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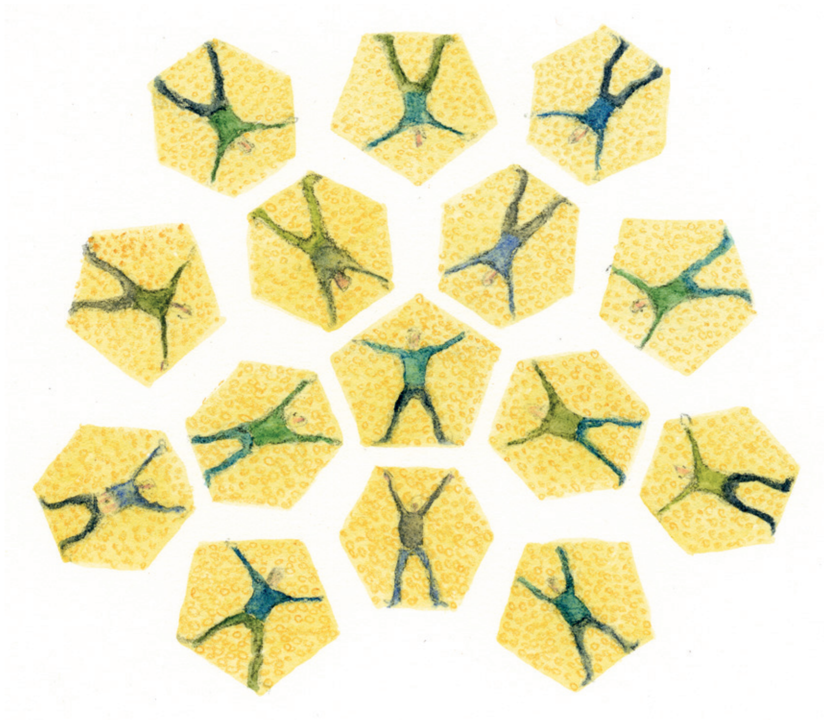

Estimating added and free sugars intake in Swedish adolescents

Methods, food sources, nutritional implications, and potential food label impact

Julia Wanselius

UNIVERSITY OF GOTHENBURG

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Abstract

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Excessive intakes of added and free sugars are associated with several adverse health effects. However, due to an absence of objective or standardised methods to measure intake, there is limited knowledge about consumption, including in Swedish adolescents.

Adolescence is a critical period for establishing healthy dietary habits, as food patterns formed during these years often persist into adulthood, influencing long-term health. Dietary habits of Swedish adolescents overall fail to meet dietary guidelines. The adolescent diet is generally low in vegetables and fruit, dietary fibre and wholegrains, alongside high in saturated fats, salt, and sugars. Despite these concerns, intake levels of added or free sugars have not previously been quantified in Swedish adolescents.

The overarching aim of this doctoral thesis is to examine dietary intake in Swedish adolescents, emphasising added and free sugars intake. This includes refining methods for estimating intake, identifying contributing food sources, investigating contextual and dietary associations, as well as the potential nutritional impact of the Keyhole symbol in guiding healthier food choices. The thesis builds on the findings of four original papers, each addressing a specific research aim and contributing unique insights to the thesis.

The thesis presents a systematic approach to quantifying added and free sugars intake, applied to the Swedish Food Agency's nationally representative dietary survey Riksmaten Adolescents 2016-17. Main findings are that, on average, Swedish adolescents were over-consuming added and free sugars with respect to dietary guidelines; 45% respectively 30% had a lower daily intake of added respectively free sugars than the maximal recommended intake. Main sources of sugars were foods with low nutritional content, with major contributors in sugar-sweetened beverages, sweets and chocolates. Intakes of added and free sugars were higher during weekends, and the sugars were mostly consumed outside of main meals, predominantly within the home environment. Furthermore, higher intakes of added and free sugars were observed to be associated with progressively less favourable dietary intakes. A shift to Keyhole alternatives for everyday foods would improve adolescents' overall nutrient intakes, even with smaller exchanges. However, the impact on reducing sugars were limited as most contributing sources are not eligible for labelling.

As a few nutritionally poor food groups are the primary sources of added and free sugars in the adolescent diet, refining dietary guidelines to target these specific foods rather than emphasising sugars reduction alone could enhance clarity and effectiveness in public health communication.

Contents

List of tables and figures

List of original papers

This thesis is based on the following original papers, which are cited in text using their Roman numerals.

I. **Wanselius, J.**, Axelsson, C., Moraeus, L., Berg, C., Mattisson, I., & Larsson, C. (2019). Procedure to Estimate Added and Free Sugars in Food Items from the Swedish Food Composition Database Used in the National Dietary Survey Riksmaten Adolescents 2016-17. *Nutrients*, *11*(6). https://doi.org/10.3390/nu11061342

II. **Wanselius, J.**, Lindroos, A. K., Moraeus, L., Patterson, E., Berg, C., & Larsson, C. (2024). Dietary sources of free, added, and total sugars in Swedish adolescents. *Eur J Nutr*, *64*(1), 57. https://doi.org/10.1007/s00394-024-03568-8

III. **Wanselius, J.**, Lindroos, A. K., Moraeus, L., Patterson, E., Berg, C., & Larsson, C. (2025). Associations of free and added sugars intakes with nutrient intake and food consumption in Swedish adolescents. *Manuscript submitted for publication.*

IV. **Wanselius, J.**, Larsson, C., Berg, C., Öhrvik, V., Lindroos, A. K., & Lissner, L. (2022). Consumption of foods with the Keyhole front-of-pack nutrition label: potential impact on energy and nutrient intakes of Swedish adolescents. *Public Health Nutr*, *25*(12), 1-12. https://doi.org/10.1017/s1368980022002178

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Abbreviations

BMI	Body mass index
E%	Percent of total energy intake
EFSA	European food safety authority
FFQ	Food frequency questionnaire
FOPL	Front-of-pack label
g	Grams
IQR	Interquartile range
kJ	Kilojoule
MJ	Megajoule
MSM	Multiple Source Method
MUFA	Monounsaturated fatty acids
NNR	Nordic Nutrition Recommendations
PUFA	Polyunsaturated fatty acids
SFA	Saturated fatty acids
SNR	Swedish Nutrition Recommendations
SSB	Sugar-sweetened beverage
USDA	United States Department of Agriculture
WHO	World Health Organization

Background

A poor diet is among the most impactful lifestyle factors influencing the global burden of disease, associated with obesity and diet related non-communicable diseases. A recent systematic analysis from the Global Burden of Disease project identified poor diet as one of the primary risk factors for death worldwide in 2021 (GBD 2021 Risk Factors Collaborators, 2024) through their comprehensive analysis covering risk factors across 204 countries. In particular, diets high in sodium and low in dietary components as whole grains, fruits, and vegetables were seen to significantly contribute to the disease burden. In addition, a diet high in sugar-sweetened beverages (SSBs) was identified as a risk factor that has seen increasing exposure and burden over time (GBD 2021 Risk Factors Collaborators, 2024). In Sweden, dietary risk factors are after tobacco smoking the leading modifiable risk factor for disease burden (Institute for Health Metrics and Evaluation (IHME), 2024).

Diet and health of young people in Sweden

Overweight and obesity are significant contributors to the disease burden in Sweden (GBD 2021 Risk Factors Collaborators, 2024), affecting many and posing serious health risks. The prevalence of childhood and adolescent obesity has increased alarmingly over the recent decades and has become one of the main serious health challenges. Obesity in childhood and adolescence tend to remain through adulthood (Simmonds et al., 2016) and leads to an increased risk of cardiovascular diseases later in life (Sommer & Twig, 2018). Diet undoubtedly plays a significant role in the development of overweight and obesity, which can be influenced through changes in eating habits. In Sweden, about one fifth of adolescents are either overweight or obese, reported both subjectively in 2021-2022 by the Public Health Agency of Sweden (The Public Health Agency of Sweden, 2023), and objectively in 2016-2017 by the Swedish Food Agency (Warensjö Lemming et al., 2018a).

The Swedish Food Agency continuously carries out national dietary surveys to identify dietary habits representative of the Swedish population (Warensjö

Lemming et al., 2018a). In the Swedish food agency's 2012 report on Swedish adults' dietary intake (Riksmaten adults 2010-11) it was shown that among the youngest category of adults (18-30 years old) the lowest reported intakes of vegetables and legumes, and fruits and berries was seen. Furthermore, high reported intakes of foods high in fats and sugars as well as sugar-sweetened beverages were seen in the same age group. The youngest category of adults thus appeared to have the least healthy dietary habits among all adults (Amcoff et al., 2012).

In 2016-2017, the Swedish Food Agency conducted a national survey of Swedish adolescents (Riksmaten adolescents 2016-17). This survey is to date the only dietary survey on a national representative sample of Swedish adolescents. Findings in Riksmaten adolescents 2016-17 were insufficient intakes of vegetables and fruits and conversely excessive intakes of foods such as sweets, cookies, snacks and sugary drinks contributing with high energy but low nutritious content, with nearly 40% of Swedish adolescents' total energy intake coming from discretionary foods and beverages (Lindroos et al., 2021). These are foods contributing with energy from saturated fat, sugars and/or alcohol, but are of low nutritional value to the diet (Australian Bureau of Statistics, 2015; Lindroos et al., 2021). Vegetable and fruit intakes in adolescents' diet were at about half of recommended intakes, and approximately 17% of adolescents' energy contribution came from sweets, cookies, snacks and sugary drinks. Other aspects of concern in adolescents' dietary intake were high intakes of processed and red meats and on average lower consumption of fish than recommended (Warensjö Lemming et al., 2018a). Nutrient wise, adolescents consume too much saturated fat, salt and sugars, while having too low intakes of polyunsaturated fats and dietary fiber, and also too low intakes of whole grain. Most adolescents get sufficient amounts of vitamins and minerals necessary for growth and well-being through diet, however concerns are warranted regarding the intakes of vitamin D, and iron (especially regarding older adolescent girls), as many adolescents have values below the average requirement. Additionally, there are some concerns for folate, selenium, vitamin A, and vitamin C. While the majority of adolescents meet their average requirements for these micronutrients, a notable portion still does not (Warensjö Lemming et al., 2018b).

Dietary habits adopted in childhood and adolescence are suggested to track into adulthood (Craigie et al., 2011; Lien et al., 2001; Mikkila et al., 2005; Movassagh et al., 2017; Patterson et al., 2009), therefore, adolescence marks a critical period for shaping lifelong habits, as this stage of life offers opportunities to influence dietary behaviours that can persist into healthy habits in adulthood.

Adolescence is by the WHO referred to as the life phase between childhood and adulthood, covering ages from 10 to 19, and highlighted as a unique period of human development as well as an important time for establishing the basis of good health (World Health Organization, 2020).

Disparities in diet and health

Results from the Swedish food agency's national survey Riksmaten Adolescents 2016-17 (Warensjö Lemming et al., 2018a), also declared that dietary habits among adolescents to parents with low education or income are less healthy than in adolescents to parents with high. In a complementary survey, out-of-school adolescents' dietary habits and health were assessed (Warensjö Lemming et al., 2018a). Out-of-school adolescents (mean age 19 years old) had a considerably higher prevalence of overweight and obesity. In the study population, 42% had either overweight or obesity, where 23% had obesity as compared to six percent in the comparative age group where the participants were enrolled in school (Warensjö Lemming et al., 2018a). The out-of-school adolescents also extensively reported a worsened health and dissatisfaction with their body weight. Earlier results from the Swedish food agency's national survey on children (4 year olds, and children in school year 2 and school year 5) with dietary intake assessed in 2003 (Enghardt Barbieri et al., 2006) found that children to parents with post-secondary education consumed more fruits and vegetables as well as having a higher nutrient density in their diets.

In Sweden, health disparities are well-documented among different population groups. People with lower socioeconomic position (determined by education, occupation, and income) are more prone to have a worsened health than those with higher socioeconomic position (The Public Health Agency of Sweden, 2020, 2024). Particularly, there is a strong association observed between educational level and health (The Public Health Agency of Sweden, 2024). Numerous studies have shown that individuals with low socioeconomic position, and children and adolescents in families with low socioeconomic position, are more likely to have less healthy dietary habits, have a higher prevalence of overweight and obesity, report poorer health, and have shorter life expectancy than individuals with higher socioeconomic position (Giskes et al., 2010; Mackenbach et al., 2008; Mattisson, 2016; Moraeus et al., 2012).

Causes that may explain differences in dietary habits between individuals with high and low socioeconomic position are price of foods in relation to income

(Beydoun & Wang, 2008; Konttinen et al., 2013; Ryden & Hagfors, 2011), differences in lifestyle (Stringhini et al., 2010), and individual choice of familiar foods (Konttinen et al., 2013). Particularly, discrepancies in dietary habits between individuals with high and low socioeconomic position are found in intakes of vegetables, fruits and energy-dense foods (Amcoff et al., 2012; Konttinen et al., 2013; Mattisson, 2016), where people with higher socioeconomic position have more beneficial intakes.

Given the well-documented presence of dietary disparities across different social groups, it is important to incorporate these factors when analysing dietary intake. Food choice is influenced by a complex interplay of factors, where socioeconomic position, biological features, psychological components, habits, knowledge, attitudes, physical environment, and personal identity (e.g., age, gender and ethnic identity) play important roles (Chen & Antonelli, 2020). Failing to account for these discrepancies risks ignoring critical determinants of dietary behaviour, which can effect existing health inequalities. By integrating sociodemographic analyses, researchers and policymakers can develop more targeted, effective interventions to promote equitable dietary health.

Dietary guidelines

The Swedish national dietary guidelines are set, by the Swedish Food Agency, to promote healthy eating and decrease risks of common non-communicable diseases, as cardiovascular diseases, obesity, type II diabetes and certain cancer forms (Brugård Konde et al., 2015), and since 2015 also incorporating strategies to reduce the environmental impact of food consumption (Swedish Food Agency, 2024b). The dietary guidelines are based on the Nordic Nutrition Recommendations (Blomhoff et al., 2023) which were first released in 1980 and have since been continuously updated to reflect the latest scientific research, large population based surveys on dietary habits and scientific evidence on the environmental impact of different foods. Emphasised in the Swedish guidelines are a diet containing vegetables, fruits, whole grains, fish and healthy fats. The dietary guidelines also recommends limitations of foods such as sweets, cookies and sugar sweetened beverages contributing with high energy and low nutritious content, as well as general limitations of salt, added sugars (Brugård Konde et al., 2015) and free sugars (Blomhoff et al., 2023). The Nordic Nutrition Recommendations were updated in 2023 (Blomhoff et al., 2023), and the revised guidelines for Swedish adults have recently undergone public consultation (Swedish Food Agency, 2024b) and will be released later this year (2025).

Recommendations on dietary sugars

A limited intake of certain dietary sugars is recommended due to potential associations with adverse health effects (EFSA Panel on Nutrition et al., 2022). High intakes of dietary sugars contribute with energy but low nutritious content in the diet, and may further contribute to overweight and obesity if intakes are above energy requirements (Te Morenga et al., 2012), dental caries (Jepsen et al., 2017; Moynihan & Kelly, 2014), and risk of chronic diseases such as cardiovascular diseases and type 2 diabetes (Kell et al., 2014; Te Morenga et al., 2014). Consequently, dietary guidelines worldwide recommend a limitation of dietary sugars in its refined form. Several terms with varying definitions of sugars exist, most commonly distinguished as 'total sugars', 'added sugars' and 'free sugars'. The recommendations on added and free sugars aim to give guidance on limitations of sugars added to products or in processed products, not limiting the intake of foods as vegetables and fruits where sugars are incorporated in the cell structures. Dietary guidelines are typically recommending a limitation in intake to a maximum of 10% of total energy intake (E%) of these 'extra' sugars for reasons of the above-mentioned adverse health effects, but also as high intakes may compromise the intakes of micronutrients and dietary fibre (Blomhoff et al., 2023; Sonestedt & Øverby, 2023; U.S. Department of Agriculture, 2020; World Health Organization, 2015). However, the European food safety authority (EFSA) could not identify a level of intake without adverse health effects in their recent extensive review of dietary sugars and health outcomes for providing scientific advice on dietary sugars, and thus recommend it to be as low as possible (EFSA Panel on Nutrition et al., 2022). In the latest NNR, intakes of added or free sugars are recommended to be kept below 10 E%, and preferentially lower (Blomhoff et al., 2023).

Definitions of dietary sugars

Dietary sugars are the smallest and simplest carbohydrates, composed of mono- and disaccharides. They are commonly found as simple sugars in many foods, as well as they act as building blocks for more complex carbohydrates. The term 'sugars' is generally used to declare mono- and disaccharides while 'sugar' often is used to describe purified sucrose (World Health Organization & Food and Agriculture Organization of the United Nations, 1998). Naturally, sugars are found in foods as milk, fruit and vegetables, but sugars may also be added to foods for taste or functional reasons. Sugars added to foods or sugars naturally occurring in foods do not differ, and thus cannot be differentiated by their molecular structure. Hence there is no analytical laboratory method to declare whether the sugars are added or not. Consequently, in nutrition labelling this has led to nutrition declarations mainly stating the only available measurement for sugars i.e., total sugars. Total sugars, as implicated by its name, is the total sugars content in foods, added as well as naturally occurring. Thereby the consumer, by reading the nutrition declaration, is not informed of how much of the sugars in the food product are added, and further if limited intakes of sugars are attained.

Today, recommendations regarding sugars are, as mentioned, mostly focusing on limiting intakes of added or free sugars. However, measuring adherence to these recommendations presents a significant challenge due to the inability to accurately differentiate added or free sugars from naturally occurring sugars in foods as there are no objective methods for differentiation (e.g., objective biomarkers). Most food composition databases and labelling systems do not provide this distinction. This lack of clarity makes it difficult for researchers, policymakers, and consumers to monitor intake and to evaluate compliance with dietary guidelines.

Non-milk extrinsic sugars

In 1989 the Committee on Medical Aspects of Food Policy (COMA) Panel on Dietary Sugars at the United Kingdom Department of Health and Social Security first developed classifications of sugars based on their natural forms to assist consumers' choice of what was considered to be 'healthy' sugars (Department of Health and Social Security & Committee on Medical Aspects of Food Policy, 1989; World Health Organization & Food and Agriculture Organization of the United Nations, 1998). Sugars were classified by their natural form as intrinsic or extrinsic sugars. Intrinsic sugars were described as sugars incorporated within the cell structure of intact vegetables and fruits. Conversely, extrinsic sugars were described as sugars that are not naturally incorporated within the cell structure of foods (Scientific Advisory Committee on Nutriton (SACN), 2015). Lactose in milk is by this definition an extrinsic sugar, which caused further division to milk extrinsic sugars and non-milk extrinsic sugars (NMES) since milk extrinsic sugars did not account as 'unhealthy' type of sugars (Department of Health and Social Security & Committee on Medical Aspects of Food Policy, 1989). NMES typically include sugars in fruit juices, table sugar, honey, sucrose, glucose and glucose syrups added to food plus 50% of sugars in canned, stewed, dried or preserved fruits (Kelly et al., 2005). Dietary advice on NMES has exclusively been used within the UK, where previous recommendations were replaced with recommendations on free sugars in 2018 (Scientific Advisory Committee on Nutriton (SACN), 2015; Swan et al., 2018).

Added sugars

Added sugars is a term without a universally agreed definition, thus varying definitions are circulating.

In 1998, the World Health Organization (WHO) equated sugar, defined as purified sucrose, with added sugars as well as 'refined sugars', establishing the same definition for these two terms (World Health Organization & Food and Agriculture Organization of the United Nations, 1998).

The United States Department of Agriculture (USDA) first mentioned added sugars in their fourth edition of the Dietary guidelines for Americans in 1995, although without any definition (U.S. Department of Agriculture, 1995). In the fifth edition, added sugars were defined as being all sugars used as ingredients in processed and prepared foods, excluding sugars naturally occurring in foods such as fruit and milk (U.S. Department of Agriculture, 2000) The first quantitative dietary advice regarding added sugars intake were launched in the U.S. in 2005 (Bowman, 2017; U.S. Department of Agriculture, 2005), and recommendations within the U.S. are still regarding intake of added sugars (U.S. Department of Agriculture, 2020). The USDA definition of added sugars includes, apart from refined sugars, sugars in fruit juice concentrates, honey and syrups (U.S. Department of Agriculture, 2005). The Institute of Medicine (IOM) adopted the same definition as USDA in 2002 (Institute of Medicine (IOM) & Food and Nutrition Board, 2002) and so has the American Heart Association (Bowman, 2017; U.S. Department of Agriculture, 2005).

In Sweden, recommendations regarding intake of added sugars originated from guidance on refined sugars which was used until 2014 (Abrahamsson et al., 1983; Nordic Council of ministers, 1989, 1996, 2004). The focus was shifted to added sugars with the NNR 2012, with a comparable definition as the previous for refined sugars (Nordic Council of Ministers, 2014), i.e., similar to how the WHO originally defined added sugars. All official recommendations on sugar intake used in Sweden since the first NNR can be viewed in Table 1. In the latest NNR (Blomhoff et al., 2023), both the definition of and recommendations regarding added sugars are equivalent to the previous NNR recommendation. However, the NNR 2023 is in addition giving recommendations regarding free sugars intake (more details provided in the following section).

EFSA's definition for added sugars (European Food Safety Authority, 2018) used to be identical with the NNR definition (Nordic Council of Ministers, 2014), however now the EFSA has slightly changed the wording to 'mono- and disaccharides added to foods as ingredients during processing or preparation at home, and sugars eaten separately or added to foods at the table' (EFSA Panel on Nutrition et al., 2022).

Table 1. Sugar intake recommendations used in Sweden since the first edition of the Nordic Nutrition Recommendations

Recommen-dation	Term and intake recommendation	Definition description of sugars in recommendation
NNR 1980 / SNR 1981 (1st ed.)[1]	Intake of **refined**[2] **or industrially produced sugar** should be at maximum 10 E%.	Refined or industrially produced sugar refer to sucrose and other sugars. This does not include naturally occurring sugars in fruit, vegetables, and milk, but does include starch syrup, glucose, and other hydrolysed starch derivatives.
NNR 1989 / SNR 1989 (2nd ed.)[1]	Intake of **sugar (so-called refined**[2] **sugars)** should not exceed 10 E%	By sugar is meant refined or industrially produced sugar (sucrose and other sugars). However, naturally occurring sugars in fruits, vegetables, milk, etc., are not included.
NNR 1996 / SNR 1997 (3rd ed.)[1]	Intake of **refined**[2] **sugars** should not exceed 10 E%	Refined sugars include sucrose, fructose, starch hydrolysate (glucose, high fructose syrup), etc., as a component in food or added during cooking.
NNR 2004 / SNR 2005 (4th ed.)	Intake of **refined**[2] **sugars** should not exceed 10 E%	Refined sugars include sucrose, fructose, glucose, starch hydrolysates (glucose syrup, high-fructose syrup) and other isolated sugar preparations such as food components used as such or added during food preparation and manufacturing.
NNR 2012 (5th ed.)	Intake of **added sugars** should be kept below 10 E%	Added sugars include sucrose, fructose, glucose, starch hydrolysates (glucose syrup and high-fructose syrup), and other isolated sugar preparations used as such or added during food preparation and manufacturing.
NNR 2023 (6th ed.)	Intake of **added or free sugars** should be kept below 10 E%, and preferentially lower	*Added sugars*: Refined sugars such as sucrose, fructose, glucose, starch hydrolysates (glucose syrup, high-fructose syrup), and other isolated sugar preparations used as such or added during food preparation and manufacturing. *Free sugars*: Added sugars plus sugars naturally present in honey, syrups, fruit juices and fruit juice concentrates.

The terms, intake recommendations, and definition descriptions are consistent with those stated in each nutrition guideline respectively.
[1]Freely translated from Swedish to English.
[2]In 1981 and 1989 (and in 2012) referred to as ‘raffinerat socker/raffinerade sockerarter’; in 1997 and 2005 as ‘renframställda sockerarter’.
NNR, Nordic Nutrition Recommendations; SNR, Swedish Nutrition Recommendations

Free sugars

The WHO extended the added sugars concept in 2002 (World Health Organization & Food and Agriculture Organization of the United Nations, 2003), and introduced free sugars, which besides added sugars also include sugars in forms of honey, syrup, fruit juice and fruit juice concentrate. These sugars are termed 'free' because they are not within the cellular structure of foods (alike extrinsic sugars), however they do not include sugars naturally occurring in dairy. The current WHO free sugars definition, which is the most commonly used definition, is (World Health Organization, 2015):

> 'Free sugars include monosaccharides and disaccharides added to foods and beverages by the manufacturer, cook or consumer, and sugars naturally present in honey, syrups, fruit juices and fruit juice concentrates'

The WHO recommends a limited intake of free sugars with a maximum intake of 10 E%, with conditional recommendations to aim for a free sugars intake below 5 E% (World Health Organization, 2015).

As mentioned, the NNR 2023 introduced recommendations regarding free sugars in addition to added sugars. The NNR 2023 adopted the WHO definition for free sugars, recommending that the intake of added or free sugars should be below 10 E%, and preferentially lower (Blomhoff et al., 2023). Also, the EFSA are currently focusing on both added and free sugars (EFSA Panel on Nutrition et al., 2022).

With the shift from NMES to free sugars intake recommendations in the U.K., the definition of free sugars now differs from the WHO definition. The U.K. definition also includes sugars naturally present in smoothies made from fruit and vegetable, purées, pastes, powders and extruded fruit and vegetable products (Swan et al., 2018), i.e., similar to the definition of the previous NMES recommendation.

This preceding text, which includes added and free sugars definitions from various authorities, highlights differences between definitions. Presented are well-known and widely used examples, among many others. Accordingly, the inconsistency in defining added sugars spans from whether the term only includes refined sugars (also with various definitions) to whether sugars in fruit and vegetable juices, juice concentrates, honey, and syrups are included. For free sugars, the extent to which fruit and vegetables must be processed to be considered 'free' is inconsistent.

Figure 1 illustrates the definitions of added, free and total sugars in relation to each other, according to how they are defined in this thesis.

Figure 1. Definitions of dietary sugars
According to how they are defined in this thesis. Added sugars were defined as sugars from all foods and beverages where refined sugars were used as such or added during cooking or manufacturing, in line with the definition from the Nordic Nutrition Recommendations. Free sugars were defined as all added sugars as well as sugars naturally present in honey, syrups, and fruit and vegetable juices and concentrates, in line with the definition from the World Health Organization. Total sugars were defined as all sugars (total mono- and disaccharides) present in diet.

Assessing usual dietary intake

When researching dietary intake among populations or individuals, we are often interested in capturing the usual dietary intake, also referred to as the habitual dietary intake, or simply the 'true' dietary intake. The usual dietary intake is defined as the long-term average food or nutrient intake of an individual. The time frame required for reporting the long-term intake lacks a standardised interpretation and may be specified differently depending on context. Therefore, the usual intake can be specified in various ways, for example (often) over a research data collection period, over a year, over a decade, over a lifespan, etcetera, depending on what the research interest may be.

The usual dietary intake measure is important, particularly when assessing nutrient adequacy to determine if an individual's or population's dietary intake meets dietary recommendations or requirements, which are intended to be met over time. Similarly, this is highly relevant when we are researching long-term relationships between dietary patterns and health or disease outcomes as we typically are interested to know how the usual diet is related to an outcome.

There is no dietary assessment method that can perfectly capture the real food intake, or the usual intake. This is due to inherent challenges associated with assessing dietary behaviour, as well as practical and logistical limitations of dietary assessment methods. This is further presented and discussed below.

Challenges in measuring usual dietary intake

In theory, we could assess the usual intake by collecting an extensive number of accurately reported uninfluenced food records until the intake distribution would stabilise, however this approach is clearly impractical. Food frequency questionnaires (FFQs) attempt to capture usual intakes directly, however short-term methods, as 24-hour dietary recalls, have been shown to more accurately capture the individual dietary intake (Freedman et al., 2014; Freedman et al., 2015). Nevertheless, short-term methods cannot capture the usual intake well, especially not regarding episodically consumed foods (Tooze, 2020), i.e. foods not eaten every day but that are periodically part of the diet. Since many foods are not consumed on a daily basis, the intake will frequently be reported as zero for a given day.

A common and simple way to estimate the daily intake is by calculating the average intake over two or a few days of assessed intake, typically by 24-hour recalls. However, these averages, do not accurately reflect a person's usual intake because they contain a lot of random error, particularly due to day-to-day variations in dietary intake. In the context of 24-hour recalls, the day-to-day variation is known as the within-person variation, and it can also be expressed as within-person random error. These random errors decrease the precision of the measurement (increase the spread of distribution), in contrast to systematic errors (or bias) which decrease the accuracy (wrongly placing the mean). In other words, single measures are not inaccurate but imprecise, as they reflect the random variation in dietary intake which is characterised by natural variations in an individual's food consumption patterns. With a sufficient quantity of repeated measurements, the random errors would average out in the long run (Dodd et al., 2006), resulting in the 'true' intake, however still with potential systematic errors. Although in practice, dietary assessments often require so many repeated measurements to obtain an average unaffected by random error that it becomes unfeasible. It has been estimated that between 31 and 433 days of data are needed to predict one individual's usual nutrient intake, depending on nutrient of interest (Basiotis et al., 1987). And if we are to measure individual consumption of episodically consumed foods eaten very rarely, even more assessment days would be necessary.

Despite greater random error due to the day-to-day intake variations, short term assessment tools (as 24-hour recalls) are often preferable over long term assessment tools (as FFQs) for estimating usual dietary intake. This is because 24-hour recalls offer less systematic bias compared to FFQs (Freedman et al., 2014; Freedman et al., 2015), which are more prone to recall bias. The 24-hour recall method also benefits from its detailed dietary data which allows for better error correction through statistical methods. Apart from these advantages, there is also a shortage of external reference measures for bias correction (e.g., biomarkers) (Kirkpatrick et al., 2022), consequently it is difficult to assess and correct for systematic errors like misreporting or underestimation of food intake. This lack of external validation tools, for sugars as well as for many other nutrients and foods, means that systematic errors can go undetected or remain uncorrected, further complicating the accuracy of dietary assessment.

Modelling usual dietary intake

To overcome the limitations with short-term measurements, but still take advantage of the richer detail they provide compared with methods created to directly capture usual intake, statistical methods to estimate usual intake distributions have been developed. These methods all follow the same three fundamental steps (Dodd et al., 2006; Tooze, 2020) using dietary data from at least two non-consecutive assessment days. Step 1: Data adjustment, which includes transformation of the data to approximate normality and adjusting for factors like sequence, day of the week, or seasonality, Step 2: Estimation of mean intake on a transformed scale and separation of within-person and between-person variance, and Step 3: Estimation of the usual intake distribution, including removal of the within-person variation (shrinking the distribution), and including back-transforming the data to its original scale.

Four of the most frequently used methods for modelling usual intakes today are, in order of development, the Iowa State University (ISU) method (Nusser et al., 1996), the National Cancer Institute (NCI) method (Tooze et al., 2006), the Multiple Source Method (MSM) (Haubrock et al., 2011), and the Statistical Program to Assess Dietary Exposure (SPADE) (Dekkers et al., 2014). All these methods, in contrast to preceding methods, specifically address episodically consumed foods, apart from also including regularly consumed foods (Tooze, 2020). These approaches help estimate occasional consumption and handle non-consumers; however, the ISU and SPADE methods have certain limitations when it comes to estimating intakes of episodically consumed foods, which are not present in the NCI method and MSM. These limitations make the ISU and SPADE methods less suitable for general use with episodically consumed foods. The NCI method and MSM have however been shown by simulation studies to perform similarly in modelling usual intake distributions for episodically consumed foods (Laureano et al., 2016; Souverein et al., 2011). Most of the methods developed for usual intake estimation focus on estimating group-level distributions of usual intake rather than precise individual-level estimates. However, if we want to research diet-health relationships, individual usual intake estimates must be present, not only usual intake distributions, and episodically consumed foods must be addressed. Apart from being able to estimate usual intakes from episodically consumed foods, both the NCI method and the MSM provides estimates of individual usual intakes (Souverein et al., 2011). The individual usual intake from these methods can be described as the probability of consuming a food, nutrient, or other dietary component on any given day, multiplied by the average intake amount on a consumption day (Conrad & Nöthlings, 2017; Tooze et al., 2006).

To further improve the modelling of usual dietary intakes, covariates can be incorporated into some of these statistical methods (Souverein et al., 2011) and are chosen depending on the specific focus of analysis. These covariates allow for more nuanced estimates by accounting for individual or contextual factors that may influence the dietary intake, as the usual dietary intakes will be estimated within the given groups. Commonly used covariates are demographic factors as sex and age groups, which are fundamental in capturing inherent differences in dietary intake (e.g., energy intake varies between men and women and between children and adults). Other relevant covariates may include socioeconomic variables like income and educational levels, which can provide insights into how economic and educational disparities influence eating behaviours. Additionally, temporal factors such as day of the week or seasonal variations can be included to account for variations in intake patterns over time. By integrating these kinds of covariates, we can obtain more accurate and representative estimates of usual dietary intakes, particularly when we are analysing sub-populations.

Usual intakes modelled from two recall days may not be enough for estimating accurate individual intakes, however, if combined with additional data from other dietary instruments, such as intake frequencies from an FFQ, the strengths of each method can be utilised while minimising their weaknesses. The food propensity questionnaire (Subar et al., 2006), a type of FFQ, is a dietary assessment tool that was specifically designed for usual intake assessment, and to be used as a covariate in estimations of usual intakes.

Nutrient profiling and front-of-pack nutrition labelling

Nutrient profiling is used in various contexts to promote public health and guide consumer choices. The definition of nutrient profiling is 'the science of classifying or ranking foods according to their nutritional composition for reasons related to preventing disease and promoting health' (Kelly & Jewell, 2018). Nutrient profiling is typically used either to refer to nutrient levels in foods (e.g. 'high fat', 'low fat') or to refer to overall health effects of consuming the food as being a more healthy or unhealthy option. The use of nutrient profiling is common in nutrition labelling, where front-of-pack labels (FOPL) assist the consumer towards making healthier food choices (Lehmann et al., 2017).

Nutrition fact panels have been recognised to be difficult to interpret for consumers, wherefore FOPLs can be a good complement (Anastasiou et al., 2019). The FOPLs gives additional nutritional and health advice to the mandatory nutrition facts panel and are most often based on nutrient profiling criteria. Interpretive FOPL, such as e.g., the Keyhole symbol or Nutri-Score, is a policy priority to improve diet and health in the WHO Regional Office for Europe as well as a recognised policy priority for national governments (Kelly & Jewell, 2018). On an international level, more than 40 countries use some sort of government-endorsed nutritional labelling scheme on the front of pack of food products (Storcksdieck genannt Bonsmann et al., 2020). The FOPL labelling schemes vary in several ways, for instance in terms of presentation, health messages to be communicated and nutrient focus. Most FOPL mainly focus on nutrients of concern for diet-related non-communicable diseases, where commonly included nutrients are sodium, saturated and trans fatty acids and added, free or total sugars. The FOPL schemes may also include other components of food items and diets, such as promoting intakes of fruits and vegetables, whole grains and fibre. The FOPL is one tool in supporting a healthier diet, primarily as it guides the consumer to make informed food choices, but also as it may drive manufacturers to make more healthy food products (Kelly & Jewell, 2018). In the EU, the most common type of FOPL system is endorsement logos, which are logos communicating healthful food options. These types of logos will be displayed on products that fulfil certain nutritional criteria, while the vast majority will not be carrying the logo (Kelly & Jewell, 2018). Other types of FOPL systems are grading systems, colour coded nutrient-based systems, and nutrient specific warning labels.

Real-life evidence on the nutritional effects of front-of-pack nutrition labels on diet is limited. However, modelling studies simulating hypothetical effects of different labels have investigated the impact, generally demonstrating improvements in the diet for the particular nutrients of concern in the labelling schemes (Emrich et al., 2017; Julia et al., 2016; Mendoza et al., 2018; Raulio et al., 2017; Roodenburg et al., 2013). Although also negative effects have been observed, in one study on intakes of fat-soluble vitamins (Roodenburg et al., 2013).

The Keyhole symbol

The very first endorsement logo created, and the first FOPL, is the Keyhole symbol. It was established by the Swedish Food Agency in 1989 (World Health Organization, 2011), and is now used in multiple countries. The aim of the Keyhole is to guide consumers toward healthier food choices by highlighting products that are considered healthier based on their nutritional content. The label have been used in Sweden since then, with reformation latest in 2021 (Swedish Food Agency, 2021).

The Keyhole symbol is a criteria-based FOPL in line with the Nordic Nutrition Recommendations (Amcoff et al., 2015), with different criteria for different food groups. The Keyhole symbol is used to highlight the healthier options within a food category, targeting nutritional composition of total fat, saturated fat, trans-fat, salt, free sugars and dietary fiber, as well as the content of whole grains, fruits and vegetables including legumes. Additionally, it is used to label healthy unprocessed foods, such as vegetables, fruit and fish. There are 11 food categories with additional sub groups, 32 food groups in total, available for labelling (Swedish Food Agency, 2021). The symbol is available for core foods only, meaning foods such as snack foods cannot carry the logo.

The Keyhole symbol is widely recognised in Sweden (Swedish Food Agency, 2014), although the nutritional effects of shifting to a Keyhole compliant diet on adolescents' dietary intake have previously not been investigated.

Rationale for the present research

Excessive consumption of added and free sugars has been associated with several adverse health effects. However, due to a lack of objective or standardised methods to measure intake fairly little is known about consumption, including in Swedish adolescents.

Children and adolescents have been approximated to have the highest intakes of added and free sugars both globally (Walton et al., 2023) and in Europe (Azaïs-Braesco et al., 2017), compared to adults. This elevated consumption is especially concerning during these formative years, as it may not only impact direct nutritional adequacy and health, but also contribute to the establishment of dietary patterns that often persist into adulthood. Eating habits developed in childhood and adolescence may track over time (Chong, 2022; Craigie et al., 2011; Patterson et al., 2009), making these young years critical for establishing healthy eating behaviours. Understanding and addressing intakes of added and free sugars during this period in life is crucial for promoting long-term health and preventing diet-related diseases.

Adolescents in Sweden are not meeting national dietary guidelines, and about 17% of the adolescents' total energy intake comes from sweets, cakes, snacks and sugar sweetened beverages (Warensjö Lemming et al., 2018a). This indicates potential overconsumption of added and free sugars among adolescents, although actual intake levels have not previously been identified, neither has contributing food sources, nor associations of added and free sugars intakes with nutrient intake and food consumption.

Health promotion efforts in terms of front-of-pack nutrition labels can give further guidance to a healthier diet, where the Keyhole symbol is a well-recognised and established health logo in Sweden. However, the nutritional impact of eating in accordance with Keyhole nutritional criteria needs to be evaluated to understand its effect on the nutritional intake of adolescents.

Research aims

The overarching aim of this doctoral thesis is to examine dietary intake in Swedish adolescents, with a particular emphasis on added and free sugars intake. This includes refining methods for estimating added and free sugars intake, identifying contributing food sources, investigating contextual and dietary associations, and model the potential nutritional impact of dietary shifts toward foods meeting the Keyhole criteria.

Specific aims of each paper are:

I. to refine and develop a systematic procedure to estimate added and free sugars content in food items, to implement this to all food items used in a Swedish national dietary survey on adolescents, and further to describe sugars intake in Swedish adolescents.

II. to describe and identify contributing food sources to added, free, and total sugars intake among Swedish adolescents, explore differences in consumption of sources of free sugars between sociodemographic groups, and investigate when and where free sugars are consumed.

III. to investigate associations between added and free sugars intake and nutrient intake, adherence to nutrient reference values, as well as food consumption in a nationally representative sample of Swedish adolescents.

IV. to investigate the potential impact of the front-of-pack label the Keyhole on Swedish adolescents' nutrient intake by modelling a shift from reported dietary intakes to foods meeting the Keyhole nutritional criteria.

Subjects and methods

This thesis builds on the findings of four original research papers, each addressing a specific research aim and contributing unique insights to the overall study. In the thesis, dietary data of adolescents in Swedish school years 5, 8 and 11 (year two in Swedish secondary school/high school) are included, covering ages mainly ranging from 11-19 years old. This research is based on data from the Riksmaten Adolescents 2016-17 survey, collected by the Swedish Food Agency.

Paper I lays the groundwork for the subsequent three papers by providing food content estimates of added and free sugars which further are applied to the Riksmaten Adolescents 2016-17 survey data. Paper II and Paper III follows a branch of exploring and understanding added and free sugars intake in Swedish adolescents, including describing and identifying contributing food sources as well as examining associations with nutrient intake and food consumption. Paper IV follows another route by investigating the potential impact of the Keyhole symbol on Swedish adolescents' nutrient intake. Since the Keyhole criteria include restrictions regarding free sugars in food items, obtaining free sugars estimates is necessary to fully investigate the impact of all criteria. An overview of the research papers included in the thesis and their relationships is illustrated in Figure 2.

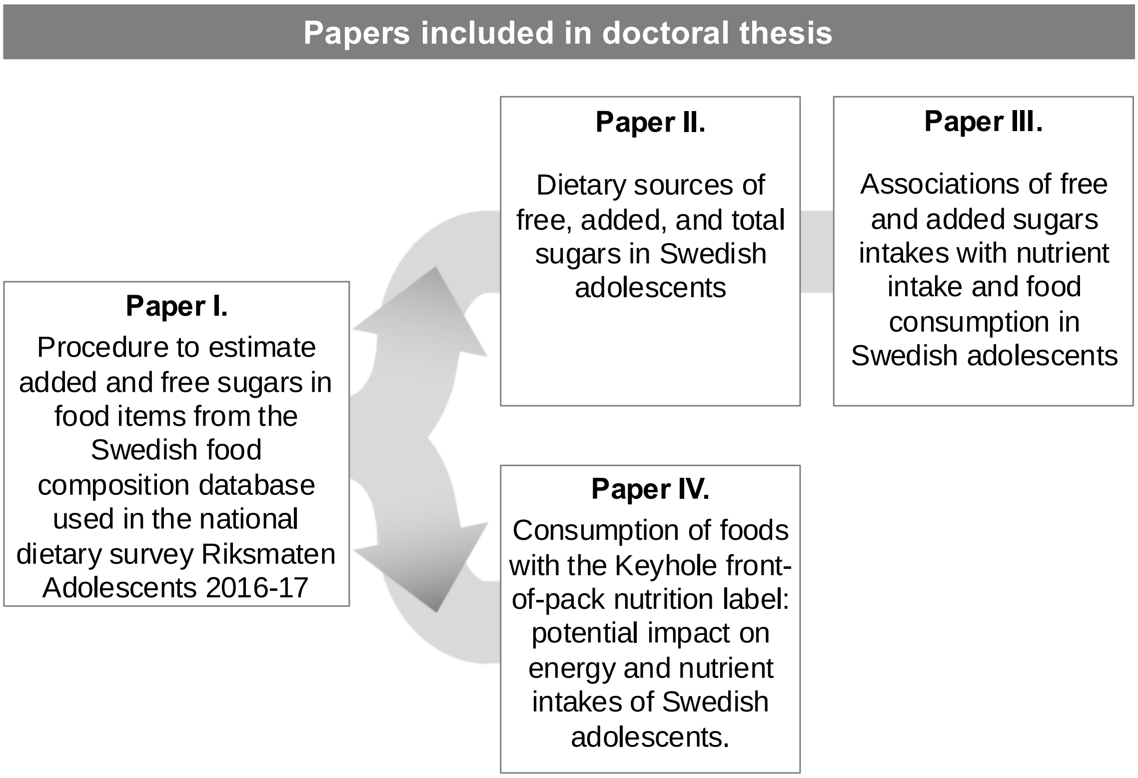


Figure 2. Overview of the thesis papers and their relationships.
Paper I provides the foundation for the subsequent papers, as its findings and estimates of added and free sugars are essential for their analyses. The top branch with Paper II and III explores intakes of added and free sugars in Swedish adolescents, while the lower branch focuses on potential food label impacts.

Study sample and participants

The Riksmaten Adolescents 2016-17 survey

Riksmaten Adolescents 2016-17 was designed as a cross-sectional dietary survey on a nationally representative sample of Swedish adolescents (Moraeus et al., 2018). Starting in September 2016 and ongoing to May 2017, the Swedish Food Agency carried out the dietary survey on adolescents in grades 5, 8 and 11 (mean ages 12, 15 and 18 years old respectively). The recruitment process, carried out by Statistics Sweden, involved a random selection of 619 schools, around 200 schools per school year, stratified by geographic location, municipality type, and school size, to ensure national representativeness. From 5145 adolescents initially invited, 3477 (68%) participated, and 3099 (60%) provided complete dietary data. An analysis of non-participation indicated that the sample was representative of the population in terms of socioeconomic background and school organisation (Moraeus et al., 2018).

Data collection occurred class-wise, with approximately half of the students participating in each academic semester over the 2016–2017 school year. Trained personnel from the Swedish Food Agency visited the recruited classes during the first data collection day to instruct the adolescents on how to report their dietary intake in a web-based system, to collect anthropometric data and to collect blood and urine samples on a subset of participants (biological sampling data are not included in this thesis). Height and weight were measured on-site using standardised equipment. Accelerometers (Actigraph GT3X and GT3X+) were used to objectively assess physical activity among the adolescents, instructing them to wear them for 7 days. Additionally, both students and their legal guardians completed questionnaires covering background information.

This thesis includes the 3099 adolescents who had complete dietary registration.

Ethical considerations

The Riksmaten Adolescents 2016-17 survey was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving research study participants were approved by the Regional Ethical Review Board of Uppsala (registration no. 2015/190). The participants and their legal guardian received information about the study one month prior the start and could withdraw from the study at any time without giving any reason. Informed consent, either written or verbal, was obtained from all participants.

Dietary intake assessment

The dietary assessment in Riksmaten Adolescents 2016-17 was conducted using RiksmatenFlex, a web-based tool developed by the Swedish Food Agency specifically for this survey (Lindroos et al., 2019). The assessment tool was designed to provide flexibility and ease of use across devices like smartphones and tablets. The tool combines a diet recording component (RiksmatenFlexDiet) and a questionnaire component (RiksmatenFlexQ).

The participants completed two non-consecutive 24-hour dietary recalls with RiksmatenFlexDiet over a specified period, with the first recall day occurring the day before the school visit, and the second on a randomly assigned day within the next 2-7 days (Moraeus et al., 2018). This approach ensured data collection from weekdays and weekends to capture typical eating patterns. The registration of one day's dietary intake typically took 15 to 30 minutes. Dietary data were also collected for one more day, which was partially recorded during the school visit and completed during the next day. However, this day was excluded from the analyses because it used a mixed method and included the offering of fruit and juice to the adolescents undergoing biological sampling, which could influence their reported food intake.

The diet recording component RiksmatenFlexDiet is a self-administered dietary registration method comparable with the 24-hour dietary recall, which have been validated for reliable intakes estimates of energy, fruit, vegetables, and whole grains (Lindroos et al., 2019). To ensure usability for adolescents, the tool was developed based on statistics on food intake in the age groups and refined with focus groups and user testing sessions. This dietary assessment method allowed participants to report foods by selecting from a food list of 778 foods and beverages, including mostly generic food items. Participants recorded the type of food, intake amounts either as standard portions, sizes, pieces, in household measurements or through portion pictures, and location of each meal. After completing a day's entry, automated prompts reminded the participants of commonly forgotten foods.

The questionnaire component RiksmatenFlexQ was designed to collect detailed contextual information on adolescents' dietary habits and lifestyle factors. Created alongside the RiksmatenFlexDiet, it included questions on various lifestyle behaviours, food choices, and eating habits to complement the dietary recall data. The RiksmatenFlexQ also included food propensity questionnaires to capture food items episodically consumed (Moraeus et al., 2018).

Food composition data and data preparation

All food items in RiksmatenFlexDiet were derived from the Swedish food composition database. This enabled automatic calculations for energy and nutrient intake of nutrients included in the database.

The Swedish food composition database

The Swedish food composition database contain more than 2400 food items with detailed nutritional information, and is designed to reflect Sweden's current food supply, updated regularly. The database represents typical nutrient values of certain foods by aggregating data from the most common brands within each food category (Swedish Food Agency, 2024c). Nutrient values in the Swedish Food Database are determined through multiple methods (Swedish Food Agency, 2024a):

- Analytical values: most nutrients are directly analysed by the Swedish Food Agency using rigorous quality-controlled methods, considering the food's structure and nutritional components.
- Transferred values: some nutrient data are sourced from the food industry, publications, or food composition databases from other, preferably Nordic, countries. These values are often re-calculated to align with Swedish standards.
- Estimated values: for certain foods, nutrient values are estimated from similar items, or by product information, ingredient lists or recipes, with some nutrients set to zero in the case of non-occurrence of naturally present nutrients.
- Calculated values: some nutrients are derived from other measurements, such as calculating protein from nitrogen content using a conversion factor.

Calculations also apply to numerous composite dishes, where calculations are performed by preparing virtual recipes in the system and adding ingredients that can be either analysed, transferred, estimated, or calculated. These types of calculations adjust for changes in weight, water, fat, and nutrient levels due to food preparation. Aggregated similar foods are as well types of calculated foods were, e.g., 'green, yellow, red bell pepper' are aggregated to create a generic bell pepper food category.

The food composition database used in the dietary survey

The 778 food items in the food list in RiksmatenFlexDiet were derived from 844 single food items from the Swedish food composition database (i.e., single food items with nutrient values mainly determined through laboratory analysis, but also transferred, estimated, or calculated values), creating the Swedish food composition database, version Riksmaten Adolescents 2016-17. These 844 single food items were either included as they were in RiksmatenFlexDiet, or used to create composite food items (i.e., foods composed of two or more food items), with single food items appearing in composite food items as ingredients in up to six stages. In total, 1483 food items formed the database in RiksmatenFlexDiet. Figure 3 illustrates the structure of the food items included in RiksmatenFlexDiet.

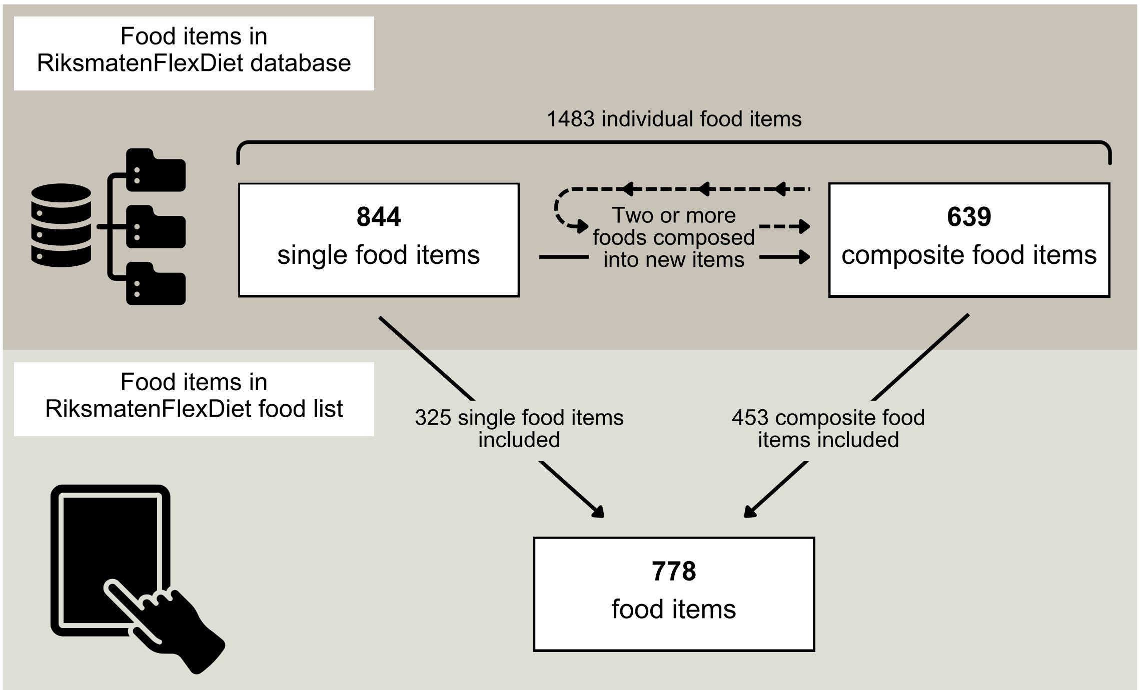


Figure 3. Structure of food items included in the dietary survey

In the Riksmaten Adolescents 2016-17 survey the participants could choose from 778 food items in the food list in RiksmatenFlexDiet. These food items originated from 844 single food items from the Swedish food composition database. The single food items were both transferred directly to the food list (325 items) and used for creating composite food items, where 453 composite items were transferred to the food list.

Procedure to estimate added and free sugars

In the first paper (Paper I), a procedure to estimate added and free sugars in food items from the Swedish food composition database was developed and applied. The results from this paper provide the basis for the other three papers.

Two systematic methods for estimation of added sugars content (Louie et al., 2015) and free sugars content (Kibblewhite et al., 2017) were refined and combined to get an overarching ten-step procedure for estimation of both added and free sugars. Added sugars were defined as sugars from all foods and beverages where refined sugars were added during cooking or manufacturing, in line with the NNR (Nordic Council of Ministers, 2014). Free sugars were defined as all added sugars as well as sugars naturally present in honey, syrups, and fruit and vegetable juices and juice concentrates, in line with the WHO (World Health Organization, 2015). Total sugars were defined as all sugars (total mono- and disaccharides) present in diet.

The developed procedure was adapted on all 1483 food items forming the database in RiksmatenFlexDiet. Estimations were based on total sugars in each individual food item, giving every food item an added and a free sugars value. This further enabled sugars intake estimates in the adolescents' diet.

Categorisation of food items into food categories

Food items in the RiksmatenFlexDiet food list were categorised into broader food categories based on similarities in food composition and culinary use to demonstrate food source contribution to added, free and total sugars (Paper II), and for exploring associations from various food sources with added and free sugars intake (Paper III). Table 2 shows how this was done for the respective paper.

Table 2. Food category description for Paper II and Paper III

Food category Paper II	**Description**	**Food category Paper III**
Breads	All types of plain breads and rolls, including yeast breads, crisp breads, and tortillas.	Bread, breakfast cereals, porridge
Breakfast cereals and porridge	Breakfast cereals, mueslis, porridge, and gruel.	
Dairy products (sweetened)	Sweetened yoghurt, sour milk, fresh cheese, condensed milk, milk drinks, and plant-based dairy alternatives.	Dairy products
Dairy products (unsweetened)	Unsweetened milk, yoghurt, sour milk, fresh cheese, cured cheese, butter, butter blends, cream, crème fraiche, sour cream, and plant-based dairy alternatives.	
Fruits and vegetables	All types of fruits including berries. Fresh, frozen, dried, cooked, canned, or candied.	Fruits and berries
	All types of vegetables, including legumes and mushrooms. Fresh, frozen, dried, cooked, canned, or candied.	Vegetables
Juices	Juices from 100% fruits and/or vegetables.	Juices
Miscellaneous	Alcoholic beverages: beer, wine, hard cider, spirits, and liqueurs. Nutritional products: energy and protein bars, meal replacements, and protein supplements. Nuts: all sorts of whole nuts (natural, salted, spiced, or candied).	Miscellaneous
	Snack foods: crisps and popcorn.	Crisps, popcorn and similar snacks

Table 2. cont.

Food category Paper II	Description	Food category Paper III
Mixed dishes	Mixed dishes, home cooked and ready-made foods, including whole or products from meat, poultry, fish, seafood, eggs, plant-based meat alternatives, oils, margarines, potatoes, pasta, rice, and pseudocereals. Cold cuts. Mixed dishes and products including vegetables and legumes.	Fish[1] Meat[1] Pizza, pie, ready-made sandwiches Vegetables[1]
Sauces and condiments	Sauces, dressings, condiments (e.g., ketchup, mustard, mayonnaise, and sweet chili sauce), and dips for savoury foods.	-
Sugar sweetened beverages	Soda, cordial, energy drinks, and sugar sweetened juice drinks.	Sugar sweetened beverages
Sugars, syrups, and honey	Sugars, syrups, and honey.	-
Sweet bakery products and desserts	Sweet pastries, cakes, cookies, ice cream, desserts (e.g., chocolate pudding, pannacotta, tiramisu), sweet fruit soup, fruit cream, and dessert toppings (e.g., chocolate and caramel sauce).	Sweet bakery products and desserts
Sweet spreads	Jams, marmalades, jellies, apple sauce, and sweet nut and cocoa spread.	-
Sweets and chocolates	Sweets and chocolates.	Sweets and chocolates

[1]Composite food items were disaggregated into their individual ingredients for accurate assignment of fish, meat and vegetables in Paper III.

Food consumption data preparation

The food consumption data assessed with RiksmatenFlex were handled differently in the different papers to meet the different aims. An overview of dietary components included, dietary intake data processing and preparation, and statistical outcomes in the respective papers is presented in Table 3, and more details described within this section.

Table 3. Dietary components, data processing, and statistical outcomes by paper

Paper number and aim	**Dietary components**	**Dietary intake data processing and preparation**	**Statistical outcomes**
I. to refine and develop a procedure to estimate added and free sugars content in food items, to implement this to all food items used in a Swedish national dietary survey on adolescents, and further to describe sugars intake in Swedish adolescents.	Sugars Energy	Procedure for estimation of added and free sugars within diet developed and applied on the participants food intake. Usual intakes estimated for the dietary components with the Multiple source method.	Descriptive statistics on added, free and total sugars intake presented. Sugars intake compared with sugars recommendations. Differences in sugars intake between girls and boys within school years analysed.
II. to describe and identify contributing food sources to added, free, and total sugars intake among Swedish adolescents, explore differences in consumption of sources of free sugars between sociodemographic groups, and investigate when and where free sugars are consumed.	Sugars Energy Food groups	Sugars intake contribution calculated proportional to total intake of sugars (1), and per consumer (2): 1. all participant's two-day records were summed and divided into food categories; 2. only participants who reported food items within the respective food categories were included. Estimated average intakes of dietary components calculated as the average intake over the two days. Quintile categorisation based on free sugars intake.	Population proportions derived for all foods contributing to sugars intake. Descriptive statistics on most contributing sources among consumers presented. Differences in intake of most contributing sources between girls and boys, and between different school years analysed for consumers. Quintile comparison of top five contributors to free sugars. Associations with sociodemographic factors investigated. Time and location of sugars consumption investigated.

Table 3. cont.

Paper number and aim	Dietary components	Dietary intake data processing and preparation	Statistical outcomes
III. to investigate associations between added and free sugars intake and nutrient intake, adherence to nutrient reference values, as well as food consumption in a nationally representative sample of Swedish adolescents.	Sugars Energy Food groups Nutrients Whole grains	Usual intakes estimated for the dietary components with the Multiple source method. Quintile and decile categorisation based on free sugars intake.	Differences in sociodemographic characteristics between the intake quintiles investigated. Trends between free sugars intake and nutrient and food group intake across free sugars intake quintiles were assessed. Nutrient intake compared with nutrition recommendations across the sugars intake divisions.
IV. to investigate the potential impact of the front-of-pack label the Keyhole on Swedish adolescents' nutrient intake by modelling a shift from reported dietary intakes to foods meeting the Keyhole nutritional criteria, using dietary data from a Swedish national dietary survey of adolescents.	Sugars Energy Nutrients Whole grains	Multiple scenarios were calculated where Keyhole-compliant foods replaced non-compliant foods in varying proportions. Estimated average intakes of dietary components calculated as the average intake over the two days.	Descriptive statistics on intake of nutrients with Keyhole criteria presented across scenarios. Differences in macro- and micronutrients between reported intake and the modelled scenarios investigated. Nutrient intake compared with nutrition recommendations in the different scenarios. Associations with sociodemographic factors investigated.

Estimating usual sugars, nutrient and food intake from two-day intake

Dietary intake in Riksmaten Adolescents 2016-17 was assessed over two days per participant, which is not representative to usual dietary intake. In Paper I and Paper III, estimated usual dietary intake was used in analysis to enable comparisons with dietary recommendations and assess trends across levels of free sugars intake. However, for Paper II, the study aim was concentrated to describe population proportions of sugars contributors in adolescents' diet, therefore usual intake estimates were not appropriate.

In Paper I, two-day collected sugars intake and energy intake data were transferred to usual intake using the MSM statistical program package (Harttig et al., 2011; Haubrock et al., 2011). The MSM provides estimation of usual dietary intake, combining dietary data from multiple short-time assessments (for more information, see section Assessing usual dietary intake), here using the two retrospective days collected per participant. School year and sex were included as covariates in the model. Usual sugars and energy intake values were generated to enable both sugars intake values in grams and calculation of percent of energy intake.

In Paper III, usual dietary intake was estimated for all food groups and nutrients with the MSM, using sex and school year as covariates. For intake of red meat, poultry, and fish, food propensity questionnaire information collected per individual was used to classify participants as consumers or not, which were included in the MSM transformation. For other dietary variables, all participants were assumed to be consumers. Total food intake from the food groups vegetables, fruits and berries, meat (red, poultry, processed), and fish and shellfish was categorised accordingly, with composite foods disaggregated into their individual ingredients for accurate assignment. The intake of other food groups was calculated only if they were consumed in their original form, not including being part of composite foods.

Food category contribution

Contributing sources to added, free and total sugars in adolescents' diet were obtained by calculating food category contribution of total intakes of the sugars respectively (Paper II). The contribution to sugars intake from different food categories was calculated across all participants, i.e. proportional to total intake of sugars, and per consumer. For the proportional calculations, all participant's two-day records were summated and divided into the defined food categories, expressed as percent contribution to total intake (%). For the per consumer analyses, only participants who reported food items within the respective food categories were included. Food category intake per consumer is expressed as percent of total energy intake (E%) to adjust for differences in energy intake and requirement.

Modelling dietary intake scenarios

In Paper IV, potential effects on nutritional quality in dietary intake when shifting into Keyhole labelled food intake were investigated in adolescents. Potential effects were investigated by modelling food replacement scenarios, where food items not complying with the Keyhole nutritional criteria in adolescents' reported diet were replaced with items that complies. Food replacements were made on an individual basis by partially replacing each participant's food intake. Five scenarios were modelled to explore effects of exchanging adolescents' diet at different levels of agreement to Keyhole criteria compliant foods. Scenarios 1-4 explored nutritional effects of replacing food items at 25, 50, 75 and 100% respectively. In scenario 5, an energy adjustment factor was applied to the 100% scenario as it was assumed that total energy intake would decrease when modelling diets with Keyhole compliant foods, as decreased fat content and increased dietary fiber content are criteria. The different scenarios are illustrated in figure 4.

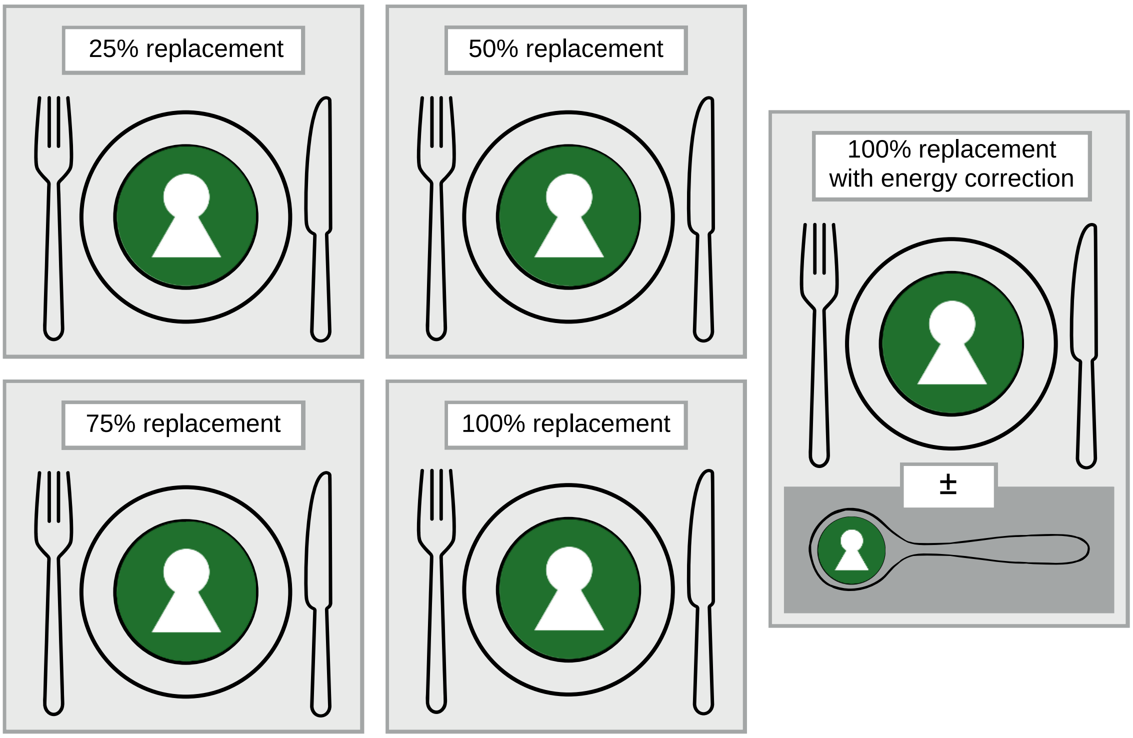


Figure 4. Replacement scenarios in Paper IV

Five scenarios were modelled to explore effects of exchanging adolescents' diet at different levels of agreement to Keyhole criteria compliant foods. Different scenarios explored nutritional effects of replacing food items at 25%, 50%, 75% and 100% respectively, i.e., assuming dietary changes to an extent of replacing every fourth meal, every other meal, three of four meals, and all meals. In a fifth scenario, an energy adjustment factor was applied to account for differences due to these replacements, i.e., assuming consumption of the same amount of energy with dietary changes of eating slightly more or less than reported.

Statistical methods

Descriptive, comparative and predictive analyses were performed using appropriate statistical methods, details within each paper respectively.

Statistical analyses were performed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA) for Paper I, and Stata statistical software (StataCorp) for Paper II-IV. In Paper II and Paper III, Stata version 18.0[2] was used and in Paper IV Stata version 16.1[3] was used.

To further explore the credibility of the results, additional sensitivity analyses were conducted in Paper II and Paper IV considering plausible energy reporting, given the well-documented bias of misreporting within dietary intake assessment. Plausible energy reporters were determined by comparing energy intake captured by RiksmatenFlex with total energy expenditure following the methods of Goldberg and Black (Black, 2000; Goldberg et al., 1991), utilising data derived from accelerometers, body weight, and height (Warensjö Lemming et al., 2018a).

[2] StataCorp. 2023. Stata Statistical Software: Release 18. College Station, TX: StataCorp LLC.
[3] StataCorp. 2019. Stata Statistical Software: Release 16. College Station, TX: StataCorp LLC

Results

The results from the four original research papers are summarised in the following section, highlighting the key discoveries. Additionally, other relevant findings are included to provide a more comprehensive understanding of the research and its broader implications.

Participant characteristics

The 3099 adolescents from Riksmaten Adolescents 2016-17 included in this study were almost equally distributed across the school years with slight under-representation in school year 11, and 55% were girls. Table 4 shows characteristics of the sample including BMI status, parental education level, school municipality size and how they reported their energy intake in relation to their energy expenditure. These variables were used in different analyses in the different papers. Of the total sample 72% had normal weight, and 61% had parents with education level >12 years (not accounting for missing values). Most adolescents resided in medium sized towns (42%), compared to 29% in both large cities and smaller towns/rural areas. The majority had reported their energy intake as plausible relative to their energy expenditure (61%), however many had missing values for this comparison due to incomplete assessment of physical activity.

Table 4. Characteristics of the participants in Riksmaten Adolescents 2016-17

	School year 5 (n=1049)		**School year 8** (n=1050)		**School year 11** (n=1000)	
	Girls (n=559)	**Boys** (n=490)	**Girls** (n=574)	**Boys** (n=476)	**Girls** (n=577)	**Boys** (n=423)
BMI status[a] (%)						
Underweight	8.6	6.5	7.0	7.4	5.2	5.7
Normal weight	68	70	75	76	72	68
Overweight	18	18	15	13	18	18
Obese	4.3	3.1	2.3	4.2	4.5	7.3
Missing	*1.3*	*2.2*	*0.3*	*0.2*	*0.5*	*0.7*
Parental education level (%)						
≤12 years	33	38	32	35	42	37
>12 years	63	58	61	55	54	52
Missing	*3.8*	*3.9*	*6.8*	*9.9*	*4.3*	*10*
School municipality size (%)						
Large cities	37	31	27	28	24	27
Medium sized towns	32	40	56	52	36	38
Smaller towns	31	29	17	20	40	35
Reported energy intake[b] (%)						
Under reporting	12	20	12	11	8.8	8.3
Plausible	51	46	46	38	45	35
Over reporting	20	12	19	16	18	13
Missing	*18*	*23*	*24*	*35*	*29*	*43*

Mean ages school year 5, 8, and 11: 12, 15, and 18 years old.

Values were missing due to missing questionnaires, missing body height or weight data, and incomplete accelerometer measurements.

[a]BMI status was determined according to International Obesity Task Force cutoffs (Cole & Lobstein, 2012).

[b]Energy intake was considered implausible if the energy intake to expenditure ratio was outside ±1 SD.

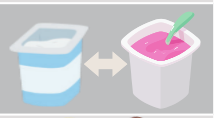
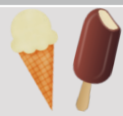
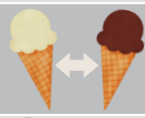
Procedure to estimate added and free sugars

One main outcome from the study on estimating added and free sugars within the database used in the Riksmaten Adolescents 2016-17 survey in Sweden (Paper I) were that a refined, systematic ten-step procedure for estimating sugars was developed and applied to all food items in the RiksmatenFlexDiet database. This generated added and free sugars intake estimates for all participants in Riksmaten Adolescents 2016-17. Step assignment of food items according to the ten-step procedure in a simplified version of the procedure can be viewed in Table 5.

Adaptations of the two previous systematic methods for estimations of sugars content in foods (Kibblewhite et al., 2017; Louie et al., 2015) introduced modifications to address foods specifically in the Swedish diet. Modifications included added sugars definition adjustments to align with the Nordic Nutrition Recommendations (Nordic Council of Ministers, 2014), expansion of food categories (e.g., including culturally specific foods as gravlax and pickled herring), additions of food categories (e.g., additions of non-dairy alternative products), reclassification of foods (particularly breads which are commonly sweetened in Sweden as opposed to other parts of the world), and calculation modifications (for both sugars estimate calculations and for contents of composite foods).

The procedure was constructed as a ten-step decision making process, where assumptions were made on added and free sugars content based on the total sugars (total mono- and disaccharides) value of the food of interest. If a food item did not meet the criteria within the first step you moved on to the next step and so forth, until the food met the given assumptions or conditions. The first six steps are considered as objective steps as these are based on pre-defined assumptions. The last four steps are considered as subjective steps, as these require further subjective estimations. Within the RiksmatenFlexDiet database, added and free sugars estimates for each individual food item were largely based on objective steps (92-93% for the sugars respectively).

Table 5. Assignment of food items according to the ten-step procedure

Step	Foods assigned
1	Foods with 0 g total sugars 
2	Foods with 0 g added or free sugars (but not 0 g total sugars) 
3	Foods where content of total sugars equals to added or free sugars 
4	Recipe calculation of foods with estimates from step 1-4 
5	Added or free sugars content is based on comparison with an unsweetened variety 
6	Added or free sugars content based on analytical data (lactose and/or fructose) 
7	Borrowing added or free sugars content from a similar food 
8	Added or free sugars subjectively estimated from ingredient list or recipe 
9	Recipe calculation of foods with estimates from all steps 
10	None of the above applicable: added or free sugars are assumed to be 50% of total sugars 

This is a simplified version of the systematic ten-step procedure for estimating added and free sugars content in food items, with food assignment examples of each step respectively. The primarily principle in the procedure is to base the estimations on data of total and naturally occurring sugars in each food item. Begin at step one and proceed until you reach the step that matches the given assumptions or conditions. Full details of the procedure for estimating added and free sugars can be found in Paper I.

Added and free sugars intake and compliance with recommendations

Results from Paper I revealed that 45% of Swedish adolescents kept their added sugars intake below the recommended maximum (<10 E%), while 30% met the recommendation for free sugars (<10 E%). Only 3% met the WHO conditional recommendation for free sugars (<5 E%). Boys had higher absolute intakes of sugars than girls, but lower relative values, consequently more boys complied with recommended intakes. Median usual intakes of added sugars were 10 E%, and of free sugars 12 E% among the adolescents. Table 6 presents added and free sugars intake and compliance with recommendations.

Table 6. Added and free sugars intake and compliance with recommendations

	School year 5		School year 8		School year 11	
	Girls (n=559)	**Boys** (n=490)	**Girls** (n=574)	**Boys** (n=476)	**Girls** (n=577)	**Boys** (n=423)
Sugars intake (E%) ***median (p25; p75)***						
Added sugars	10 (8;12)	10 (7;12)	11 (9;12)	10 (8;13)	11 (9;13)	9 (7;12)
Free sugars	13 (10;15)	11 (8;14)	12 (10;15)	12 (9;15)	12 (10;15)	11 (8;14)
Complying with sugars recommendations (%)						
free sugars <10 E%	25	38	21	33	25	45
free sugars <5 E%	0.9	4.5	0.4	5.0	0.9	6.4
added sugars <10 E%	45	54	34	45	41	57

Calculated to estimate usual dietary intake using the Multiple Source Method.

Estimated usual intake versus two-day average intake

Figure 5 illustrates the differences in intake distributions between short-term measures (two day within person mean intake) and usual intakes (estimated from the two days of reported dietary intake with the MSM) and displays intake distributions of free sugars in adolescents. The estimated usual intake distribution has a relatively symmetric shape, with a distinct peak above 10 E%. The two-day mean intake distribution is wider and shifts toward the left, suggesting lower intake levels compared to the usual intakes. This comparison illustrates how short-term intake data can overestimate nutrient adequacy, emphasising the importance of adjusted intake data for accurate assessment.

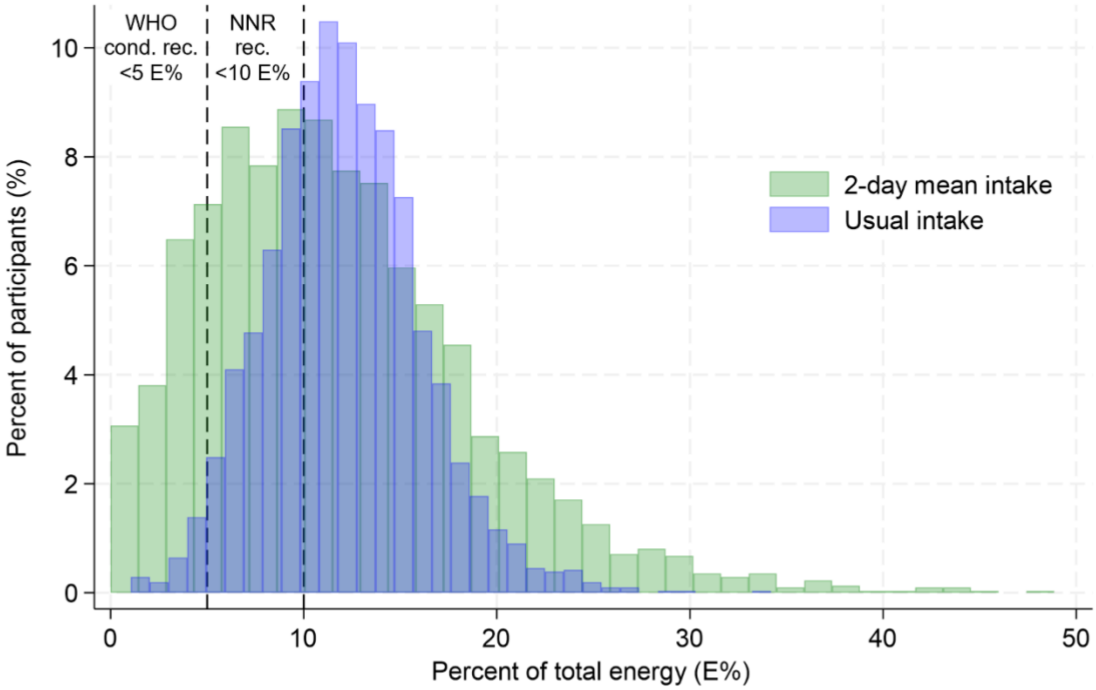


Figure 5. Free sugars intake (E%) distributions from two-day means compared to from usual intake estimation
Intake distributions of free sugars in adolescents (n=3099) based on within-person means of two 24-hour recalls (green), and usual intakes estimated with the Multiple Source Method (blue).

The median intakes of free sugars were 10.7 E% and 11.9 E% from the two-day mean intake and estimated usual intake respectively, Table 7. When observing the two-day mean intake, 55% of the adolescents exceeded an intake of 10 E%. However, when observing the estimated usual intake, 70% exceeded the recommended maximum intake. The difference between the types of intakes became proportionally larger when comparing intakes to the WHO conditional recommendations (<5 E%), which falls within in the tail of the usual intake distribution. For this conditional recommendation, 16.9% and 2.7% complied from two-day mean intake respectively estimated usual intake.

Table 7. Free sugars intake (E%) two-day mean intake vs. estimated usual intake

	Min.	p25	Med.	p75	Max.	Intake <5 E%	Intake <10 E%
	(E%)					(%)	
2-day mean	0.0	6.6	10.7	15.7	48.9	16.9	45.4
Usual intake	1.1	9.5	11.9	14.6	34.2	2.7	30.2

Descriptive statistics of free sugars intake in adolescents (n=3099) based on within-person means of two 24-hour recalls, and usual intakes estimated with the Multiple Source Method.

Food sources of sugars in adolescents' diet

The primary source of sugars within the diet of Swedish adolescents was SSBs (Paper II), with 34%, 30% and 18% contribution to total intakes of added, free and total sugars respectively, Figure 6. SSBs were particularly consumed by boys, adolescents to parents with lower education levels, and those residing in smaller cities/rural areas. Other food categories contributing substantially to both added and free sugars intake were sweets and chocolates (23% respectively 20%), sweet bakery products and desserts (13% respectively 11%), and sweetened dairy products (10% respectively 9%), Figure 6. Fruit and vegetable juices contributed with 11% of the free sugars intake, and this food category was the only source that showed an apparent difference between sources to added and free sugars.

During the two days of dietary assessment, 61% reported consumption of SSBs, 37% consumption of juices, 44% consumption of sweets and chocolates, and 49% consumption of sweet bakery products and desserts. Among consumers, median intake of free sugars from SSBs were 4.4 E%, from juices and from sweets and chocolates 3.1 E% each, and from sweet bakery products and desserts 1.9 E%.

Fewer food groups contributed substantially to added and free sugars intake among the high sugars consumers than among those consuming less, where SSBs and sweets and chocolates accounted for most of the intake in the high consumers (64% of all free sugars in those consuming more than 17 E%).

Intakes of free sugars were higher during weekends, mostly consumed outside of main meals, and predominantly consumed within the home environment.

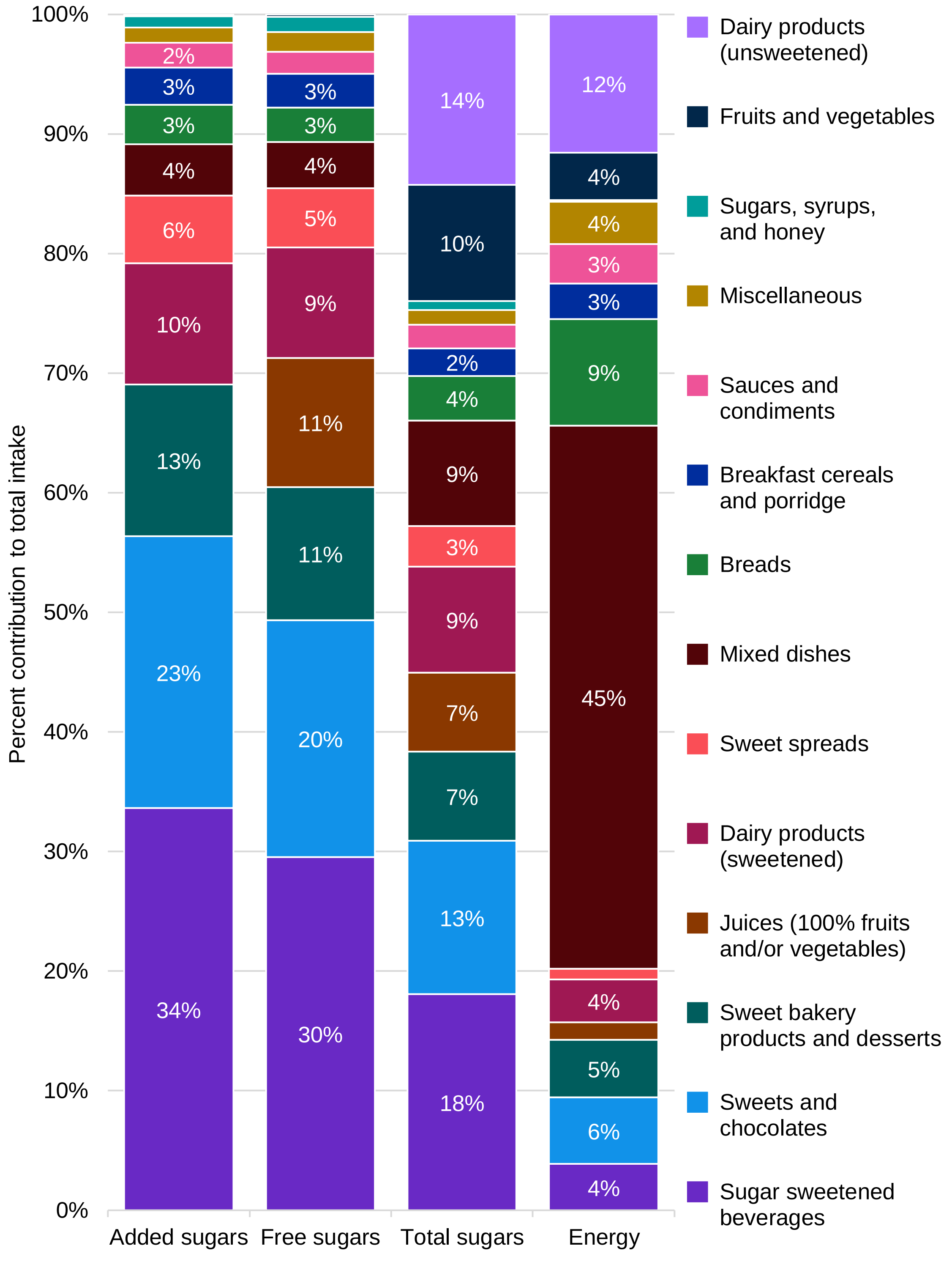


Figure 6. Food sources of added, free, and total sugars in adolescents' diet

Food categories are ranked according to contribution to free sugars intake. Food category 'Miscellaneous' comprises alcoholic beverages, nutritional products, nuts, and snack foods (e.g., crisps, popcorn). Food category 'Mixed dishes' comprises foods commonly included in main meals (e.g., pasta, rice, potatoes, meats, fish). Numbers are displayed when food categories are contributing with >2% to total intake.

Associations of sugars intake with nutrient intake and food consumption

Paper III identified associations between higher added and free sugars intake and progressively less favourable nutrient and food intakes in Swedish adolescents. This included lowered intakes of most micronutrients, dietary fibre, and essential fatty acids with increased added and free sugars intake. Other findings were that energy intake was gradually lower across the rising levels of added and free sugars intake, and intakes of sodium, vitamin C (to some extent for free sugars) and saturated fats showed a beneficial pattern.

A higher intake of added and free sugars was negatively associated with foods included in analysis that typically are considered as part of a healthy diverse diet; vegetables, fruits and berries, fish and shellfish, meat, whole grains, dairy products, and bread, breakfast cereals and porridge ($p<0.01$), Figure 7 shows food intake across deciles of free sugars intake.

At higher energy intakes from added and free sugars, >11.3 E% for added sugars and >12.9 E% for free sugars, the likelihood of meeting nutrient reference values decreased significantly. Although, for nutrients critical within the adolescent diet, such as vitamin D, selenium, dietary fiber and polyunsaturated fats, lower odds of meeting reference values were observed even at lower intake levels of added and free sugars. Micronutrient intake in absolute (per day) and relative intakes (per MJ) across free sugars intake deciles are presented for calcium, folate, iron, selenium, vitamin C and vitamin D in Figure 8. Significant trends were observed indicating a decline in micronutrient intake across the free sugars intake levels for both absolute and relative intakes for the micronutrients ($p<0.001$), except for vitamin C were a positive association was observed in relative intake ($p<0.05$) but no significant association for absolute intake.

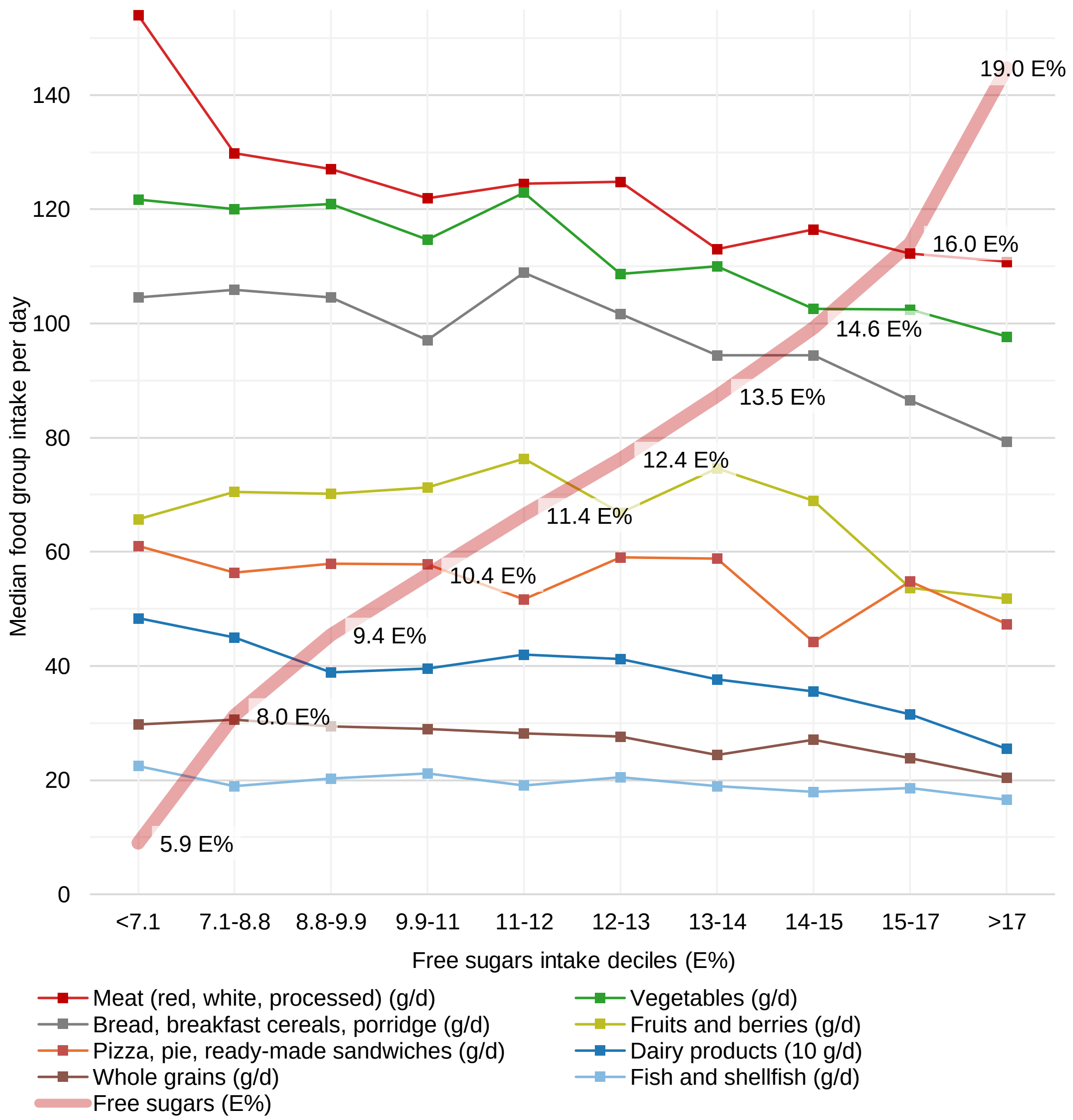


Figure 7. Food intake across intake levels of free sugars
Median intakes presented per free sugars decile. Observe that the food category dairy products uses a different unit (10 g/d) to fit the graph. Calculated to estimate usual dietary intake using the Multiple Source Method.

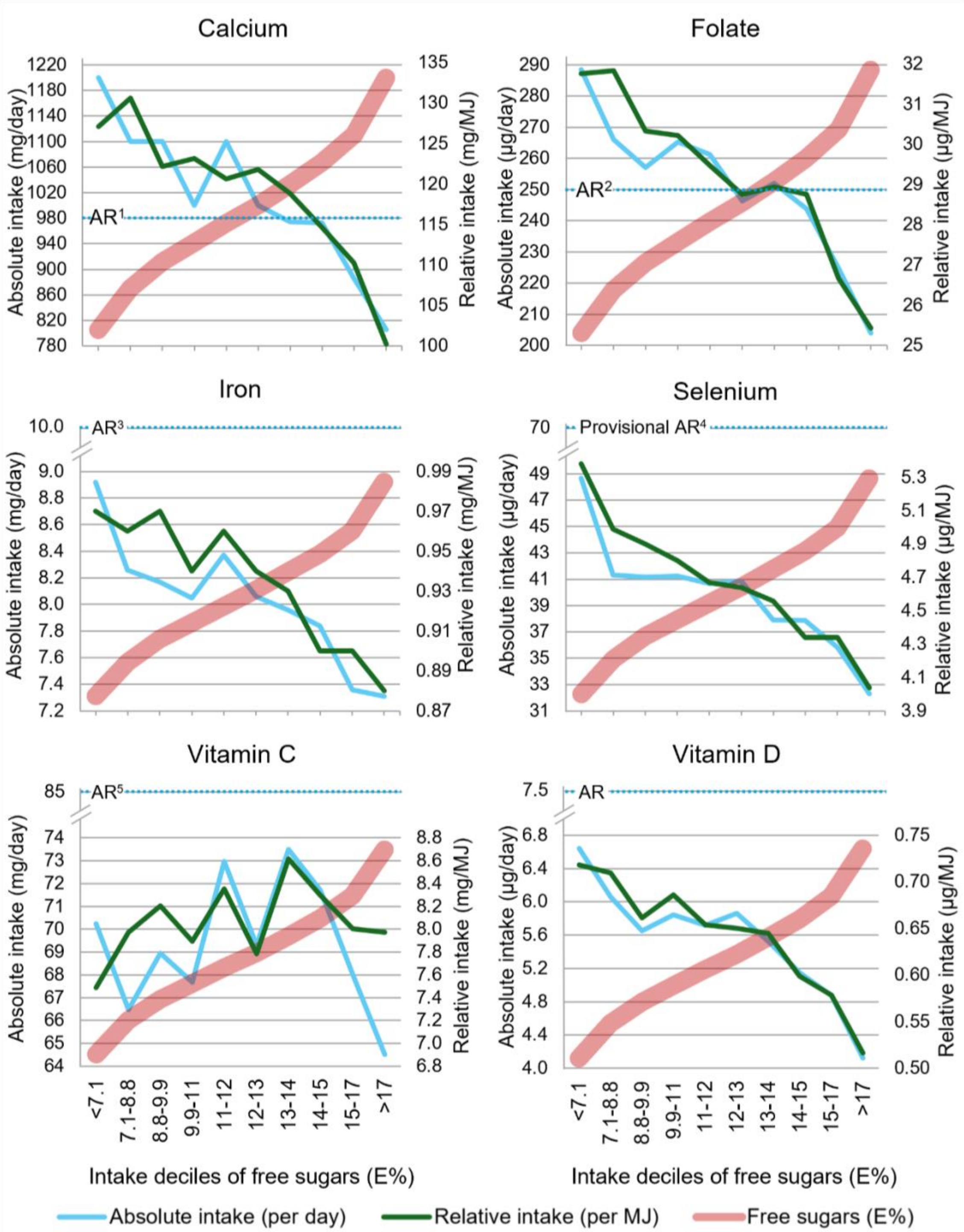


Figure 8. Median micronutrient intake across intake levels of free sugars

Micronutrient intake is expressed in both absolute intake per day (blue) and relative to energy intake (green). Calculated to estimate usual dietary intake using the Multiple Source Method. The highest average requirement (AR) or provisional AR for adolescents is plotted in each graph, i.e. for sex and age groups [1]females & males 11-17 y; [2]males ≥15 y; females ≥18 y; [3]females 11-14 y; [4]males ≥15 y; [5]males 15-17 y. For vitamin D, AR is the same for all.

Potential effects of the Keyhole symbol on adolescents' nutrient intake

Paper IV demonstrated that shifting adolescents' diets to include more Keyhole-compliant foods led to improved overall nutrient intake. Replacing non-compliant foods with Keyhole-compliant alternatives led to increased intakes of whole grains, dietary fibre, and polyunsaturated fats, while decreasing saturated fats and total fat. Even at partial replacement levels, there were noticeable improvements in nutrient intake, particularly for whole grains, dietary fibre, and fats. Intake of energy, nutrients and whole grains in replacement scenarios 50%, 100% and 100% energy corrected is presented with recommendations in Table 8.

However, the impact on reducing free sugars and salt intake was limited. Free sugars saw only a modest reduction of around 3% in the 100% replacement scenario, as many high-sugar items, like sugar sweetened beverages and sweets and chocolates, are ineligible for Keyhole labelling and were therefore not replaced. Similarly, salt intake saw only minor reductions since salt-rich foods as ready meals were excluded from the replacement scenarios.

This study found that while shifting to Keyhole-compliant foods generally improved nutrient intake, it led to some unintended adverse effects. Specifically, there were reductions in monounsaturated fats, vitamin A, thiamine, and riboflavin. These decreases occurred due to replacing butter, breakfast cereals and certain meat and dairy products with Keyhole-compliant alternatives that contained lower levels of these nutrients.

Younger adolescents showed greater improvements than older adolescents from the modelled replacements in meeting dietary recommendations, particularly for saturated fats, polyunsaturated fats, dietary fibre, and whole grains. Additionally, girls showed a greater reduction (but small in absolute terms) in salt intake compared to boys, likely due to different dietary patterns. However, no significant differences were found based on the other characteristics: parental education level, municipality size, or BMI status. This suggests that while age and sex influenced some dietary outcomes, the Keyhole label's impact was largely consistent across different socioeconomic backgrounds and body weight categories.

Overall, the Keyhole label proved useful for promoting healthier dietary choices, although further strategies beyond the Keyhole label system are needed to more effectively reduce free sugars and salt consumption among adolescents.

Table 8. Intake of energy, nutrients and whole grains in replacement scenarios

Nutrient/ component	Reported intake	50% replacement	100% replacement	100% replacement energy-corrected	Rec.
	Median (p25; p75)				
Energy (kJ)	8338 (6598; 10597)	8194 (6481; 10440)	8070 (6358; 10269)	8338 (6598; 10597)	
Total fat (E%)	34 (30; 39)	33 (29; 38)	32 (28; 36)	32 (28; 36)	25-40
SFA (E%)	13 (11; 16)	12 (11; 14)	11 (9; 13)	11 (10; 13)	<10
MUFA (E%)	13 (11; 15)	13 (10; 15)	12 (10; 14)	12 (10; 14)	10-20
PUFA (E%)	4.4 (3.6; 5.4)	4.9 (4.0; 6.0)	5.4 (4.3; 6.8)	5.3 (4.3; 6.6)	5-10
Protein (E%)	16 (14; 19)	17 (15; 20)	18 (15; 21)	18 (16; 21)	10-20
Carbohydrates (E%)	47 (42; 51)	47 (43; 52)	48 (43; 52)	47 (42; 51)	45-60
Dietary fiber (g/MJ)	2.0 (1.6; 2.5)	2.2 (1.8; 2.7)	2.3 (1.9; 2.9)	2.3 (1.9; 2.8)	2-3[a] >3[b]
Whole grains (g/MJ)	2.4 (1.0; 4.8)	5.3 (3.1; 8.2)	8 (4.7; 12)	7.6 (4.5; 11.4)	7.5[c]
Added sugars (E%)	9 (5.1; 14)	8.8 (4.7; 13)	8.4 (4.3; 13)	8.3 (4.2; 13)	<10
Free sugars (E%)	11 (6.6; 16)	10 (6.2; 15)	10 (5.8; 15)	10 (5.7; 15)	<10
Sodium (g)	3.1 (2.4; 4.1)	3.0 (2.3; 4.0)	3.0 (2.3; 3.9)	3.1 (2.4; 4.1)	2.4
Salt (g)	7.8 (6.0; 10)	7.6 (5.9; 10)	7.5 (5.8; 9.8)	7.8 (6.0; 10)	6.0

[a]Nutrition recommendations 1-17 years old
[b]Nutrition recommendations ≥18 years old
[c]Based on recommendations of 75 g whole grains per 10 MJ (Becker et al., 2012)
SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.
Nutrition recommendations were derived from the Nordic Nutrition Recommendations 2012.
All differences between reported intakes and the Keyhole 100% replacement scenario were statistically significant (p<0.001, Wilcoxon signed rank test).

Discussion

Due to the absence of objective methods for accurately measuring intake of added or free sugars it is crucial to develop and utilise reliable alternative methods. These methods play a vital role in assessing dietary intake and is essential for monitoring adherence to dietary guidelines. This thesis aimed to provide reliable, standardised estimates of added and free sugars, allowing for consistent comparisons and greater transparency in dietary assessments. The developed procedure and application facilitated description and identification of food sources to added and free sugars, and investigation of associations between intakes of added and free sugars and nutrient and food intake in Swedish adolescents. Furthermore, the availability of free sugars food content estimates within the Swedish food composition database enabled investigation of the potential impact of the Keyhole in adolescents' diet, covering all aspects of the Keyhole criteria.

Methodological considerations

The dietary data used in this thesis primarily comprises two different types related to food and nutrient intake: food composition data and food consumption data.

Food composition data refer to the detailed nutritional and chemical information about food items. It includes energy, macro- and micronutrients, and may include other bioactive compounds in individual food items. This type of data is typically compiled in food composition databases, such as the Swedish food composition database, or the food composition data extract to RiksmatenFlexDiet database. Food composition data are fundamental for estimating nutrient intake, formulating dietary guidelines, and assessing the nutritional quality of diets at both individual and population levels. The food composition data provide the fundamental resource that enables the translation of food consumption data into nutrient intake data in individuals.

Food consumption data, on the other hand, describes the dietary intake of individuals or populations. This data can be collected with different types of dietary assessment methods. Food consumption data capture the quantities, types, and frequencies of food items consumed, often categorised by demographic variables like age, sex, or other sociodemographic information. Unlike food composition data, which offers static nutrient profiles of food items, food consumption data can reflect dynamic eating behaviours and dietary trends, offering understandings of dietary diversity, adherence to nutrition recommendations, and the sociodemographic factors influencing food choices.

Both the food composition data and the food consumption data are essential in dietary research, however, have limitations that can affect the accuracy of dietary assessments. Food composition data can suffer from outdated or incomplete nutrient information on individual food items, while food consumption data are prone to self-reporting bias and may not accurately capture usual intake. Recognising these limitations is crucial for improving data collection and interpreting results in nutritional epidemiology and public health research.

Estimating added and free sugars content in foods

In dietary research, particularly for added and free sugars, the absence of objective analytical methods presents a significant challenge. One of the primary strengths of the developed procedure for estimating added and free sugars, and similar methods, is its ability to address this lack of direct analytical techniques for differentiating added and free sugars from naturally occurring sugars in a systematic and largely transparent way.

The origin of this paper (Paper I) stemmed from an initial intention to apply previously established methods for sugars content estimation (Kibblewhite et al., 2017; Louie et al., 2015). However, the application process revealed numerous necessary changes, requiring major adjustments of the procedure to fit the context of the Swedish dietary survey on adolescents. This ultimately led to the development of the systematic procedure utilised here. These findings highlight the complexity involved when researching dietary intake and habits in different settings and contexts.

By providing a systematic framework, the ten-step procedure ensured consistency and transparency in estimating sugars content across a wide variety of foods. The method combined objective measures, such as total sugars content and naturally occurring lactose and fructose within foods, with logical subjective steps, making it both flexible and adaptable to diverse dietary patterns. For example, the inclusion of culturally specific foods like sweetened breads and pickled products in the Swedish context increased its relevance and applicability within the Swedish setting. This could be expanded to an even broader context, with inclusions of even more specific foods added within the established ten-step food categories. The procedure was successfully implemented for the EFSA scientific opinion regarding the tolerable upper intake level for dietary sugars (EFSA Panel on Nutrition et al., 2022), however encountered other methodological issues due to the massive amount of data with varying level of detail from the different European countries (EFSA Panel on Nutrition & Novel Foods and Food Allergens (NDA), 2022a). Furthermore, the procedure is continuously used to update the Swedish food composition database, Figure 9.

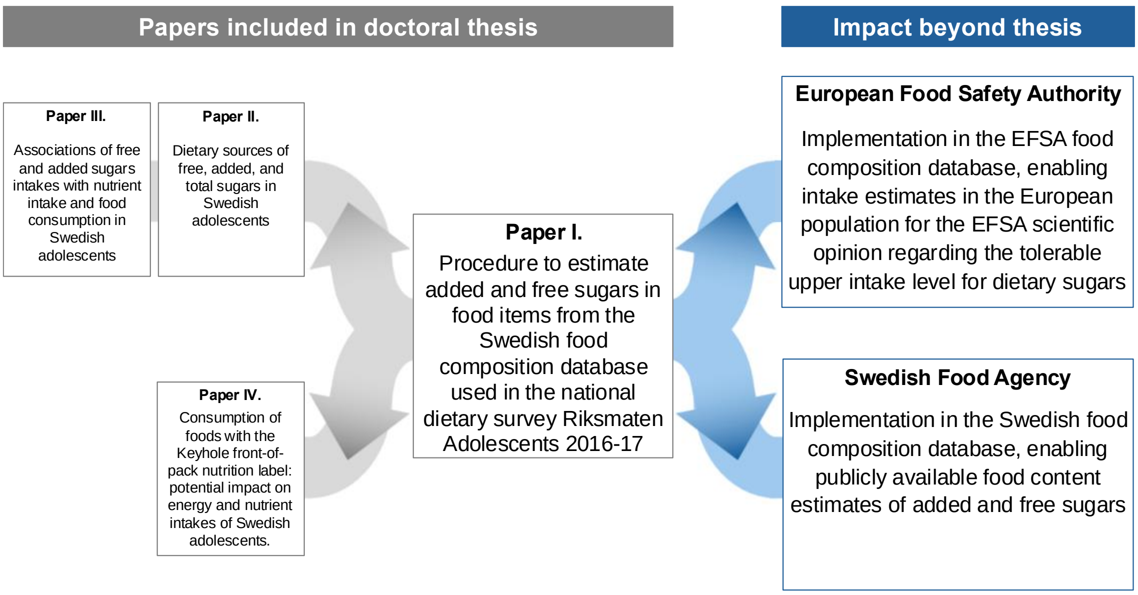


Figure 9. Papers included in thesis and impact beyond thesis

The high proportion of objective steps (92-93% for foods in the Riksmaten-FlexDiet database) minimised the subjectivity and strengthened the reliability of the estimates.

However, the ten-step procedure also has limitations. Despite efforts to minimise subjectivity, a small proportion of estimates still relied on subjective judgments, which introduces a potential risk of variability and biases. These subjective decisions may depend on the expertise and interpretation of the researcher applying the method, which could lead to inconsistencies if the procedure is applied by different teams or in different contexts. If these subjective judgements are made on commonly consumed foods, this can have major consequences in dietary intake evaluations, however this was not the case in the present study.

While the procedure is designed to be systematic, it is time-consuming and requires expertise to implement correctly. This can limit its scalability and be a major limitation in contexts where resources or expertise are lacking. As there are some subjective decisions to the model, estimations cannot be made automatically.

Another key limitation is the fundamental reliance on available food composition data. To achieve appropriate estimates of population intakes of sugars (or any nutrient for that matter) it is essential to have continuous updated food composition data – we eat what is available in-store. If nutrient data for specific foods are incomplete or inaccurate, the estimates may not fully capture the true sugars content. For composite or prepared foods, assumptions about ingredient proportions and preparation methods might oversimplify complex recipes, resulting in less precise estimates. Furthermore, the method does not account for individual differences in food preparation at home or in food production. In this dietary survey, the food list provided participants with a large selection of food items that were specifically selected to suit the dietary habits of the Swedish adolescent population, and the food items had detailed up-to-date nutrient data. While the food list was not designed explicitly to optimise the accuracy of sugars intake estimation, this may introduce some limitations in the precision of the sugars intake assessment. Nonetheless, given the wide variety of food options included and their relevance to the population, the assessed sugars intakes are likely sufficiently accurate for the purposes of this study. However, there are other issues with dietary intake assessment that are more likely to limit the accuracy of the sugars intake assessment.

Strengths and limitations with the dietary recall

The absence of objective methods to capture dietary intake requires our reliance on self-reported dietary data. The dietary data were in this study assessed with what can be described as a computer-administered 24-hour dietary recall. The 24-hour dietary recall method is a widely used method in nutritional research because of its ability to provide detailed information on an individual's food intake over a specific day. One of its primary strengths lies in its capacity to capture a thorough snapshot of dietary intake, which is particularly useful for assessing nutrient intake. Furthermore, the assessment method is relatively low in participant burden, as it typically requires only a short interview (RiksmatenFlexDiet took about 15-30 minutes per one day's registration), and it can be administered multiple times to improve accuracy or modelled with statistical methods to reflect usual intake (Gibson R.S., 2024).

However, there are notable limitations with self-reported dietary data. In 24-hour dietary recalls, the reliance on participants' memory can lead to recall bias, where individuals may forget or misreport their intake. Misreporting may occur due to social desirability bias, which can be described as participants altering their responses to meet perceived social norms or expectations, leading them to underreport foods considered 'unhealthy' or overreport those viewed as 'healthy' (Kirkpatrick S, 2024). Given the negative focus on dietary sugars in media as well as in dietary guidelines during the recent years, this awareness may unconsciously encourage underreporting in dietary intake as individuals become more conscious of a stigma attached to added and free sugars intake.

High sugars contributing foods like SSBs, sweets and chocolates, sweet bakery products and desserts are further often consumed by adolescents in informal contexts outside of main meals (Rebuli et al., 2020; Souza et al., 2022), which was also found in Paper II, and this may complicate accurate reporting. These items may be overlooked or forgotten during the dietary recall, particularly when consumed outside the regular meals or in small quantities. This issue was addressed with the RiksmatenFlexDiet by using probing questions of easily forgotten foods before the submission of the recall, however it is unlikely that this eliminated the issue completely.

Another bias in dietary surveys is self-selection bias. Self-selection bias occurs when participants choose to participate in a study rather than being randomly selected. It is often observed that healthier individuals with healthier dietary habits are more likely to participate in dietary surveys due to e.g., personal interests in diet and health (Young et al., 2020). In Riksmaten Adolescents, school classes were randomly selected for participation to ensure representativeness with regards to demographic factors. The participation rate was rather high, with 60% of the invited adolescent participating in the dietary survey. However, it is uncertain whether these adolescents are representative of the general population in terms of dietary intake. It is likely that those who chose to participate have healthier dietary habits than the general adolescent population, i.e., eating less sugar-rich foods than average, which could introduce further bias in the study results.

Together, these factors highlight the challenges in accurately capturing added and free sugars intake through self-reported 24-hour recalls. Therefore, the results require careful interpretation. It is reasonable to assume that added and free sugars intake are higher among Swedish adolescents than reported within this study.

Despite the inherent limitations associated with self-reported dietary intake assessment which are discussed here, it is important to emphasise the strengths of the dietary assessment methods used in this study. The dietary assessment methods used in Riksmaten Adolescents 2016-17 are carefully considered, taking into account the limitations of self-reported dietary assessment, to collect dietary data in the best possible way in a large-scale study for the intended adolescent population. Additionally, the participation rate of 60% is quite unusual for dietary research, and it reflects a significant engagement level from the invited adolescents. The quality and comprehensiveness of the available food composition data further enhance the reliability of the findings.

Estimating and understanding the need for usual dietary intakes

Information on individual dietary intake is typically assessed over one or a few days, balancing practicality with the difficulty of capturing long-term dietary habits, as done in Riksmaten Adolescents 2016-17, with the two days of retrospective registration included for this study. This approach is fundamental for assessing population-wide dietary patterns, given the unfeasibility of collecting accurate and representative long-term dietary data. However, as food intake is prone to day-to-day variations the intake distribution of these observed short-term individual means is too wide, with both the low- and high-end tails overestimating the frequency of low and high consumption. This make it seem like there are more individuals with very low or very high intakes than there would be if we were observing the long-term intake (as demonstrated in Figure 5). If we compare the number of individuals meeting dietary recommendations based on short term intakes, we are likely to draw the wrong conclusion regarding compliance with guidelines. The differences in compliance with dietary guidelines become particularly significant when the recommendation cut-offs are within the tails of the intake distribution, where small variations in intake can lead to large discrepancies in whether individuals are classified as meeting or not meeting the recommendations, which is the case in terms of added and free sugars intake. There were 16.9% versus 2.7% of adolescents meeting the WHO conditional recommendation of <5 E% of free sugars (Table 7), depending on if we were observing the two day mean intake or the estimated usual intake, which is a substantial difference.

The need for usual dietary intake measurements in research analysis varies according to research question, as exemplified in the background. The level of detail needed from dietary data increases as the research objectives become more complex, and can be expressed as four levels of research objectives (Gibson R.S., 2024). When exploring mean usual dietary intakes of a group (level one), we do not need repeated measures or to model the usual intake as it will be roughly the same, but we need to make sure samples are representative of what is researched. However, when the objective is to determine the proportion of a population that meets a certain reference measure (level two), such as dietary guidelines, it is necessary to capture distributions of usual intake. The usual intake distribution can be estimated from at minimum two days of dietary recalls, which is sufficient to determine the proportion of a population at risk of inadequate intakes for foods and nutrients, with more replicate measures or adjustments needed for episodically consumed foods and nutrients. At level three, objectives are to rank individuals by their usual intake within a group, typically to relate dietary intake with health outcomes. And finally, at level four the objective is to estimate individuals' usual intakes for correlation or regression analyses, such as relating intake with biochemical markers, which requires the highest level of data detail. Therefore, usual intakes measures were needed in Paper I and Paper III, in order to more accurately compare adolescent intake with nutrition recommendations, and to explore trends across the spectrum of free sugars intake. Although, for Paper II, research objectives required population proportions and measures of central tendency only, therefore usual intake measures were not appropriate or necessary. However, some analyses in Paper IV could benefit from usual intake estimates to increase accuracy for, in particular, comparisons between micronutrient intake and requirements (it is published as a supplement to Paper IV). Due to intake data already being modelled in different ways in the intake scenarios, we choose to not also model usual intakes on top of that. However, to demonstrate potential changes in relation to the different scenarios this information was also included, but caution should be taken when interpreting the proportions adhering to the requirements.

The statistical models to estimate usual dietary intakes from short-term intake assessments are all based on one same flawed assumption. The assumption that the dietary recalls are unbiased tools for measuring usual food intake (Dodd et al., 2006). However, the presence of systematic errors must be thought of as unavoidable in all types of self-reported dietary assessment methods. Systematic errors can result in biased estimates of both the mean usual intake and the proportions of individuals meeting dietary recommendations. For instance, if certain food sources are systematically underreported or intake is underestimated due to e.g., limitations in the food composition database used, this may lead to exaggerated estimates of the number of individuals falling below recommended intake levels (Kirkpatrick et al., 2022). As several validation studies have shown misreporting of, in particular energy (Freedman et al., 2014), intake in 24-hour recalls, some foods must be misreported as well. Hence, foods reported with bias in the recall will result in biased usual intake estimates as well. Misreporting may be handled in several ways, e.g., by examining outliers in energy and nutrient intake, or as we did in our sensitivity analyses, by excluding participants with implausible energy intakes. However, it is difficult to distinguish reporting error from the broad spectrum of possible dietary intake values (Schoeller & Westerterp, 2017).

Discussion of results

Added and free sugars intake in Swedish adolescents

A majority of adolescents exceeded the maximum recommended intakes for both added and free sugars, with median intakes of 10 E% and 12 E% (Paper I). As previously mentioned, the same procedure for estimating sugars content was implemented for the EFSA scientific opinion regarding the tolerable upper intake level for dietary sugars (EFSA Panel on Nutrition et al., 2022) on a substantial material of European dietary data. The intake results in Swedish adolescents are within range of European adolescents, however the span was wide, with mean intakes ranging from 5-19 E% and 8-22 E% for added and free sugars respectively (EFSA Panel on Nutrition & Novel Foods and Food Allergens (NDA), 2022b). Compared to previous population based Swedish dietary surveys in children (Enghardt Barbieri et al., 2006) and adults (Amcoff et al., 2012), the reported intake of sugars appears to have decreased among the younger population. Earlier surveys found that approximates of added sugars (calculated as the sum of total sucrose and monosaccharides) accounted for about 13–15% of energy intake in children in 2003 and 11% in younger adults in 2010-11. This decline may reflect changing dietary trends. However, it could be a result from differences in dietary habits between adolescents and younger children and adults, or could be due to differences in methodological approaches. The calculation of added sugars in previous surveys may overestimate the intake as some sugars naturally occurring in fruits and vegetables are included in the added sugars approximates as well.

There were 45% respectively 30% of adolescents meeting the added and free sugars recommendation of a maximum of 10 E%, and only 3% achieving the WHO conditional recommendation of below 5 E%. While reducing added and free sugars consumption is a public health goal, achieving the stricter recommendation may require extensive social changes.

Food sources to added and free sugars

Most added and free sugars consumed by Swedish adolescents comes from nutrient-poor food sources (Paper II). SSBs, including sodas, energy drinks, and cordial, accounted for about a third of the added and free sugars intake, making them the largest single contributor. This is consistent with global patterns where SSBs consistently have been found to be major sources of added and free sugars among adolescents (Amoutzopoulos et al., 2020; Bailey et al., 2018; Jomaa et al., 2021; Kovalskys et al., 2019; Louie et al., 2016; Marinho et al., 2020; Mesana et al., 2018; Monge-Rojas et al., 2022; Ricciuto et al., 2021; Ruiz et al., 2017; Sluik et al., 2016). The high contribution from SSBs is concerning due to their low satiety and provision of 'empty calories', which may result in overconsumption of energy without providing essential nutrients. The top three food categories contributing most to both added and free sugars in Swedish adolescents were all nutrient poor food choices. SSBs, sweets and chocolates, and sweet bakery products and desserts contributed with 70% and 61% to the added and free sugars intake, with the contribution of juice consumption being the main difference between the two definitions.

The foods that mainly contribute to added and free sugars are foods outside of what would be considered essential or necessary for a balanced and healthy diet. Therefore, targets for interventions to limit sugars intake could emphasise not just reducing added and free sugars intake but instead these high sugars contributing food sources as SSBs, sweets and chocolates.

Sugars intake and associations with nutrient and food intake

Higher intakes of added and free sugars are associated with compromised nutrient and food intake in Swedish adolescents (Paper III). All food group intake trends were significant for both absolute intake and intake relative to energy consumption. This indicates that as added and free sugars intakes increase in Swedish adolescents, there is a shift towards less nutrient-dense foods. This shift suggests that higher added and free sugars intakes are associated with dietary patterns favouring less nutritious food options over a balanced diverse diet. Thus, the excess intake of added and free sugars among Swedish adolescents does not appear to be eaten in addition to other healthy foods but rather replacing healthy foods.

A few studies on this matter have suggested higher cut-offs for recommendations than the conventional 10 E% regarding the association with micronutrient dilution and diet quality. Cut-offs have been suggested at 13 E% free sugars in British children and adolescents (Gibson et al., 2016), around 20 E% for Australian children and adolescents (Wong et al., 2019), at 19 E% added sugars for American children and adolescents (Fulgoni et al., 2019), and an optimum intake range of free sugars has been observed between 5-15 E% in Australian adults (Mok et al., 2018).

Conforming to these results, nutrient adequacy in Swedish adolescents were substantially reduced among mid-to-high consumers of added and free sugars, starting from a quintile division in intakes at 11.3 E% added sugars and 12.9 E% free sugars. However, compromised intakes among adolescents with the lowest intakes of added and free sugars intake were not observed. In fact, those who consumed the least generally had the highest nutrient intakes and highest proportions meeting reference values. While there were substantial declines in the number of adolescents meeting nutrient reference values from the 4th added and free sugars intake quintiles (>11.3 E% and >12.9 E%) in our sample, critical nutrients within the diet of Swedish adolescents such as vitamin D, selenium, dietary fiber and PUFA (including vitamin C for added sugars) were distinctly reduced even in lower quintiles. These findings suggest that an intake of no more than 10 E% from free sugars, or potentially lower, would be beneficial to support nutrient adequacy in Swedish adolescents. Consequently, with regards to associations with micronutrient and food intake, it seems plausible to limit consumption of added and free sugars in Swedish adolescents and these findings suggest that an intake of no more than 10 E% from free sugars, or potentially lower, would be beneficial to support nutrient adequacy in Swedish adolescents.

Potential nutritional effects of the Keyhole in adolescents' diet

The findings of Paper IV demonstrated that theoretical replacements of foods in adolescents' diet to meet Keyhole criteria generally improved compliance with nutritional recommendations. These improvements were observed even with partial food replacements, suggesting the potential effectiveness of Keyhole-labelled foods in promoting healthier diets even with smaller dietary changes.

However, reductions in free sugars and salt intake were less pronounced than other nutrients with criterion, largely due to the ineligibility of many high-sugars and high-salt foods for Keyhole labelling. As the Keyhole label is a positive endorsement logo, it is only displayed on foods that are encouraged to be consumed, targeting foods with healthier nutrient profiles than others in the same food category.

The primary sources to free sugars in adolescent diets fall outside the categories eligible for the Keyhole. As the contribution to sugars from the sugar-rich food sources within the diet of Swedish diet was not extensively studied at the time of this modelling study, the potential impact with regards to free sugars could not be estimated beforehand. However, it was known that these food sources are popular foods in the adolescent diet, so the results are not surprising. As the major sources to free sugars intake in Swedish adolescents cannot be labelled with the Keyhole, this limits the potential impact of the Keyhole system on reducing overall sugars consumption, as it cannot directly address these discretionary food choices.

Ethical reflections

Although the application for ethical review and the data collection both were completed and approved before my involvement, I believe it is important to reflect on the ethical considerations. Even though I may not be fully aware of all decisions made, reflecting on potential ethical issues from an external perspective can be valuable. This reflection helps ensure that ethical standards are maintained and highlights the importance of ethical practices in the research process, particularly within the field of Food and Nutrition.

The child and adolescent populations are vulnerable in the research context as there may be challenges in regard to their comprehension and ability to understand the risks and consequences the research is posing (Swedish Research Council & Uppsala University, 2020). In general, children, especially of older age, and adolescents seem to be able to understand the purpose of research and grasp the concept of voluntariness of participation (Crane & Broome, 2017). Nevertheless, this population encounter individual needs and different levels of understanding (Crane & Broome, 2017).

The Swedish Research Council's codex state that 'research on a vulnerable population such as children shall never be performed if it is possible to carry out on another population less vulnerable' (Swedish Research Council & Uppsala University, 2020). In relation to this research, the adolescent study population is obviously necessary to assess information about adolescent food consumption. When capturing dietary intake to enable suitable dietary advice for prevention of potential diet related health issues, it is important to monitor dietary intake of the whole population and thus it is unavoidable to include both children and adolescents.

Balancing ethics, morals, and the possibility of gaining new important knowledge is essential in research, as it ensures that the quest for important scientific discoveries does not compromise the integrity of the research or the well-being of participants. Ethical review is necessary when the research falls within the scope of the law, the Act concerning the Ethical Review of Research Involving

Humans (SFS 2003:460), which is when certain conditions exist, to protect the individual and the respect for human dignity in research (Swedish Research Council, 2024). As this thesis focuses on dietary intake of adolescents, health issues might indirectly be linked to dietary habits. Also, dietary habits may reveal other highly personal information such as cultural factors and social determinants of health (Hurlimann et al., 2017). Individual information collected and included in this thesis was about food intake, body height, body weight, physical activity and information about socioeconomic background. This collected information beyond food intake may also be argued to be crucial for monitoring dietary intake because it may significantly influence dietary habits. Understanding these factors is necessary to develop targeted interventions and promote equitable health outcomes. Apart from these variables, the full survey also included the collection of blood and urine samples. The Riksmaten Adolescents 2016-17 survey was approved by the Regional Ethical Review Board of Uppsala before the start of the study (registration no. 2015/190).

In Riksmaten Adolescents 2016-17 the participants and their legal guardians received information about the study one month prior the start, and the participants who were undergoing biological sampling had to give their written informed consent prior to the study (or their legal guardian). For the remaining participants verbal consent was applied, and the participants agreed to participate by taking part in the dietary survey. During the first day of dietary registration, a research group visited the participants to help them register their food intake, and to present and inform about the study. As the research group started their visit with a presentation of study and were there throughout their first day of registration, the participants should be well-informed about the study. As the two younger age-group were grade 5 and 8 students, they included underaged participants and participants under the age of 15. By agreeing to a verbal consent from the younger adolescents, it is not assured that all participants' legal guardians were aware of the study. Even though the study was approved by an ethical review board, I think it may be morally problematic to include someone's children in research without ensuring they are aware. This also somewhat contradicts SFS 2003:460 §18, which outlines that the legal guardians must be informed.

Another critical ethical concern is that public health recommendations often focus on reducing added or free sugars, yet, in many cases, there is a lack of transparent, reliable data on the added sugar content in foods. Without clear data on these sugars, neither on labels nor in publicly available food composition databases, consumers are left without the necessary details to make informed dietary choices. This undermines their autonomy and unfairly shifts responsibility onto them. This lack of transparency may also worsen health inequities, especially among vulnerable populations. To be ethical and effective, guidelines must be accompanied by improved information, standardised measurements, and supportive policies. This thesis aimed to address these issues.

Conclusions

Adolescents in Sweden consumed, on average, too much sugars with respect to the maximal recommended intake of added and free sugars. Most added and free sugars in the adolescent diet came from nutrient-poor food sources. The top contributors were SSB:s, sweets and chocolates, accounting for 57% of the intake of added sugars and 50% of free sugars. The fundamental difference between the two sugars classifications in intake were free sugars intake from fruit juice. Intakes of added and free sugars were higher during weekends, and the sugars were mostly consumed outside of main meals, predominantly within the home environment. Increased intakes of added and free sugars were associated with a progressively less favourable dietary intake. High-sugars foods with poor nutrient content seemed to replace other more nutritious foods, rather than be eaten in addition to them. With regards to micronutrient intakes, nutrient adequacy was significantly compromised at intake levels above 11.3 E% for added sugars and 12.9 E% for free sugars, however, for critical nutrients within the diet of Swedish adolescents even at much lower intake levels. Thus, intakes of added and free sugars should be kept low in adolescents' diet to maintain a nutritionally adequate diet. A shift to Keyhole alternatives for everyday foods can improve adolescents' overall nutrient intakes, even with smaller replacement in diet. However, the impact on reducing sugars is limited as most contributing sources are not eligible for labelling.

As a few nutritionally poor food groups are the primary sources of added and free sugars in the adolescent diet, refining dietary guidelines to target these specific foods rather than emphasising sugars reduction alone could enhance clarity and effectiveness in public health communication.

Future perspectives

Free sugars or sugar free? – A need for clearer sugars communication

To effectively promote the reduction of added or free sugars intakes in adolescents' diets, as well as in the whole population, it is essential to provide clear guidance. The definitions of added and free sugars and related terms entails several challenges, with one major issue being inconsistency. While free sugars include both added sugars and those naturally present in honey, syrups, and fruit juices, added sugars typically refer only to sugars added during processing or preparation. This overlap can confuse consumers as well as professionals who try to adhere to dietary guidelines and communicate health messages. The term free sugars might at first seem easy to interpret, compared to added sugars with its numerous definitions, yet the free sugars definition unfolds a variety of perspectives including consumer understanding. From a consumer perspective, this definition can be both helpful and difficult as it has not been used for as long in nutrition recommendations or is as straightforward as the term added sugars. Potentially, consumers could easily mix up free sugars with 'sugar free' because the terms sound similar although having fundamentally different meanings. Furthermore, food manufacturers may exploit these inconsistencies to present their products in a more favourable light. The complexity of these definitions highlights a need for clearer, more consistent communication to bridge the gap between research, nutrition recommendations and everyday food choices.

The recent NNR 2023 (Blomhoff et al., 2023) includes recommendations for both added sugars and free sugars, which can be problematic for several reasons. First, because the definitions of added sugars and free sugars overlap but are not identical. This difference can create confusion for consumers, who may not easily distinguish between the two terms when making food choices. Second, having two recommendations can lead to inconsistent interpretations of nutrition recommendations. Consumers, food manufacturers, and health professionals might find it challenging to navigate these distinctions, potentially undermining efforts to reduce overall sugar consumption. By focusing solely on added sugars intake, individuals might feel they are within guidelines by monitoring only these sugars, even if they are consuming significant amounts of free sugars from other sources. This means that someone could technically adhere to the recommendation if only looking at the added sugars definition while still consuming high levels of free sugars. Lastly, from a regulatory and labelling standpoint, the two different definitions complicate the development of clear, standardised labels, which could help consumers to make informed decisions. Overall, while the intentions behind the nutrition recommendations are well-grounded, the dual focus on added and free sugars in the NNR 2023 may accidentally contribute to misunderstandings and hinder effective public health messaging.

Apart from recommending limitations of both added and free sugars in the NNR 2023, there are also recommendations regarding intakes of fruit juice with the science advice being 'Low to moderate intake of fruit juice may be part of a healthy diet. Intake of fruit juice should be limited for children' (Blomhoff et al., 2023). This recommendation somewhat implies another health message than the free sugars recommendation (which could be perceived as 'moderate consumption of fruit juice is healthy for you' versus 'free sugars are not healthy and should be kept low within the diet'). From this thesis and Paper II, we now know that the principal difference between added and free sugars in adolescent consumption lies in fruit juice intake. Hence, you could say that free sugars guidance is stated twice in the recommendations. According to a recent scoping review of the health effects of fruit juice (Rosell & Nyström, 2024) for the NNR, the authors argue that that low to moderate intake of fruit juice is not associated with an apparent risk of chronic diseases. Additionally, that it may have protective effects on cardiovascular disease. However, they conclude that there is limited evidence regarding health effects of fruit juice.

Based on current terms and recommendations it could be sufficient to limit the sugars guidance to explicitly added sugars, with the inclusion of all mono- and disaccharides that are added to foods and beverages (including those in e.g., honey, syrups, fruit and vegetable juices and concentrates when these are added to foods), as the term is well-recognised and quite easy to understand, and keeping the additional recommendations on fruit juice if we want to communicate that fruit juice has different health outcomes than other sources of free sugars. A guidance on limiting added sugars, combined with clear recommendations about fruit juice consumption, provides a robust framework for healthy dietary choices regarding sugars intake.

Bear in mind that both added and free sugars, and the related terms, are 'constructed' nutrients. We are the ones defining which sugars that are included and not, and this is why we cannot objectively measure it – it is not the total amount of mono- and disaccharides in the diet. Even though there are negative health effects associated with both added and free sugars, negative health effects are more clearly attributed to sources of added and free sugars, i.e., particularly SSBs, rather than added or free sugars in general (Mela & Woolner, 2018; Yan et al., 2022). This can be for several reasons such as that sugars from liquid sources are easier to consume in excess as they have been identified to have lower effect on satiety compared to solid foods (Pan & Hu, 2011), that research has been more concentrated to SSBs than other sources of sugars (Yan et al., 2022), and that these sources do not or barely contribute with anything else to the diet than energy in the form of added sugars. Also, SSBs, unlike many other foods, come in standard, pre-packaged serving sizes (such as 33 cl cans or bottles) with labelled nutritional information. This uniformity makes it easier for individuals to report consumption accurately in surveys and for researchers to measure the intakes of added and free sugars from these sources. In contrast, other solid sources to added and free sugars often vary widely in portion sizes, preparation, and ingredient composition, leading to more measurement error and less precise estimates of added or free sugars intake. Consequently, the clarity and consistency in beverage data help produce more robust associations between SSB consumption and adverse health effects.

In Swedish adolescents, a few nutritionally poor food sources primarily contributed to intakes of added and free sugars (Paper II). Also, higher intakes of both added and free sugars were associated with a poorer diet (Paper III), which were mainly driven by the same nutrient poor sources in those consuming more sugars. By shifting dietary guidelines to highlight the primary food sources to added and free sugars, instead of focusing on reducing added or free sugars intakes overall, public health messages could become clearer and more effective.

Future research directions on sugars intake

Continuous representative dietary surveys are necessary for monitoring dietary habits and improving public health. These studies can provide comprehensive dietary information that helps identify dietary trends and patterns in food consumption across different populations. Added and free sugars intake may be different in other populations as well as the major dietary sources. Could adults perhaps allow for a higher relative contribution to sugars intake with regards to micronutrient intake and food consumption, due to healthier dietary habits? Is a different dietary pattern observed in younger children, maybe with higher intakes of juices and sweetened dairy products? By understanding the food patterns, targeted interventions and policies to promote healthier eating habits can be developed, which aids in reducing the prevalence of diet-related diseases. Therefore, it is important that we continue to measure intakes of added and free sugars through these kinds of surveys.

Another perspective to research is how adolescents and their parents are reasoning with regards to sugars consumption and food choices. Are they aware of the major sugar sources and the added and free sugars content within foods? Or are they maybe cutting sugars from everyday foods and neglect the sugars from discretionary foods? Given the complexity of sugars recommendations with its inconsistent and varying definitions, it is plausible that there is a need for enhancing consumer understanding, which is essential for enabling informed dietary decisions that could promote healthier food choices.

Previous research has mostly associated high intakes of added or free sugars to poor health outcomes and dietary intakes, but has most often overlooked the different sources, which could have distinct effects on dietary intake. In paper III, adverse associations of added and free sugars intakes with dietary intake were observed. From these analyses, there was a potential displacement effect observed, however, exploring associations with sources to sugars could help clarify if certain sources more clearly contribute to poor diet quality or nutrient inadequacy. Especially considering that some sources may be eaten together with more nutrient-dense foods. Focusing on the sources to added or free sugars, rather than the total intake, would be valuable to gain deeper understandings for improving diet quality and refining public health strategies.

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Göteborg, February 2025
Julia Wanselius

Svensk sammanfattning

Bakgrund

Konsumtionen av tillsatta och fria sockerarter (eller tillsatt och fritt socker) är kopplad till en rad negativa hälsoeffekter och utgör ett betydande folkhälso-problem globalt. Dock finns det en brist på studier som visar hur mycket av dessa sockerarter som konsumeras. Detta beror främst på en brist på objektiva eller standardiserade mätmetoder för att särskilja intaget av tillsatta och fria sockerarter från naturligt förekommande sockerarter.

Sockerarter är de grundläggande och minsta komponenterna i kolhydrater och består av mono- och disackarider. Ordet socker används ofta synonymt med vanligt strösocker eller sackaros, medan ordet sockerarter på ett mer tydligt sätt anger att det handlar om mono- och disackarider. Därför används här sockerarter som begrepp. Naturligt förkommande sockerarter finns i livsmedel som mjölk, frukt, och grönsaker, men sockerarter tillsätts även livsmedel för smak eller funktion. Eftersom både naturligt förekommande och tillsatta sockerarter har samma kemiska uppbyggnad går det inte att särskilja dem analytiskt.

Ett begränsat intag av framför allt tillsatta sockerarter har rekommenderats globalt såväl som i Sverige under de senaste decennierna, ofta med en rekommendation om ett maximalt intag om 10% av det totala energiintaget (E%). Tillsatta sockerarter definieras på olika sätt av olika aktörer men definitionerna handlar om de sockerarter som tillsätts livsmedel av tillverkare, matlagare eller konsumenter, det vill säga inte om de sockerarter som förekommer naturligt i livsmedel. Under senare tid har rekommendationerna även kommit att handla om fria sockerarter. Fria sockerarter innefattar oftast alla tillsatta sockerarter inklusive de sockerarter som är naturligt förekommande i honung, sirap, samt juice och juicekoncentrat från frukt och grönsaker. I de senaste nordiska närings-rekommendationerna (2023) rekommenderas en begränsning av intaget av både tillsatta och fria sockerarter till maximalt 10 E% men helst lägre.

Ungdomsåren är en avgörande period för att etablera hälsosamma kostvanor då de tenderar att kvarstå i vuxen ålder, vilket har långsiktig påverkan på hälsan. Generellt sett uppfyller inte svenska ungdomars kostvanor rekommendationerna, och ungdomars kost tenderar att ha ett för lågt intag av grönsaker, frukt, kostfiber och fullkorn, samt ett för högt intag av mättat fett, salt och socker. Uppskattningsvis kommer ca 17% av den totala andelen energi i ungdomars kost från godis, kakor, snacks och läsk. Trots detta har inte intaget av tillsatta och fria sockerarter hos svenska ungdomar tidigare identifierats och där med inte heller följsamheten till den begränsning av sockerintaget som rekommenderas i närings-rekommendationerna.

För att främja ett hälsosamt kostintag finns olika hälsofrämjande insatser, där-ibland framsidesmärkningar på livsmedelsförpackningar. Framsidesmärkningar syftar till att ge konsumenter lättillgänglig information om ett livsmedels närings-sammansättning för att hjälpa dem att göra hälsosammare val. Framsides-märkningar bygger ofta på näringsprofilering vilket enligt Världshälso-organisationen är ”vetenskapen om att klassificera eller rangordna livsmedel baserat på deras näringssammansättning för att förebygga sjukdomar och främja hälsa”. I Sverige har den positiva framsidesmärkningen Nyckelhålet använts sedan slutet av 1980-talet och kriterierna har kontinuerligt uppdaterats av Livsmedels-verket, senast 2021. Nyckelhålet benämns som en positiv märkning då märkningen endast sker av livsmedel som uppfyller särskilda kriterier för att vara hälsosammare livsmedelsval. Kriterierna är utformade för att främja en kost med mer kostfiber och fullkorn, hälsosammare fettsammansättning, samt mindre salt och fria sockerarter. Nyckelhålet är en välkänd märkning i Sverige och nästan alla känner till den. Hur en högre andel nyckelhålsmärkta livsmedel påverkar näringsintaget hos svenska ungdomar har dock inte undersökts

Genom mer kunskap om ungdomars intag av tillsatta och fria sockerarter kan riktlinjer och insatser utvecklas för att främja bättre livsmedelsval, vilket i sin tur kan bidra till förbättrad hälsa på längre sikt.

Syfte

Det övergripande syftet med denna sammanläggningsavhandling är att undersöka svenska ungdomars kostintag, specifikt med fokus på konsumtionen av tillsatta och fria sockerarter. Detta undersöks i fyra fristående delarbeten som var och ett besvarar ett särskilt delsyfte.

Det första delsyftet är att utveckla en systematisk metod för att uppskatta intaget av tillsatta och fria sockerarter i livsmedel, att implementera metoden på alla livsmedel som utgör livsmedelsdatabasen i en svensk matvaneundersökning utförd på ungdomar, och vidare att beskriva intaget av tillsatta och fria sockerarter hos svenska ungdomar.

Det andra delsyftet är att beskriva och identifiera bidragande livsmedelskällor till intaget av tillsatta, fria och totala sockerarter bland svenska ungdomar, utforska skillnader i konsumtion av livsmedelskällor till fria sockerarter mellan sociodemografiska grupper, och undersöka när och var fria sockerarter konsumeras.

Det tredje delsyftet är att undersöka associationerna mellan näringsintag, följsamhet till referensvärden för näringsämnen, och livsmedelskonsumtion i relation till intaget av tillsatta respektive fria sockerarter bland svenska ungdomar.

Det fjärde delsyftet är att undersöka de potentiella näringsmässiga effekterna av framsidesmärkningen Nyckelhålet på svenska ungdomar kostintag, genom att modellera ett byte från självrapporterat livsmedelsintag till livsmedel som uppfyller Nyckelhålets kriterier.

Metod

Ett nationellt representativt urval av 3099 ungdomar i årskurs 5, 8 och årskurs 2 på gymnasiet (i åldrarna ca 12, 15 och 18 år) från Livsmedelsverkets matvaneundersökning Riksmaten ungdom 2016-17 utgör det empiriska underlaget för denna avhandling. Riksmaten ungdom 2016-17 var en tvärsnittsstudie som genomfördes under höstterminen 2016 och vårterminen 2017. Det är den första och enda nationella matvaneundersökningen som har genomförts på svenska ungdomar. Ungdomarnas kostintag var självrapporterat under två ej på varandra påföljande dagar med en retrospektiv kostregistrering. En webbaserad metod användes för att samla in information om kostintaget, jämförbar med 24-timmars intervjuer. Kostdatan var insamlad under en period med en representativ fördelning av vardagar (måndag-torsdag) och helgdagar (fredag-söndag). Information om livsmedelssammansättning hämtades från den svenska livsmedelsdatabasen Både data från matvaneundersökningen och livsmedelsdatabasen tillhandahölls av Livsmedelsverket.

En systematisk metod för att på ett kvalificerat sätt uppskatta livsmedelsinnehållet av tillsatta och fria sockerarter utvecklades utifrån två tidigare metoder som utformats i Australien respektive i Nya Zealand. Metoden applicerades på alla livsmedel i livsmedelsdatabasen som användes i Riksmaten ungdom 2016-17, vilket möjliggjorde beräkning av ungdomarnas totala intag av tillsatta och fria sockerarter.

I de fall där intagsnivåer av socker, mikronäringsämnen eller livsmedelsgrupper skulle jämföras med näringsrekommendationer och referensintag mer ingående än i medeltal justerades kostdatan utifrån de två självrapporterade dagarna till uppskattat långtidsintag med Multiple Source Method. Långtidsintag, vilket också kan benämnas som habituellt intag eller vanemässigt intag, innebär den genomsnittliga mängden av ett näringsämne eller livsmedel som en individ konsumerar över en längre tidsperiod. Detta mått är viktigt eftersom det ger en mer rättvis bild av en persons kostvanor och potentiella hälsoeffekter jämfört med kortvariga eller enstaka mätningar av kostintaget. Långtidsintag är också nödvändigt för att mäta följsamhet till näringsrekommendationer, eftersom rekommendationerna är utformade för att uppfyllas över tid.

För att undersöka effekterna av att ersätta livsmedel som inte uppfyller Nyckelhålets kriterier med Nyckelhålsmärkta livsmedel i ungdomars kost modellerades olika scenarier. Livsmedel som inte uppfyllde Nyckelhålets kriterier ersattes med Nyckelhålsmärkta alternativ, där ersättningsnivåerna var 25%, 50%, 75% och 100%. Ett ytterligare scenario modellerades där energiintaget hölls konstant.

Beskrivande, jämförande och prediktiva statistiska analyser utfördes med lämpliga statistiska metoder. Ungdomarnas näringsintag jämfördes främst med rekommendationer och referensvärden från de nordiska näringsrekommendationerna, samt i några fall andra relevanta riktlinjer.

Resultat och konklusion

Resultaten visar i korthet att svenska ungdomar i genomsnitt åt för mycket tillsatta och fria sockerarter i relation till näringsrekommendationerna. Medianintaget av tillsatta och fria sockerarter var 10 E% respektive 12 E%, och 45% respektive 30% av ungdomarna uppfyllde rekommenderade intagsnivåer. De huvudsakliga källorna till socker i ungdomars kost var livsmedel med lågt näringsinnehåll, där de största livsmedelskällorna var sockersötad dryck och godis. Dessa två livsmedelsgrupper stod tillsammans för runt halva intaget av tillsatta och fria sockerarter i ungdomarnas kost. Intaget av fria sockerarter var högre under helgen och sockret åts mest utanför huvudmålen, främst i hemmet. Dessutom observerades ett negativt samband där ett ökande intag av tillsatta och fria sockerarter var associerat med ett mindre och mindre gynnsamt närings- och livsmedelsintag. Resultaten indikerar att vid en högre konsumtion av socker sker intaget på bekostnad av ”vanlig mat”, vilket resulterar i ett sämre kost- och näringsintag över lag.

En övergång till nyckelhålsmärkta alternativ skulle förbättra det totala näringsintaget i ungdomars kost, även vid mindre förändringar i kosten. Resultaten visade framför allt potentiella förbättringar gällande intaget av fullkorn och fiber, samt en förbättrad fettsammansättning i kosten. Generellt skulle även intaget även av mikronäringsämnen förbättras. Effekterna på sockerintaget skulle dock vara begränsade eftersom de största livsmedelskällorna till tillsatta och fria sockerarter inte kan märkas med nyckelhålet.

Eftersom de främsta källorna till tillsatta och fria sockerarter i svenska ungdomars kost är några få näringsfattiga livsmedelsgrupper, skulle en omformulering av rekommendationerna kunna leda till en tydligare kommunikation kring hälsosamma kostvanor. I stället för att fokusera på att minska intaget av tillsatta och fria sockerarter, som är begrepp som kan vara svåra att förstå, skulle man kunna fokusera på att begränsa konsumtionen av dessa livsmedelsgrupper. Detta kan bidra till ett tydligare och mer målgruppsanpassat budskap.

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Sugar is a highly debated nutrient, with excessive intake of added and free sugars being associated with several adverse health effects. Due to a lack of objective or standardised methods to measure intake, there is limited knowledge about consumption, including in Swedish adolescents. This doctoral thesis aims to provide a comprehensive understanding of added and free sugars intake among Swedish adolescents, including its food sources, and its contextual and dietary associations. It also investigates the potential role of the Keyhole symbol in guiding adolescents toward healthier food selections. The thesis presents a systematic approach to quantifying added and free sugars content in the Swedish food composition database, further applied to the Swedish Food Agency's nationally representative dietary survey Riksmaten Adolescents 2016-17, and used to fully investigate the potential impact of all Keyhole nutritional criteria. By shedding light on these aspects of their diet, this research can contribute to informing better dietary practices and public health policies to promote healthier food intakes for adolescents.

Julia Wanselius is a registered dietitian and holds a Master of Medical Science in Clinical Nutrition. Her research interests include public health nutrition.

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