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Review Article

A systematic review of cigarette smoking trajectories in adolescents

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ABSTRACT

Trajectory analyses differentiate subgroups of smokers based on early patterns of cigarette use, but no study has summarized this literature. We systematically reviewed the literature on adolescent cigarette smoking trajectories to document the number and shapes of trajectories identified, assess if certain study characteristics influence the number or shapes of trajectories identified, summarize factors associated with and outcomes of trajectory group membership, and assess whether the results of trajectory analyses help identify windows of opportunity for intervention. We searched PubMed and EMBASE (1/1/1980 to 1/11/2018) and identified 1695 articles. Forty-three articles with data from 37 unique datasets were retained. Each trajectory was categorized into one of three groups (i.e., low-stable, increasing, other). Number of trajectories ranged from 2 to 6 (mode = 4); 44–76% of participants were low-stable cigarette consumers, 11–21% increased consumption, and 3–11% were categorized as "other." Number of data points, smoking indicator used, and time axis influenced the number of trajectories identified. Only two articles depicted the natural course of smoking since onset. Factors associated with trajectory membership included age, sex/gender, race/ethnicity, parental education, behavior problems, depression, academic performance, baseline cigarette use, parental and friends smoking, alcohol use, and cannabis use. Outcomes included illicit drug and alcohol use. Beyond parsimoniously describing cigarette smoking patterns, it is not clear whether trajectory analyses offer increased insight into the natural course, determinants or outcomes of cigarette smoking in ways that inform the development of intervention.

Introduction

Nearly all cigarette smoking begins in adolescence (US Department of Health Human Services, 2012), and research over decades has attempted to describe how smoking becomes habitual. Herein we focus on studies that use trajectory analyses to identify developmental patterns of cigarette smoking in adolescents. This analytic method has proliferated in the past two decades because of the appeal of summarizing longitudinal data into clear easily-interpretable graphical representations, the availability of easy-to-use statistical packages (e.g., Proc Traj (SAS), TRAJ (STATA)), and ever-improving add-ons for handling time-varying covariates and attrition (Haviland, Jones & Nagin, 2011; Jones, Nagin & Roeder, 2001). The increasing number of such studies has led to Guidelines for Reporting on Latent Trajectory Studies (GRoLTS) (Van De Schoot, Sijbrandij, Winter, Depaoli & Vermunt, 2017), a checklist of items to report in articles describing trajectory analyses. In addition to depicting developmental patterns, trajectory analyses help identify subgroups at higher risk of sustained and heavier smoking, and they elucidate outcomes of specific trajectory patterns. Proponents of trajectory analyses argue that the differing risk profiles across developmental patterns increase understanding of the natural course of smoking onset (Nagin, 2005), and that these analyses can pinpoint windows of opportunity for intervening to prevent addiction and long-term smoking.

Although smoking trajectory studies are on the increase, there are no systematic reviews of this literature, possibly because trajectory analyses cannot be easily pooled or meta-analyzed. The co-existence of two types of trajectories also complicate synthesis. The first type uses calendar time as the time axis among adolescents who initiate smoking either before or after baseline (i.e., "age/grade" analyses), and the second uses time since smoking onset as the time axis among smokers who begin smoking after baseline (i.e. "time-since-onset" analyses). It is

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unclear if use of different time axes influences the number, shape, factors associated with, or outcomes of trajectories identified.

Herein we explore these issues by reviewing studies that describe smoking trajectories across adolescence. The objectives were to: (i) document the number and shapes of trajectories identified, (ii) assess if sample size, number of data points, indicator of cigarette smoking used, or time axis influence the number or shapes of trajectories identified, (iii) summarize factors associated with membership in specific trajectory groups, (iv) summarize trajectory-related outcomes, and (v) assess whether trajectories identify windows of opportunity for intervention.

Methods

PubMed and EMBASE were searched up to November 23, 2018 for articles published between January 1, 1980 and November 1, 2018 using key words *smoking* OR *tobacco* AND *trajectories*. The detailed search terms were: (i) PubMed (limited to 'humans', 'English language', 'publication date 01/01/1980 – 1/11/2018'): (("smoking"[MeSH Terms] OR "smoking"[All Fields]) **OR** ("tobacco"[MeSH Terms] OR "tobacco"[All Fields] OR "tobacco products"[MeSH Terms]) **OR** (("tobacco"[All Fields] AND "products"[All Fields]) OR ("tobacco products"[All Fields])) **AND** trajectories[All Fields]; and (ii) EMBASE (limited to 'humans', 'English language', 'publication year 1980 – 2018', as well as to journal articles): ['smoking' ('smoking', 'smoking habit', 'adolescent smoking', "smoking and smoking related phenomena" as subject headings, 'smoking' as a keyword) **OR** 'tobacco' ('tobacco', 'tobacco consumption', 'tobacco dependence', 'tobacco smoke', "tobacco use" as subject headings, 'tobacco' as a keyword)] **AND** ['trajectories' ('illness trajectory', 'model' as subject headings, 'trajectories' as a keyword)].

Titles and abstracts of the 1695 articles identified were scanned by four authors (BL, MNA, SE, CBC) to filter out articles that were not relevant. Articles mentioning adolescent cigarette smoking trajectories in the title or abstract, and those in which the title or abstract was not sufficiently informative to determine relevance (n = 359), were retained for the next stage of review. The same four authors then reviewed each article according to pre-established inclusion and exclusion criteria. The single inclusion criterion was that the article reported more than one empirically derived cigarette smoking trajectory based on prospective participant self-reports of cigarette smoking over time. Exclusion criteria included that the study was a review, that its design or analysis was cross-sectional, that the data or analyses were qualitative, that they estimated joint trajectories of smoking and another behavior, or that they estimated trajectories of e-cigarette smoking. In addition, to assure that changes in cigarette smoking during adolescence were captured, we excluded studies that had < 3 data points between ages 12 and 18 (Curran & Muthen, 1999). Disagreements between the four authors at the abstract/title and full review stages were resolved in team discussions with MPS and JOL. Fig. 1 presents a PRISMA flow chart of the results of the article selection process (Moher, Liberati, Tetzlaff & Altman, 2009).

In the next step, BL and MNA used a two-step verification process to extract data from each article retained on study population (i.e., sample size, age range of participants, cohort/sample used); setting and design (i.e., country, age at assessments, number of data points required to be included in the analysis); statistical analyses (i.e., statistical model, software, number of trajectory groups considered, polynomial orders considered, if and how attrition and missingness were dealt with, the statistical and non-statistical criteria used for model selection); and results (i.e., number of trajectories reported in the final model, average posterior probability of trajectory group membership, prevalence of each trajectory in the analytical sample, reported trajectory shapes, factors associated with trajectories, outcomes of trajectory membership investigated and which factor(s) were statistically significant) (Tables S1–S4).

To assess whether study design features might have influenced the number or shapes of trajectories, we collapsed articles into categories based on sample size (<500, 500–2000, >2000), type of cigarette smoking indicator (intensity, frequency, a metric combining intensity and frequency, any use), time axis (time since cigarette smoking onset, age/grade or other measure of calendar time) and number of data points used to estimate trajectories (<5, 5–10, >10), and examined the distributions of the number and shapes of trajectories identified according to these characteristics.

GRoLTS

We used the GRoLTS to assess the quality of reporting in the articles retained (Van De Schoot et al., 2017). This checklist comprises 21 yes/no items assessing whether details such as the time metric used and how missing data were dealt with, are reported. No article reported all 21 items (mean (SD) number of items reported = 7.4 (1.7), range 4–11). Items reported in ≥50% of articles included time metric, variables related to attrition/missing data, how missing data were dealt with, distributions of observed variables, software, model comparison tools, total number of fitted models considered, and a plot of the final model solution. No article reported the mean or variance of time within a data collection wave, plots of the mean estimated trajectories for each model considered, plots of the observed individual trajectories split for each latent class, and none made the syntax files for their models available (Fig. 2). Table S5 describes whether each item is reported in each article.

Results

A total of 1695 articles were identified in the bibliographic databases reviewed; 43 articles were retained (Fig. 1). The references of all 43 articles can be found in the Online Supplementary Material. These articles used data from 37 unique datasets including longitudinal birth cohorts (e.g., Avon Longitudinal Study of Parents and Children), longitudinal national surveys (e.g., [Canadian] National Longitudinal Survey of Children and Youth), and community samples (Table 1). Twenty-eight articles used data from studies conducted in the US, six were conducted in Canada, two in Sweden, and one in each of the Czech Republic, China, the United Kingdom, South Korea, New Zealand, Taiwan, and The Netherlands. Sample size ranged from 203 to 15 828 (median = 975), and the youngest and oldest age of participants at first smoking assessment was 9 and 17 years, respectively (median age = 13 years). Duration of follow-up varied between 1.5 to 23 years (median = 5 years). Most articles tracked smoking into later adolescence and 28 continued assessments past age 18. In articles where it was ascertainable, the minimum time window between data points was three months and the maximum was 4.5 years (median = 1 year). Number of data points used to estimate trajectories ranged from 3 to 16 (median = 6); the range was 1 to 4 (median = 1) per year, and 0.5 to 5 (median = 1.3) per year from age 12 to 18. While an adequate number of data points are needed to capture inflections in the estimated trajectories, denser follow-up (beyond a certain point) will not impact the number or shape of the trajectories – it only makes them smoother (Tan, Dierker, Rose, Li & Network, 2011). Articles with more data points and shorter time intervals between data points had smoother trajectories (e.g., (Riggs, Chou, Li & Pentz, 2007; White, Nagin, Replogle & Stouthamer-Loeber, 2004)). Table 1 reports the countries in which articles were conducted, the cohorts/samples used, sample size, age range of participants, and labels used to describe trajectories identified.

Smoking indicator

Smoking was generally assessed using one of four indicators. Frequency (n = 16 articles) was defined as number of days on which participants had smoked in a given time period (e.g., past 7 days, past

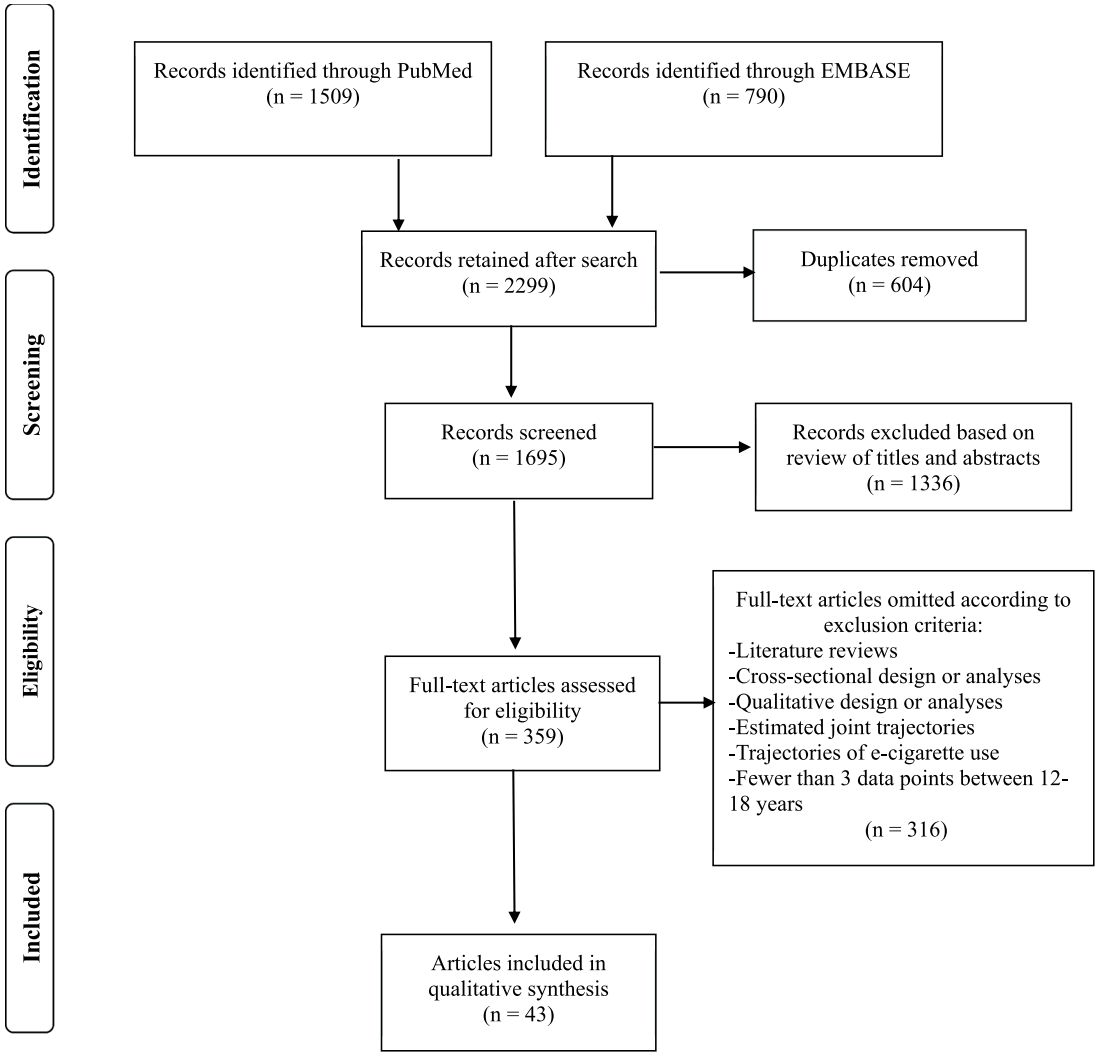

Fig. 1. PRISMA flow diagram showing the number of articles retained at each step in the article selection process.

30 days, past year, lifetime). Intensity (n = 17 articles) was defined as the number of cigarettes smoked in a given time period, and "any use" (n = 4 articles) indicated whether participants had smoked any cigarettes (yes, no) in a given time period. Eight articles created a metric combining intensity and frequency. One article (Maggi, Hertzman & Vaillancourt, 2007) conducted three trajectory analyses with different numbers of participants from the same sample, using indicators of frequency, intensity, and "any use".

Number of trajectories

The number of smoking trajectory groups reported ranged from 2 to 6. The most frequently reported number of trajectories (i.e., in 15 of 43 articles) was four. Four articles reported two trajectories, 12 reported three trajectories, 9 reported five trajectories, and 5 reported six trajectories. The article that investigated three smoking indicators (Maggi et al., 2007) reported two trajectories for the smoking intensity model (n = 260), five for the frequency model (n = 280), and three for the "any use" model (n = 2886).

Articles reporting studies with <5 data points identified three trajectories on average, compared to four in studies with more data points (Table 2). The 41 models with intensity, frequency, or a metric combining intensity and frequency as the y-axis had an average of four trajectory groups; the four models that used "any use" reported three.

Trajectory shapes

To enable comparison across articles, we categorized each trajectory in each article into one of three broadly defined groups based on visual inspection of the curves (Table 2), although heterogeneity in shapes within these groups remained substantial. Trajectories representing the lowest level of smoking across all time-points in each article were categorized as "low-stable." An "increasing" group comprised trajectories in which level of smoking increased; although the time-point at which the slope increased, and rate of increase differed. All other trajectories, which generally comprised trajectories that increased and then decreased or decreased and then increased were labelled "other". The time-point at which these slopes increased or decreased, and rates of increase or decrease varied across articles. The highest proportion of participants was categorized as "low-stable" (median range: 44.1–75.8%), followed by "increasing" (11.1–21.0%) and then "other" (3.1–10.8%). Not all articles reported participants in all three trajectory groups (e.g., some such as Vitaro et al.(2004) reported trajectories in the "low-stable" and "increasing" groups, but none in the "other" group). Also, some articles (e.g., Rosendahl et al.(2008)) provided number of participants for some trajectories, but not for others.

Regardless of sample size, number of data points, smoking indicator, or time axis, most participants were categorized as low-stable (44–76%), followed by increasing (11–21%), and then "other"

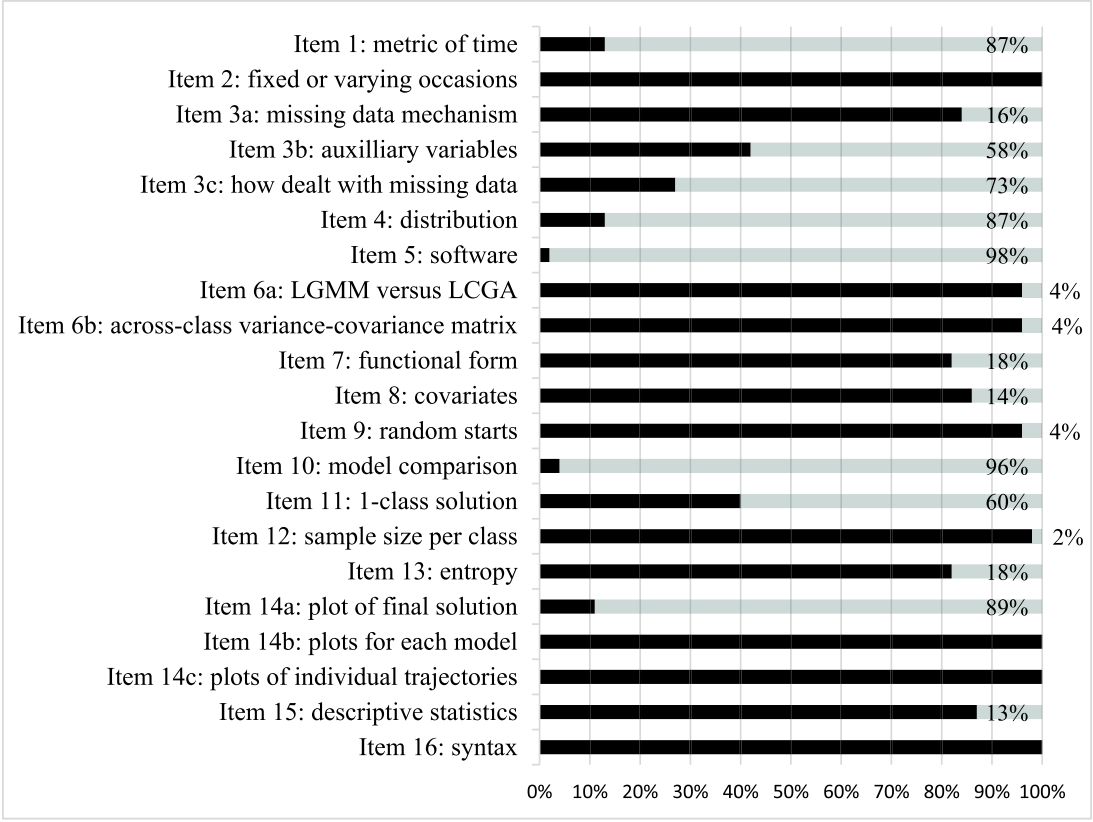

Fig. 2. Percent of all articles included in the systematic review ($n = 43$) reporting each item of the Guidelines for Reporting on Latent Trajectory Studies (GRoLTS). Percentages are reported in the light grey bar.

(3–11%), suggesting that although many adolescents tried cigarettes, only 1 in 3 or 4 increased use over time. Appendix Table S1 provides details on trajectory shapes and number of participants in each trajectory group. Table S2 provides data on years of follow-up, age at assessments, minimum number of data points required to estimate trajectories, density of data points from age 12 to 18, whether information on the distribution of the smoking measure was provided in the article, and methods used to account for missing values and attrition. Table S3 describes number of trajectories considered and used in the final model, polynomial orders considered, model comparison tools used, range of average posterior probabilities, software used, and whether alternative specifications of within-class heterogeneity were considered. While several articles reported using latent growth mixture modeling, most described results from models in which the variance and covariance estimates for the growth factors within each group were set to zero (Van De Schoot et al., 2017), akin to latent class growth analysis.

Factors associated with trajectories

All but nine (Cance, Talley, Morgan-Lopez & Fromme, 2017; Chang et al., 2018; Chung & Chun, 2010; Colder et al., 2001; Guo et al., 2002; Huang, Lanza & Anglin, 2013; Maggi, 2008; Maggi et al., 2007; Orpinas, Lacy, Nahapetyan, Dube & Song, 2015) of the 43 articles identified factors associated with trajectory group membership. Table S4 describes factors and outcomes potentially associated with trajectories investigated in each article. Table 3 summarizes the number of articles that examined each factor and that reported a significant association with trajectory group membership for that factor. The direction of the associations is not reported due to heterogeneity across articles in the trajectory group used as the reference and use of omnibus tests that do not distinguish direction of associations.

Of 86 distinct concepts investigated, 73 were examined in <5 articles. Among the 13 concepts examined in ≥ 5 articles, at least half of the articles reported a significant difference between at least two trajectories for age (6 of 7 articles), sex/gender (12 of 24), race/ethnicity (10 of 13), parental education (7 of 10), behavior problems (6 of 7), depression/depressive symptoms (6 of 8), academic performance (8 of 8), baseline cigarette use (5 of 5), parental smoking (9 of 14), friend's smoking (12 of 13), alcohol use (6 of 7), and cannabis use (6 of 6). In general, older age at baseline, being male, and being Caucasian were associated with membership in trajectory groups with higher cigarette consumption. For the remaining factors, the least favorable categories were associated with membership in trajectory groups with higher cigarette consumption. Only one of six articles that investigated school-related attitudes, and only two of six that investigated family functioning reported significant differences across trajectories.

Trajectory-related outcomes

Sixteen (Chang et al., 2018; Chassin, Presson, Pitts & Sherman, 2000; Dutra, Glantz, Lisha & Song, 2017; Guo et al., 2002; Hampson, Tildesley, Andrews, Barckley & Peterson, 2013; Huang et al., 2013; Karp, O'Loughlin, Paradis, Hanley & Difranza, 2005; Lessov-Schlaggar et al., 2008; Lynne-Landsman, Bradshaw & Ialongo, 2010; Nelson, Van Ryzin & Dishion, 2015; Orlando, Tucker, Ellickson & Klein, 2004; Orpinas et al., 2015; Riggs et al., 2007; Tucker, Ellickson, Orlando & Klein, 2006; Tucker, Ellickson, Orlando, Martino & Klein, 2005; Vuolo & Staff, 2013) of the 43 articles investigated outcomes of trajectory group membership. Of 21 outcomes examined, four were statistically significant in ≥ 5 articles (Table 4). Higher cigarette consumption trajectories were associated with illicit drug use and alcohol use, lower levels of education, and being unmarried.

Only the two articles that used “time since smoking onset” as the time metric (Karp et al., 2005; Rosendahl, Galanti & Gilljam, 2008) investigated

Table 1
Number and description of smoking trajectory studies in 43 studies of cigarette smoking trajectories.

First author & year of publication; Country; Cohort/study sample[a]	Sample size[b]	Age range[c], y	Number of trajectories	Description of cigarette smoking trajectories (prevalence)[d]
AGE/GRADE ANALYSES				
Outcome variable[e]: Intensity of smoking				
Colder 2001; US Project STAR	260	12–16.6	5	Stable puffers (25%), stable light smokers, late slow escalators, late moderate escalators, early rapid escalators
Guo 2002; US Seattle Social Development Project	786	13–18	5	Non-smokers (73.0%), experimenters (7.3%), late-onsetters (10.9%), escalators (7.5%), chronic smokers (1.3%)
Vitaro 2004; Canada Quebec sample (1)	812	9–11.5 to 12.5–15	4	Never (75.4%), 13–14y starters (7.9%), 12–13y starters (11.1%), 11–12y starters (5.7%)
Stanton 2004; New Zealand Dunedin Multidisciplinary Health and Development Study	307	9–18	6	Late slow-escalators [puffers] (11.4%), stable puffers (12.7%), late slow escalators [smokers] (11.4%), late moderate escalators (14.3%), late rapid escalators (38.8%), early rapid escalators (11.4%)
White 2004; US Pittsburgh Youth Study	983	10–25	European Americans: 3 African Americans: 3	European Americans – Non-smokers (44.3%), light smokers (23.7%), heavy smokers (32%). African Americans – Non-smokers (55.9%), light smokers (27.3%), heavy smokers (16.7%)
Maggi 2007; Canada National Longitudinal Survey of Children and Youth	260	10–11 to 16–17	2	Late slow escalators (97.7%), early rapid escalators (2.3%)
Riggs 2007; US Kansas City sample	1 017	12–24	4	Abstainers (47%), low users (24%), late heavy users (16%), early heavy users (12%)
Lessov-Schlaggar 2008; US Smoking in Families Study	481	13.1–24	5	Experimenters (48.5%), late increasers (16.3%), early increasers (15.5%), quitters (9.2%), persistent (10.5%)
Otten 2008; Canada Quebec sample (2)	203	12–14	3	Low-rate (71.4%), increasing-rate (18.2%), high-rate (10.3%)
Chung 2010; South Korea Youth Panel Survey		13–17	4	Non-initiator (85.1%), late onsetter (7.0%), experimenter (4.5%), escalator (3.4%)
Gabrhelik 2012; Czech Republic Czech sample	1 874	11–13 to 13.6–15.6	2	Slow cigarette smoking escalators (91%), rapid/moderate cigarette smoking escalators (9%)
Vuolo 2013; US Youth Development Study	1 010	15–38	4	Stable non-smokers (54.1%), early onset light smokers who quit/reduce (16.2%), late onset persistent smokers (13.5%), early onset persistent heavy smokers (16.2%)
Roberts 2014; US Nurses' Health Study II and Growing Up Today Study	15 828	12–23	4	Non-smoker, experimenter, late initiator/moderate consumption, early initiator/high consumption
Nelson 2015; US Northwest sample	890	12–23	6	Abstainers (38.8%), very low users (10%), post-high school onset low decreasers (9.8%), young adult onset moderate increasers (11.5%), post-high school onset steep increasers (18.9%), early onset steep increasers (11.1%)
Orpinas 2015; US Healthy Teens Longitudinal Study	611	Grade 6–12	4	Abstainers/sporadic users (71.5%), late starters (11.3%), experimenters (9%), continuous users (8.2%)
Outcome variable[e]: Frequency of smoking				
First author & year of publication; Country; Cohort/study sample[a]	Sample size[b]	Age range[c], y	Number of trajectories	Description of cigarette smoking trajectories (prevalence)[d]
Abroms 2005; US Maryland sample (1)	1 320	Grade 6–9	5	Never smokers (41.2%), intenders (33.5%), delayed escalators (8.9%), early experimenters (13.9%), early users (2.5%)
Simons-Morton 2005; US Maryland sample (1)	1 320	Grade 6–9	Control Group:5; Treatment Group:5	Control Group – Class 1 (41.7%), class 2 (32.2%), class 3 (11.9%), class 4 (11%), class 5 (3.2%) Treatment Group – Class 1 (44.5%), class 2 (31.5%), class 3 (10.7%), class 4 (11.2%), class 5 (2%)
Maggi 2007; Canada National Longitudinal Survey of Children and Youth	280	10–11 to 16–17	5	Late infrequent experimenters (6.1%), late frequent smokers (38%), early frequent experimenters (5.2%), early frequent smokers (34%), early infrequent experimenters (6.8%)
Bernat 2008; US Minnesota Adolescent Community Cohort		12–16 to 15–19	6	Non-smokers (54%), late established (8%), triers (17%), occasional users (10%), early established (7%), decliners (4%)
Maggi 2008; Canada National Longitudinal Survey of Children and Youth	3 959	10–11 to 20–21	6	Stable non-smokers (48.4%), late experimenters-non-smokers (17.2%), late experimenters (13.9%), late experimenters-daily smokers (4.1%), early experimenters-daily smokers (5.8%), early experimenters-occasional smokers (10.5%)
Kimber 2009; Sweden Stockholm sample	662	13–14 to 15–16	3	Largely non-users (40%), largely moderate users (39%), heavy users (21%)
de Leeuw 2010; Netherlands Family and Health Project	428	15–18	4	Non-smokers (62.3%), stable smokers (13.7%), increasers (17.7%), decreasers (6.3%)
Lynne-Landsman 2010; US Maryland sample (2)	533	Grade 9–12	2	Abstaining (82%), increasing (18%)
Heron 2011; UK Avon Longitudinal Study of Parents and Children	3 038	14–16	4	Non-smokers (85.4%), experimenters (8.7%), late-onset regular smokers (4.3%), early-onset regular smokers (1.7%)
Hampson 2013; US Oregon Youth Substance Use Project	963	Grade 9–12	4	Stable non-smokers (71%), experimenters (15%), rapid escalators (8%), stable high smokers (6%)
Metzger 2013; US Family Talk about Smoking Study	344	15.6–17.9	3	Non-smokers (18.6%), infrequent/non-escalators (53.8%), escalators (27.6%)
Xie 2013; China Wuhan Smoking Prevention Trial	3 521	12–15 to 14–17	3	Non-smokers (48.7%), stable light/occasional smokers (48.6%), accelerating smokers (2.7%)
Musci 2015; US Maryland sample (3)		12–21	2	Low but increasing users (68%), moderate users (32%)

(*continued on next page*)

Table 1 (*continued*)

First author & year of publication; Country; Cohort/study sample[a]	Sample size[b]	Age range[c], y	Number of trajectories	Description of cigarette smoking trajectories (prevalence)[d]
Cance 2017; US Southwestern sample	2 244	17–19 to 23–25	5	Abstaining (68%), low-increasing (11%), decreasing (11%), moderate-increasing (6%), steady high (4%)
Dutra 2017; US National Longitudinal Survey of Youth 1997	8 791	12–16 to 26–30	4	Experimenters (13.6%), quitters (8.1%), early established smokers (39.0%), late escalators (5.2%)
; Chang 2018; Taiwan Child and Adolescent Behaviors in Long-term Evolution Project	2 510	13–18	3	Non-smokers (71%), late increasing (22%), escalating smokers (7%)
Outcome variable[e]: Intensity and frequency of smoking				
First author & year of publication; Country; Cohort/study sample[a]	Sample size[b]	Age range[c], y	Number of trajectories	Description of cigarette smoking trajectories (prevalence)[d]
Chassin 2000[f]; US Midwest sample	6 929	Grade 6–12 to age 21–31	4	Experimenter (6%), quitter (5%), late stable (16%), early stable (12%)
White 2002; US New Jersey sample	374	12–30/31	3	Non/experimental smokers (39.6%), occasional/maturing out smokers (19%), heavy/regular smokers (41.4%)
Audrain-McGovern 2004; US Virginia sample (1)	968	14–15 to 17–18	4	Never smokers (45%), early/fast adopters (8%), late/slow adopters (24%), experimenters (23%)
Orlando 2004; US RAND Adolescent/Young Adult Panel Study	5 914	13–23	5	Triers (55%), late increasers (14%), decreasers (9%), early increasers (14%), stable highs (8%)
Tucker 2005; US RAND Adolescent/Young Adult Panel Study	4 245	13–23	5	Triers (55.3%), stable highs (7.8%), early increasers (14%), decreasers (8.7%), steady increasers (14.2%)
Tucker 2006[g]; US RAND Adolescent/Young Adult Panel Study	1 442	13–23	6	Abstainers (29.5%), triers (40.5%), early increasers (8.5%), late increasers (11%), decreasers (5.7%), stable highs (4.8%).
Audrain-McGovern 2009; US Virginia sample (1)	909	15–20	3	Non-smokers (61.2%), fast adopters (12.3%), slow progressors (26.5%)
Otten 2009; Canada Quebec sample (3)	312	13–15	3	Low-rate (38.4%), medium-rate (46.5%), high-rate (15.1%).
Outcome variable[e]: Any use of cigarettes				
First author & year of publication; Country; Cohort/study sample[a]	Sample size[b]	Age range[c], y	Number of trajectories	Description of cigarette smoking trajectories (prevalence)[d]
Maggi 2007; Canada National Longitudinal Survey of Children and Youth	2 886	10–11 to 16–17	3	Late onset (40.5%), middle onset (49.3%), early onset (10.2%)
Weden 2012; US National Longitudinal Survey of Youth 1979	6 349	14–15 to 24–25	4	Non-smokers (63.7%), late onset (18.8%), early-experiment smokers (2.7%), early-onset smokers (14.7%)
Huang 2013; US National Longitudinal Survey of Youth 1979	5 141	12–18	3	Low (75.8%), increased (21.1%), high-decreasing (3.1%)
Lynne-Landsman 2016; US Cherokee Nation sample	684	<14–16 to <15–17	3	None (82%), increasing (3%), high (15%)
TIME SINCE ONSET ANALYSES				
Outcome variable[e]: Intensity of smoking				
First author & year of publication; Country; Cohort/study sample[a]	Sample size[b]	Age range[c], y	Number of trajectories	Description of cigarette smoking trajectories (prevalence)[d]
Rosendahl 2008; Sweden Children's Smoking and Environment in the Stockholm County (BROMS) Study	2 175	11–18	Males: 4; Females: 4	Males – Group 1, early extinction, Group 3, early escalation (21.1%) Females – Late trial (14.7%), early extinction (26.1%), late escalation (18.3%), early escalation (25.2%)
Karp 2005; Canada Natural History of Nicotine Dependence Study	369	13–16.9	4	Low-intensity non-progressing (72.4%), slow escalators (11.1%), moderate escalators (10.8%), rapid escalators (5.7%)

Note: Missing information (i.e. empty cells) indicates that information was not clearly provided in the article.

[a] Refers to cohort data used to estimate trajectories. Where cohorts were not used, the city/state/country where data was collected was specified. Studies using the same data from a given city/state/country have the same number (e.g. Quebec sample (1)).

[b] Number of participants in the model used to estimate smoking trajectories.

[c] Age range of all participants from baseline to last data point. Some studies provided school grade rather than age.

[d] Refers to the trajectories identified in the final model (using labels as reported in the article) and percentage of participants in each trajectory (if reported).

[e] Refers to the way in which smoking was assessed: intensity was assessed as the number of cigarettes smoked over a given time period (day(s), week(s), month(s), year); frequency was assessed as the number of days on which participants smoked over a given time period (week(s), month(s), year); any use was assessed by asking participants whether they had ever smoked cigarettes or whether they had smoked in the past week/month/year with a yes/no response option.

[f] An “erratic” group was determined a priori and was not included in trajectory analyses.

[g] The “abstainer” group was determined a priori and therefore not included in trajectory analyses.

Table 2
Shape of cigarette smoking trajectories in 43 articles and median percentage[a] of participants in each trajectory shape grouping according to selected characteristics of articles included in the review.

		No. trajectories		Trajectory shape		
	No. articles	Median	Range	Low stablemedian %	Increasingmedian %	Othermedian %
Sample size[b]						
Small (<500)	11	3.5	2–6	39.6	17.7	10.8
Medium (500–2000)	17	4	2–6	51.5	11.9	9.9
Large (>2000)	14	4	3–6	63.7	14.0	8.4
Cigarette smoking indicator[c]						
Intensity	17	4	2–6	55.9	14.3	10.0
Frequency	16	4	2–6	48.6	11.1	8.7
Metric combining intensity and frequency	8	4	3–6	42.3	14.0	8.4
Any use	4	3	3–4	75.8	18.8	3.1
Time axis used						
Time since onset	2	4	4,4	72.4	18.3	10.8
Age/grade	41	4	2–6	54.0	13.9	9.0
Number of data points used to estimate trajectories						
<5	12	3	2–3	62.3	21.0	6.8
5–10	27	4	2–6	54.1	12.0	9.2
>10	4	4	3–4	47.0	20.2	8.1

[a] Articles which did not report the percent of participants in a given trajectory group are not included in the calculations of median percentages.
[b] Excludes 3 articles (Bernat et al., 2008; Chung & Chun, 2010; Musci, Uhl, Maher, & Ialongo, 2015) that did not report the number of participants included in trajectory analyses. Maggi et al. (2007) used three different sample sizes for the three trajectory models estimated, two sample sizes were <500 and one was >2000.
[c] Maggi et al. (2007) estimated three trajectory models, one using intensity as the cigarette smoking indicator, one using frequency, and the third using any use. This article is counted in the intensity, frequency, and any use rows.

the natural course of smoking onset. Of the 13 concepts examined in these articles (Table 3), sex/gender and peer smoking were significantly associated with trajectory group membership in both articles. Rosendahl et al. (2008) reported a significant association between trajectory group and each of parental education, parental tobacco use, and school smoking environment. Only Karp et al.(2005) examined potential outcomes – members of trajectory groups with higher cigarette consumption were more likely to develop nicotine dependence and tolerance.

Modeling approaches for testing factors and outcomes across trajectories differed. Nelson et al.(2015) included factors in the model that estimated trajectories, thereby accounting for the uncertainty associated with trajectory assignment. Others (e.g., Dutra et al., 2017; Lessov-Schlaggar et al., 2008) used post-hoc testing after individuals were classified into groups. This method does not account for this uncertainty unless posterior probabilities (e.g., Otten et al.(2009)) or more sophisticated approaches (see GRoLTS list (Van De Schoot et al., 2017)) are used, which is uncommon. Further, the assumptions underlying post-hoc testing varied across articles. While some used omnibus chi-square tests that considered trajectory groups as a nominal variable (Lessov-Schlaggar et al., 2008), others (Dutra et al., 2017) imposed an implicit ordering (e.g., from low to high) on the trajectories.

Windows of opportunity for intervention

Twelve of 43 articles discussed implications of trajectories for prevention; only two (Dutra et al., 2017; Orlando et al., 2004) described critical windows for high-risk trajectories. Orlando et al.(2004) suggested that the period between high school and young adulthood was a critical intervention period for "late increasers", but that "early increasers" would benefit from earlier intervention. Dutra et al.(2017) suggested interventions in early childhood and young adulthood for "early established smokers" and "late escalators", respectively. In the remaining 10 articles, some authors advocated that interventions should target the entire adolescent period (Audrain-McGovern et al., 2004; Lynne-Landsman et al., 2010; Nelson et al., 2015), while others – given the increased likelihood of smoking uptake (Abroms, Simons-Morton, Haynie & Chen, 2005) and experimentation (Bernat, Erickson, Widome, Perry & Forster, 2008) at specific time points – argued for late childhood or early adolescence (Abroms et al., 2005; Audrain-McGovern et al., 2009; Bernat et al., 2008; Gabrhelik et al., 2012; Hampson et al., 2013; Riggs et al., 2007). Others (Huang et al., 2013; Tucker et al., 2005) suggested late adolescence or emerging adulthood due to the transition to increased autonomy and adult roles.

Discussion

The main findings of this review are that: (i) in addition to possibly reflecting real patterns of cigarette smoking, heterogeneity across articles in trajectory number and shape may relate to study design features and modeling decisions; (ii) "risk" factors and outcomes identified in trajectory studies mirror those from studies that do not use trajectory analyses; (iii) few articles report windows of opportunity for intervention; (iv) only two articles depict the natural course of smoking since most used age/grade as the time axis; and (v) only two of 43 articles reported at least half of items in the GRoLTS checklist so that it is generally difficult to understand how the final models were selected, thereby decreasing the possibility of replicability.

This review comes at a time when trajectory analyses are apparently increasingly popular despite warnings that modeled trajectories may not represent real constructs (Sher, Jackson & Steinley, 2011; Vachon, Krueger, Irons, Iacono & McGue, 2017; Van De Schoot et al., 2017). Their appeal is explained by three key potentials including ease of summarizing longitudinal data into easily interpretable graphical presentations, increased understanding of factors associated with different patterns of smoking, and informing intervention by identifying at-risk subgroups and windows of opportunity for intervention.

Summarizing data

Trajectory analyses identify patterns in complex data which facilitate describing longitudinal data succinctly. However, differences across datasets such as in the density of measurements, may affect the number and shape of the estimated trajectories (e.g., having fewer data points or longer time intervals between data points could result in detecting fewer smoking patterns). Given the data-driven nature of the decision-making process in selecting a latent growth model, researchers should provide clear and detailed reports of the methods used to facilitate replicability and critical appraisal of the results. The GRoLTS checklist (Van De Schoot et al., 2017) includes detailed yet concise items concerning each step of the model selection process and reporting these items will increase understanding on how the models were derived and the quality of the model selection

Table 3
Number of articles[a] that investigated a potential factor associated with trajectory group membership, and among these articles, the number that reported a statistically significant association.

	Age/grade analyses			Time since onset analyses		
	First author, date	n	Reported significant association[b] n	First author, date	n	Reported significant association n
SOCIODEMOGRAPHIC FACTORS[c]						
Baseline age, grade (education level, school enrollment)4	Lessov-Schlaggar 2008, Bernat 2008, Orpinas 2016, de Leeuw 2010, Weden 2012, Dutra 2017	6	6	Karp 2005	1	0
Sex, gender	Vitaro 2004, Lessov-Schlaggar 2008, Otten 2008, Nelson 2015, Bernat 2008, Otten 2009, Orpinas 2016, White 2002, Gabrhelik 2012, Abroms 2005, de Leeuw 2010, Lynne-Landsman 2010, Heron 2011, Metzger 2013, Musci 2015, Hampson 2013, Audrain-McGovern 2004, Orlando 2004, Audrain-McGovern 2009, Weden 2012, Lynne-Landsman 2016, Dutra 2017	22	10	Karp 2005, Rosendahl 2008	2	2
Race, ethnicity (white, black, Hispanic, Asian, other, non-white)	White 2004, Nelson 2015, Bernat 2008, Orpinas 2016, Abroms 2005, Metzger 2013, Audrain-McGovern 2004, Weden 2012, Lynne-Landsman 2016, Orlando 2004, Tucker 2006, Audrain-McGovern 2009, Dutra 2017	13	10	–	–	–
Socioeconomic status	White 2004, Otten 2009, White 2002	3	1	–	–	–
Parental education	Vitaro 2004, Lessov-Schlaggar 2008, Lynne-Landsman 2010, Heron 2011, Orlando 2004, Tucker 2006, Weden 2012, Dutra 2017	8	6	Karp 2005, Rosendahl 2008	2	1
Household income	Lessov-Schlaggar 2008, Otten 2008, Dutra 2017	3	2	Karp 2005	1	0
Father's occupation	Stanton 2004	1	0	–	–	–
Free or reduced lunch	Musci 2015, Hampson 2013	2	2	–	–	–
Housing tenure	Heron 2011	1	1	–	–	–
No. of address changes in past 2yrs	Stanton 2004	1	1	–	–	–
Overcrowding	Heron 2011	1	1	–	–	–
Community type (urban, rural, small city)	Bernat 2008	1	1	–	–	–
Parity	Heron 2011	1	1	–	–	–
PSYCHOSOCIAL FACTORS						
	First author, date	n	Reported significant association[b] N	First author, date	n	Reported significant association n
Behavior problems (maladjustment, delinquency, conduct disorder score)	Stanton 2004, Otten 2009 , Vitaro 2004, White 2002, Weden 2012, Heron 2011, Dutra 2017	7	6	–	–	–
Sensation-seeking, disinhibition	Hampson 2013. White 2002	2	2	–	–	–
Novelty-seeking, impulsivity	Audrain-McGovern 2004, Audrain-McGovern J. 2009	2	2	Karp 2005	1	0
Tolerance for deviance	Chassin 2000, Abroms 2005, Orlando M. 2004	3	3	–	–	–
Locus of control	Chassin 2000	1	1	–	–	–
Delay discounting	Audrain-McGovern 2009	1	1	–	–	–
Child's sexual, physical, emotional abuse	Roberts 2014	1	1	–	–	–
Life satisfaction	Stanton 2004	1	0	–	–	–
Social competence	Stanton 2004, Abroms 2005	2	0	–	–	–
Social preference (popularity among peers, isolation from peers)	Otten 2008, Otten 2009 , Xie 2013	3	1	–	–	–
Friend-related psychosocial factors						
Peers' antisocial behavior, friends' disruptiveness, problem-behaving friends	Otten 2009, Abroms 2005	2	1	–	–	–
Attachment to friends	Stanton 2004	1	1	–	–	–
Friend support	Chassin 2000	1	0	–	–	–
Friend strictness	Chassin 2000	1	0	–	–	–
Peers' social preference	Otten 2008	1	0	–	–	–
Smoking-related psychosocial factors						
Low self-efficacy for smoking resistance	Orlando 2004	1	1	–	–	–

(*continued on next page*)

Table 3 (*continued*)

	Age/grade analyses	Time since onset analyses				
Beliefs about smoking (belief in smoking benefits, outcome expectations, smoking difficulty, lack of belief in smoking costs, psychological beliefs, social beliefs, functional meaning of smoking	Bernat 2008, Chassin 2000, Abroms 2005 , Orlando M. 2004,	4	4	–	–	–
Attitude(s) toward smoking	Otten 2008, White 2002, Xie 2013	3	1	–	–	–
Intention to smoke	Stanton 2004	1	1	–	–	–
Smoking social norms	Abroms 2005	1	1	–	–	–
Perception of tobacco industry (tobacco ad receptivity)	Bernat 2008, Audrain-McGovern 2004	2	2	–	–	–
MENTAL HEALTH						
	First author, date	n	Reported significant association[b] N	First author, date	n	Reported significant association n
Depression, depressive symptoms	White 2002, Xie 2013, Stanton 2004, Abroms 2005 , Audrain-McGovern 2004 , Audrain-McGovern 2009 , Dutra 2017	7	6	Karp 2005	1	0
Anxiety	Stanton 2004	1	0	–	–	–
Stress		–	–	Karp 2005	1	0
Self-esteem, self-derogation	White 2002	1	0	Karp 2005	1	0
Attention deficit disorder score, ADHD-attention, ADHD-hyperactivity	Stanton 2004, Audrain-McGovern 2009	2	1	–	–	–
Help-seeking for emotional or behavioral problem	Stanton 2004	1	0	–	–	–
Internalizing problems (depressive symptoms, social anxiety, and social loneliness)	Chang 2018	1	1	–	–	–
ACADEMIC-RELATED VARIABLES						
Academic performance (grades, GPA, school performance, school qualification)	White 2002, Xie 2013, Audrain-McGovern 2004 , Orlando 2004 , Audrain-McGovern 2009 , Lessov-Schlaggar ,2008 Stanton 2004	7	7	Karp 2005	1	1
School-related attitudes (value/expectations placed on academic success and independence, confident in ability to succeed at school, academic engagement, school adjustment, school attachment, perceived trouble with teachers, likes school	Chassin 2000, Abroms 2005, White 2002, Stanton 2004, Xie 2013	5	1	Karp 2005	1	0
Year level intending to leave school	Stanton 2004	1	0	–	–	–
School climate	Abroms 2005	1	0	–	–	–
College attendance[e]	Nelson 2015	1	1	–	–	–
SMOKING-RELATED FACTORS						
(Prior to) Baseline cigarette use, age first tried smoking	Riggs 2007, Lessov-Schlaggar 2008 , Heron 2011, Metzger 2013, Hampson	5	5	–	–	–
Baseline nicotine dependence	Lessov-Schlaggar 2008	1	1	–	–	–
SMOKING IN SOCIAL ENVIRONMENT						
	First author, date	n	Reported significant association[b] N	First author, date	n	Reported significant association n
No. of adults who smoke	Bernat 2008	1	1	–	–	–
School-related smoking (school has clear smoking rules, teachers/staff smoke near school, attends school where breaking smoking rules results in punishment, attends school where many students smoke where they are not allowed to, teachers sanction smoking, baseline prevalence of tobacco use in class	Xie 2013	1	1	Karp 2005, Rosendahl K. I. 2008	2	1
Family-related smoking						
Home smoking rules (smoking policies, non-smoking agreement, family rules about substance use)	Bernat 2008, de Leeuw 2010. Metzger 2013	3	2	–	–	–
Sibling smoking	White 2002	1	0	–	–	–
Parents' smoking, tobacco use, ever smoker, no. parents who smoke, household smoking, persons at home smoke, adult smoking	Vitaro 2004, Lessov-Schlaggar C. N. 2008, Otten R. 2008, Bernat D. H. 2008, Otten R. 2009, Chassin 2000, White 2002, Xie 2013, Abroms L. 2005, de Leeuw 2010, Orlando M. 2004, Audrain-McGovern J. 2009	12	8	Karp 2005, Rosendahl K. I. 2008	2	1
Mother smokes	Stanton 2004, Heron 2011, Metzger 2013, Weden 2012	4	3	–	–	–
Father smokes	Stanton 2004, Metzger 2013	2	0	–	–	–

(*continued on next page*)

Table 3 (*continued*)

	Age/grade analyses	Time since onset analyses				
Parental disapproval/sanctioning of smoking	Xie 2013, Orlando M. 2004, Metzger 2013	3	3	–	–	–
Parent communication (about smoking)	de Leeuw 2010, Metzger 2013	2	2	–	–	–
Parental smoking expectancies	Metzger 2013	1	0	–	–	–
Friend-related smoking						
Peer and friends smoking	Vitaro 2004, Otten R. 2008, Bernat D. H. 2008, Chassin 2000, White 2002, Stanton 2004, Abroms L. 2005, Audrain-McGovern J. 2004, Orlando M. 2004, Audrain-McGovern J. 2009, Dutra L. M. 2017	11	10	Karp 2005, Rosendahl K. I. 2008	2	2
Peer smoking attitudes, peer sanctioning of smoking, friend smoking norm	Otten 2008, Xie 2013	2	1	–	–	–
FAMILY-RELATED VARIABLES						
	First author, date	n	Reported significant association[b] n	First author, date	n	Reported significant association n
Family functioning (family relationships, parent-child conflict, family disharmony, parental involvement, monitoring, support, strictness, expectation, warmth)	Xie 2013, Stanton 2004, Abroms L. 2005, de Leeuw 2010, Chassin 2000, Metzger 2013	6	2	–	–	–
Nuclear family, two-parent family	Bernat 2008, Orlando M. 2004, Tucker 2006, Dutra L. M. 2017	4	4	–	–	–
Attachment to family	Stanton 2004	1	0	–	–	–
Maternal characteristics						
Obtained prenatal care	Weden 2012	1	0	–	–	–
Age at birth	Weden 2012	1	1	–	–	–
Breastfed child	Weden 2012	1	0	–	–	–
Smoked during pregnancy	White 2002	1	0	–	–	–
Marital status when child was age 14	Weden 2012	1	1	–	–	–
Maternal weekly alcohol use when child was age 12	Heron 2011	1	0	–	–	–
Maternal alcohol binge when child was age 12	Heron 2011	1	1	–	–	–
Maternal cannabis use when child was age 9	Heron 2011	1	1	–	–	–
Mother's psychological symptoms	Stanton 2004	1	1	–	–	–
Mother's abuse (sexual, physical, emotional)	Roberts 2014	1	1	–	–	–
SUBSTANCE USE						
	First author, date	n	Reported significant association[b] n	First author, date	n	Reported significant association n
Alcohol use (been drunk, binge drinking)	Xie 2013, Stanton 2004, Audrain-McGovern J. 2004, Audrain-McGovern J. 2009, Orlando M. 2004, Heron 2011	7	6	–	–	–
Intention to get drunk	Stanton 2004	1	0	–	–	–
Cannabis use (marijuana, pot)	Stanton 2004, Heron 2011, Audrain-McGovern J. 2004, Orlando M. 2004, Audrain-McGovern J. 2009, Dutra L. M. 2017	6	6	–	–	–
Drug use (other illicit drugs)	White 2002, Dutra L. M. 2017	2	2	–	–	–
Team sport	Audrain-McGovern 2004	1	1	–	–	–
MISCELLANEOUS						
Extracurricular activities (belongs to organized club, regular part-time job)	Stanton 2004	1	1	–	–	–
Genetics (polygenic score, population stratification)	Musci 2015	1	1	–	–	–
Environmental profile (parental monitoring, peer substance use)	Musci 2015	1	1	–	–	–

[a] When two or more articles used the same data, they were included as separate articles.
[b] The direction of associations is not reported due to heterogeneity across articles in the trajectory group used as the reference group.
[c] If a factor was studied in both univariate and multivariate models, results from the latter are reported.
[d] Variables in parentheses are the labels used by the authors to describe the concept of interest.
[e] It is not clear how "college" is defined in this study. Authors indicate college attendance both as a baseline variable and as an outcome.

Table 4
Number of articles[a] that report the association between trajectory group membership and a potential outcome, and among these articles, the number that reported a statistically significant association.

Potential outcome	First author, date	Total articlesn	Articles reporting a significant association[b]n
SOCIODEMOGRAPHIC FACTORS			
Education (college, high school dropout, graduate on time)[c]	Lessov-Schlaggar C. N. 2008, Chassin 2000 Orlando M. 2004, Tucker J. S. 2005, Tucker 2006 Orpinas 2016 Lynne-Landsman 2010, Dutra L. M. 2017	8	7
Income (welfare recipient)	Lessov-Schlaggar C. N. 2008, Tucker 2006	2	2
Employment (job problems)	Tucker 2006, Chassin 2000	2	0
Marital status	Lessov-Schlaggar C. N. 2008, Chassin 2000, Orlando M. 2004, Tucker J. S. 2005, Tucker 2006, Dutra L. M. 2017	6	3
Parenthood	Chassin 2000, Tucker 2006, Dutra L. M. 2017	3	3
PSYCHOSOCIAL FACTORS			
Personality risk (extroversion, conscientiousness)	Chassin 2000	1	1
Life satisfaction	Chassin 2000	1	1
Affect (negative, positive)	Chassin 2000	1	1
Stress	Chassin 2000	1	0
Major depressive disorder	Lynne-Landsman 2010	1	0
PHYSICAL AND MENTAL HEALTH			
Physical or mental health (respiratory symptoms, obesity)	Orlando M. 2004, Tucker J. S. 2005, Tucker 2006, Huang D. Y. 2013	4	4
Antisocial behavior (arrest history, criminal record stealing, selling drugs, violence)	Lynne-Landsman 2010, Tucker 2006 Orlando M. 2004, Tucker J. S. 2005	4	4
Sexual activity (no. sex partners, condom use, unsafe sex, pregnant, early sex, abortion)	Guo 2002, Lynne-Landsman 2010, Tucker 2006	3	3
SMOKING-RELATED FACTORS			
Smoking health and psychological beliefs	Chassin 2000	1	1
Nicotine dependence[4]	Riggs 2007, Lessov-Schlaggar C. N. 2008	2	2
Cigarette (or tobacco) use	Riggs 2007, Nelson 2015, Hampson S. E. 2013	3	3
Hookah use	Hampson S. E. 2013	1	1
Family smoking (offspring smoking)	Lessov-Schlaggar C. N. 2008, Vuolo M. 2013	2	2
SUBSTANCE USE			
Cannabis (marijuana (problematic use, dependence))	Orpinas 2016, Lynne-Landsman 2010, Nelson 2015	3	3
Illicit drug use (cocaine, methamphetamine, problematic use)	Orlando M. 2004, Tucker J. S. 2005, Tucker 2006	5	5
Alcohol use (inebriated, problematic use, dependence)	Orpinas, 2016 Nelson 2015, Lynne-Landsman 2010, Orlando M. 2004, Tucker J. S. 2005, Tucker 2006	6	6

[a] When two or more articles used data from the same cohort, they were included as separate articles.
[b] The direction of associations is not reported due to heterogeneity across articles in the trajectory group used as the reference group.
[c] Variables in parentheses are the labels used by the authors to describe the concept of interest.

process. However, few studies report these details – only two of the 43 studies in this review (Audrain-McGovern et al., 2004; Otten, Wanner, Vitaro & Engels, 2008) reported at least half of the GRoLTS items. Key information (e.g., missing data mechanism used, consideration of alternative specifications of within-class heterogeneity) was not reported in most studies, and these omissions make it harder to understand how the final models were selected, decreasing the possibility of replication. Reporting the details of the decision-making process will increase transparency and enable other researchers to replicate the findings and evaluate the quality of the latent growth models.

Factors associated with trajectories

Synthesizing evidence on factors associated with trajectories is challenged by using different smoking indicators across articles and the choice of which trajectory is used as a reference. In addition, most factors were investigated in a few articles only. However, factors associated with "riskier" trajectories mirrored predictors of cigarette smoking onset identified in a recent systematic review (Wellman et al., 2016), suggestive that risk factors for smoking onset may also discriminate smoking trajectories. Because trajectories represent patterns of smoking over time, they are necessarily more complex than single point-in-time indicators of smoking such as onset or sustained use. Studying factors associated with trajectories in their entirety likely obscures identification of factors associated with single point-in-time smoking indicators and may therefore complicate rather than clarify our understanding of smoking. Future work will need to ascertain whether identification of factors associated with trajectories add value to analyses identifying risk factors for single point-in-time smoking indicators.

Outcomes of smoking trajectories identified herein are convergent with those identified in non-trajectory studies (Chassin, Presson, Sherman & Edwards, 1990), but may be more useful than single point-in-time outcomes if for example, they distinguish early initiators who sustain smoking from early initiators who decrease. However, the feasibility of collecting data over time and plotting an individual's trajectory likely limits the utility of trajectory analyses in practice.

Are trajectories real?

Our review (and the trajectory approach in general) cannot determine whether smokers remain in a single trajectory over time, and several authors warn against considering trajectories as real constructs (Sher et al., 2011; Vachon et al., 2017; Van De Schoot et al., 2017). Most trajectories in our review were estimated using latent class growth analysis which assumes that individual trajectories within each group are homogeneous. However, the assumption of homogeneity may not be met, and estimated trajectories may not represent meaningful entities. Vachon et al.(2017) argue that for distinct *true* trajectories to exist, strong, discriminating, categorical factors (e.g., a specific risk allele or event) must set individuals on a deterministic course. Smoking behavior may have a more dynamic nature than what trajectory analyses model (i.e., it may be fluid and subject to change across development, rather than static within a single trajectory) (Van De Schoot et al., 2017). This concern (Zuk, Hechter, Sunyaev & Lander, 2012) is augmented by the tendency for trajectory analyses to provide the same four forms (i.e., increasing, decreasing, stable

high, stable-low), regardless of participant age at time zero or study duration, suggesting that some findings may be artefacts of the trajectory method (Sher et al., 2011). These four patterns were not systematically observed in the articles reviewed herein, although this could relate to the fact that no single strong discriminating categorial factor was identified across articles that sets adolescents on a deterministic course of smoking.

Time axis

If there is important variation in the natural course of smoking, time of smoking onset may be a more meaningful time zero in trajectory analyses than calendar time (Sher et al., 2011). Trajectory groups in age/grade analyses include members with different durations and levels of cigarette consumption at a single time-point, whereas "time-since-onset" trajectory groups include members with the same duration of smoking. This could explain our observation that 72% of smokers in "time-since-onset" studies were stable-low smokers, compared to 54% in age/grade studies. The proportion of smokers that initiate smoking after baseline may differ in each trajectory in age/grade studies, thus obscuring comparison across trajectory groups and across studies of persons with different ages at baseline. Further, risk factors for smoking onset and continuing to smoke at a given age may not coincide (Sher et al., 2011).

Recommendations for future research

Future studies on youth smoking trajectories should begin measuring smoking during childhood to ensure that smoking onset is observed. Further, they should incorporate frequent measurement of smoking to capture critical changes in smoking patterns. Continuous measures of smoking (i.e., mean number of cigarettes smoked per month) should be favored over categorical measures since they provide more nuanced data that can be easily measured and compared across studies (Royston, Altman & Sauerbrei, 2006). We recommend that researchers use the GRoLTS checklist (Van De Schoot et al., 2017) to report each step of the model selection process. Addressing the issue of heterogeneity of results across studies necessitates transparency in data-driven decisions, but also requires replication studies that reproduce the analytical plan in independent datasets that share the same design features as the initial studies including age range, frequency and timing of measuring smoking, as well as measurement of factors associated with smoking such as sex and socioeconomic status. Further, depending on the study objectives, future studies should consider using smoking onset as time zero. In addition to improving understanding of the natural course of smoking, knowledge on the timing of onset can facilitate comparison of results across studies. Finally, future work will need to critically appraise the usefulness of trajectory modeling against other statistical approaches that aim to describe longitudinal patterns of smoking (e.g., to ascertain whether identification of factors associated with trajectories add value to analyses identifying risk factors for single point-in-time smoking indicators).

Implications for intervention and policy

Our work has two important implications for intervention and policy. First, program planners and policy makers should consider the high proportion of young people who begin smoking in late childhood or early adolescence (Maggi et al., 2007; Riggs et al., 2007). Emerging evidence suggests that education and counselling at these ages may prevent initiation (Harvey, Chadi, & Canadian Paediatric Society Adolescent Health Committee, 2016). Second, the extant smoking trajectory literature does not provide consistent messages on at-risk individuals or windows of opportunity for intervention. Pinpointing the intervention needs of specific subgroups necessitates identifying factors amenable to intervention that differentiate trajectory groups at specific points-in-time. If trajectories depend on age, sex, and contextual factors, then using the current trajectory literature to inform policy could be harmful because of lack of specificity. Even if windows of opportunity are identified, it is unclear whether differences across trajectories at a given point-in-time are sufficiently important to warrant targeted intervention (Vachon et al., 2017). Recommendations from the two articles (Dutra et al., 2017; Orlando et al., 2004) that identified time windows for intervention differed, and only one article (Dutra et al., 2017) discussed specific intervention strategies. Therefore, we suggest that the potential of trajectory analyses to inform intervention and policy has yet to be identified.

Limitations

Study limitations include the methodological heterogeneity which made it difficult to synthesize the 43 articles retained. Despite the existence of objective criteria (e.g. the Bayesian Information Criterion), many articles used subjective criteria (e.g., substantive relevance of trajectories) to select the optimal model. Further, the criteria used were not always reported. Modeling decisions (e.g., dropping higher order polynomials which do not attain significance; requiring each trajectory group to have a minimum sample size) may also affect results and should be reported. Only two articles investigated individuals who initiated smoking after baseline, which limited detection of critical windows of opportunity relevant to intervention (Sher et al., 2011). Categorizing trajectories into three groups was necessary to facilitate summarizing trajectory shapes, but limited capturing unique trajectory patterns across articles. Finally, we did not adhere to the Cochrane recommendation of vote-counting based on direction-of-effect (as opposed to statistical significance) when meta-analysis is not possible (McKenzie & Brennan, 2019). Although direction-of-effect is useful in reviews of intervention studies, this approach cannot be used in synthesizing trajectory studies because of differences in the smoking indicator used, variation in the reference trajectory group, and use of different methods to test associations. Collating information on risk factors and outcomes across articles was also limited by differing indicators used for specific risk factors and outcomes across articles and because most factors or outcomes were investigated in only a few articles. Future reviews of specific factors associated with smoking trajectories using small subsets of articles reviewed herein might be better suited to this exercise.

Conclusion

Differences across studies in trajectory number and shape may reflect real-life smoking patterns, study design features, MNA and BL are co-first authors, and/or the data-driven nature of trajectory modeling. Factors and outcomes associated with trajectory membership mirror those reported in non-trajectory studies, so that the added value of trajectory analyses with these objectives remains to be demonstrated. Trajectory analysis may prove more useful in describing smoking patterns in a given population, than in identifying specific subgroups or specific time windows of opportunity for intervention.

Declaration of Competing Interest

None.

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Supplementary materials

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