



Sixteen-year trends in adolescent consumption of sugar-sweetened soda in six European countries with a soda tax and comparison countries: a repeated cross-sectional survey analysis

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Abstract

Objective: To examine changes in the proportions of daily, weekly and occasional consumers of sugar-sweetened soda in six European countries that introduced/updated a tax between 2001–2002 and 2017–2018 and in neighbouring comparison countries (without a tax).

Design: Repeated cross-sectional surveys.

Setting: Health Behaviour in School-aged Children study, spanning five survey years (school years 2001–2002 to 2017–2018).

Participants: Nationally representative samples of 13-year- and 15-year-old adolescents (n 236 623, 51.0% girls).

Results: Tax sizes (€0.02/l to €0.22/l) and pre-tax soda consumption were heterogeneous across countries. Prevalence of daily soda consumption reduced in the survey year following tax implementation in Latvia (from 17.9 to 11.9%, $P=0.01$), Finland (4.2 to 2.5%, $P=0.001$), Belgium (35.1 to 27.8%, $P<0.001$) and Portugal (17.4 to 14.9%, $P=0.02$), but not in Hungary (29.8 to 31.3%, $P=0.47$) or France (29.4 to 28.2%, $P=0.27$). However, reductions were similar (Finland) or smaller (Belgium, Portugal) than those in the comparison countries, except in Latvia where the reduction was larger ($P_{\text{interaction}} < 0.001$). Prevalence of weekly soda consumption remained stable (Finland, Hungary and France) or increased (Latvia, Belgium); only Portugal experienced a decline ($P < 0.001$), which was larger than in the comparison country ($P_{\text{interaction}} < 0.001$). Prevalence of occasional soda consumption ($< 1x/\text{week}$) did not rise after implementation of the tax in Latvia, Finland, Hungary, France or Belgium, or the rise was similar to the comparison country in Portugal ($P_{\text{interaction}} = 0.15$).

Conclusions: Countries with a soda tax did not experience larger beneficial changes in post-tax adolescent consumption frequency of soda than comparison countries. Further studies, with different taxation types, are needed in the adolescent population.

Keywords
Sugary drink tax
Sugar-sweetened beverages
Sugar-sweetened soda
Trends
Adolescents
HBSC study
FFQ

Sugar-sweetened sodas, also known as sugary soft drinks, are the most consumed types of sugar-sweetened beverages (SSB)^(1,2). In Europe, one in six (16%) adolescents consumes soda every day⁽³⁾. This is of concern because a high soda intake of soda at a young age contributes to excessive weight gain^(4,5) and cardiometabolic risk⁽⁵⁾. To

reduce soda consumption, the WHO recommends taxing these beverages^(6,7). Since 2010, an increasing number of countries and jurisdictions (over forty five in 2020) have introduced such a tax^(8,9). Studying the impact of soda taxes in adolescents is important because (1) they are among the largest consumers of SSB worldwide^(10,11); (2) food price

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and healthiness have a lower priority to them^(12,13) and (3) poor dietary habits established in adolescence are likely to track into adulthood⁽¹⁴⁾.

Econometric studies in the US estimated the price elasticity of demand for SSB at -1.2 , implying that a tax raising the price by 20% would reduce the consumption of SSB by 24%⁽¹⁵⁾. A recent meta-analysis using real-world data from six countries confirmed the previous estimation (price elasticity: -1.0) and showed that the higher the tax rate was the more the SSB consumption reduced⁽¹⁶⁾. However, most studies relied on sales or purchase data, often aggregated at the household level. Although this is a robust evaluation, it does not assess the differential impact of taxes across household members, especially adolescents. To this end, individual-level studies investigating whether post-tax SSB consumption was reduced compared with pre-tax consumption are useful, but most^(17–26) recruited only adults^(17–21). In addition, most studies assessed changes in SSB consumption in the year following the tax introduction^(17–19,22–24), which limits evidence on long-term tax effects. Therefore, real-world data estimating the longer term effects of taxes on adolescents are needed to better understand their potential benefits.

Given the range of interventions addressing diet, it is essential when examining the effects of a soda tax to (1) know the pre-tax consumption trend; (2) compare the post-tax consumption evolution in a similar population not exposed to the tax and (3) be aware of the established diet-related interventions. Hence, we examined 16-year trends in daily, weekly and occasional soda consumption in six European countries that implemented a soda tax between 2001–2002 and 2017–2018. We also assessed whether changes in consumption of sugar-sweetened soda were different from those observed in neighbouring countries without such a tax (comparison countries). Our hypothesis was that the tax would be followed by a decline in daily soda consumption along with a rise in occasional consumption, indicating a shift favourable to health at the population level.

Methods

Study design and data sets

We used repeated cross-sectional data of the Health Behaviour in School-aged Children (HBSC) study⁽²⁷⁾, spanning five survey years: 2001–2002, 2005–2006, 2009–2010, 2013–2014 and 2017–2018. HBSC is an ongoing international school-based survey on health behaviours and well-being of adolescents aged 11, 13 and 15 years. The HBSC survey involves an increasing number of countries (up to forty seven in 2017–2018) that follow the same international protocol every 4 years⁽²⁷⁾. The sample size in each country is recommended to be at least 1500 per age group (precision of $\pm 3\%$ for a 50% prevalence)⁽²⁷⁾. Country-level teams recruited nationally representative

samples, stratified by geo-political regions and school categories. They randomly selected one or several classes for each targeted age group in each randomly selected school. Adolescents voluntarily filled out an anonymous, standardised questionnaire after receiving instructions in class. Response rates at the school level (and pupil level for 2017–2018) varied by country and survey year (Additional file 1): e.g. 2017–2018 school rates $\geq 69\%$ in 6/12 countries (no data for Latvia) and pupil rates $\geq 71\%$ in 8/10 countries (no data for Sweden, Portugal and Spain). More detailed information about the HBSC methodology can be found elsewhere⁽²⁷⁾.

Selection of countries with a soda tax

From the literature^(8,9,28–30) and personal contacts with local experts, we identified six European countries that introduced or updated a national tax on soda between the first (2001–2002) and last (2017–2018) survey years, providing at least one time point before and after the tax was implemented. Included countries, by chronological order of tax implementation, were Latvia, Finland, Hungary, France, Belgium and Portugal. Other European countries, including the United Kingdom and Norway, implemented a tax, but this was after the most recent HBSC data collection. This search also allowed us to identify other diet-related public health interventions.

Table 1 describes soda taxes and implementation date(s) for each country^(8,9,28,29). Tax sizes were heterogeneous across countries (€0.02/l to €0.22/l). Because most taxes are excise duties applied to manufacturers/importers (not consumers), the relative price increase may vary according to soda brands as well as places and volumes of purchase⁽³¹⁾. In Finland, France and Hungary, where such data are available, average tax rates were estimated at 20% (€0.22/l)⁽²⁸⁾, 7–10% (€0.07/l)⁽¹⁶⁾ and 5% (€0.02/l)⁽¹⁶⁾, respectively.

Selection of comparison countries

For comparison, we selected neighbouring countries with similar demographic, economic and nutritional characteristics that did not implement a soda tax before 2017–2018. Thus, Latvia was matched to Lithuania; Finland to Sweden; Hungary to Poland; France to Germany and Italy; Belgium to the Netherlands and Portugal to Spain. The Netherlands has implemented a ‘consumption tax’ on sugary and diet sodas, fruit juices and mineral water since 2002⁽¹⁶⁾. Given that the tax is old, small (0.04 to 0.08/l) and applied across all drinks, we still considered the Netherlands as a relevant comparison country for Belgium between 2013–2014 and 2017–2018. France was matched to two comparison countries because this is a large country with diverse dietary habits between the north and the south⁽³²⁾. Additional file 2 shows the similarity between pairs of countries, based on ten indicators.

Table 1 European countries with a soda tax introduced/updated between 2001–2002 and 2017–2018 and tax description^(8,9,16,28–30)

Countries (Regions in Europe)	Tax introduction or update	Types of tax and taxed sugary drinks*	Tax size (Euros†/l)	Tax rate (% price increase)	2010 Gross National Income (US\$/capita)‡
Latvia (Eastern, Northern)	Introduction: 1 May 2004	Volumetric, excise tax on non-alcoholic drinks with added sugars, other sweeteners or flavours	0.05 LVL (€0.03)	Unknown	21 304
	Update: 1 January 2016	Idem	€0.07	Unknown	
Finland (Northern)	Introduction: 20th century	Volumetric, excise tax on non-alcoholic drinks with added sugars	Before 2011: €0.05		46 500
	Update: 1 January 2011	Idem	€0.08		
	Update: 1 January 2012	Idem	€0.11		
	Update: 1 January 2014	Sugar content-based, excise tax on non-alcoholic drinks with added sugars	€0.22 (>5 g of sugars/100 ml) and €0.11 (<5 g/100 ml)	20% from December 2010	
Hungary (Eastern)	Introduction: 1 September 2011	Volumetric, excise/sales tax on sugar-sweetened beverages (>8 g of sugars/100 ml) (also artificially sweetened beverages: lower tax)	5 HUF (€0.02)		23 389
	Update: 1 January 2012	Idem	7 HUF (€0.02)	5% from August 2011	
France (Western)	Introduction: 1 January 2012§	Volumetric, excise tax on non-alcoholic drinks with added sugars (also with artificial sweeteners: lower tax)	€0.07	7–10%	43 253
Belgium (Western)	Introduction: Unknown	Unknown	Before 2016: €0.03	Unknown	44 814
	Update: 1 January 2016	Volumetric, excise tax on non-alcoholic drinks with added sugars, other sweeteners or flavours	€0.07	Unknown	
	Update: 1 January 2018	Idem	€0.12	Unknown	
Portugal (Southern)	Introduction: 1 January 2017	Sugar content-based, excise tax on non-alcoholic drinks with added sugars, other sweeteners or flavours	€0.16 (>8 g of sugars/100 ml) and €0.08 (<8 g/100 ml)	Unknown	30 905

*Excise tax is a duty levied on a particular product at point of manufacture (i.e. soda producers/importers), whereas sales taxes applied to end consumers at the point of purchase.

†1 Euro ≈ 1 US dollar.

‡World Bank data: <https://data.worldbank.org/indicator/NY.GNP.PCAP.PP.KD>.

§Updated on 1 July 2018 (after 2017–2018 HBSC data collection).

Sugar-sweetened soda consumption

A short FFQ (sFFQ) assessed soda consumption on a usual week. The general question was: 'How many times a week do you usually eat or drink . . . ?' and the item was phrased as follows: 'Coke® or other soft drinks that contain sugar'⁽²⁷⁾. Adolescents could tick one answer among seven options: (1) 'every day, more than once'; (2) 'once a day, every day'; (3) '5–6 d a week'; (4) '2–4 d a week'; (5) 'once a week'; (6) 'less than once a week' or (7) 'never'⁽²⁷⁾. The sFFQ has been validated against 7-d food records in a similar sample of adolescents as ours (within the HBSC network), and reliability and validity were moderate^(33,34). To make our results comparable to previous literature⁽²¹⁾, we grouped soda consumers into three categories: daily (≥1x/d), weekly (1–6x/week) or occasional (<1x/week)

consumers. Non-consumers were rare and categorised into occasional consumers.

Covariates: sex, age group, temperature

Sex and age are major determinants of soda consumption⁽³⁾. HBSC international databases include participants with complete data on sex (boys or girls). For our analyses, we excluded 11-year-old children to get more homogeneous samples (only adolescents attending secondary schools) and fewer missing data (more frequent among younger adolescents). Analyses were thus carried out on 13- and 15-year-olds. Variations in months of data collection were observed across survey years (within a country) and between matched countries. We, therefore, accounted

for the mean temperature of the month and year at which each participant completed the questionnaire because SSB are more likely to be consumed in warmer weather conditions⁽³⁵⁾. We used world climatic data from U.S. National Centers for Environmental Information and recorded the mean monthly temperature at the nearest land-based station to the capital city (most often an international airport) and with available data from 2001 to 2018 (Additional file 3). Mean temperature at data collection time was relatively similar across matched countries, except between Hungary and Poland (colder temperature in Poland, the comparison country).

Statistical analyses

For all analyses, we used STATA[®] version 15, and statistical significance was set at $P \leq 0.05$. We applied multilevel logistic models with random intercept. Level 1 was set for the pupil and level 2 for the class (mean cluster size: 18 pupils/class, no information on clustering in Germany for 2001–2002). All analyses were at the country level and adjusted for sex, age group and temperature at the time of data collection. Changes in proportions of daily, weekly and occasional soda consumers were investigated independently (each coded 0/1) to investigate how these three types of consumption evolved with and without the soda tax separately. In each country with a soda tax, we first tested whether there was a change in the prevalence of daily, weekly and occasional soda consumption between the last measure before and the first measure after the tax implementation, hence focusing on short-term changes. The pre-tax survey year (independent variable) was coded as the reference survey year in the models:

*Simplified equations (one country, change between 2001 – 2002 and 2005 – 2006) : $\text{logit}(P) = \beta_0 + \beta_1 * \text{survey year 2} + \beta_2 * \text{survey year 3} + \dots + \beta_5 * \text{sex} + \beta_6 * \text{age group} + \beta_7 * \text{temperature}$*

Second, we tested whether this change was larger, smaller or similar to that in the comparison country. Therefore, we analysed data of both matched countries, added the country as a new covariate and applied an interaction term between survey year and country⁽³⁶⁾:

*Simplified equations (larger, similar, or smaller change from 2001 – 2002 to 2005 – 2006 between two countries) : $\text{logit}(P) = \beta_0 + \beta_1 * \text{survey year 2} + \beta_2 * \text{survey year 3} + \dots + \beta_5 * \text{country} + \beta_6 * \text{survey year 2} * \text{country} + \beta_7 * \text{survey year 3} * \text{country} + \dots + \beta_{10} * \text{sex} + \beta_{11} * \text{age group} + \beta_{12} * \text{temperature}$*

We assessed the coefficient sign and P value of this interaction for the period of interest (last pre-tax *v.* first post-tax

survey year). We then computed (-margins- STATA command) and plotted prevalence (95 % CI) of daily, weekly and occasional soda consumption by country and survey year for each pair of countries.

Complementary analyses

Because Finland, Hungary and France had two time points before and after the tax implementation, we modelled pre- and post-tax time trends (slopes) in daily, weekly and occasional soda consumption. Thus, we could estimate whether there was a change in consumption trend in the longer term after the tax. For that, we set the survey year (2001–2002 to 2017–2018) as a continuous time variable, scaled 1 to 5 (survey year 2001–2002 coded as 1, 2005–2006 as 2, etc.) and applied two-piecewise linear spline multilevel logistic models (-mkspline-). We used one knot at the year 2009–2010 (time = 3), composing thus two periods of analyses: the pre-tax (2001–2002 – 2009–2010) and the post-tax (2009–2010 – 2017–2018) periods. To assess whether the trend (slope) in both pre-tax and post-tax periods was larger, smaller or similar to the trend in the comparison country, we again added data from the comparison country (country becoming a covariate) and applied two interaction terms in the models: (1) between pre-tax time and country and (2) between post-tax time and country. We then assessed the sign and P value of the coefficient for interaction terms in both periods (pre- and post-tax).

Results

After excluding 11-year-olds and those with missing data on soda consumption (0.6 % of the remaining sample, Additional file 4), 236 623 HBSC participants (51.0 % of girls) were included in this study. Table 2 shows their characteristics by country. Age and sex distributions were relatively similar across matched countries. Additional file 5 presents similar characteristics for each of the five survey years by country.

Latvia (comparison country: Lithuania)

The Latvian tax was introduced in 2004 (€0.03/l) and updated in 2016 (€0.07/l, Table 1). A decline in the prevalence of daily soda consumption ($\geq 1x/d$) was observed between survey years 2001–2002 and 2005–2006 (–6.0 % points, –33.6 %, see Fig. 1; $P = 0.006$, see Table 3), but not between 2013–2014 and 2017–2018 ($P = 0.42$). The decline between 2001–2002 and 2005–2006 was larger than in Lithuania ($P_{\text{interaction}} < 0.001$), where a rise in daily soda consumers was observed during this period. The prevalence of occasional soda consumption ($< 1x/week$) did not change neither between 2001–2002 and 2005–2006 ($P = 0.93$) nor between 2013–2014 and 2017–2018 ($P = 0.25$, Table 3).

**Table 2** Description of survey participants, by country (T = with a soda tax, C = comparison, without such a tax)

Countries	Total (n)	Sex		Age group		Survey year				
		Girls (%)	Boys (%)	13 years (%)	15 years (%)	2001–2002 (%)	2005–2006 (%)	2009–2010 (%)	2013–2014 (%)	2017–2018 (%)
Latvia (T)	14 270	52.1	47.9	51.9	48.1	15.4	19.5	19.3	25.8	20.0
Lithuania (C)	17 144	48.8	51.2	51.0	49.0	22.0	21.9	20.4	21.6	14.2
Finland (T)	17 154	51.1	48.9	50.1	49.9	20.2	19.8	24.8	22.4	12.7
Sweden (C)	17 532	50.6	49.4	48.0	52.0	13.7	16.2	24.6	28.6	16.9
Hungary (T)	13 350	53.7	46.3	51.7	48.3	20.5	17.9	24.7	18.2	18.7
Poland (C)	17 465	51.4	48.6	48.1	51.9	24.1	22.5	16.2	17.2	20.0
France (T)	23 823	50.7	49.3	55.2	44.8	22.8	19.4	16.6	16.3	24.9
Germany (C)	18 798	51.1	48.9	49.3	50.7	18.8	26.4	17.3	22.1	15.4
Italy (C)	14 110	51.1	48.9	53.0	47.0	20.0	18.9	22.8	18.9	19.4
Belgium (T)	29 619	49.7	50.3	49.7	50.3	23.7	20.3	18.2	22.9	15.0
The Netherlands (C)	14 744	50.2	49.8	52.8	47.2	18.8	19.4	20.5	19.5	21.7
Portugal (T)	14 166	53.1	46.9	54.2	45.8	12.6	19.0	20.0	23.3	25.1
Spain (C)	24 448	51.2	48.8	50.6	49.4	15.2	24.1	15.4	32.5	12.8
All countries	236 623	51.0	49.0	51.1	48.9	19.4	20.6	19.6	22.5	17.9

Finland (comparison country: Sweden)

Finland updated its tax in several stages between 2011 and 2014 (Table 1). After January 2014, soda was taxed at €0.22/l (>5 g of sugars/100 ml) and €0.11/l (<5 g/100 ml). A decline in daily soda consumption was observed between 2009–2010 and 2013–2014 (data collected in Spring 2014, -1.7% points, -41.5% , $P=0.001$). Yet, this decline was similar to the one observed in Sweden at the same period ($P_{\text{interaction}}=0.29$). In Finland, no significant change in weekly (1–6x/week) and occasional soda consumption was observed between 2009–2010 and 2013–2014 ($P=0.84$, $P=0.17$, respectively, Table 3).

Hungary (comparison country: Poland)

The Hungarian tax was introduced in 2011, with an update in 2012 (€0.02/l). We documented no change in daily soda consumers ($P=0.47$) and a decrease in occasional consumers between 2009–2010 and 2013–2014 (-3.6% points, -12.8% , $P=0.02$, Fig. 1 and Table 3). By contrast, we observed, during this period, changes more favourable to health among Polish adolescents, who were not exposed to a soda tax (e.g. a decrease in daily soda consumption).

France (comparison countries: Germany and Italy)

In France, a tax of €0.07/l was introduced in 2012 (Table 1). Between 2009–2010 and 2013–2014, the prevalence of daily, weekly and occasional soda consumption of soda did not change neither in France ($P\geq 0.27$, Table 3) nor in Germany ($P_{\text{interaction}}\geq 0.25$, Table 3), one of the two comparison countries. Compared with France, Italy experienced a decline in daily soda consumption between 2009–2010 and 2013–2014 ($P_{\text{interaction}}=0.01$).

Belgium (comparison country: Netherlands)

Belgium updated its tax in 2016 and 2018 (€0.12/l after 2018, Table 1). Figure 1 and Table 3 indicate that Belgium had a reduction in the prevalence of daily soda consumption between 2013–2014 and 2017–2018 (-7.3% points, -20.8% , $P<0.001$), which was smaller than the one observed in the Netherlands during that period ($P_{\text{interaction}}=0.03$). The proportion of occasional soda consumers remains stable over the period of interest, although we observed a tendency to increase ($P=0.06$). This trend was, however, of a smaller extent than the rise in occasional soda consumption observed in the Netherlands between 2013–2014 and 2017–2018 ($P_{\text{interaction}}<0.001$).

Portugal (comparison country: Spain)

In January 2017, a tax on SSB was introduced in Portugal: €0.16/l (>8 g of sugars/100 ml) and €0.08 (<8 g/100 ml) (Table 1). Similar pre-tax patterns in daily, weekly and occasional consumption were found in Portugal and Spain. After the tax introduction in Portugal, daily soda consumption decreased (-2.5% points, -14.3% , $P=0.02$), but this decrease was smaller than in Spain at the same period ($P_{\text{interaction}}=0.008$). In Portugal, weekly soda consumption dropped in 2017–2018 (-7.5% points, -14.0% , Fig. 1; $P<0.001$, Table 3), which was not the case in Spain ($P_{\text{interaction}}<0.001$). Finally, the prevalence of occasional soda consumers increased between 2013–2014 and 2017–2018 ($+10.0\%$ points, $+36.3\%$, $P<0.001$), similarly as in Spain ($P_{\text{interaction}}=0.15$).

Pre-tax and post-tax trends in Finland, Hungary and France

In Finland, we found no long-term reduction in daily soda consumers between 2009–2010 and 2017–2018 (tax

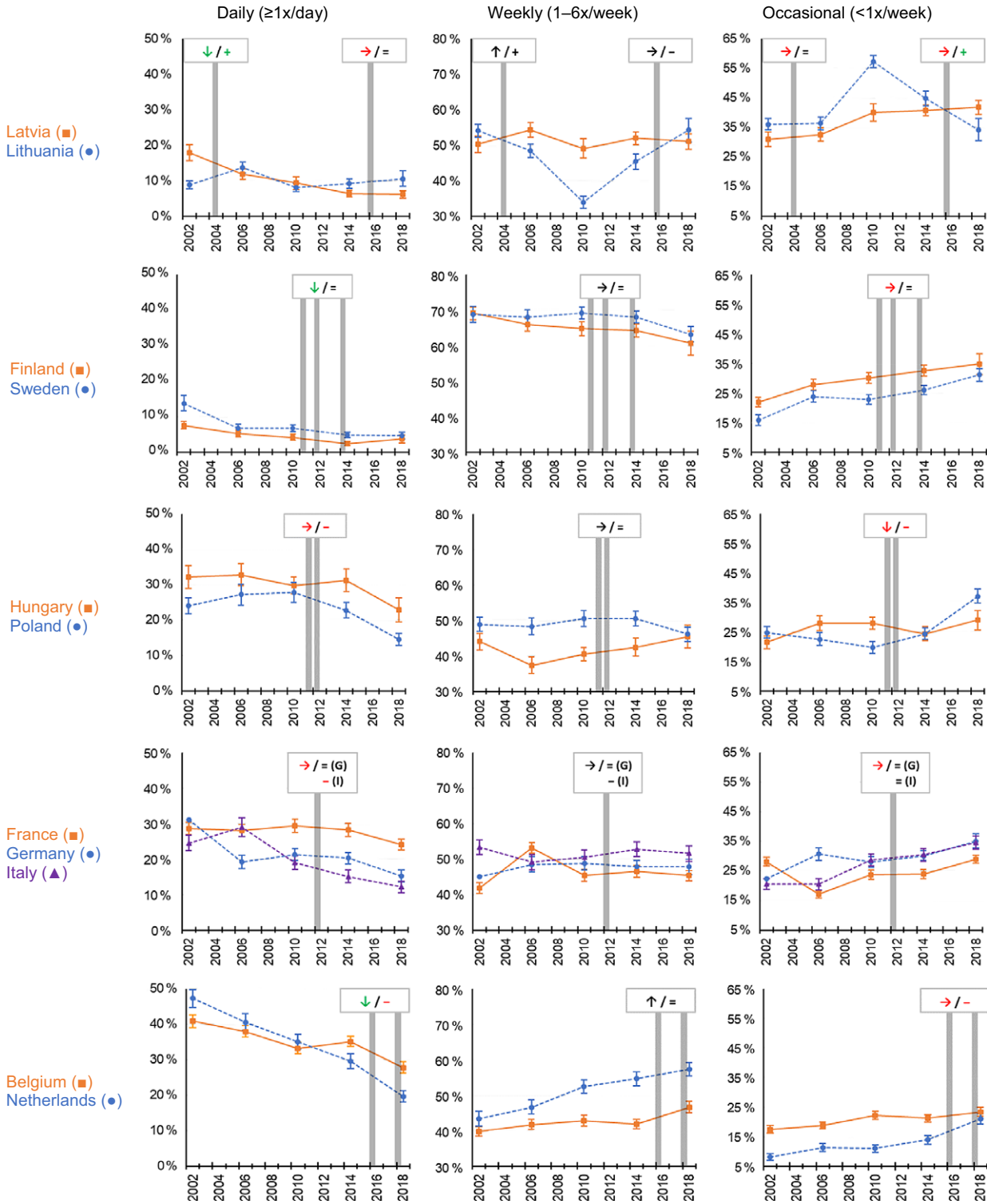


Fig. 1 Prevalence of daily, weekly and occasional consumption of soda. Prevalences (95 % CI) are presented by survey year in country that introduced/updated a tax (in orange, plain line) and in the comparison country (in blue or violet, dashed line). Grey bars represent the date of the tax introduction/update. The arrows above the grey bar indicate that the country with a tax had a significant reduction (\downarrow , $P < 0.05$), a stagnation (\rightarrow , $P > 0.05$) or a significant increase (\uparrow , $P < 0.05$) in the prevalence of daily, weekly and occasional consumers between just before and after the tax introduction. The signs after the arrow indicate whether this short-term change was significantly larger (+, $P < 0.05$), similar (=, $P > 0.05$) or significantly smaller (-, $P < 0.05$) than in the comparison country. Green colour indicates favourable changes in terms of public health (e.g. post-tax decline in daily consumers that was larger than that in the comparison country) (more details in Table 3). G: Germany; I: Italy

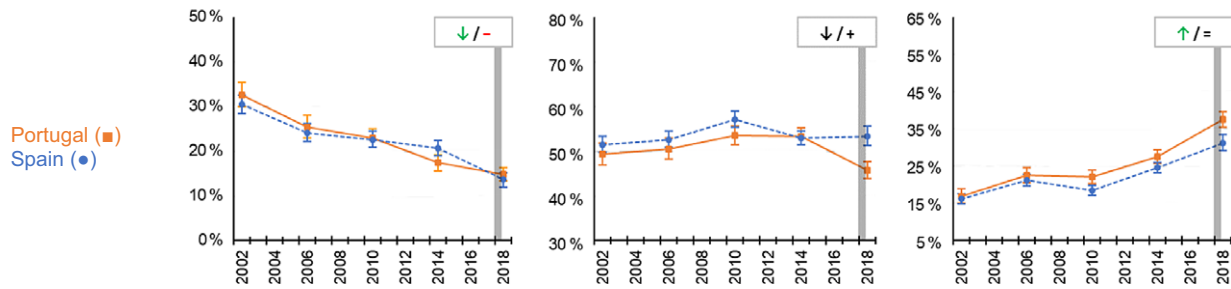


Fig. 1 (Continued).

Table 3 Changes*,‡ in the prevalence of daily, weekly and occasional soda consumption between the last measure before the tax implementation and the first measure after the tax implementation, compared with the comparison country (interaction between both countries†)

Countries	Daily (≥1x/d)			Weekly (1–6x/week)			Occasional (<1x/week)		
	β	95 % CI	P-val.	β	95 % CI	P-val.	β	95 % CI	P-val.
Latvia (introduction)*	-0.36	-0.61, -0.10	0.006	0.20	0.04, 0.35	0.014	-0.01	-0.20, 0.18	0.93
Interaction with Lithuania†	-0.98	-1.30, -0.66	<0.001	0.39	0.21, 0.58	<0.001	0.07	-0.16, 0.29	0.57
Latvia (update)*	-0.10	-0.33, 0.14	0.42	-0.05	-0.16, 0.06	0.39	0.08	-0.05, 0.21	0.25
Interaction with Lithuania†	-0.21	-0.54, 0.12	0.22	-0.40	-0.57, -0.22	<0.001	0.51	0.30, 0.71	<0.001
Finland*	-0.51	-0.82, -0.21	0.001	-0.01	-0.15, 0.12	0.84	0.11	-0.04, 0.26	0.17
Interaction with Sweden†	-0.22	-0.61, 0.18	0.29	0.03	-0.15, 0.21	0.73	-0.06	-0.25, 0.14	0.56
Hungary*	0.10	-0.17, 0.37	0.47	0.12	-0.05, 0.29	0.16	-0.27	-0.49, -0.05	0.015
Interaction with Poland†	0.34	0.09, 0.59	0.007	0.08	-0.09, 0.25	0.36	-0.46	-0.68, -0.24	<0.001
France*	-0.07	-0.21, 0.06	0.27	0.05	-0.05, 0.14	0.34	0.02	-0.10, 0.14	0.78
Interaction with Germany†	0.00	-0.19, 0.19	0.99	0.08	-0.06, 0.22	0.25	-0.09	-0.26, 0.08	0.28
Interaction with Italy†	0.32	0.07, 0.57	0.012	-0.05	-0.21, 0.12	0.57	-0.15	-0.36, 0.06	0.15
Belgium*	-0.34	-0.44, -0.23	<0.001	0.20	0.12, 0.29	<0.001	0.11	0.00, 0.22	0.06
Interaction with the Netherlands†	0.20	0.02, 0.37	0.027	0.09	-0.05, 0.22	0.22	-0.37	-0.56, -0.18	<0.001
Portugal*	-0.19	-0.34, -0.03	0.018	-0.30	-0.40, -0.20	<0.001	0.47	0.34, 0.59	<0.001
Interaction with Spain†	0.32	0.08, 0.56	0.008	-0.32	-0.47, -0.17	<0.001	0.13	-0.05, 0.31	0.15

*β were modelled using multilevel logistic models (dependent variable: daily, weekly and occasional consumption: 0/1, independent variable: survey years), adjusted for sex, age group and temperature at the time of data collection). β < 0 (negative) = reduction in daily, weekly and occasional soda consumption between pre-tax and post-tax surveys; β > 0 (positive) = increase in daily, weekly and occasional soda consumption.

†β of the interactions (survey years*country) were modelled using multilevel logistic models (dependent variable: daily, weekly and occasional consumption: 0/1), adjusted for survey years, country, sex, age group, temperature at the time of data collection). β for the interaction < 0 (negative) = more reduction or less increase in the country with the tax compared with the comparison country, β for interactions > 0 (positive) = more increase or less reduction in the country with the tax compared with the comparison country. ‡β are in bold when P < 0.05.

implemented between 2011 and 2014, post-tax trend: β = -0.07, 95 % CI (-0.28, 0.14), Additional files 6 and 7). However, there was a declining trend before the tax was updated (2001–2002 to 2009–2010, P < 0.001). The tax was not associated with a long-term downward trend in daily soda consumers. The trend in occasional consumers did not change after the tax update in Finland (P = 0.19), whereas occasional consumers increased in Sweden during this period (P < 0.001). Hungary experienced a long-term decline in daily consumers after tax introduction (β = -0.20, 95 % CI (-0.38, -0.02)), but this decline was smaller than in Poland (P_{interaction} = 0.001). France had a long-term reduction in daily consumers of soda in the post-tax period (β = -0.16, 95 % CI (-0.22, -0.10), Additional files 6 and 7), while no change was documented in the pre-tax period (β = 0.01, 95 % CI (-0.06, 0.07)). The

French post-tax trend in daily soda consumption was, however, similar to the German one (P_{interaction} = 0.44), and the reduction was less marked than that observed in Italy (P_{interaction} < 0.001).

Discussion

Prevalence of adolescent daily consumption of sugar-sweetened soda reduced in 4/6 countries in the survey year following the tax introduction or update, corresponding to a few months to 2 years post-tax. Exceptions were Hungary and France, where declines in daily consumption were observed only in the longer term (6 years post-tax). Declines were, however, not larger than those documented in the comparison countries in 3/4 countries (Finland,

Belgium and Portugal). In Latvia, the decline in daily consumption was larger than that observed in Lithuania only after the tax introduction. Prevalence of weekly consumption remained stable or increased, except in Portugal, which experienced a net decline. Finally, prevalence of occasional soda consumption did not rise in 5/6 countries, or the rise was similar to the comparison country (Portugal).

Changes in sugar-sweetened beverage sales/purchases in the studied countries

Worldwide, several studies have found that SSB taxation was associated with a decline in sales or purchases⁽¹⁶⁾, including in Finland^(28,37) and Portugal⁽³⁸⁾. We also found that both countries experienced a decline in adolescent soda consumption in the survey year shortly after the tax implementation. In France, post-tax reduction in SSB sales/purchases was estimated to be limited^(39,40): about -0.5 l/year/capita 1 year post-tax, compared with Italian comparison regions⁽³⁹⁾. Thus, although not directly comparable to ours, econometric results seem in line with our findings not showing a net short-term decline in daily or weekly soda consumption in French adolescents. Associating the longer term reduction in daily soda consumption and rise in occasional consumers to the tax is difficult. Indeed, other public health nutrition measures between 2009–2010 and 2017–2018 have been implemented in France, such as mandatory dietary standards for school meals, encouraging water provision, in 2011–2012 and the Nutri-score in 2016–2017, a voluntary front-of-pack nutrition label⁽⁸⁾. In Hungary, other authors established that SSB sales declined in the years immediately after the tax came into effect^(37,40) but caught up 2 years later (in 2014)⁽⁴⁰⁾. Similarly, our findings showed no change neither in daily nor weekly soda consumers between 2009–2010 and 2013–2014. However, in the absence of a tax, the prevalence of daily soda consumption might have increased. Regarding the last two studied countries (Latvia and Belgium), we did not find studies assessing changes in SSB sales or purchases, limiting comparison with our findings.

Changes in sugar-sweetened beverage consumption in other countries

While self-reported data on individual-level soda consumption are more prone to declaration bias than sales/purchase data, they provide valuable information on behaviours within households and have the advantage of considering cross-border shopping. Studies using individual-level self-reported consumption data were conducted in Mexico⁽²¹⁾, three U.S. cities (Berkeley^(17,18,20), Philadelphia^(19,24,26) and Oakland⁽²³⁾) and a Spanish city⁽²²⁾. In these jurisdictions, reductions in the consumption of SSB, especially soda, were often observed in adults after tax introduction^(17–19,21,22,24,26). The few studies including

adolescents found less beneficial changes in SSB consumption. In Philadelphia and Oakland (tax rate > 20%), children aged 2 to 17 years did not reduce their consumption of soda, or any SSB subcategory, 1 year post tax (small-scale longitudinal household survey data)^(23,24). Why children and adolescents might be less responsive to soda taxes than adults is unclear. Their food choices might be more influenced by food taste and peer pressure than price and healthiness^(12,13). Further studies are also needed to better understand if changes for cheaper soda brands or places of purchase occur⁽⁴¹⁾ and if soda companies adapt their sales and marketing practices in the context of tax implementation⁽⁴²⁾.

Different taxes, different jurisdictions and different comparison countries

As noted earlier, tax size/rate plays a crucial role in the reduction of SSB purchase/consumption^(15,16). In the US, tax rates lower than 5% were considered unlikely to affect childhood SSB consumption at the population level⁽⁴¹⁾. Low taxes in Hungary (€0.02/l, rate: 5%) and France (€0.07/l, rate: 7–10%)⁽¹⁶⁾ could explain why they were not followed by a decline in adolescent soda consumption. In addition, tax effects might reduce over time as we found in Finland and as previously shown in Hungary⁽⁴⁰⁾. In Berkeley too, reduction in mean consumption frequency seemed to have stagnated 2 years post tax⁽²⁰⁾. Another important point is the pre-tax level of soda consumption. In Berkeley, pre-tax consumption was high (mean consumption frequency: 1.25x/d)⁽²⁰⁾. By contrast, a large reduction in daily SSB consumers was seen among Mexican health workers, whose pre-tax prevalence was relatively low (13%)⁽²¹⁾. In our study, reductions in daily soda consumption were also seen in countries with low pre-tax levels (Finland: 4%, Latvia: 18%). Thus, taxing SSB may be worthwhile even when daily SSB consumption is low, but further research is needed to confirm this hypothesis.

Public health implications

Larger taxes on SSB (>20%) might be one solution to reduce adolescent SSB consumption⁽¹⁶⁾, which remains elevated in several European countries⁽³⁾. Introducing a tax based on sugar content (larger tax for SSB higher in sugar) might also help decrease sugar intake, especially by encouraging SSB manufacturers to reduce the sugar content of their products⁽⁴³⁾. Tax introduction or updates are also an opportunity to effectively communicate the detrimental effects of SSB on health^(9,44) or raise revenues to fund public health or social programmes⁽⁴⁵⁾. Large taxes on SSB should also come with subsidies for healthy foods to limit tax financial regressivity on low-income households⁽⁴⁶⁾.

Moreover, slight differences found in adolescent soda consumption patterns between countries, with and without



a soda tax, illustrate that dietary behaviour changes are complex, and taxation is only one of a range of possible public health instruments. The WHO highlights the importance of implementing comprehensive policies and programmes⁽⁷⁾. As young people spend a large part of the day at school, restricting physical access to SSB in school premises (e.g. ban on vending machines, standards for healthy school meals) is, for instance, an effective measure to reduce SSB intake⁽⁴⁷⁾. School food policies, nutrition education programmes and other population-based interventions, such as media campaigns and traffic-light-labelling, could have together partly contributed to the overall downward trend in SSB consumption observed in Europe since 2000–2010s^(1,10,48).

Strengths and limitations

An important limitation of this study is the observational design and the uncontrolled environment. Indeed, public health interventions, as well as social and economic events (e.g. media campaigns, financial crises, inflation) possibly impacting diet and soda prices, have occurred during the periods under scrutiny. Their complex interplays prevented us from controlling for them. While selecting countries, we did our best to: (1) inventory major national public health interventions that might have impacted soda consumption in the thirteen studied countries^(8,49,50) and (2) select comparison countries without such interventions, especially during the period under scrutiny. Still, several national and local policies were implemented; for example, a tax on SSB was introduced in Catalonia, a province of Spain, in March 2017; yet the country of Spain served as a comparison for Portugal. In addition, the absence of fully parallel pre-tax soda consumption trend highlights how comparison results should be interpreted with caution. For instance, it is possible that comparison countries did not introduce a soda tax because they already experienced a favourable decreasing trend in soda consumption (e.g. Netherlands and Sweden) or focused on other policies, such as decentralised/targeted programmes we could not find in the international literature^(8,49,50). Including several comparison countries would have been of interest but was impracticable due to the limited number of similar countries neighbouring the country with a soda tax within the HBSC network. Despite large sample sizes, our study was underpowered to detect small changes when prevalence was high. For instance, a sample size of 3000 in pre- and post-tax survey years could not detect a change of less than $\pm 3\%$ when prevalence was 50% (power 80%; α at 0.05).

HBSC self-reported dietary data also lead to limitations in the interpretation of our findings. Our methodology based on consumption frequency was not precise enough to detect small changes. Additionally, no information was captured on: (1) soda brands; (2) consumed quantities (in ml/d); and (3) consumption of other SSB or other

beverages. Thus, we could not estimate the potentially associated reduction in sugar intake expected with sugar content-based taxes, like in Finland and Portugal. We could not assess possible substitution effects either. Following taxation, soda substitution towards 100% fruit juices (untaxed in 6/6 countries, Table 1) and artificially sweetened beverages (taxed in 5/6 countries, but at lower rate in 2/5 countries) was likely. While substitution towards water^(18,19) would be beneficial in terms of obesity prevention, substituting sodas with other sugary drinks^(1,28,44) would produce little health benefits.

Underreporting of unhealthy foods in FFQ is a well-known bias in nutritional epidemiology. The media attention around a tax might have created a 'signalling effect', which, in turn, could exacerbate the risk of underreporting soda consumption. This could have overestimated the favourable effect of taxation to health. Furthermore, school-level response rates declined over time (e.g. Portugal between 2013–2014 (97%) and 2017–2018 (51%)). Supposing that schools already involved in health promotion actions were more likely to accept participating in HBSC surveys, there was a risk of overrepresenting pupils from the most favoured schools in the more recent samples. This could have overestimated the reductions in daily soft drink consumers, for instance, in Portugal compared with Spain (Spanish response rates: 59% in 2013–2014 *v.* 69% in 2017–2018). A last limitation is the variations in the data collection month(s) across survey years and/or countries. We partly accounted for this issue in adjusting for the mean temperature at the month and year of data collection in the capital city. However, this does not allow fine granulation, especially in climatically diverse countries, such as France.

The present study has also several strengths. First, data came from nationally representative samples drawn from procedures optimised to the country background. Second, the protocol was standardised across survey years and countries, allowing the analysis of 16-year trends in soda consumption with five time points and with comparison countries. Third, the inclusion of six European countries contributes to better understand tax effects in various situations: e.g. small *v.* large tax size/rate; short *v.* long period after tax implementation; low *v.* high pre-tax level of soda consumption. Finally, we also modelled ordered logistic regressions (daily = 2, weekly = 1, occasional = 0, –meologit–) to test whether shifts from daily to weekly and from weekly to occasional occurred, and our findings were confirmed (analyses not shown).

Conclusions

Overall, no country experienced large beneficial changes in post-tax adolescent consumption frequency of soda, when compared with similar neighbouring countries. However, many factors other than taxes drive the changes

in sugar-sweetened soda consumption, in comparison countries too. Continued monitoring of the intake of SSB and possible substitution beverages, especially by socio-economic status, is needed to better understand the effects of soda taxes among adolescents. Long-term trend analyses are also important to evaluate whether tax effects plateau after several years of introduction. In this context, information on the intake of SSB (by subcategory) and potential substitution beverages is needed in Europe. In the meantime, comprehensive nutrition policies and programmes, complementary to taxes on SSB, should be continuously implemented, or reinforced, to improve European adolescents' diet.

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Supplementary material

For supplementary material accompanying this paper visit <https://doi.org/10.1017/S1368980022002361>

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