Food Quality and Preference 113 (2024) 105071

Contents lists available at ScienceDirect

Food Quality and Preference

journal homepage: www.elsevier.com/locate/foodqual

Sweet rules: Parental restriction linked to lower free sugar and higher fruit intake in 4–7-year-old children

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ARTICLE INFO

Keywords:
Sweet taste preference
Parental restriction
Children
Sugar consumption
Fruit intake

ABSTRACT

In the Netherlands, 4–8-year-old children consume proportionally the highest amounts of free sugars among all age groups, and in European countries, children's sugar intake exceeds the World Health Organization's recommendation. Restricting children's access to sugary products could help reduce this consumption. However, it is unclear whether and how restriction is linked to children's sugar intake and sweet taste preference. This study investigated the relationship between parental restriction of sugary products, children's free sugar and fruit intake, as well as their sweet taste preference. Parents (N = 243) of 4–7-year-old children were asked to complete a survey that asked for their child's consumption of fruits and free-sugar-containing products via a three-day food recall (three specified, non-consecutive days). Parental restriction was assessed via the Restricted Access Questionnaire. In a subset of children (N = 60), psycho-hedonic functions were mapped using the Monell two-series forced-choice paired comparison tracking test to estimate children's optimal sweet taste preference. Regression analyses showed that more restricted children consumed less free sugars but more fruits than less restricted children as reported by the parents ($p < 0.05$). Parental restriction was unrelated to children's sweet taste preference. In conclusion, our results imply that restriction is negatively linked to free sugar intake, positively linked to fruit consumption, and unrelated to sweet taste preference in 4–8-year-olds. Future research is needed to determine the causal and long-term effects of parental restrictions on children's sugar intake and sweet taste preference.

1. Introduction

In the Netherlands, the consumption of free sugars accounts for 19 % of the total daily energy intake of 4–8-year-old children. This is the highest proportion among all Dutch age groups (RIVM, 2022) and also exceeds the World Health Organization's (WHO) recommendation of keeping free sugar below 10 % of the total daily energy intake (World Health Organization, 2015). This is not only a Dutch problem, with European children consuming on average 16–26 % of their daily calorie intake from sources with added sugars (Azaïs-Braesco et al., 2017). Added sugars refer to mono- and disaccharides (MDS) added to foods and beverages in the preparation process. The term free sugars, in turn, refers to all added sugars plus naturally occurring sugars in products where the original cell structure is broken down, such as fruit - or vegetable juices, concentrates, or purées. Naturally occurring sugars in dairy products, fresh and dried fruits and vegetables, cereal grains, nuts, and seeds are excluded from this (Swan et al., 2018). Total sugars on the other hand include all MDS in the diet, including dairy products and fruit and vegetables with intact cell structures (Mela & Woolner, 2018). While all of the above terms are used in public health guidelines when addressing sugar intake, we refer to free sugars as addressed by the WHO as they were found to be more strongly related to negative health outcomes than added or total sugars (Mela & Woolner, 2018).

Reducing children's free sugar intake is easier said than done. To develop effective strategies, understanding underlying factors contributing to free sugar intake is crucial. Previous research has identified several of those factors: Parent's educational level was negatively associated with young children's intake frequency of sweets (Brekke, van Odijk, & Ludvigsson, 2007), sugar-sweetened beverages, and added sugar intake (Kranz & Siega-Riz, 2002; Vinke et al., 2020). Age was found to be positively associated with sugar intake and sugar-sweetened beverage consumption in childhood but negatively associated with sugar intake after childhood (Azaïs-Braesco et al., 2017; Moraeus et al., 2015; Pawellek et al., 2017). Boys were found to have a higher total

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https://doi.org/10.1016/j.foodqual.2023.105071
Received 9 June 2023; Received in revised form 24 November 2023; Accepted 4 December 2023
Available online 12 December 2023

sugar consumption than girls (Pawellek et al., 2017), and the relationship with BMI is equivocal across genders, with BMI negatively associated with added sugar consumption in eighth-grade girls but positively associated with added sugar consumption in four-year-old boys (Øverby et al., 2004). Lastly, breastfeeding duration was inversely related to children's sugar-sweetened beverage consumption at six years (Perrine et al., 2014). While there seems to be agreement that these factors are related to children's sugar consumption, it is less clear whether or how children's sweet taste preference and sweetness liking are linked to these factors.

Liking is believed to be a strong predictor of food choice and intake, but for children, findings suggest that liking is a better predictor for the intake of less liked than for highly-liked products (Keller et al., 2022). Hence, higher sweetness liking does not necessarily translate into higher sweet food intake in children. Further, while it is widely accepted that humans have an innate preference for sweet taste (Jackson, Jansen & Mallan, 2020; Mennella, 2014; Steiner, 1979), recent research suggests differences in 'sweet liker' phenotypes (Armitage et al., 2021). We can group children into 'sweet likers' and 'dislikers', where the latter group's dislike for sweetness increases at higher sweetness concentrations (Armitage et al., 2021). However, it should be noted that only a minority of children seem to classify as sweet dislikers (Armitage et al., 2021). Similarly, a higher sweet liking may not automatically result in children that have higher sweet food intakes, as parents can restrict access to sweet food and act as a barrier to consumption.

Parents have a big influence on children's eating behavior by regulating the access to and availability of food (De Cosmi et al., 2017; Benton, 2004). At the same time, it has been shown that the relationship between children's eating behaviors and the parents' feeding styles is bidirectional: not only can parents impact the child's eating behavior, but the child can also impact the parent's feeding style (Faith & Kerns, 2005; Jansen et al., 2018). Yet, parents feeding practices and attitudes play a pivotal role in children's food habits and intake (Battram et al., 2016; Scaglioni et al., 2018). As gatekeepers, parents can limit their child's access to sugar through restriction practices (Scaglioni et al., 2008) and this approach is more adopted by parents with a higher educational background (Vereecken et al., 2004). The parental restriction is defined in our study as limiting the number of free-sugar-containing foods and drinks offered to the child and reducing opportunities for the child to consume those products, for example, by not buying them.

In the past, parental restriction was often reported to have negative child outcomes, such as reduced appetite control (Johnson & Birch, 1994), eating in the absence of hunger (Fisher & Birch, 2002), higher snack and sweetened drink consumption (McGowan et al., 2012), and higher weight status (Faith et al., 2004). In contrast, some studies have shown protective effects of restriction on unhealthy weight gain in young children (Campbell et al., 2010) and linked restriction to a lower sucrose preference (Woo & Lee, 2019). In line with those findings, restriction was related to lower consumption of high-calorie snacks and sugar-sweetened beverages among children, when the restriction was defined as a combination of 'overt' and 'covert' control practices, i.e. easily detectable and barely detectable restriction practices (Rodenburg et al., 2014). Since restriction was defined similarly in our study, we expected a negative association between parental restriction and free sugar intake.

It is unclear whether sugary food and drink restrictions are also related to children's fruit consumption with limited research on this relationship to date. One study reported that more restricted 4-year-olds were less likely to consume fruits (Durão et al., 2015) while another study showed no link between restriction and fruit intake in preschoolers (Warkentin et al., 2020). Yet, it has also been reported that prohibiting the consumption of snacks, soft drinks, cookies, and cakes was associated with lower consumption of sweets, chocolate, cookies, and cake, and a higher intake of fruits in 2-year-old children (Gubbels et al., 2009). This is supported by a longitudinal study, in which covert control practices were positively related to 9-year-olds' fruit consumption (Rodenburg et al., 2014). Children may consume more fruits when not allowed to eat other sweet products to soothe the innate preference for sweet taste. Based on these studies, we expected to find a positive relationship between restriction and children's fruit intake.

Current research draws a fragmented picture not only of how the restriction of sugary products relates to children's sugar intake but also to their sweet taste preference. Previous research linked parental restriction to a heightened preference for sugary and fatty foods in 3–7-year-olds (Vollmer & Baietto, 2017), and a heightened sweet taste preference in 5-year-olds (Liem, Mars & De Graaf, 2004). In contrast, when 5–7-year-old children were restricted to eating sugary foods, they showed a lower sweetness preference (Woo & Lee, 2019). Those contrary findings are embedded in the overall discussion of 'sweet adaptation' - whether repeated exposure to sweet-tasting foods and drinks alters sweet taste preference or not. To date, limited research has examined the effect of repeated exposure to sweet-tasting foods and drinks on children's sweet taste preference (Appleton et al., 2018). Findings on the link vary (Appleton et al., 2018), and our recent research did not show a link between sweetness exposure and sweetness liking in infants (Müller et al., 2022). Following these recent findings, we expected parental restriction to be unrelated to children's sweet taste preference in our study.

This study investigated whether and how restricting 4–7-year-old children's consumption of sugary products is related to their free sugar and fruit intake as well as their sweet taste preference. We further explored parental beliefs, attitudes to sugar, and educational levels between those parents who use more and less restrictive practices. To achieve this, we performed a two-step study with 4–7-year-old Dutch children and their parents. First, we conducted an online survey among parents to capture children's sugar and fruit intake, parental restrictions, and background beliefs about sugar. Second, we conducted sweetness preference tests with the children to estimate their preferred level of sweetness. In summary, we hypothesized that parental restriction is negatively associated with free sugar intake but positively related to fruit consumption in children. Further, we expected parental restriction to be unrelated to children's sweet taste preference.

2. Methods

Using a cross-sectional design we investigated the relationship between the restriction of sugary products and 4–7-year old children's free sugar and fruit intake, as well as their sweet taste preference. The study consisted of two consecutive parts. First, an online survey was completed by parents, covering children's free sugar and fruit intake, parental restriction of sugary products, and parents' beliefs about sugar (part 1). Second, sensory tests were conducted with a sub-sample of part 1, to assess children's sweet taste preference (part 2). This study was conducted according to the guidelines laid down in the Declaration of Helsinki. The study protocol was submitted to the medical ethics committee of Wageningen University & Research (METC-WU) and exempted from the obligation to obtain ethics approval as the study was not subject to the Medical Research Involving Human Subjects Act (WMO). Informed consent was obtained from the parents in part 1 as well as in part 2 of the study. The survey was distributed between January and March 2021 and the preference tests were conducted between April and September 2021. The study was conducted during the Covid-19 pandemic and the surveys were distributed while the Netherlands was under a strict lockdown. The preference tests were conducted while some lockdown restrictions were still in place. The lead author has full access to the data reported here and the data can be accessed upon request.

2.1. Study sample

Part 1 (online survey): Potential participants were recruited via newsletters that were distributed via primary schools in the Wageningen region (The Netherlands). In addition, the study was advertised via social media and the EU school fruit newsletter which is sent regularly to around 13,000 parents living in the Netherlands. Interested parents contacted the research team, whereupon they received a comprehensive information brochure on both parts of the study, a document to give informed consent for participation, as well as a personalized link to the online survey. To be eligible for part 1, participants had to be either the parent or main caregiver of a 4–7-year-old child and needed to be proficient in Dutch. Individuals were excluded if the parent perceived the child not to be in full health or when the child had medical problems affecting his/her ability to eat or drink. Participants received a €25 voucher after finishing the survey to thank them for their participation. Survey links were sent to 329 parents from which 294 started the survey.

To ensure the quality of the data derived from the survey, several tools were implemented. For example, participants could not proceed with the survey if they did not answer all required previous questions. In addition, participants who took less than 10 min to complete the survey were excluded because the pilot tests required at least 10 min to answer the survey truthfully. Children's weight and height were checked during data cleaning to remove those with unlikely values (no exclusion of participants). Fifty-one participants were removed from the dataset during data cleaning because they did not complete the survey ($n = 44$), took less than 10 min to complete the survey ($n = 1$), withdrew their participation ($n = 3$), or because their child had medical problems that affected eating/drinking ($n = 1$), had allergies to the study product ($n = 1$), or did not fall within the studied age range ($n = 1$). This led to a final sample of 243 parent–child dyads for the final analyses.

Part 2 (preference tests): Parents could indicate in part 1 whether they and their child were interested in participating in part 2 and from those participants, a sub-set was selected via stratified random sampling. Three strata were built based on parents' level of restrictiveness regarding sugary products: 1) low restrictive tertile 2) middle restrictive tertile 3) highly restrictive tertile. As the aim was to investigate whether higher and lower-restricted children differed in their reported sugar and fruit intake, as well as in their sweet taste preference, participants were selected from the high and low-restrictive tertile. Within those tertiles, clusters were formed based on children's age and sex to invite a comparable number of 4, 5, 6, and 7-year-old boys and girls. Within each cluster, children were randomly selected for participation through a random number generator. A sample of 62 children was involved in part 2. As two children refused to finish the test, the final sample of part 2 consisted of 60 children.

Using the statistical power analysis tool G-Power, the current study was powered based on previous findings by Liem et al. (2004), as we followed a similar study design and investigated parental restriction, sugar intake, and sweet taste preference in a comparable age group. In detail, the effect size (0.22) was obtained through Cohen's d by subtracting the mean sugar consumption of the highly restricted children from the mean sugar consumption of low-restricted children, divided by the standard deviation of the whole population (Liem et al., 2004). We calculated that at least 204 participants were needed for part 1, to detect such an effect size of 0.22 (80 % power, alpha 0.05) for the difference in consumption of sweet foods and drinks between children with high, medium, and low restrictive parents. Similarly, as Liem et al. (2004) found significant differences in sweet taste preference between high and low-restricted children, we chose a medium effect size of 0.45 (80 % power, alpha 0.05) for differences in sweet taste preference between high- and low-restricted children, and calculated that at least 51 participants were needed for part 2. Following that a different test was used to determine sweet taste preference in Liem et al. (2004), no values could be derived from that study to calculate Cohen's d. The requisite sample sizes were achieved for both parts of the present study.

2.2. Measures and survey design

2.2.1. Part 1: Parental survey

The survey was conducted in Dutch via the online survey platform Qualtrics (version 2021) and covered four parts: (1) Child- and family characteristics, (2) A three-day food recall, (3) Parental restriction of sugary products, and (4) Parents' background beliefs about sugar. In the first section of the survey, the following child characteristics were included: the child's date of birth, sex, health status (healthy yes/no), weight, height, food allergies and problems with swallowing and digestion, and the amount of time he/she was breastfed (no differentiation between exclusive/non-exclusive breastfeeding). In addition, the parent who filled out the survey was asked to indicate his/her sex, birth year, country of birth, and highest level of education. Regarding the latter, respondents could choose from six possible answers which were classified into three educational levels. A high educational level referred to university or higher vocational education, a middle educational level to intermediate vocational training, and a low educational level referred to elementary school, intermediate secondary school, or higher secondary school. Based on children's height and weight, their body mass index (BMI) was calculated (weight (kg) / height $(m)^2$) and the BMI percentile was determined via the CDC growth charts to receive a BMI classification (Kuczmarski et al. 2002). The following classifications were used: BMI < 5th percentile = underweight; > 5th and < 85th percentile = normal weight; > 85th and < 95th percentile = overweight; > 95th percentile = obese.

In the second section of the survey, children's habitual free sugar and fruit intakes were reported. A three-day food recall was filled out on one occasion covering two non-consecutive weekdays and one weekend day. This recall was used to estimate children's habitual sugar intake, covering intake frequencies of products containing free sugars based on the following 16 food and drink categories: Sweet milk drinks; Sugar-sweetened (soft) drinks; Sugar-free, non-nutritively sweetened beverages; Non-homemade juices; Candy; Chocolate; Candy bars; Granola-, cereal-, or fruit bars; Small biscuits or gingerbread; Large cookies, cakes or pies; Sweetened yogurt or custard; Sweet desserts other than yogurts and custards; Sweet bread spreads or sugar-containing sweeteners; Sweet cereals; Sweet buns; Dried fruits. Due to the low consumption of sugar-free, non-nutritively sweetened beverages in our sample, we do not discuss their consumption further. For each category, examples were given, such as 'Snickers' in the candy bar food group. Parents were given extensive explanations on how to fill in the template and could further add foods to the list they may have missed. The three-day food recall was designed with the help of a qualified research dietician and categories were determined based on the Dutch National Food Consumption Survey of 2012–2016 covering commonly consumed sweet products by 4–7-year-old Dutch children (RIVM, 2020). Parents were asked to recall the number of portions consumed by their child during six eating occasions (breakfast, morning snack, lunch, afternoon snack, dinner, evening snack) on two weekdays (Tuesday and Thursday) and one weekend day (Saturday).

To estimate children's habitual free sugar consumption, the Dutch food composition table was used (RIVM, 2019). The free sugar content per 100 g of commonly consumed products among each food category was summed and averaged. From this, the average free sugar content per 100 g for each of the 16 food or drink categories was determined and this was used to calculate grams of free sugars per portion according to the portion sizes that were given as references per food group. To calculate an estimated daily consumption, the average free sugar consumption for the three diet recall days was summed and averaged. This was done based on all food categories except the dried fruits category which was grouped together with the fresh fruits (see below). In addition to the 16 categories, children's fresh fruit consumption was assessed by showing a list of fruits including the associated portion sizes for each fruit. Following a similar approach, parents were asked to report the number of consumed fruit portions at each eating occasion of their child for each of the three days of diet recall. Parents were also asked to indicate the fruits most preferred by their child, with a maximum of six fruits they could name. The natural sugar content for one fruit portion was calculated by summing and averaging the natural sugar content of children's six most preferred fruits in our sample. Those were mandarins, apples, bananas, grapes, strawberries, and pears. The average sugar content per fruit portion was multiplied by the number of fruit portions a child consumed. Children's sugar consumption from fresh and dried fruits was summed and averaged for the three days, as dried fruit consumption was very low, with an average daily consumption of 2 g MDS from dried fruits in the sample, and to obtain an average daily consumption of MDS from whole fruits compared to MDS from free sugars. Fresh and dried fruits are hereinafter referred to as fruits.

In the third section of the survey, the level of parental restriction of sugary products was assessed using the Restricted Access Questionnaire (RAQ; Fisher & Birch 1999a). The RAQ consists of nine items. To cover potential differences in food and drink restriction, we assessed each item twice, once for sweet foods and a second time for sweet drinks. The order of the nine items was randomized within the sweet food and sweet drinks group. The nine items are: (1) "Limiting the availability of the food to special occasions; (2) Getting upset if the child obtained the food without asking; (3) Monitoring the child's consumption of the food; (4) Generally limiting the amount consumed; (5) Specifically limiting the portion size; (6) Generally limiting opportunities to consume the food; (7) Specifically limiting when the food is available; (8) Keeping the food out of reach; and (9) Limiting how often the food is in the home" (Fisher & Birch, 1999a). Fruits were not included in this part as parental restriction usually refers to the restriction of unhealthy foods in research.

For each item, parents rated on a 7-point Likert scale (1-strongly disagree, 7-strongly agree) to which extent they agreed or disagreed with the statement. As each of the 9 sweet food restriction items was highly positively correlated with the corresponding sweet beverage restriction item (all $p < 0.001$), we created a summary measure of sweet food and beverage restriction. For that, the score of each statement concerning sweet food was summed and averaged with its corresponding statement regarding sweet beverages. Following that, nine items were generated with scores about the restriction of sweet food and beverages. Higher scores indicated higher restriction of sugary products. The internal consistency for these nine aspects of restriction, as measured by Cronbach's alpha, was 0.85. To receive a single summary measure for the level of parental restriction which can be used for further analyses, we adopted Fisher and Birch's (1999a) method by standardizing and weighting the nine variables using principal components analysis. The Kaiser–Meyer–Olkin measure verified great sampling adequacy for the analysis (KMO = 0.86; Kaiser 1974). All KMO values for individual items were > 0.80, which is well above the acceptable limit of 0.50. The first principal component accounted for roughly 50 % of the variation in the data and was used for further analyses.

In the fourth section of the survey, parents' background beliefs about sugar were assessed using 23 statements with a 5-point scale as used by Liem et al. (2004). Parents were asked to rate their (dis)agreement with each statement (1-strongly disagree, 5-strongly agree). The statements covered three main topics: 1) The modifiability of sweetness preferences, 2) The negative health effect of sugar consumption, and 3) The instrumental function of sweetness (see Table 6). To reduce the influence of one statement on the other, the statements were presented in random order.

2.2.2. Part 2: Sensory tests

A two-series forced choice, paired-comparison tracking test (Mennella & Bobowski, 2016) was used to assess children's sweet taste preference. Due to the Covid-19 restrictions, the test was executed via an online medium (MS Teams) to minimize physical contact between researchers and participants. All materials were prepared in the research unit and delivered to the participants' homes. Each parent–child dyad received five variants of apple juices in semi-transparent bottles (labeled A-E), transparent medicine cups (labeled A-E), a board game-like sheet to place the juices on, and a comic book as a gift for the child. The five beverages were prepared in the research lab, based on previously used recipes, by dissolving different concentrations of sucrose in water and apple juice concentrate (*AH biologische diksap appel*; Table 1; Urbano et al., 2016). The beverages were prepared a maximum of two days before each test and refrigerated throughout. Parents were asked to take the drinks out of the fridge two hours before the test and not let their children eat or drink anything besides water for one hour before the test.

During the session, the parent and the child participated in a video call to virtually meet the researcher. The whole test was set up in the online survey platform Qualtrics to record responses and standardize the test procedure. While the researcher conducted the test with the child, the parents functioned as 'helping hands', for example by putting the correct pair of juices in front of the child. Each of the two series started with juices in the middle range of sweetness (B & D). In series 1, the weaker stimulus was tasted first throughout the whole series. In series 2, the stronger stimulus was tasted first throughout the whole series. This was done to prevent choices were made based on a bias toward the first or second offered option (Mennella & Bobowski, 2016). In between the two series, the child had a three-minute break during which he/she watched a Donald Duck video as a distraction from the choices made before.

The test was presented in a gamified way by asking the child whether he/she would help Donald Duck to pick the best juice for his birthday party to address the child's cognitive development and to meet the challenge of attracting and motivating children to participate in the test procedure (Knof et al., 2011). The first drink (i.e., "B" in Series 1) was poured into the corresponding cup (marked with "B") and placed in Circle 1 on the sheet showing two numbered circles for each pair's testing order. The child was then asked by the researcher to take a sip of the juice. The same was done for the second stimulus and the child was asked to point at or tell which of the two drinks he/she preferred. The parent was instructed to take the cups off the sheet as soon as the child made his/her choice. Each subsequent pair contained the participant's preceding preferred concentration, paired with an adjacent stimulus concentration. This pattern continued until the child chose two consecutive times either the same concentration of sugar paired with both a higher and lower concentration or two times the highest (E) or lowest (A) concentration. After tasting each pair, the child took a sip of water to neutralize the flavor. The child's preferred level of sucrose was then determined as percent in w/v, i.e. the concentration of sucrose in weight/volume, by calculating the geometric mean of the concentrations chosen in the two series as follows:

$$Geometric\ Mean = \sqrt{(series\ 1\ preference) \times (series\ 2\ preference)}$$

2.3. Statistical analysis

Data were analyzed using the statistical package R, version 4.1.1 for Windows. Hypotheses and the analytic plan were pre-specified in the study protocol before data collection. Descriptive statistics were performed to determine means, standard deviations, and ranges for

Table 1
Recipes and sugar level variations[1] for the five drinks used in the preference test.

Solution code	A	B	C	D	E
Apple juice concentrate (ml)	5	5	5	5	5
Water (ml)	105	105	105	105	105
Sugar (g)	0	2.8	7	10.5	17.5
% added sucrose (w/v)	0	2.5	6.4	9.5	15.9
% simple carbohydrates (w/v)	3.9	6.4	10.3	13.4	19.8

[1]Sweetness levels are labelled for each product range from A to E; A corresponding to the lowest sweetness level, E to the highest sweetness level, and C to the medium level. For more details, see Urbano et al. (2016).

continuous variables. Before conducting the main analyses, the outcome variables were checked for outliers and the residuals were checked for normality by examining Q-Q plots, histograms, and Shapiro-Wilks values. Whenever BMI was included in the statistical analyses, the absolute values for BMI were used instead of the BMI classification (i.e. underweight, normal weight, overweight/obese).

Linear regression analyses were conducted to investigate the association between children's free sugar consumption and parental restriction (Model 1.0, n = 243). Due to the abnormal distribution of residuals, the dependent variable (free sugar consumption) was transformed via square root transformation. Potential confounders were added to the initial model. Model 1.1 had a slightly reduced sample size (n = 240) after adjusting for parents' educational level (low, middle, high), the child's sex, age, BMI, and the duration of breastfeeding, due to missing values in education and BMI. An interaction term between restriction and education was incorporated to assess whether parental restriction had a different effect on free sugar intake for different educational levels. Due to the insignificance of the interaction, this data is not reported in this paper. To assess the relationship between fruit consumption and parental restriction, the same analyses as above were performed. Due to non-normality in the distribution of residuals, the dependent variable (fruit consumption) was transformed via square root transformation. Due to missing data, 241 participants were included in Model 2.0. In Model 2.1, we adjusted for parents' educational level (low, middle, high), the child's sex, age, BMI, and the duration of breastfeeding which reduced the sample size slightly due to missing data (n = 239). Again, an interaction term between restriction and education was incorporated to assess whether restriction had a different effect on fruit intake for different educational levels. Similar to above, this data is not reported due to the insignificance of the interaction.

Linear regression analyses were conducted to predict children's sweet taste preference based on the level of parental restriction (Model 3.0, n = 60). Potential confounders were added and Model 3.1 (n = 60) was adjusted for the child's sex, age, BMI, and duration of breastfeeding. Parents' level of education was not included as a confounder in this model as the low education level was under-represented with only one participant. Model 3.2 (n = 60) was adjusted for free sugar and fruit consumption in addition to the child's sex, age, BMI, and duration of breastfeeding.

To investigate differences in parents' motives for sugar restriction between higher and lower restrictive parents, the procedure by Liem et al. (2004) was adopted. For each statement as well as for the three overarching topics (modifiability of sweetness preference, negative health effects of sugar, and instrumental function of sweetness), the mean score and standard deviations were calculated. The internal consistencies for each of the three main topics, as measured by Cronbach's alpha, were 0.40 for the modifiability of sweetness preferences, 0.63 for the negative health effect of sugar consumption, and 0.65 for the instrumental function of sweetness. Due to the low Cronbach's alpha for the modifiability of sweetness preference, only the first seven statements were taken into account for further analysis which improved the internal consistency to a Cronbach's alpha of 0.66. Following Liem et al. (2004), we conducted a Principal Component Analysis and used a median split on the first principal component regarding parental restriction to classify participants as either high- (n = 122) or low-restrictive (n = 121). To assess whether high and low restrictive parents differed in the three overarching topics, an independent samples *t*-test (or Mann-Whitney *U* test in case of missing normal distribution) was performed.

3. Results

3.1. Participants

In part 1, 243 parent–child dyads were included (Table 2), from which a subset of 60 children participated in part 2. The data demonstrate similar proportions regarding children's sex, age, and parents' educational levels in both parts of the study. The majority of children were of normal weight (>70 %), with highly educated parents (58–70 %).

Table 2
Sample characteristics for part 1 (survey) and part 2 (sweetness preference test), (n).

Child characteristics		*Part 1 (n = 243)*		*Part 2 (n = 60)*	
Gender (n)	Boys	127		30	
	Girls	116		30	
Age (n)		*Male*	*Female*	*Male*	*Female*
	4	25	27	7	8
	5	35	39	10	7
	6	38	30	6	7
	7	29	20	7	8
BMI Categories[1] (n)	Underweight	37		9	
	Normal weight	175		44	
	Overweight	18		5	
	Obese	11		2	
Breastfeeding in months (n)	No breastfeeding	63		14	
	>0 to 3 months	57		12	
	4 to 12 months	87		25	
	>12 months	36		9	
Parent characteristics		*Part 1 (n = 243)*		*Part 2 (n = 60)*	
Gender (n)	Men	20		4	
	Women	222		56	
	Other	1		0	
Age (in years)	∅ (Min-Max)	39 (28–55)		40 (30–48)	
Highest level of education[2] (n)	Low	19		1	
	Middle	81		17	
	High	142		42	
	Not reported	1		–	

[1]BMI = Weight (kg)/Height (m)^2; Classification based on CDC growth charts (Kuczmarski et al. 2002).
[2]Low = Elementary school, intermediate secondary school, or higher secondary school; Middle = Intermediate vocational training; High = University or higher vocational education

3.2. Children's sugar intake

Parents completed food recalls covering three separate days and 16 food and drink categories to provide insight into their child's habitual sugar intake. We found that children habitually consumed on average 103 ± 36 g (range: 37 – 256 g) MDS per day of which 79 ± 35 g (range: 11 – 222 g) came from free sugars and 24 ± 12 g (range: 0 – 73 g) from fruits. The latter corresponded to 2 ± 1 (range: 0 – 6) portions of fresh fruits daily. Sugar-sweetened (soft) drinks contributed the most to children's free-sugar intake with almost 30 % of intake, followed by sweetened yogurts and desserts (~18 %; see Fig. 1). The results show that children in our sample consumed on average more free sugar than recommended.

3.3. Parental restriction

To examine how strict parents were regarding their children's consumption of sugary products, the RAQ scores were analyzed. We found a normal distribution of restriction with parents scoring on average 4.5 ± 0.9 (range: 1.9 – 6.8). This indicates that parents scored on average close to neutral but were heterogeneous in their scores, as shown by the range.

3.4. Children's sweet taste preference

The results of the two-series forced-choice paired comparison tracking test (Mennella & Bobowski, 2016) showed that children's most preferred level of sucrose was 13.6 ± 4.1 % w/v (range: 6.4 – 19.8 % w/v). This corresponds to 13.6 g ± 4.1 g sugar in 100 g solution, which is higher than the sugar content in a Coca-Cola (10.6 g sugar per ~ 100

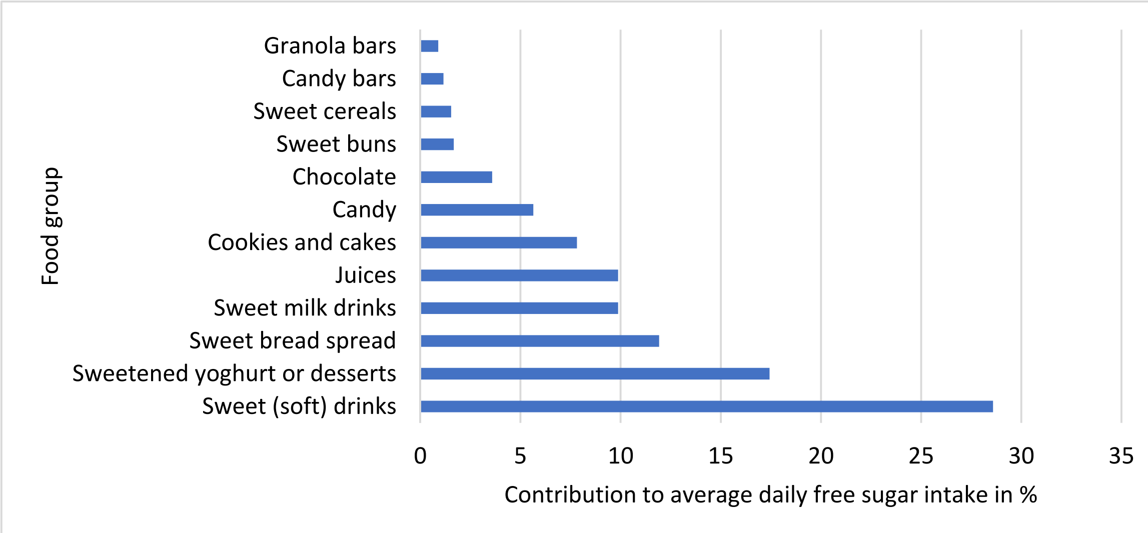

Fig. 1. Contributions of the different food groups (in %) to children's daily average free sugar intake (all food group contributions together equals 100% of children's daily average free sugar intake); Of the 16 food groups, fruits, and sugar-free, non-nutritively sweetened beverages are not represented here as they do not contain free sugars; The food groups 'small biscuits' and 'large cookies/cakes' are summarized as 'cookies and cakes'; The food groups 'sweetened yogurt' and 'other sweet desserts' are summarized as 'sweetened yogurt or desserts'.

ml). This suggests that children preferred on average the sweeter drinks over the less sweet drinks. Most children (63 %) chose the same or next closest concentration in series 1 and 2 (e.g. children who chose "C" in series 1 chose "B" in series 2). For 23 % of the children, the choice differed by 2, for 8 % by 3, and 5 % by 4 between series 1 and 2.

3.5. *Parental restriction, sugar intake and sweet taste preference*

To examine how parental restriction related to children's free-sugar and fruit intake, linear regression analyses were conducted. A higher level of parental restriction was associated with lower free-sugar consumption (Table 3; Models 1.0 and 1.1), and this pattern remained the same when controlling for parents' educational level (low, middle, high), the child's sex, age, BMI, and duration of breastfeeding (Model 1.1). The results imply that for every one-unit increase in parental restriction, children's free sugar consumption is estimated to decrease by 0.08 g (Model 1.0).

By contrast, linear regression analyses showed that a higher level of parental restriction was associated with higher fruit intake (Table 4; Model 2.0) and was again stable when controlling for parents' educational level (low, middle, high), the child's sex, age, BMI, and duration of breastfeeding (Model 2.1). The results imply that for every one-unit increase in parental restriction, children's natural consumption coming from fruits is estimated to increase by 0.05 g (Model 2.0).

Table 3
Regression models investigating the relationship between children's free sugar consumption (dependent variable) and parental restriction [β (Standard Error)].

Independent and outcome variable	Model 1.0	Model 1.1
Observations (n)	243	240
Parental restriction (PC1)[1]	−0.08*** (<0.001)	−0.07*** (0.01)
Parents' education		
Middle level		−0.01 (0.11)
High level		−0.25* (0.11)
Children's gender		−0.00 (0.06)
Children's age		0.01 (0.03)
Children's BMI		0.02 (0.02)
Duration of breastfeeding in months		−0.01*** (0.00)
Adjusted R-Squared	0.11	0.21

[1]PC1 = Principal Component 1.
*p <.05; ** p <.01; *** p <.001.

Table 4
Regression models investigating the relationship between children's fruit consumption (dependent variable) and parental restriction [β (Standard Error)].

Independent and outcome variable	Model 2.0	Model 2.1
Observations (n)	241	239
Parental restriction (PC1)[1]	0.05** (0.02)	0.04** (0.02)
Parents' education		
Middle level		0.19 (0.13)
High level		0.26* (0.13)
Children's gender		−0.02 (0.07)
Children's age		−0.01 (0.03)
Children's BMI		0.03 (0.02)
Duration of breastfeeding in months		0.01 (0.00)
Adjusted R-Squared	0.03	0.06

[1]PC1 = Principal Component 1.
*p <.05; ** p <.01; *** p <.001.

To examine how parental restriction was related to children's sweet taste preference, linear regression analyses were conducted. These demonstrated no association between parental restriction and children's sweet taste preference (Table 5; Model 3.0). This stayed the same when controlling for the child's sex, age, BMI, and duration of breastfeeding (Model 3.1) as well as when controlling for free sugar and fruit consumption (Model 3.2).

Table 5
Regression models investigating the relationship between children's sweet taste preference (dependent variable) and parental restriction [β (Standard Error)].

Independent and outcome variable	Model 3.0	Model 3.1	Model 3.2
Observations (n)	60	60	60
Parental restriction (PC1)[1]	0.41 (0.21)	0.40 (0.20)	0.33 (0.22)
Children's gender		−1.01 (1.09)	−1.11 (1.11)
Children's age		0.92 (0.49)	0.92 (0.50)
Children's BMI		−0.26 (0.31)	−0.27 (0.32)
Duration of breastfeeding in months		0.05 (0.07)	0.03 (0.08)
Free sugar consumption			−0.01 (0.02)
Sugar consumption from fruits			−0.02 (0.04)
Adjusted R-Squared	0.05	0.06	0.04

[1] PC1 = Principal Component 1

3.6. Background beliefs about sugar of higher and lower restricted parents

To explore whether higher- and lower-restrictive parents differed in their beliefs about sugar, parents rated their agreement or disagreement with statements about the modifiability of sweetness preferences, the negative health effect of sugar consumption, and the instrumental function of sweetness (Table 6). We found that higher restrictive parents believed stronger in the negative health effect of sugar ($W = 4186$, $p < 0.001$) and the modifiability of sweetness preferences ($t(241) = -4.72$, $p < 0.001$), compared to lower restrictive parents. No significant difference was observed regarding the instrumental function of sweetness ($t(241) = 0.76$, $p = 0.45$).

4. Discussion

This study sought to understand how the restriction of sugary products is linked to children's sugar consumption, fruit intake and sweet taste preferences. We showed that parental restriction was negatively associated with children's free sugar intake but positively associated with children's fruit intake. We found no link between parental restriction and children's sweet taste preference.

Table 6
Parents' background beliefs regarding restriction of sugary foods (Mean ± SD).

	Low restrictive N = 122	High restrictive N = 121
Negative health effect of sugar***	3.6 ± 0.5	4.0 ± 0.5
When children eat too much of sweet foods, they will eat less healthy foods	3.4 ± 1.0	3.9 ± 0.9
Children will grow fat after eating many sweet foods	3.7 ± 0.9	4.1 ± 0.8
Sweet foods are usually unhealthy for children	3.3 ± 0.9	3.7 ± 0.9
Eating too much sugar is bad for children	4.4 ± 0.6	4.6 ± 0.5
As long as my child brushes his/her teeth, I do not have to limit his/her sugar consumption[2]	4.3 ± 0.7	4.7 ± 0.6
Sweet foods will make kids more active	2.9 ± 1.0	3.2 ± 1.1
Children will become hyperactive from eating many sweet foods	3.4 ± 1.0	3.7 ± 1.1
Modifiability of sweetness preference***	2.8 ± 0.4	3.0 ± 0.4
A sweet tooth is caused by predisposition rather than upbringing[1]	3.4 ± 1.0	3.7 ± 1.0
The fewer sweet foods your child eats, the lower his or her appetite for sweet foods will be	2.1 ± 0.8	2.2 ± 0.8
Children just like sweet foods and there is nothing you can do about it[1]	3.3 ± 1.0	3.5 ± 1.1
When your child likes many sweet foods, you gave him/her too many of them	2.2 ± 0.8	2.4 ± 0.9
Eating sweet foods causes children to become less sensitive to other flavors	2.7 ± 0.8	3.1 ± 1.0
You can teach children to like sweets less	3.1 ± 0.9	3.4 ± 1.1
The less candy you give your child, the less he/she will like it	3.2 ± 1.0	3.6 ± 1.0
If I do not set rules, my child will only eat sweet foods[22]	2.5 ± 1.1	3.0 ± 1.2
By prohibiting sweet foods, they will become more attractive[2]	3.8 ± 0.9	3.5 ± 1.1
Children simply need a lot of energy which they mainly get from sugar[2]	1.8 ± 0.7	1.9 ± 0.8
The instrumental function of sweetness	2.6 ± 0.6	2.6 ± 0.7
Sweetness is one of the most pleasant things in life for children	2.0 ± 0.9	2.4 ± 1.1
Withholding sweet foods from children is unkind	2.7 ± 1.0	2.4 ± 1.1
Sweet foods can sometimes soften pain	2.3 ± 1.1	2.1 ± 0.9
Sweet foods can sometimes easily be used as a reward	2.8 ± 1.1	2.8 ± 1.2
Sweet foods can sometimes easily be used as comfort	2.5 ± 1.0	2.5 ± 1.2
Sweet foods can sometimes easily be used as a treat	3.4 ± 0.9	3.4 ± 1.0

[1]Reversed scores.
Low restrictive = less strict than half of all the participants (<median); High restrictive = as strict or stricter than half of all the participants (≥median).
***p <.000 = High and low restrictive group differ from each other (in the present study).
[2]Statement not included in comparing the difference in the main topics in the two groups, excluded in analysis to increase Cronbach's alpha.

The children in our study who were more restricted had a lower intake of free sugars compared to their less restricted peers. This is consistent with research by Park, Li, and Birch (2015) who reported that 6-year-olds who were restricted to consuming sweets and 'junk' food, consumed sugar-sweetened beverages less frequently. Stronger parental control practices have been shown to predict lower energy-dense snack and sugar-sweetened beverage intake one year later among 9-year-old children (Rodenburg et al., 2014). Conversely, lower restriction of sweets has been linked to a higher intake frequency of sweets at 5–7 years of age (Woo et al., 2019). Taken together, these findings imply that restriction is associated with lower free sugar intake in children. This link could be bi-directional: Parental restriction could lead to lower free sugar intake on the one hand, but on the other hand, children who consume less free sugar, for example, because of sweet-disliker phenotypes (Armitage et al., 2021), could also be easier to restrict.

Notably, higher-restricted children consumed more fruits in our study than lower-restricted children. This is in line with a previous study where a positive association between parental control and children's fruit intake was found (Rodenburg et al., 2014). Several explanations are conceivable for this positive relationship. First, when not allowed to consume sugary products, children may try to compensate by consuming naturally sweet foods, such as fruits. Similarly, parents that use restrictions may offer fruits when sweet/sugary products are requested by their child. It is also plausible that children that are more restricted live in households where more fruits are available and consumed. This is supported by a study among households with 3–6-year-old children, where higher fruit and vegetable availability in the home was negatively related to sweets consumption and positively related to fruit consumption (Vepsäläinen et al., 2018). Similarly, the availability of foods with added sugars has been positively associated with sweets intake in the same study. Parents that apply more restrictions are also more likely to be health conscious which is supported by our finding that stricter parents held stronger beliefs in the negative health impact of sugar and the modifiability of children's sweet taste preference. By imposing restriction rules, these parents may believe that restriction could help to alter their child's preference for sweet foods and beverages, and as such restrict added sugar intake while providing access to sweet-tasting fruits.

We found no association between parental restriction and children's sweet taste preference, which is in contrast to previous research. Woo and Lee (2019) reported a negative relationship between sweets restriction and children's sucrose preference in Korean 5–7-year-olds. Whereas other studies reported a positive relationship between restriction and sweet taste preference in Dutch 4–5-year-olds (Liem, Mars, & de Graaf, 2004), and between restriction and preference for sugary and fatty foods in US 3–7-year-olds (Vollmer & Baietto, 2017). These contrasting findings reflect the heterogenous evidence about whether repeated exposure can alter sweet taste preference or not, which is still under debate (Appleton et al., 2018). Recent studies have shown no link between sweet taste exposure and sweet taste preference in infants (Müller et al., 2022), and repeated exposure to a sweet breakfast did not affect taste pleasantness, motivation to eat, or the perceived sweetness level of sweet foods in adults (Appleton et al., 2022). By considering restriction as a form of limited sweet taste exposure, these recent studies did not show a sustained link between sweet taste exposure and sweet taste preference. General sweet taste preference may be more stable and rather set by genetic differences (Armitage et al., 2021) rather than restriction of taste exposure. Furthermore, sweet taste preference may not be the best indicator of whether children consume sweet foods and beverages or not. In children, disliking may be a better predictor for the lower intake of less-liked products, than a predictor for the intake of highly-liked products (Keller et al., 2022).

Our findings suggest that restricting the intake of products containing free sugars is associated with lower reported free sugar and higher reported fruit intake patterns, while not being linked to sweet taste preference in 4–7-year-old children. There remain several reasons to be cautious about recommending wholesale restriction of sweets without further consideration. Our results are observational and therefore do not allow us to conclude a causal relationship between parental restrictions and children's sugar intake. Parental restriction may have impacted children's free sugar and fruit intake in our sample but it is also possible that children's consumption patterns impacted parents' use of restriction. Parents and children have a bi-directional relationship, where the parent can influence the child's behavior, but the parent's feeding practices and restrictions are also informed by the child's behaviors (Faith & Kerns, 2005). Previous research has shown that children's weight status was a significant predictor of the level of restriction mothers imposed (Fisher & Birch, 1999a). Further, a link between obesity and restriction was only found for children born at high risk for obesity (Faith & Kerns, 2005). It is therefore plausible that parents are more restrictive in response to a demanding child with a strong appetite for sweet foods and drinks. As such, restrictions may help to reduce sugar intake while the child remains in a restricted environment, but the current results do not allow us to draw any conclusions about whether restriction negatively impacts sugar intake when the child is in an unrestricted food environment.

Even if restriction would lead to excessive sugar consumption in an unrestricted environment, we need to weigh up whether it is not more beneficial to limit children's daily sugar consumption through restriction and accept that they may consume larger amounts of sugar on rare occasions when being unrestricted. A high sugar environment may promote overconsumption, regardless of whether the child usually experiences restrictions or not. It was recently shown that children as young as 18 months tended to eat in the absence of hunger when presented with palatable snack foods, both sweet and savory, after dinner (Schultink et al., 2021). Children's inborn preference for sweet taste (Jackson, Jansen & Mallan, 2020; Mennella, 2014; Steiner, 1979) could be one of the drivers for eating sweet snack foods without being hungry, independently of restrictions in their home environment.

Differences in the parental approach to how sweet food restrictions are enforced may also play an important role in the effectiveness of these approaches to limit sweet food intake. Overt control of the child's access to sweet foods is perceived by the child and often communicated openly, whereas covert control is more subtle and less perceived by the child (Ogden, Reynolds, & Smith, 2006). Overt and covert restrictions may impact children's behavior differentially in unrestricted settings. In three experimental studies, 3–5-year-old (Fisher & Birch, 1999b; Rollins et al., 2014), and 5–7-year-old children (Jansen et al., 2008) were made fully aware of being restricted. During the experiment, restricted foods were kept in a clear jar, visible and within reach for the children (Fisher & Birch, 1999b; Rollins et al., 2014) or placed in front of them (Jansen et al., 2008). After the intervention, the children were allowed to eat these foods for a few minutes without restriction, and findings showed that overt control led to increased consumption of the restricted food items (Fisher & Birch, 1999b; Jansen et al., 2008; Rollins et al., 2014). The use of such overt control practices may introduce a 'scarcity bias', which is a psychological effect that increases the desire for rare products/objects, also linked to the 'forbidden fruit' effect (Gibbon et al., 2020). Research suggests that children as young as five years are prone to scarcity bias where children presented with objects either scarce or abundant in number, are more prone to choose the scarce object (Ferera, Benozio & Diesendruck, 2020).

Our findings are in line with what is known from previous dietary survey data, that children frequently consume high amounts of free sugars. In 2016, the Dutch National Institute for Public Health and the Environment (RIVM) reported that 4–8-year-old Dutch children consumed on average 71–81 g of added sugar daily (Ocké et al., 2005). This is in line with our sample which had an average estimated habitual intake of 80 g of free sugars per day. If we take sucrose as an exemplary sugar source, the intake would translate to roughly 320 kcal. For 4–7-year-olds who have an energy intake of around 1200–1400 kcal/day, this means that they get around 23–27 % of their total daily energy intake from free sugars. This exceeds the WHO's recommendation of keeping the contribution of free sugar below 10 % of children's daily energy intake (World Health Organization, 2015).

A combination of strategies, of which restriction may be one, will be needed to lower free sugar intake and meet dietary recommendations for energy from sugar. This is confirmed by the relatively small effects of the correlations between restriction and free sugar and fruit consumption. It was estimated that for every one-unit increase in parental restriction children's free sugar consumption would decrease by 0.08 g per day while their fruit consumption would increase by 0.05 g per day. Hence, it is unlikely that restriction alone would result in meaningful changes in children's free sugar intake, but rather the combination of several interrelated strategies. When creating those strategies, it will be important to give special attention to lower-educated families as our exploratory result showed that children from higher-educated parents consumed less free sugars and more fruits than their peers from lower-educated parents. One might argue that this is mediated through restriction as previous research has shown that parents from a higher-education background tend to use restrictions more often (Vereecken et al., 2004). We did not find this link in our sample. Further, several other studies also reported a higher fruit intake in children from higher-educated parents (Rodenburg et al., 2012; Bassul et al., 2020; Lehtho et al., 2015), which is potentially caused by a higher health literacy of those parents (Van der Heide et al., 2013).

Our results demonstrate that parental restriction of free-sugar-containing products is linked to a lower reported added sugar intake, and a higher reported fruit intake, while not being related to children's sweet taste preference. Further research is needed to confirm those findings through longitudinal studies, focusing on restrictions and child free-sugar intake before recommending the use of restrictions to parents. Further, experimental research with well-designed restriction interventions is needed to distinguish between the effect of overt versus covert restriction and to prove a causal effect of restriction on children's sugar intake and sweet taste preference. How parents enforce restriction may be key to its effectiveness and long-term impact. The most promising approach may be to use covert restriction to create healthier home environments by having fewer sugary products and more fruit within children's reach and sight. This may lead to fewer occasions being confronted with sugary products (Vepsäläinen et al., 2018). However, we should keep in mind that every child is different and restrictions may have different effects on individuals based on children's personalities and their regulatory and appetitive tendencies (Rollins et al., 2014).

The current study had several strengths including adequate power, and relatively large sample sizes in our analyses compared to previous research. This is one of the few studies that has also taken fruit consumption into account when investigating the link between parental restriction and sugar intake. This gives a more comprehensive picture and increased explanatory power than only assessing the relationship considering free sugar intake (FAO, 2018; Pawellek et al., 2017). The dietary reported data in the current trial was also quite robust, as children's sugar consumption was estimated through multiple food recalls which reduced errors and increased the reliability of this method (FAO, 2018).

The study is not without its limitations and although the RAQ showed good internal consistency, and is a validated tool to assess restriction (Fisher & Birch, 1999a), it is important to acknowledge that this could be measured more precisely by using nine restriction items for each of our 16 food categories separately. We chose not to use this approach in the current trial due to respondent burden, and instead as a compromise assessed the nine items separately for sweet food and drinks to acknowledge that restrictions may differ between those groups. In addition, the survey of the current study was completed during the Covid-19 pandemic while The Netherlands was under a lockdown. Sweet food and beverage consumption of our participants may have differed compared to before the pandemic. However, over 80 percent of Dutch adults did not change their eating behavior during the Covid-19 lockdown in 2020 (Poelman et al., 2021). Based on this, we assume that children's sugar intake was comparable to pre-pandemic levels. This is supported by the fact that free sugar intake in our sample was comparable to previously recorded intake data of Dutch children (RIVM, 2016).

Also, since the food recalls were filled in by parents, social desirability bias may have led to an overreport of fresh fruits and an underreport of sugary products in line with social norms. However, if anything, a higher sugar intake than already reported would have led to even stronger results. We aimed to address this in the data collection phase by reminding parents throughout the survey that it was anonymous and that truthful answers were most valuable. Still, higher restrictive parents may have under-reported their child's consumption of free-sugar-containing products to be consistent with their restriction level. However, if that was the case, it is unlikely to have been provoked by the questionnaire as parents were unaware that they would be asked about their restriction level later in the survey when filling in the food recalls. Lastly, the three food recalls were reported by parents on one day for three specified days of the preceding week, which may be less accurate than reporting children's intake for the last 24 h on three different days. However, we wanted to cover all aspects in one survey to reduce the burden on parents. The inclusion of three food recalls on two weekdays and one weekend day instead of one 24-hour recall was considered the best compromise between the effort for parents and the accuracy of the measurement.

To conclude, we found that a higher level of parental restriction regarding sugary products is associated with lower free sugar intake and higher fruit consumption in 4–7-year-old children while not being linked to their sweet taste preference. Children's sugar consumption still exceeds public health recommendations which emphasizes the importance of finding effective strategies to reduce children's sugar intake. Shifting our understanding of restriction towards limiting the possibilities to consume sugary products instead of actively communicating restriction rules to children could be a promising strategy to explore in the future.

5. Ethics

This study was conducted according to the guidelines laid down in the Declaration of Helsinki. The study protocol was submitted to the medical ethics committee of Wageningen University & Research (METC-WU) and exempted from the obligation to obtain ethics approval as the study was not subject to the Medical Research Involving Human Subjects Act (WMO).

CRediT authorship contribution statement

Carina Mueller: Data curation, Conceptualization, Project administration, Methodology, Writing – original draft, Formal analysis, Visualization. **Gertrude G. Zeinstra:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Ciarán G. Forde:** Supervision, Writing – review & editing. **Gerry Jager:** Funding acquisition, Conceptualization, Methodology, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Carina Mueller reports financial support was provided by Horizon Europe.

Data availability

Data will be made available on request.

Acknowledgements

The authors wish to thank the children and parents who took part in the present study, as well as MSc-students L. van Seeters and J. Augusson for their help with data collection and Dr J. Paulo for her statistical support.

Financial support

This work was supported by the European Union's horizon 2020 research and innovation program under the Edulia project, a Marie Sklodowska-Curie Innovative Training Network program [grant agreement No. 764985].

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