma_1 = -0.002$, $z = -0.50$, $P > 0.05$), indicating that depression at baseline did not affect smoking progression. Furthermore, the path from race (Caucasian or non-Caucasian) to smoking trend was not significant ($\gamma_1 = -0.21$, $z = -1.75$, $P > 0.05$), indicating no significant race difference in smoking progression over time. However, the path from gender to smoking trend was significant ($\gamma_1 = -0.28$, $z = -2.27$, $P < 0.05$), indicating that the risk of smoking progression was greater for males than females. Exponentiation of the log odds of gender on smoking progression resulted in an increase in the odds of smoking progression of 1.32 for males.

The paths from gender ($\gamma_1 = -0.60$, $z = -5.70$, $P < 0.002$), race ($\gamma_1 = -0.58$, $z = -5.21$, $P < 0.002$), and baseline depression ($\gamma_1 = -.02$, $z = -3.86$, $P < 0.002$) to physical activity trend were significant and negative, indicating greater decrease in physical activity for females than males, non-Caucasians over Caucasians, and those with lower levels of depression over time. Finally, the path from 9th grade PE to physical activity trend was not significant ($\gamma_1 = 0.16$, $z = 1.40$,

$P > 0.05$), indicating that higher levels of baseline PE participation had no effect on the physical activity trend.

Discussion

In this study we assessed the relationship between smoking progression and physical activity with a prospective cohort of adolescents. We conducted LGM with the parallel processes of smoking and physical activity, with gender, race, baseline depression, and PE as covariates. Our results indicated that physical activity had a direct and negative effect on smoking progression, suggesting that physical activity may protect against smoking progression in adolescents. There was a decreasing trend in physical activity over time, with greater declines for females, non-Caucasians, and adolescents with higher levels of baseline depression. Although physical activity levels declined less for males than females, males tended to progress in smoking more than females.

Our hypothesis that physical activity would protect against smoking progression was supported. Physical activity reduced the odds of progressing to smoking or higher levels of smoking nearly 1.5 times. This finding supports the contention that physical activity, including activities characterized as high and moderate intensity (*e.g.*, running, bicycling, and brisk walking), strength and toning activities (*e.g.*, weight training), and team sport involvement, act as a buffer against smoking progression. Furthermore, the effects of physical activity on smoking progression were independent of the effects of participation in PE. This suggests that physical activity beyond that accrued in PE class is important in preventing smoking progression. It is also important to note that this finding took place in the context of a model whereby the set of variables, physical activity, depression, PE, gender, and race, accounted for 48% of the variance in smoking progression.

There are several plausible reasons why physical activity may serve as a protective factor for smoking behavior. Physical activity has been shown to be negatively associated with depression and with smoking (10, 14, 37–39), whereas depression has been shown to be positively associated with smoking (40, 41). Physical activity may protect against smoking because of its beneficial effects on mood. We found some evidence for this explanation in the current study. An analysis of the measurement model with the inclusion of baseline depression as a single covariate indicated that baseline depression had a significant effect on smoking trend. However, inclusion of the parallel process of physical activity with no other covariates resulted in a nonsignificant effect of depression on smoking trend, indicating that the relationship between depression and smoking progression is attenuated by physical activity. Further support for this idea would come from an investigation of changes in depression, physical activity, and smoking across time.

Consistent with the above explanation, physical activity and smoking can both be considered sources of reward. Alternative rewards or alternative reinforcers to smoking may compete with smoking such that physically active adolescents are less likely to experiment and/or escalate to higher levels of smoking (50, 51). Alternative reinforcers do not have to be physically similar but may have shared characteristics that may not be qualitatively or physically apparent (51). For example, both physical activity and smoking elevate mood, decrease perceived stress, and promote weight maintenance (52–55), which may make them functionally similar and substitutable. Studies have shown adolescents who were involved in interscholastic sports and non-school-related physical activity were less likely to be regular smokers (10, 15, 56). Similar findings have been noted in college students (57–59). In addition, physical activity has been shown to facilitate smoking cessation in adults, and recent data also suggest that athletic performance is one of the most frequently reported motivations for quitting smoking among adolescents (60, 61). Thus, physical activity may provide an alternative reward to smoking, smoking may be incompatible with physical activity, or possibly involvement in sports provides social affiliation among nonsmokers, which may reinforce remaining smoke free. These potential mechanisms for the effect of physical activity on smoking progression should be evaluated in future research.

In addition to the effect of physical activity on smoking progression, there was a gender effect, suggesting that males were over 1.3 times more likely to escalate in smoking than females. In contrast, previous research has not shown a gender difference in smoking transitions across different smoking stages (27, 62). However, the current study evaluated any smoking progression longitudinally in one model rather than several models that contrasted different smoking stages cross-sectionally or that only evaluated the transition to regular smoking. Indeed, the relationship between gender and smoking is complex. The factors that account for smoking transitions in males and females are not completely clear; however, it appears that gender differences in psychosocial factors, such as risk-taking behavior in males (27), and the subjective and physiological effects of nicotine may aid in clarifying the relationship (63). It is important to note that the propensity to progress in smoking occurred in males despite the observation that physical activity levels declined less for males than females. This finding suggests that smoking progression for males may be more sensitive to declines in physical activity than smoking progression for females.

These results herein suggest a protective role for physical activity against smoking initiation and progression and a possible role for physical activity in smoking prevention and intervention efforts in adolescents. However, race and gender differences in physical activity are troubling, suggesting that females and Non-Caucasians are particularly at risk for low physical activity. We did not find any racial differences in smoking transitions as other studies have found with Caucasians more likely to escalate in smoking compared with non-Caucasians (27, 62). These racial differences in smoking progression may not have been observed in the current study given that Caucasians were more physically active than non-Caucasians. Previous studies have shown that females and non-Caucasian youth tend to have lower levels of physical activity compared with males and Caucasian youth (26, 64). Therefore, if physical activity is to be a useful prevention and intervention strategy against adolescent smoking, strategies must be used that will make physical activity an attractive alternative to smoking and other unhealthy activities across gender and racial groups. In addition, higher levels of baseline depression were associated with lower levels of physical activity. Given that depression and lower levels of physical activity are associated with smoking, youth with depressive symptoms may especially benefit from physical activity interventions.

Two public health concerns addressed in the objectives of United States Department of Health and Human Services HP2010 initiative are to increase the proportion of adolescents engaging in vigorous physical activity for 20 min, 3 times per week, from 65% in 1999 to 85% by 2010, and to decrease the proportion of adolescents (grades 9–12) who smoked at least one cigarette in the past 30 days from 35% in 1999 to 16% in 2010 (65). The findings of this study indicate that adolescent smoking continued to progress as physical activity declined.

These trends indicate that the goals of the HP2010 are likely overoptimistic. To make progress toward the HP2010 objectives, physical activity promotion and smoking prevention may need to be addressed concurrently in youth smoking prevention programs.

It is important to note the limitations of our study. One common limitation of active consent protocols for observational studies is nonresponse rates (66–68). Although 72% of the parents of the eligible participants returned a response regarding study participation, we are unable to make comparisons with the 28% who did not provide a response. Seventy-five percent of those who responded did provide consent, and the differences between those who provided consent and those who declined were relatively small and few (19). However, some caution is warranted in generalizing the results of this study, especially in light of the study's consent rate (54%). It is important to point out that our sample was demographically representative of the sample of high school students from the county in which it was drawn. Furthermore, based on a random sample of 40% of 10th grade students in the county in which the sample was drawn, smoking prevalence was similar for those adolescents who did and those adolescents who did not participate in the current study (lifetime, 41% *versus* 43%; current, 12% *versus* 15%, respectively).

A second limitation relates to the validity of self-report data on physical activity. Although research generally supports the validity of self-report measures of physical activity (25), some research suggests that factors like skinfold thickness and gender may affect the convergent validity of self-recall instruments (69, 70). For instance, one study found that although moderate physical activity is a valid measure of physical activity in females, it has weaker validity for males (69). The present study used four measures as indicators of overall physical activity, which should decrease the impact of any one item (*e.g.,* moderate physical activity) on the validity of the total physical activity score (71). Although self-report measures of physical activity cannot be considered the definitive measure of adolescent activity, they represent a feasible alternative to objective measurement in longitudinal cohort investigations.

Another limitation of the current study is our ability to make clear causal statements about the directional relationship between physical activity and smoking progression. The growth model permitted the assessment of a parallel process model and relationships among growth factors, such that conclusions could be made about the effects of physical activity trend on smoking trend. In other words, declines in physical activity across time were paralleled by increases in smoking progression across time. Unfortunately, our data do not establish that the influence of physical activity was present before adolescents showed a progression in smoking. Nor does our data establish that adolescents were escalating in smoking before adolescents showed a decline in physical activity, although adolescents who were regularly smoking at baseline showed declines in physical activity across time. However, we can clearly state that changes in physical activity did predict changes in smoking. The reverse was not true; changes in smoking did not predict changes in physical activity.

Finally, it is possible that other social and lifestyle behaviors that cluster with physical activity may also be associated with not smoking or not progressing to higher levels of smoking in adolescents. For example, research has shown that academic performance is positively related to physical activity and negatively related to smoking (14, 62). However, one study found that team sport participation was associated with reduced smoking even after controlling for academic performance (10). Substance use has also been shown to relate negatively to physical activity but positively to smoking (14, 72). In addition, fruit and vegetable intake have been shown to be positively related to physical activity, and poor diet has been shown to be associated with cigarette smoking (13, 14). Thus, it is possible that not smoking is related to an overall healthy lifestyle cluster, which includes physical activity.

In summary, the present study evaluated the longitudinal relationship between smoking progression and physical activity in a cohort of adolescents. Physical activity reduced the odds of progressing to smoking or higher levels of smoking nearly 1.5 times, suggesting that physical activity may protect against smoking progression in adolescents. Adolescent physical activity decreased over time, with greater declines for females, non-Caucasians, and adolescents with higher levels of baseline depression. Although physical activity levels declined less for males than females, males were over 1.3 times more likely to escalate in smoking than females. Future research should seek to identify the mechanisms by which physical activity has a protective effect on smoking. Furthermore, it would be clinically informative to evaluate whether promoting physical activity in a sample of youth prevents initiation of smoking and transitions to greater levels of use.

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