

Prevalence of electronic nicotine delivery systems (ENDS) use among youth globally: a systematic review and meta-analysis of country level data

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Electronic nicotine delivery systems (henceforth referred to as ENDS), are handheld battery-operated devices that aim to simulate conventional cigarettes by delivering a solution typically comprising nicotine, propylene glycol, glycerine and flavouring agents, which is heated and inhaled as an aerosol by users.¹ Since being introduced into markets in the mid-to-late 2000s, ENDS use has risen significantly among adults in many countries.^{2,3} At the same time, there has been considerable public health debate regarding the potential benefits and harms of ENDS use.⁴⁻⁶ ENDS have been marketed as an aid to reduce or cease tobacco smoking,⁷ and are endorsed as such by the Royal Society for Public Health, the Royal College of Physicians, and Public Health England in the UK.⁸⁻¹⁰ However, many other organisations including the World Health Organization (WHO), American Lung Association and Australian Medical Association do not support the use of ENDS as a cessation aid in youth, citing concerns regarding product safety and the potential that experimentation with ENDS could lead to nicotine dependence and subsequent tobacco use.¹¹⁻¹³ Evidence supporting such concerns was also documented in the recent US Surgeon General Report.¹⁴

As experimentation with cigarettes primarily occurs in youth (ages 10–24 years),^{15,16} and the developing brain is particularly sensitive to nicotine,¹⁷ the use of ENDS during youth has received considerable attention.^{8,18}

Abstract

Objective: To describe the prevalence and change in prevalence of electronic nicotine delivery systems (ENDS) use in youth by country and combustible smoking status.

Methods: Databases and the grey literature were systematically searched to December 2015. Studies describing the prevalence of ENDS use in the general population aged ≤20 years in a defined geographical region were included. Where multiple estimates were available within countries, prevalence estimates of ENDS use were pooled for each country separately.

Results: Data from 27 publications (36 surveys) from 13 countries were included. The prevalence of ENDS ever use in 2013–2015 among youth were highest in Poland (62.1%; 95%CI: 59.9–64.2%), and lowest in Italy (5.9%; 95%CI: 3.3–9.2%). Among non-smoking youth, the prevalence of ENDS ever use in 2013–2015 varied, ranging from 4.2% (95%CI: 3.8–4.6%) in the US to 14.0% in New Zealand (95%CI: 12.7–15.4%). The prevalence of ENDS ever use among current tobacco smoking youth was the highest in Canada (71.9%, 95%CI: 70.9–72.8%) and lowest in Italy (29.9%, 95%CI: 18.5–42.5%). Between 2008 and 2015, ENDS ever use among youth increased in Poland, Korea, New Zealand and the US; decreased in Italy and Canada; and remained stable in the UK.

Conclusions: There is considerable heterogeneity in ENDS use among youth globally across countries and also between current smokers and non-smokers.

Implications for public health: Population-level survey data on ENDS use is needed to inform public health policy and messaging globally.

Key words: electronic nicotine delivery systems, smoking, youth

In many jurisdictions, ENDS products are actively marketed in ways that appeal to young people, including the use of celebrity product endorsements and promotion of flavoured products (e.g. 'candy' flavour), and via social media.¹⁹ Although many jurisdictions where ENDS can be legally purchased have bans on sales to minors when the e-liquid contains nicotine,²⁰⁻²² ENDS are often easily obtained through informal social sources, such as friends and family

members.²³ Further, few countries enforce age restrictions on the purchase of e-liquids that do not contain nicotine.²² Recent meta-analyses of youth cohort studies published by the WHO²⁴ and others⁶⁹ suggest that use of ENDS by non-smoking young people can as much as quadruple the odds of later tobacco use.²⁵ Given the availability and promotion of ENDS in many countries, and their potential to influence tobacco use in youth, an understanding of the prevalence

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of ENDS use in young people generally, and among smokers and non-smokers, is needed to assess their potential impact on population health.

To our knowledge, just three systematic reviews have described the prevalence of ENDS use in young people,^{26–28} none of which synthesised findings via meta-analysis, or considered the non-English literature,^{26–28} thus limiting their ability to provide global estimates of the prevalence of ENDS use in youth. Given the documented increase in ENDS use among young people in recent years,^{29–31} a comprehensive review and meta-analyses of the prevalence of ENDS use is needed. In view of the differences across countries in the timing of the introduction of ENDS, and of the implementation of regulations regarding their availability, purchase, and use,^{32,33} it is crucial to examine the differences in the prevalence of ENDS use across countries, and to examine changes in prevalence within countries over time. Such data are required to better inform future tobacco control efforts, and public health policy as evidence regarding the potential benefits and harms of ENDS use continues to advance.

Objectives

The aims of this review are to: 1) describe the prevalence of ENDS use ('ever' and 'current') in young people aged ≤ 20 years by country and combustible tobacco smoking status (non-smokers and current smokers) during the 2013–2015 period; and 2) describe the changes in ENDS use (ever and current) in youth over time (2008–2015) by country.

Methods

The study reports data from a review undertaken on behalf of the WHO. A full description of the review methods is provided elsewhere.²⁴

Search strategy and study eligibility

EMBASE, MEDLINE, PsycInfo, CINAHL and the Cochrane library were searched from database conception to December 2015 to identify cross-sectional, repeat-cross-sectional or longitudinal studies reporting on prevalence of ENDS use among young people in the general population, and within a defined geographical region. Eligible studies employed a probability sampling method, and recruited general population samples of young people aged ≤ 20 years. For studies

that included samples aged more than 20 years, the study was included if outcomes among those aged ≤ 20 years was reported separately, or if the authors provided such results separately. For inclusion in analyses to address Aim 1, studies had to report prevalence of ENDS of samples between (and including) years 2013–2015. For inclusion in analyses of Aim 2, studies could include data on prevalence of ENDS in any year. Studies where participants were recruited based on a specific health condition or as members of particular socioeconomic groups were excluded. There were no restrictions regarding the location of the study, peer review status or language.

Broadly, the search terms included e-cig*, electronic nicotine*, electronic hookah* and e-hookah* as MESH terms (see Appendix A of the online supplementary file). A screen of the first 750 hits of a 'Google.com' search including the terms 'electronic cigarette' and 'e-cigarette' was also undertaken by one reviewer (FT) to capture the grey literature.

Information on potentially eligible studies was also sought from 30 experts recommended by the Tobacco Unit of the WHO, and from selected authors who had published two or more relevant studies in the field.

All studies identified in the searches were exported into EndNote X6 for screening by two reviewers (SY, LW). 'Google translate' was used to assist with assessing the eligibility of non-English language manuscripts.

Data extraction and study quality assessment

SLY and LW or LKC extracted the study characteristics, and prevalence of ENDS use by smoking statuses using a standardised form. Where prevalence of ENDS use by current smokers and non-smokers were not reported, estimates of use were calculated using the following information provided in the original publications: number in total sample, prevalence of ENDS users, prevalence of smokers, and prevalence of concurrent ENDS and tobacco users. A consensus process was used to resolve any differences in extraction. For the included studies, other supporting publications or reports were also sought to obtain relevant information where the data from the primary study was absent or unclear.

Two reviewers (MK and FT) independently undertook an assessment of study quality

using the Joanna Briggs Institute Critical Appraisal Checklist for Studies Reporting Prevalence Data.^{34–35} Any discrepancies were resolved via discussion with a third reviewer (SY).

Data synthesis and analyses

All analyses were undertaken using Stata version 14 software³⁶ and the METAPROP package. 'Ever' users were defined as those who had ever used ENDS in their lifetime (including studies that described participants as 'occasional' users), and 'current' use was defined as use in past 30 days, or where studies described participants as being 'current' or 'regular' users. Non-smokers were defined as those not currently smoking (including ex-smokers and never smokers) and smokers were defined as those currently smoking (including experimental, occasional or current users).

For Aim 1, where multiple studies provided estimates of ENDS prevalence between 2013 and 2015 for a single country, data were pooled using a random effects meta-analysis, weighted according to the inverse variance method. The Freeman-Tukey double arcsine transformation of prevalence was also used to allow for studies with prevalence that was close to zero and to account for data skewness. Exact 95% confidence intervals for the individual studies were computed, and stratified by country (where available). Pooled estimates of prevalence are reported as an absolute percent with 95% confidence intervals. For Aim 2, data were pooled where multiple studies reported prevalence estimates for the same country for the same year, and produced estimates for each year of data available. Heterogeneity was assessed using the I-squared statistic and reported for each point estimate, together with estimates of the between study variance, and corresponding *p*-values.

Results

Study characteristics and study quality assessment

Overall, 27 studies that reported findings from 36 individual surveys were included (see Figure S1, online supplementary Appendix for PRISMA flowchart). The included studies were conducted in 13 countries: the US (national and subnational) ($n=10$);^{34–43} Korea ($n=2$);^{44,45} New Zealand ($n=2$);^{46,47} UK, including Scotland and Wales ($n=2$);^{48,49} Poland ($n=2$);^{50,51} Canada

($n=2$);^{52,53} Hungary ($n=1$);⁵⁴ China, including Hong Kong ($n=1$);⁵⁵ France ($n=1$);⁵⁶ Ireland ($n=1$);⁵⁷ Italy ($n=1$);⁵⁸ Iceland ($n=1$);⁵⁹ and Greece ($n=1$).⁶⁰ The studies were conducted between 2008 and 2015,^{44,58} with sample sizes ranging from 99⁴⁷ to 75,643.⁴⁵ Two studies included both youth and adults and provided findings separately for youth ($n=99$ and $n=160-163$).^{46,58} ENDS use was assessed as 'ever' use in 22 studies^{34,35,37,38,41-53,56-60} and/or 'current use' in 22 studies.^{34-43,45,46,48-52,54,55,57,58,60} Four publications also reported 'regular' or 'occasional use'.^{46,48,57,58} Of all the included studies, only two^{53,58} reported the type of ENDS (i.e. with or without nicotine) used among youth. One study⁵⁸ conducted in Italy reported that the majority of regular ENDS users (96%) used ENDS containing nicotine; while the other study,⁵³ conducted in Canada, reported that the majority (72%) of ENDS ever users used ENDS without nicotine. However, these results were only presented for regular users⁵⁸ or ever users⁵³ in the studies, respectively. All study characteristics are reported in Table S1 (online supplementary file). When evaluated using the Joanna Briggs Institute Critical Appraisal Checklist, most studies used samples that were representative of the target population ($n=18$); conducted appropriate participant recruitment ($n=26$); and had an adequate sample size ($n=23$). Most ($n=19$) described the subjects and setting in detail; however, eight did not. The objectivity and reliability of the measures of ENDS use were mostly unclear, as data were collected via self-report. Important confounders or subgroup differences were accounted for in 18 studies. All 27 studies conducted appropriate statistical analyses (see Figures S2 and S3 in online supplementary Appendix C).

Current prevalence of ENDS use among adolescents

Prevalence of ENDS use among all youth

Estimates of the prevalence of ENDS use from studies conducted in nine countries between 2013 and 2015 are presented in Figures 1 and 2. Rates of ever use among youth were highest in Poland (one data point, 62.1%; 95%CI: 59.9-64.2%), and lowest in Italy (three data points, 5.9%; 95%CI: 3.3-9.2%). Rates of current use among youth were highest in Poland (one data point, 29.9%, 95%CI: 27.9-32.0%) and lowest in New Zealand (one data point, 0.0%; 95%CI: 0.0-3.7%), see Figure 2.

Prevalence of ENDS use among non-smoking youth

Estimates of the prevalence of ever ENDS use among non-smoking youth was available from 13 surveys conducted in eight countries between 2013 and 2015. Prevalence was highest in New Zealand (one data point, 14.0%, 95%CI: 12.7-15.4%) and lowest in the US (one data point, 4.2%, 95%CI: 3.8-4.6%). The prevalence of current ENDS use among non-smoking youth was reported in 10 surveys conducted in six countries between 2013 and 2015. Prevalence was highest in Poland (13.0%; 95%CI: 11.2-15.0%) and lowest in Italy (0.0%, 95%CI: 0.0-0.5%), see supplementary Figure S5.

Prevalence of ENDS use among youth who are current smokers

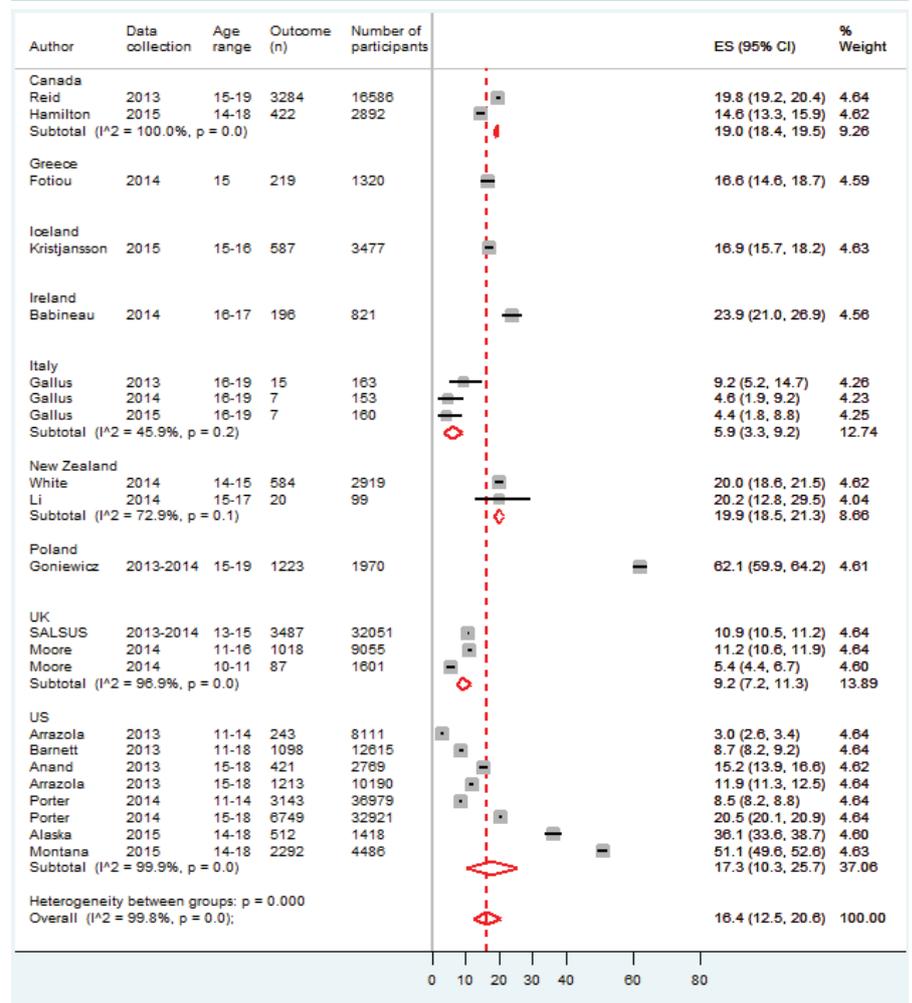
From the 13 surveys conducted between 2013 and 2015 in eight countries, the prevalence of ENDS ever use among current tobacco-smoking youth was highest in Canada (71.9%, 95%CI: 70.9-72.8%) and

lowest in Italy (29.9%, 95%CI: 18.5-42.5%), see supplementary Figure S6. The prevalence of current ENDS use among current cigarette-smoking youth was reported in 10 surveys conducted in six countries between 2013 and 2015, and ranged from 57.4% (95%CI: 53.8-61.0%) in Poland to 2.0% (95%CI: 0.7-4.7%) in Greece (see supplementary Figure S7).

Change in ENDS use among youth over time

Seven countries (US, UK, Poland, New Zealand, Korea, Canada and Italy) provided more than one comparable estimate of prevalence of ever use of ENDS among youth between 2008 and 2015. Overall, it appeared that prevalence of ever use increased in four countries: Poland (20.9% in 2010 to 62.1% in 2013); Korea (0.5% in 2008 to 9.4% in 2011); New Zealand (7.0% in 2012 to 20.0% in 2014); and the US (2.7% in 2011 to 47.3% in 2013), decreased in Italy and Canada, and remained stable in the UK. The estimates for Poland, New Zealand, the US and Italy were

Figure 1: Prevalence of ENDS ever use among youth, by country for all respondents (smokers and non-smokers).



drawn from studies with repeated samples of the same participants over time; however, estimates for Korea, Canada and the UK comprised different samples over time (see supplementary Table S2).

Five countries (US, UK, Poland, Italy and Hungary) provided more than one comparable estimate of prevalence of current use of ENDS among youth between 2010 and 2015. Prevalence of current use appeared to increase in three countries: Poland (8.2% in 2010 to 29.9% in 2013); the UK (0.9% in 2013 to 1.4% in 2014); and the US (1.1% to 25.8% in 2015). Estimates from Poland and the US were drawn from studies with repeated samples of the same participants over time; however, estimates for the UK comprised different samples over time. Prevalence of current use decreased in Hungary and remained stable in Italy (see supplementary Table S3), and both estimates were drawn from studies with repeated samples of the same participants over time.

Discussion

The findings are consistent with previous reviews that found that current smokers were more likely to use ENDS,⁶¹ and that ENDS ever and current use was increasing in the majority of countries with multiple prevalence estimates.²⁵ While considerable heterogeneity in prevalence estimates were reported across countries, ENDS use appeared to be increasing in most countries among young people. Such findings provide useful information for policy makers who are responsible for implementing tobacco control initiatives.

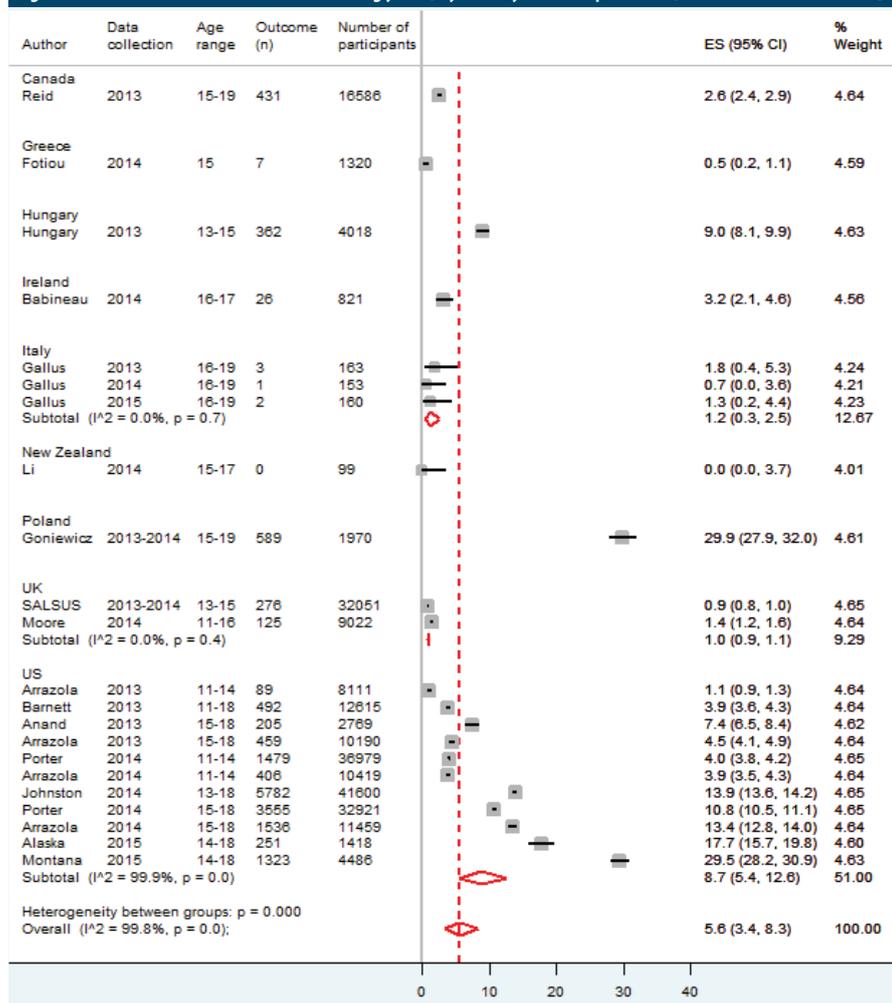
In interpreting these study results, it is important to consider that data were only available in 13 countries, with 10 of 27 included studies from the US. Systematically and consistently collected population-level survey data on ENDS use is needed in other countries. As such, items assessing ENDS use in youth should be considered for inclusion in regular national and international data collection efforts, such as the Framework

Convention on Tobacco Control (FCTC) Global Youth Tobacco Surveys. As data collection regarding ENDS use in youth progresses, researchers may consider including survey items that capture greater detail regarding the quantity and frequency of ENDS use to provide a clearer distinction between current and regular ENDS users, and use patterns that may be occasional, opportunistic or sporadic. This may be achieved by developing validated tools or common standards for assessing ENDS use, as have been established for combustible tobacco use.^{62,63}

Several limitations of this review need to be considered. First, the review pooled a variety of measures for assessment of current use, including 'regular' use and 'use in the past 30 days', which may have influenced prevalence estimates for some countries and comparisons across countries. Second, this study examined ENDS use among current non-smokers rather than never smokers. While it is possible that individuals with previous nicotine dependence may have been included, estimates of tobacco use among youth indicate that the majority of non-smoking youth (>80%) have never smoked.^{39,48,64} Third, the majority of included studies (93%) did not record whether the ENDS use included nicotine and/or non-nicotine e-liquids. This is an important distinction to consider in future studies of ENDS use in young people, given that concerns have been raised regarding the susceptibility of the adolescent brain to early exposure to nicotine, and the possibility that ENDS experimentation could lead to nicotine dependence in adulthood. Finally, although several studies conducted repeated measures of ENDS use on the same population using the same survey methods, other studies did not and, as such, the country-level changes in ENDS prevalence should be interpreted with caution and validated with longitudinal cohort studies when they become available.

While prevalence of current ENDS use was typically low among non-smokers, increasing use among this group may be a concern in light of recent longitudinal studies reporting a positive association between ENDS ever use and subsequent uptake of cigarette smoking at 12-month follow-up.^{21,66-69} Future studies should continue to monitor prevalence of ENDS ever and current use among youth, particularly among non-smokers, to enable pooling and comparisons between countries. Given the marked differences observed between countries in the prevalence of ENDS

Figure 2: Prevalence of ENDS current use among youth, by country for all respondents (smokers and non-smokers).



use, and given that more than 55 countries have already introduced legislation restricting the sale of ENDS to youth,⁷⁰ further studies are required to determine the association between prevalence of ENDS use and the ENDS regulatory environment.

Conclusions

This review identified variability in changes in the prevalence of ENDS use among youth by country, smoking status and over time. There is a need to develop validated measures of ENDS use to allow for accurate and comparable assessments and ongoing monitoring of the prevalence of ENDS use among youth, particularly non-smokers. Further research assessing the prevalence of ENDS use in other countries, and the potential impact of policies regulating the availability of ENDS use among youth, is needed.

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Supporting Information

Additional supporting information may be found in the online version of this article:

Supplementary Appendix A: Search terms employed in the electronic databases.

Supplementary Appendix B: PRISMA Flowchart.

Supplementary Appendix C: Risk of bias in included studies.

Supplementary Appendix D: Supplementary results figures and tables.