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Sweet and sour sips: No effect of repeated exposure to sweet or sour-tasting sugary drinks on children's sweetness preference and liking

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ABSTRACT

Health agencies advocate reducing children's sweetness exposure to lower sweetness preference or liking to ultimately lower sugar intake. However, the relationship between sweetness exposure, preference, and liking remains unclear. This work investigated the influence of exposure to a sucrose-containing sweet or sour-tasting drink on sweetness preference and liking for sweet and sour products in 4-7-year-old children ($n = 65$). The children were randomized into three groups with one daily exposure to either the sweet drink, sour drink, or water (control group) for 14 days. Sweetness preference was assessed at baseline (t1), day 15 (t2), and two months after the intervention (t3), using a forced-choice, paired comparison test with five beverages varying in sweetness intensity. Hedonic liking for the intervention drinks, a sweet and sour yogurt, and a sweet and sour candy was evaluated using a 5-point pictorial scale. Linear mixed models revealed a significant increase in sweetness preference from t1 to t3 ($F(2) = 7.46$, $p < 0.001$). However, ANCOVA analysis indicated that this effect was not caused by the intervention. Based on linear mixed models, we observed that children's hedonic liking for sweet and sour products remained stable from t1 to t3 and was not influenced by the intervention. These findings suggest that 14 exposures to a sucrose-containing sweet or sour-tasting drink did not affect sweetness preference or liking in 4-7-year-old children.

1. Introduction

The World Health Organization (WHO) recommends that both children and adults consume less than 10% of their total daily energy intake through free sugars (World Health Organization, 2020). Several public health organizations even recommend reducing exposure to sweet-tasting foods and drinks in general (European Commission, 2015; Public Health England, 2015; Pan American Health Organization, 2016). The rationale behind this is that fewer exposures to sweet taste would lower an individual's sweetness preference and liking and support a lower free sugar intake (Appleton, Rajska, Warwick, & Rogers, 2022; Cheon, Reister, Hunter, & Mattes, 2021). Free sugars are mono- and disaccharides intentionally incorporated into products (i.e. added sugars), and sugars that occur naturally in food and beverages when the original cellular structure is disrupted (e.g. fruit juices) (Swan, Powell, Knowles, Bush, & Levy, 2018).

Children's sugar consumption is greatly influenced by parents through passing on their dietary habits. Limiting access to sugary products would allow them to reduce their child's exposure to sweet tastes and follow the advice given by public health agencies (Mahmood, Flores-Barrantes, Moreno, Manios, & Gonzalez-Gil, 2021; Prada et al., 2021; Scaglioni, Salvioni, & Galimberti, 2008). However, despite the recommendations, the factors influencing sweetness preference and liking remain largely unclear (Cheon et al., 2021) and consistent evidence supporting a link between sweetness exposure, preference, and liking is missing (Appleton, Tuorila, Bertenshaw, De Graaf, & Mela, 2018; Nehring, Kostka, von Kries, & Rehfuess, 2015; Venditti et al., 2020). As such it remains unclear whether sweetness preference and liking can be altered by limiting sweetness exposure and based on this, whether public health organizations should advise limiting sweetness exposure to reduce preferences and thereby reduce children's free sugar intake.

Although it has been consistently demonstrated that repeated exposure to certain tastes and flavors can influence liking and intake in children through mere exposure, this effect has been predominantly shown for initially disliked foods such as bitter vegetables (Anzman-Frasca, Savage, Marini, Fisher, & Birch, 2012; Hausner, Olsen, & Møller, 2012; Lanigan, Bailey, Jackson, & Shea, 2019; Sullivan & Birch, 1994;

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Zeinstra, Vrijhof, & Kremer, 2018). The effect of mere exposure on the innately liked sweet taste is less clear (Mennella, 2014; Steiner, 1979). A systematic review including 21 studies with a total of 3433 children and adults concluded that there was no convincing evidence for an effect of repeated sweetness exposure on general sweetness preference or liking. While a negative trend between sweetness exposure and preference was observed in short-term intervention studies, ambiguous effects of exposure on preference were found in longer-term intervention and cohort studies (Appleton et al., 2018). The former could be related to sensory-specific satiety (SSS) which refers to the natural short-term decline in the hedonic valence of a stimulus during consumption which leads to satiation of the food consumed. While SSS can transfer to other products in adults, in children it appears to be product-specific (Olsen, Ritz, Hartvig, & Møller, 2011). Hence, SSS may only impact children's short-term preference or liking for the product they were exposed to.

Evidence from observational and experimental studies completed to date cannot establish a clear link between sweetness exposure, preference, and liking. For example, no association was found between added sugar intake and sweetness preference in 5-10-year-old children (Mennella, Finkbeiner, Lipchock, Hwang, & Reed, 2014), or between sweet food intake at 3-6 or 10-12 months and infants' sweetness liking at 6 or 12 months (Müller et al., 2023). Similarly, in an experimental study, adults' liking for sweetened yogurt did not change after two or ten exposures to it (Frøst, 2006). Further, whether adults ate a sweetened breakfast for three weeks did not influence sweet food intake or preferences, motivation or pleasantness to eat, or perceived sweetness of sweet foods at breakfast or lunchtime (Appleton et al., 2022). Also in another study, eating a sweetened breakfast neither influenced adults' appetite, nor intake of sweet foods later in the day (Carroll et al., 2020).

By contrast, preference has been shown to increase after repeated exposure to sweet products in intervention studies with infants and children. Yet, this did not translate into a heightened preference for other sweet products (Beauchamp & Moran, 1982, 1984; Sullivan & Birch, 1990). Interestingly, Liem, Gie, de Graaf, and Cees (2004) found that drinking a sweet lemonade for 8 days increased 6- to 11-year-old children's preference for this beverage, whereas drinking a sour-tasting lemonade with the same sugar content did not change their preference for this sour beverage. In the studies mentioned, it is unlikely that SSS had an effect on preference or liking, as the concept would only explain a decrease in preference or liking, not an increase or no association as found in the studies.

These contrasting results raise questions as to whether sweetness preference and liking can be altered through repeated sweetness exposure, and whether these changes in preference only occur when the sweet taste is presented as sucrose (perceived) or also occur when the sweet taste is masked (Liem & de Graaf, 2004). This is particularly interesting because many sugary foods consumed by children, such as candy, often contain citric acid, which reduces product perceived sweetness intensity through mixture suppression with sour tastes (Junge et al., 2020). To our knowledge, there has not been an intervention study to investigate whether repeated exposure to a 'sour tasting' sucrose-containing beverage affects sweetness preference differently from exposure to a 'sweet tasting' sucrose-containing beverage when the flavors used for the exposure and preference measures are different. Previously an existing effect of repeated sweetness exposure on preference or liking has only been demonstrated for the same 'sweet tasting' (Beauchamp & Moran, 1982, 1984; Sullivan & Birch, 1990), or the same 'sweet' or 'sour tasting' sucrose-containing products (Liem & de Graaf, 2004).

The current study is a randomized controlled trial to test the impact of sweetness exposure, on preference, and liking of sweet foods (Appleton et al., 2018; Nehring, Kostka, von Kries, Rüdiger, & Rehfuess, 2015). The study aimed to assess whether 14 days of exposure to a sucrose-containing 'sweet' or 'sour-tasting' beverage would alter children's liking for that drink, for other sweet or sour products, and their general sweetness preference. We further investigated whether any potential change in sweetness preference or liking could be sustained over two months. The secondary objective of the study was to examine observationally whether children's habitual exposure to sweet foods was related to their parents' habitual exposure, to get a sense of children's usual sweetness exposure alongside the intervention. We included both aspects, preference, and liking, in our research because they reflect different concepts, although they are often used interchangeably in the literature. While both concepts are incorporated into sweet taste hedonics, (i.e. how much someone enjoys sweetness), liking is an absolute rating of acceptance. Preference, however, is a discrete choice between options that provides a comparative measure between sweetness intensity levels (Cheon et al., 2021).

We hypothesized that (i) children's sweetness preference would not be affected by repeated exposure to the sweet or sour-tasting sucrose-containing drink and that it would be stable throughout the study period. We expected (ii) children's hedonic liking for the tested drinks (acceptance) to increase throughout the exposure period, but not affect their overall liking for other sweet and sweet-sour-tasting semi-solid or solid foods. We further hypothesized that (iii) children's habitual sweetness exposure would be positively linked to that of their parents.

2. Methods

2.1. Design

We conducted a randomized controlled parallel-group trial in which parents offered their children either a sucrose-containing, sweet-tasting strawberry-flavored drink (sweet group), sour-tasting strawberry-flavored drink (sour group), or water (control group) for 14 consecutive days at home. Sweetness preference and liking tests were conducted on day 0 (baseline, t1), day 15 (post-intervention, t2), and two months after t2 (follow-up, t3). Parents filled in an online survey at baseline and post-intervention. While a strawberry flavor was used for the intervention drinks, an orange flavor was used for the sweetness preference test to rule out possible changes in sweetness preference would be caused by children becoming accustomed to the intervention drinks (mere exposure effect).

This study was conducted according to the guidelines laid down in the Declaration of Helsinki. The protocol was pre-registered at https://doi.org/10.17605/OSF.IO/PGMHU and the hypotheses were specified prior to data collection. The authors have full access to the data reported in this manuscript and access can be provided upon request. The study protocol was exempted from review by the medical ethics committee of Wageningen University & Research (METC-WU). Written informed consent was obtained from the parents at the beginning of the study when they received the participant information brochure and the baseline survey.

2.2. Participants

We recruited 4-7-year-old Dutch-speaking children and their parents throughout the Netherlands, aiming to recruit a broad and diverse sample. Several channels were used for recruitment, such as primary schools, social media platforms, and the 'EU-Schoolfruit newsletter'. The newsletter is part of a program aimed at promoting fruit and vegetable consumption in school children and is sent regularly to parents throughout the Netherlands. Parents were informed that the purpose of the study was to explore whether children's preference for sweet taste can be altered through sweet food consumption. They were further informed about the random assignment to one of the three study arms to ensure that they were willing to give their children sweet drinks or water. The children were eligible for participation if they were between 4 and 7 years old and were perceived as healthy by their parents. Multiple children from one family were allowed to enroll in the study if they met the eligibility criteria. Children were excluded from the study if they had medical problems influencing their ability to eat or drink, or if they had allergies or intolerances to any of the ingredients or products consumed in the study. A child's data was excluded from the analyses if they consumed the study drink less than 8 times and/or drank on average less than 50 ml/day over the 14-day intervention period.

The study was powered based on the results from Liem et al. (2004), as we followed a similar study design and focused on a similar age group to investigate changes in sweetness preference and liking after repeated sweetness exposure. As Liem et al. (2004; n = 59) found that sweetness preference increased in the sweet exposure but not in the control group, we used a low to medium effect size of 0.35 (80% power, alpha 0.05) to detect a potential shift in sweetness preference following three repeated measures and a three-parallel arm design. A total of 57 children were required with 19 children per group. The calculation was completed using the statistical power analysis tool G*Power 3.1. Sixty-nine children were enrolled in the study to allow for attrition rates of 20%. Four children dropped out due to sickness and three children were excluded from the final sample as they had less than 8 exposures or consumed less than an average of 50 ml during the 14-day intervention. A final sample of 62 children were included in the analyses, including 13 sibling pairs. Stratified random sampling was used to assign a comparable number of 4-, 5-, 6-, and 7-year-old boys and girls, and a comparable number of sibling pairs to each of the three study arms and was completed using a random number generator. Siblings were assigned to the same intervention group by randomizing the younger child to one of the groups and allocating the sibling to the same group. That was done to avoid parents accidently mixing up the siblings' intervention drinks.

2.3. Sensory tests

Each of the three test sessions started with the sweetness preference test, followed by a 3-min break, and then the hedonic liking test. The sensory tests were conducted at home to provide a familiar environment for the children and to include participants from different parts of the Netherlands. Parents received five orange-flavored drinks, labeled A-E, corresponding medicine cups, sweet and sour yogurt, strawberry-flavored drinks, and candy, a board game-like sheet, a 5-point smiley scale, and a small gift for the child. All materials were prepared in the research unit and sent to the families via refrigerated courier. Parents were instructed to keep the drinks and yogurt in the refrigerator until 2 h before the test session to ensure they were at room temperature during testing. They were further told not to give their children anything to eat or drink besides water for at least 1 h before the test. Adherence for this was checked at the beginning of each test session by asking the parent whether the child ate/drank anything within the last hour. On test days, a researcher met online with the child and one of the parents via video call (MS Teams). While the researcher led the child through the test, the caregiver placed the correct product in front of the child. Sensory tests were framed as a game, including child-friendly stories, videos, and a small gift after each test session to meet children's level of cognitive development and keep them motivated to finish the tests (Knof, Lanfer, Bildstein, Buchecker, & Hilz, 2011).

2.3.1. Sweetness preference

The Monell two-series, forced-choice, paired-comparison tracking method (Mennella, Lukasewycz, Griffith, & Beauchamp, 2011) was conducted to assess children's most preferred levels of sweetness. The test is validated for use with this age group (Mennella, Julie, Lukasewycz, Griffith, & Beauchamp, 2011) and has been successfully applied within a similar sample of Dutch children in a previous study (Mueller, Zeinstra, Forde, & Jager, 2023). In brief, children were presented with pairs of sweet solutions from a maximum of five orange-flavored solutions (A-E). Those differed in sweetness intensity levels, i.e. the concentration of sucrose in percent (%) in weight/volume (w/v) by adding sugar (Van Gilse Fijne Kristalsuiker) to the base solution consisting of 10 ml of sirup (Karvan Cevitam Orange, 55 g sugar/100 ml syrup) and 100 ml of water to receive the following concentration levels: A: 5% w/v, B: 8% w/v, C: 14% w/v, D: 25% w/v, E: 35% w/v.

At the beginning of the test, parents were asked to fill all cups with the corresponding solutions and place one pair of drinks on the board game sheet in the order told by the researcher. For each pair, the child was asked to take a sip of the first drink, keep the stimulus in his/her mouth as long as the researcher counted aloud for 3 s, swallow it, and do the same with the second drink. Next, he/she was asked to point at or tell which of the two he/she preferred. Parents were instructed to take the cups off the sheet as soon as the child had finished tasting, after which the child took a sip of still water to cleanse their palate. The child was then again presented with his/her preferred solution, paired with an adjacent stimulus concentration. This procedure was repeated until the child chose two consecutive times either the same concentration when paired with the next higher and lower concentration or the highest (E) or lowest (A) concentration.

Each series started with solutions B and D, which were in the middle range of sweetness. In series 1, the less sweet stimulus was presented first throughout the series. In series 2, the sweeter stimulus was presented first. This was done to reduce a bias towards the first or second presented drink (Mennella & Bobowski, 2016). Between series 1 and 2, the child was given a 3-min break while watching a comic video. Based on the preferred stimuli in series 1 and 2, the child's sweetness preference (in % in w/v) was determined through the geometric mean as follows:

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

2.3.2. Hedonic liking

Children's hedonic liking for solid, semi-solid, and liquid sweet and sweet-sour stimuli was assessed by rating their liking for sweet and sour candy, yogurt, and strawberry-flavored drinks on a 5-point-pictorial scale (1 = dislike a lot, 5 = like a lot). The order in which the child tasted the sweet and sour strawberry-flavored drinks, yogurt, and candy was randomized. However, the child always tasted both the sweet and sour versions, of each product before tasting the next product pair. Within each product, the order between sweet and sour was randomized. Sweet and sour products were labeled with numbers and only referred to with those numbers. At the beginning of the liking test, the researcher first familiarized the child with the scale by telling him which product the researcher liked and which smiley it corresponded to. The child was then asked to do the same. After tasting a stimulus, children were asked to point to the corresponding smiley face on the Likert scale. If the child was unsure how much they liked the candy, yogurt, and strawberry-flavored drink, he/she could taste it one more time. In case they still could not decide, it was noted as a missing value (n = 3, across all 3 time points). After tasting a sample, the child rinsed their mouth with tap water before tasting the next one.

For the candy, we used commercially available sweet and sour tasting fruit candy laces (Hitschler® Schnüre, 50 g sugar/100 g, and Hitschler® saure Schnüre, 59 g sugar/100 g + citric acid). Each child received two pieces 5 cm in length of sweet and sour candy and was asked to eat a piece. For the yogurt, we added sugar (Van Gilse Fijne Kristalsuiker) to plain yogurt (Campina yogurt, 2 % fat, 4.7 g sugar/100 ml) to receive a sweet (9 g sugar/100 g yogurt) and sour version (3 g sugar/100 g yogurt). Each child received 50 g of each yogurt and was asked to rate their liking after taking one teaspoon (corresponding to around 5 g). For the strawberry-flavored drinks, we prepared the same solutions as used in the intervention to determine whether children liked the product more after being exposed to it for 14 days (recipe below). Each child was asked to take a sip of the sweet and sour strawberry-flavored drink from transparent 30 ml cups.

2.4. Taste exposure intervention

Parents in the sweet and sour group received 14 bottles of the intervention drink delivered to their homes. The stimuli were prepared in the research unit and brought to parents in four refrigerated shipments. Parents were asked to store the intervention drinks in the refrigerator and take one bottle out of the fridge at least 1 h before giving it to their child every day. Parents in the control group did not receive any bottles but were asked to use tap water to reduce the number of shipments. All parents were instructed to offer their child 250 ml of tap water or one bottle of the provided strawberry-flavored drink (250 ml) in a familiar cup every day for the 14-day intervention. Parents were asked to give the intervention drink instead of a drink that is given to the child habitually. All parents received a printed two-week overview scheme on which they could indicate whether the child consumed nothing, ¼, ½, ¾, or everything from the study drink for each intervention day. Children were offered but not forced to drink the study drinks.

For the intervention drinks, we used a strawberry sirup (Karvan Cevitam Strawberry, 66 g sugar/100 ml) as a fruit flavor carrier to which we added sugar to meet the sweetness level of commercially available drinks. In detail, for the sweet drink, 9 ml of syrup was mixed with 191 ml of plain water and 12 g of added sugar (Van Gilse Fijne Kristalsuiker), resulting in 9 % w/v sugar. This was the same for the sour drink except for adding 0.6 g of citric acid to create a sour taste and suppress the sweet taste (Pelletier, Lawless, & Horne, 2004; Schifferstein & Frijters, 1990). Halfway through the study, the producer changed the recipe of the strawberry syrup (from 66 g sugar/100 ml syrup to 56 g sugar/100 ml syrup). This resulted in a 0.5 g difference in sugar per 250 ml bottle in the second half of the study compared to the first half. There was no difference in perceived taste intensity between old and new recipes noted by the research team, so the study recipe was kept the same for the duration of the intervention.

2.5. Surveys

Both, the baseline and post-intervention surveys were conducted in Dutch in the online survey platform Qualtrics and filled in by the parent/caregiver who was mainly responsible for feeding the child. Regarding the included siblings, the same parent completed the survey for both children. Hence, parental data was the same for the sibling pairs.

2.5.1. Baseline survey

The baseline survey covered the parent's relation to the child (e.g. being the mother), sex, self-measured height and weight, educational level, and the educational level of the partner. Further, we asked for the child's sex, health status, food allergies, medical problems with eating and drinking, height, weight, birth date, and breastfeeding duration. Based on parents' and children's height and weight, their body mass index (BMI) was calculated (weight (kg)/height (m)^2). Parents' BMI classification was determined based on the World Health Organization's (WHO) cut-offs, and children's BMI classification was determined based on cut-off values published by the Dutch Nutrition Center (Lanting, de Wolff, van Zoonen, & Schönbeck, 2019). In addition, we assessed children's familiarity with the same (e.g. Karvan Cevitam Strawberry) and similar products (e.g. strawberry-flavored drinks) used in the study.

Further, we assessed habitual sugar intake through two identical food frequency questionnaires (FFQ), filled out by the parent separately for themselves and their child. We used the following 18 food groups which were determined together with a qualified dietician: Sweet milk drinks; Sugar-sweetened (soft) drinks; Sugar-free, non-nutritively sweetened beverages; Commercial fruit 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 (such as honey or sugar added to products); Sweet cereals; Sweet buns; Dried fruits; Fresh fruits (other than citrus); Fresh citrus fruits.

The frequency categories needed to be applicable for products consumed once a week but also products that might be consumed several days a week. Hence, parents were asked to report the child's usual consumption of each of the food groups based on the following consumption frequencies: Never or less than once per week; 1-2 times per week; 3-4 times per week; 5-6 times per week; 7 times per week; 2-3 times per day; 4 times per day or more often. Each weekly category was divided by 7 to calculate the daily exposure. The middle of the interval was used when a range was given, i.e. 1-2 times per week was calculated as:$((1 + 2)/2)/7 = 0.21$ times per day. Next, all 18 exposures were summed to receive a rough daily sweet taste exposure value. This indicated how often the child was habitually exposed to sweet tastes. The same procedure was followed to calculate the parent's average habitual sweet taste exposure.

2.5.2. Post-intervention survey

Parents were asked in the post-intervention survey to indicate the amount their child drank from the study drink for each of the 14 intervention days separately. For that, they were asked to use the 2-week overview scheme provided at the beginning of the study, which they were asked to hang on the fridge during the intervention. Further, parents reported whether the child consumed roughly the same amount, more, or less sweet foods and drinks as usual during the intervention period.

2.6. Statistical analysis

Statistical analyses were performed using R, version 4.1.1 for Windows. Results are shown as mean values and standard deviations. Inferences were made based on P-values, regression coefficients, and confidence intervals (CI). Missing data were considered at random because they were due to missing test products or children being sick. Before modeling, we assessed the assumptions of linearity, homoscedasticity, and normality of residuals through the Shapiro-Wilk test, Levene's test, scatterplots, Q-Q plots, and histograms. For the Linear Mixed Model (LMM) approaches, we used restricted maximum likelihood estimation to obtain the parameter estimates and standard errors. The significance of the fixed effects was assessed using the Anova Type II Wald chi-square test and calculated the corresponding p-values. The effect size of the treatment was calculated using Cohen's d. Siblings were handled as individual participants. Yet, living in the same family may lead to similar sweetness exposure and sugar intake. Hence, whether children belonged to one of the sibling pairs was accounted for in all of the analyses.

To assess whether children's sweetness preference was altered by the intervention, we performed an ANCOVA which is the most efficient approach to analyze pre-post randomized designs (Wan, 2021). The relationship between post-intervention sweetness preference (dependent variable) and baseline sweetness preference was assessed while controlling for the group (sweet, sour, control; model 1). Pairwise comparisons with Bonferroni corrections were conducted to investigate differences in sweetness preference scores between the three groups while adjusting for multiple comparisons. An interaction term between the group (sweet, sour, control) and baseline sweetness preference was introduced but removed from the final models due to non-significance. Further, based on the literature and the directed acyclic graph (DAG) method, the following potential confounders were added to the model one by one to check for significance: the child's age, sex, BMI, habitual sweet taste exposure, whether the child consumed anything besides water the hour before the post-intervention test, whether the child consumed a comparable amount of sweet foods and drinks during the intervention according to the caregiver, whether the child belonged to one of the sibling pairs, and the average amount drunk of the intervention drink/water over the 14 intervention days. None of the confounders were significant, nor influenced the outcome values, and were therefore removed from the final model (model 1).

We conducted a linear mixed model (LMM) to investigate whether children's sweetness preference was stable over the study period. We included random intercepts for each participant to account for individual variability in sweetness preference. Sweetness preference (dependent variable) was modeled as a function of the fixed effects of the time (baseline, post-intervention, follow-up), and group (sweet, sour, control), as well as time and group interaction. As the interaction was not significant, it was removed from the final model (model 2). The same confounders as mentioned above were added to the model one by one to check for significance. The following three confounders were significant and added in model 3: Whether the child consumed anything besides water the hour before the post-intervention test ($p < 0.01$), the child's sex ($p < 0.05$), and whether the child belonged to a sibling pair ($p < 0.01$).

We used a linear mixed model (LMM) to investigate whether the intervention had an effect on hedonic liking for sweet and sour candy, yogurt, and strawberry-flavored drinks, as this approach can handle missing values and paired data (Gabrio, Plumpton, Banerjee, & Leurent, 2022). We included random intercepts for each participant to account for individual variability in hedonic liking. Hedonic liking (dependent variable) was modeled as a function of the fixed effects of the product (candy, yogurt, and strawberry-flavored drink), taste (sweet, or sour), time (baseline, post-intervention, and follow-up), and group (sweet, sour, or control), as well as their interactions. All non-significant interactions were excluded from the final models. Following that, the crude model only included the product-taste interaction ($p < 0.001$, model 4). The same confounders as above were added to the crude model, but removed again as they were non-significant and did not influence the outcome significantly.

To assess whether the child's habitual sweet taste exposure (dependent variable) was linked to the parent's habitual sweet taste exposure (who filled in the baseline survey; independent variable), multiple linear regressions were conducted (model 5). Further, based on the literature, the following confounders were added to the crude model one by one: the parent's education, the parent's partner's education, and the child's sex, height, BMI, breastfeeding duration, and whether the child belonged to a sibling pair. Again, none of the confounders were significant, did not influence the outcome significantly, and were removed from the final model.

3. Results

3.1. Subjects

Children ($n = 62$) were on average 5.5 years old, mainly of normal weight (79%) and female (61%; Table 1). Thirteen sibling pairs were included in our sample, of which four pairs were in the sweet, five in the sour, and four in the control group. There was no difference in sex ($F(1, 60) = 0.07$, $p = 0.79$, $\eta 2 = 0.001$), age ($F(1, 60) = 0.01$, $p = 0.95$, $\eta 2 < 0.001$), BMI ($F(1, 58) = 3.84$, $p = 0.06$, $\eta 2 = 0.06$), breastfeeding duration ($F(1, 60) = 0.75$, $p = 0.39$, $\eta 2 = 0.01$), or habitual sweetness exposure at baseline ($F(1, 60) = 0.97$, $p = 0.33$, $\eta 2 = 0.02$) between the three intervention groups.

The majority of the participating parents were female (87%), highly educated (73%), and around half of them were of normal weight (Table 1).

3.2. Familiarity with test products

The majority of children (53%) were unfamiliar with orange-flavored lemonade, and only 28% of them had ever drunk the specific syrup we used in the sweetness preference test (Karvan Cévitam Orange). Yet, most of the children (75%) were familiar with strawberry-flavored drink and 50% of them had already consumed the specific

Table 1
Child and parent characteristics.

	Sweet Group (n = 22)	Sour Group (n = 21)	Control Group (n = 19)	Total (n = 62)
Children's characteristics				
Age (years)	5.6 ± 1.1	5.4 ± 1.3	5.5 ± 1.3	5.5 ± 1.2
Sex (n)				
Male	9 (40.9 %)	8 (38.1 %)	7 (36.8 %)	24 (38.7 %)
Female	13 (59.1 %)	13 (61.9 %)	12 (63.2 %)	38 (61.3 %)
Height (cm)	120.3 ± 10.3	116.6 ± 10.6	117.2 ± 11.6	118.1 ± 10.8
Weight (kg)	22.2 ± 4.3	19.8 ± 4.1	24 ± 7.4	21.9 ± 5.5
BMI (kg/m^2)[a] (n)				
Severe underweight	1 (4.6 %)	3 (14.3 %)	–	4 (6.5 %)
Underweight	1 (4.6 %)	1 (4.8 %)	–	2 (3.2 %)
Normal weight	19 (86.4 %)	15 (71.4 %)	15 (79) %)	49 (79 %)
Overweight	1 (4.6 %)	2 (9.5 %)	1 (5.3 %)	4 (6.5 %)
Obese	–	–	1 (5.3 %)	1 (1.6 %)
Missing	–	–	2 (10.4 %)	2 (3.2 %)
Breastfeeding (months)	6.6 ± 6.3	10.4 ± 10.7	4.2 ± 4.8	7.2 ± 8
Habitual sweetness exposure (daily frequency)	7.3 ± 2.1	7.6 ± 2.2	6.6 ± 2.5	7.2 ± 2.3
Parents' characteristics				
Sex (n)				
Male	3 (13.6 %)	1 (4.8 %)	4 (21.1 %)	8 (12.9 %)
Female	19 (86.4 %)	20 (95.2 %)	15 (79 %)	54 (87.1 %)
Height (cm)	172.4 ± 8.4	169.1 ± 6.7	169.5 ± 5.8	170.4 ± 7.2
Weight (kg)	71.3 ± 15.1	69 ± 10	75.4 ± 15.6	71.7 ± 13.7
BMI (kg/m^2)[b] (n)				
Underweight	2 (9.1 %)	–	1 (5.3 %)	3 (4.8 %)
Normal weight	13 (59.1 %)	15 (71.4 %)	6 (31.6 %)	34 (54.8 %)
Overweight	5 (22.7 %)	3 (14.3 %)	7 (36.8 %)	15 (24.2 %)
Obese	2 (9.1 %)	3 (14.3 %)	4 (21.1 %)	9 (14.5 %)
Missing	–	–	1 (5.3 %)	1 (1.6 %)
Educational level (n)[c]:				
Low	1 (4.6 %)	1 (4.8 %)	1 (5.3 %)	3 (4.8 %)
Middle	3 (13.6 %)	6 (28.6 %)	5 (26.3 %)	14 (22.6 %)
High	18 (81.8 %)	14 (66.7 %)	13 (68.4 %)	45 (72.6 %)
Educational level of the partner (n)[c]:				
Low	1 (4.6 %)	2 (9.5 %)	1 (5.3 %)	4 (6.5 %)
Middle	4 (18.2 %)	5 (23.8 %)	6 (31.6 %)	15 (24.2 %)
High	17 (77.3 %)	14 (66.7 %)	11 (58 %)	42 (67.7 %)
Missing	–	–	1 (5.3 %)	1 (1.6 %)
Habitual sweetness exposure (daily frequency)	5.5 ± 2.3	5.1 ± 1.5	5.3 ± 1.9	5.3 ± 1.9

[a] Based Dutch Nutrition Center cut-offs (Lanting, de Wolff, Marianne, Renate, & Schönbeck, 2019).
[b] Based on WHO cut-offs (World Health Organization, 2018).

[c] Based on Dutch education system: low = mavo, vmbo, vbo; middle = havo, vwo, mbo; high = hbo, university degree (CBS, n.d.).

brand we used in the exposure intervention and liking test (Karvan Cévitam Strawberry).

3.3. Sweetness preference & hedonic liking at baseline

Children's sweetness preference was not correlated with their hedonic liking; this was true for all sweet and sour products at t1 (p-values >0.05). The three study groups did not differ significantly in their sweetness preference, or hedonic liking for the sour strawberry-flavored drink, candy, and yogurt at t1 (Table 2; p-values >0.10). That was the same for the sweet candy, and sweet yogurt (p-values >0.10). However, liking for the sweet strawberry-flavored drink differed between the groups at t1 ($F(1, 60) = 4.58$, $p = 0.04$, $\eta2 = 0.07$). Yet pairwise comparisons with Bonferroni correction showed no significant differences, suggesting that the difference in liking was marginal. Hence, all products were on average similarly liked in the three study groups at t1.

3.4. Sweetness preference & hedonic liking over the study period

Over the study period, children's sweetness preference (i.e. the geometric mean) was correlated with each other between all three time points (test 1 & 2: rho = 0.61, $p < 0.001$; test 2 & 3: rho = 0.37, $p = 0.003$; test 1 & 3: rho = 0.33, $p = 0.01$). This was the same for children's hedonic liking for sweet and sour candy, yogurt, and strawberry-flavored drink (all p values ≤ 0.05). Only children's liking for the sour candy was not correlated between post-intervention and follow-up ($p = 0.15$).

3.5. Intervention

Across all groups, children drank on average 187 ± 65 ml of the study drink daily during the 14-day intervention (Fig. 1). The amount consumed did not differ significantly between the groups.

Table 2
Hedonic liking for all products and all time points based on the 5-point pictorial scale (1 = dislike a lot, 5 = like a lot; means ± SD).

	Sweet group	Sour group	Control group
Hedonic liking: Sweet candy			
Baseline	4.4 ± 0.9	4.3 ± 0.9	4.5 ± 0.8
Post-intervention	4.6 ± 0.5	4.1 ± 1.3	4.4 ± 1.0
Follow-up	4.7 ± 0.6	4.6 ± 0.7	4.4 ± 0.8*
Hedonic liking: Sour candy			
Baseline	4.5 ± 1.0	4.4 ± 1.0	4.1 ± 1.5
Post-intervention	4.1 ± 1.2	4.4 ± 1.0*	4.4 ± 1.0
Follow-up	4.2 ± 1.1	4.6 ± 1.0	4.7 ± 1.0*
Hedonic liking: Sweet yogurt			
Baseline	4.4 ± 1.0	4.1 ± 1.2	4.0 ± 1.1
Post-intervention	4.3 ± 1.0	4.1 ± 1.3*	4.1 ± 1.1
Follow-up	4.5 ± 1.0	4.1 ± 1.2	3.8 ± 1.2
Hedonic liking: Sour yogurt			
Baseline	3.6 ± 1.3	3.6 ± 1.5	3.5 ± 1.6
Post-intervention	3.1 ± 1.3	3.2 ± 1.4*	3.2 ± 1.5
Follow-up	3.2 ± 1.5	3.3 ± 1.5	3.1 ± 1.0*
Hedonic liking: Sweet strawberry-flavored drink			
Baseline	4.3 ± 1.0	4.2 ± 0.9	3.6 ± 1.4
Post-intervention	3.9 ± 1.2	3.9 ± 1.2	3.9 ± 1.2*
Follow-up	3.8 ± 1.0	3.9 ± 1.4	3.4 ± 1.1*
Hedonic liking: Sour strawberry-flavored drink			
Baseline	3.5 ± 1.7	3.7 ± 1.3	3.3 ± 1.5
Post-intervention	3.1 ± 1.7	3.1 ± 1.4	3.2 ± 1.2
Follow-up	3.0 ± 1.5	3.1 ± 1.6	2.9 ± 1.5*

*n = 61 (missing value due to child sickness/delivery problems).

3.6. No effect of the taste exposure intervention on child sweetness preference

To assess whether the intervention affected children's sweetness preference at t2, ANCOVA models were conducted. Wilcoxon signed rank tests with continuity corrections showed no group effect when controlling for baseline sweetness preference (model 1: $F(2, 58) = 0.45$, $p = 0.64$, $\eta2 = 0.02$). Using pairwise comparisons with Bonferroni correction, sweetness preferences did not differ between the groups before and after the intervention (control & sour: $p = 0.45$; control & sweet: $p = 0.93$; sour & sweet group: $p = 0.39$). Only children's baseline preference positively predicted their post-intervention preference ($F(1, 58) = 30.56$, $p < 0.001$, $\eta2 = 0.35$). These results suggest that the intervention did not affect children's sweetness preference.

3.7. Children's sweetness preference increased over time

To examine whether children's sweetness preferences stayed the same from t1 to t2 and t3, we conducted a LMM. Across all groups, children had an average sweetness preference (in % w/v) of 19.63 ± 8.43 at t1, 23.15 ± 8.52 at t2, and 23.60 ± 8.38 at t3. This corresponds to 19.63 g, 23.15 g, and 23.60 g of sugar in 100 g of solution, respectively, which exceeds the sugar content of a regular coke (10.6 g sugar per ~100 ml).

The LMM showed a significant main effect of time (Fig. 2; model 2: $F(2) = 7.46$, $p < 0.001$) on sweetness preference, but not of the group (i.e. sweet, sour, control), suggesting that the intervention did not cause the increase in sweetness preference (also shown in 3.6.). Wilcoxon signed-rank tests showed that sweetness preference increased significantly from t1 to t2 and t3, but not from t2 to t3. When comparing children's sweetness preference at t2 to their preference at t1 (=reference), we found a significant average increase of 3.51 % w/v across all groups (estimate = 3.51, SE = 1.13, t = 3.10, $p < 0.01$, Cohen's d = 0.41). Similarly, when comparing sweetness preference at t3 to t1, we found a significant increase of 4.04 % w/v (estimate = 4.04, SE = 1.14, t = 3.55, $p < 0.001$, Cohen's d = 0.45). The main effect of time on sweetness preference remained significant ($F(2) = 7.47$, $p < 0.001$) when controlling for the child's sex, whether they consumed anything before the test, and whether they belonged to a sibling pair (model 3). Further, we found a main effect of children's sex on sweetness preference ($F(1) = 3.81$, $p < 0.01$) and of whether children belonged to a sibling pair on sweetness preference ($F(1) = 4.11$, $p < 0.01$). Across all three time points, girls' sweetness preference was 3.55 % w/v lower than boys' sweetness preference (estimate = −3.55, SE = 1.65, t = −2.16, $p < 0.05$, Cohen's d = 0.45), and the sibling pairs in our sample had a 4.40 % w/v lower sweetness preference than the children who had no sibling participating the study (estimate = −4.40, SE = 1.54, t = −2.87, $p < 0.01$, Cohen's d = 0.59).

Taken together, the results suggest that across all groups, children's sweetness preference increased from baseline to post-intervention, remained heightened at the follow-up, and did not change between post-intervention and follow-up.

3.8. No intervention effect on hedonic liking for candy, yogurt, and strawberry-flavored drink

To assess whether the intervention had an effect on children's hedonic liking for the sweet and sour strawberry-flavored drink (= intervention drinks), yogurt, and candy, a LMM was conducted. We found no main effect of the study group (model 4: $F(1) = 0.47$, $p = 0.33$), or time (t1, t2, t3; $F(2) = 2.09$, $p = 0.12$) on hedonic liking. This suggests that liking for the three products did not change significantly over the study period and that the intervention had no effect on children's liking for the strawberry-flavored drink they were repeatedly exposed to in the sweet and sour group. Further, the interaction between the product (i.e. strawberry-flavored drink, yogurt, and candy) and taste (i.e. sweet vs.

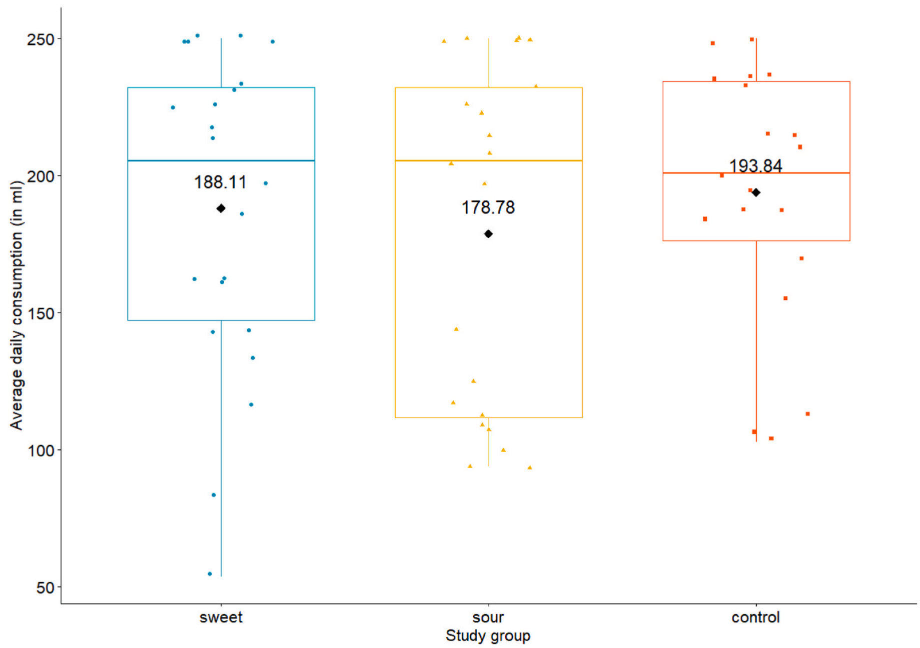

Fig. 1. Average daily consumption (in ml; including range of data) of the sweet/sour intervention drink or water over the intervention period of 14 days; separate for the sweet, sour, and control group.

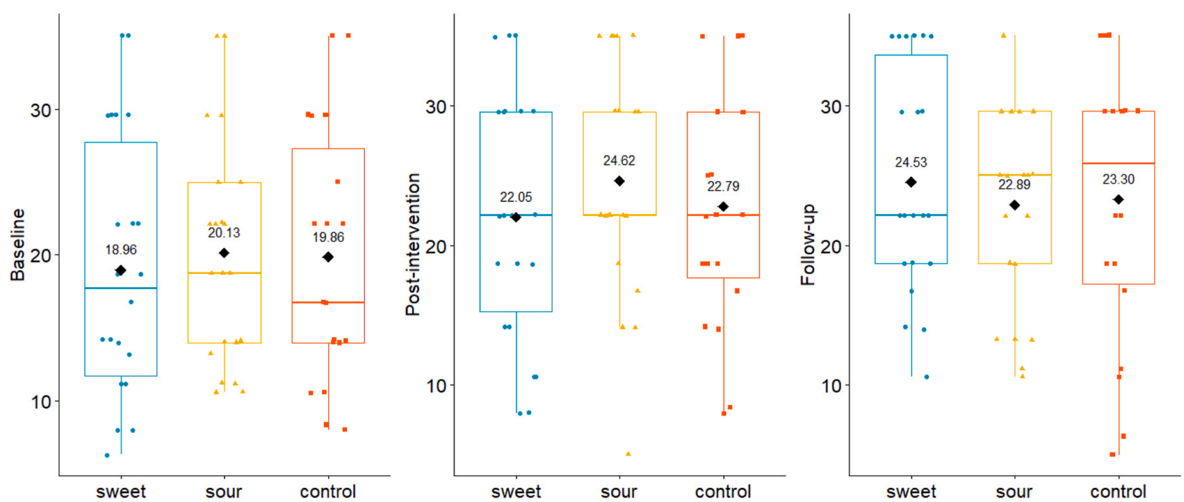

Fig. 2. Mean sweetness preference (in percent w/v sucrose) at baseline (t1), post-intervention (t2), and follow-up (t3), including standard errors; separate for the sweet, sour, and control group.

sour) had a significant effect on liking ($F(1) = 11.58$, $p < 0.001$). The results indicate that, in comparison to candy (reference), the sweet strawberry-flavored drink was liked more than the sour strawberry-flavored drink (estimate = 0.59, SE = 0.17, $t = 3.56$, $p < 0.001$, Cohen's $d = 0.49$), and the sweet yogurt was liked more than the sour yogurt (estimate = 0.76, SE = 0.17, $t = 4.58$, $p < 0.001$, Cohen's $d = 0.49$) across all time points.

3.9. Children's habitual sweet taste exposure related to parents' habitual sweet taste exposure

To investigate whether children's and parents' habitual sweet taste exposure were related to each other, we conducted a multiple linear regression analysis. On average, children had 7.18 ± 2.25 (range: 3.11–14.27) daily sweetness exposures, while parents had 5.30 ± 1.90 (range: 1.96–10.79) daily sweetness exposures. Children's habitual exposure to sweet tastes was positively associated with that of their parents (Fig. 3). Each additional exposure in parents was associated with a 0.47 increase in exposure in children (model 5: $t(60) = 3.34$, $p = 0.001$, 95% CI [0.19, 0.75]). In total, 14.3% of children's sweet taste exposure was solely predicted by parents' sweet taste exposure in the whole sample. The effect was similar when excluding two children with very high sweetness exposures (i.e. outliers; sweet taste exposure: 14.12 & 14.27; $t(55) = 4.29$, $p < 0.001$, 95% CI [0.26, 0.73]). The results suggest that children's and parents' habitual sweet taste exposures are positively linked to one another.

4. Discussion

The current study demonstrated that a 14-day exposure intervention to either a sweet or sour-tasting sucrose-containing drink neither altered children's sweetness preference nor their hedonic liking for sweet and sour candy, yogurt, or the drink they were exposed to. However, it was observed that sweetness preference increased from baseline to post-

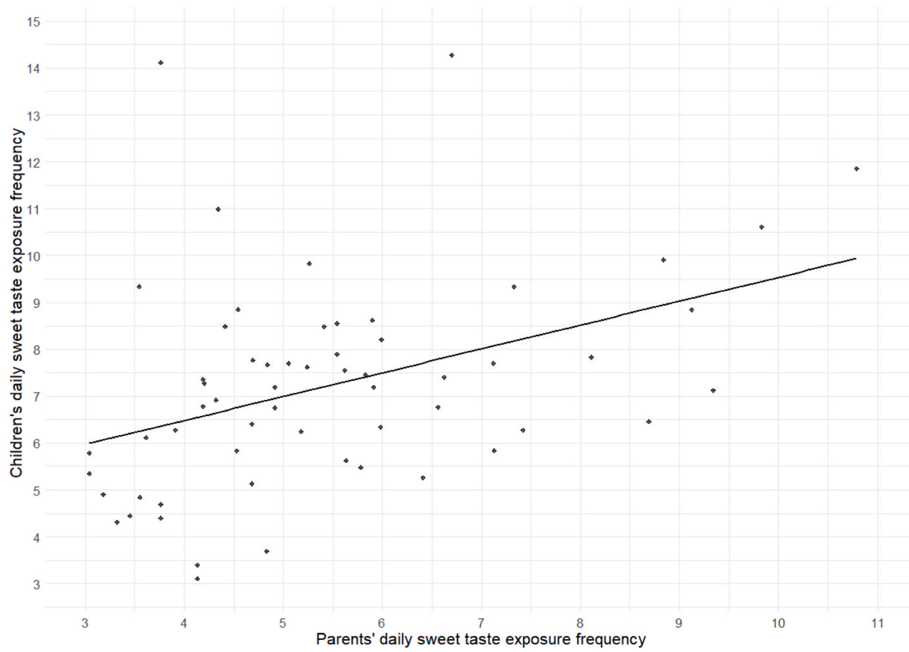

Fig. 3. The link between children's and parents' average habitual sweet taste exposure.

intervention and remained higher until the follow-up. Hedonic liking, on the other hand, was stable over the study period across all study groups. The secondary findings indicated that children's habitual sweet taste exposure was positively correlated to their parents' habitual sweet taste exposure.

We hypothesized that children's sweetness preference would not be altered through repeated sweetness exposure, regardless of whether the sweet taste is masked (such as in the sour-tasting, strawberry-flavored drink) or not. Our findings confirmed this, as the intervention did neither affect children's sweetness preference in the sweet nor in the sour study group. This is in agreement with previous findings in adults where consumption of sweet breakfast cereals for three weeks did not affect sweet food preferences, motivation to eat sweet foods, pleasantness, perceived sweetness, or intake of other sweet foods at breakfast or lunchtime, compared to a non-sweet breakfast with equivalent energy (Appleton et al., 2022). Similarly, the consumption of a sugar-sweetened porridge for three weeks at breakfast did not affect adults' appetite or intake of sweet foods later in the day, compared to the consumption of a low-sugar breakfast (Carroll et al., 2020). Further, an observational study in 5-10-year-old children, which assessed sweetness preference with the same taste test as we did, found no link between sweetness preference and regular added sugar intake (Mennella et al., 2014). While both studies indicate that repeated sweetness exposure is unrelated to sweetness preference, other studies have shown the opposite result.

Earlier studies in infants and children suggest that sweetness exposure and preference were correlated (Beauchamp & Moran, 1982, 1984; Liem & de Graaf, 2004). After regular consumption of sweetened water within the first months of life, infants showed a heightened preference for sweetened water at 6 months (Beauchamp & Moran, 1982) and at 2 years of age (Beauchamp & Moran, 1984). Similarly, after eight days of exposure to a sucrose-containing sweet orangeade, 6- to 11-year-old children showed a heightened preference for this drink (Liem & de Graaf, 2004). Yet, those effects were only present when sweetness exposure and preference were measured with the same stimuli, making it difficult to uncouple the mere exposure effect from the direct effect of repeated exposure to a sweetness intensity (Beauchamp & Moran, 1982, 1984; Liem & de Graaf, 2004). When the association between exposure and preference was later examined with different stimuli, the effect of exposure disappeared (Beauchamp & Moran, 1984; Liem & de Graaf, 2004). This may suggest that the earlier findings were due to a mere exposure effect. This effect states that individuals change their preference or liking for something, such as food, only because they become more familiar with the product through repeated exposure (Mrkva & Van Boven, 2020). Those latter findings are in line with our research where we deliberately chose different stimuli for the exposure intervention and sweetness preference task to avoid a mere exposure effect.

We hypothesized that children's sweetness preference would be consistent over all three test sessions. Yet, our results highlighted variability in sweetness preference as it increased from baseline to post-intervention and remained heightened at the 2-month follow-up. This was an unexpected finding, and it remains unclear what led to this small but significant change in preference during the exposure period. Potentially, children were more familiar with the test procedure, the task, or stimuli at t2 and t3 compared to t1. This may have induced an increased preference, similar to the repeated exposure studies where the same stimuli were used for exposure and preference. In line with that assumption is parents' statement that their children were initially unfamiliar with the orange-flavored lemonade used in the preference tests. On the other hand, it seems rather unlikely that a mere exposure effect already occurred at t2 after a single exposure at t1.

Another potential explanation is that children already knew which sweetness levels to expect at t2 and t3 while they did not know what to expect at t1 (i.e. practice effects and familiarity with the task rather than a cumulative effect of repeated taste exposure). Previous research has demonstrated that expectations of a food's taste can influence how the taste is perceived (Woods et al., 2011). Hence, the drink's sweetness intensities may have been perceived differently at t2 and t3 compared to t1. However, this effect is rather studied in the field of food packaging and labeling (Enax et al., 2015) and less in sensory testing without differences in packaging or labeling. The question of whether expectation bias can influence the results of tests such as ours therefore requires further investigation.

Based on previous findings, we hypothesized that hedonic liking is product-specific and that repeated exposure to the intervention drinks would increase children's hedonic liking for those drinks, but not their liking for other sweet and sweet-sour tasting semi-solid (yogurt), or solid foods (candy). Our results were partly in line with our hypothesis. As expected, children's liking for the sweet, and sweet-sour yogurt and candy was unaffected by the intervention and similar across all three test sessions (t1, t2, t3). This is supported by a recent observational study that could not find a link between infants' exposure to sweet-tasting foods and drinks at 3-6 or 10-12 months and their sweetness liking at 6 or 12 months (Müller et al., 2023). Yet, contrary to our expectations, children's liking for the study drinks did not change either. While other studies have shown that repeated exposure to a sweet drink can increase preference for this specific drink (Beauchamp & Moran, 1982, 1984; Liem & de Graaf, 2004), this may be different for hedonic liking. This is supported by a study in adults in which liking scores of sweet yogurts were similar at baseline, after two, and ten exposures (Frøst, 2006).

One explanation for why liking sweet products may not be affected by repeated sweetness exposure could lie in the different concepts of sweetness preference and liking. While liking is an affective evaluation and an absolute total value, preference is relative to what it is compared to and therefore a behavioral choice (Keller, Shehan, Cravener, Schlechter, & Hayes, 2022). To clarify, between two similarly disliked foods, one may still be preferred, and likewise, between two similarly liked foods, one may not be preferred (Cheon et al., 2021). If the absolute, total value of liking is already high at baseline, as was the case for test products used in our study, a ceiling effect may hinder liking from increasing further following repeated exposure.

The effect of repeated exposure on preference and liking may depend on whether a taste is innately liked or disliked. As omnivores, humans can digest a wide variety of foods, but not all of them are safe or equally liked. Thus, repeated exposure to novel (bitter) foods may increase their liking through increased familiarity and learned safety (Caton et al., 2014; Kalat & Rozin, 1973). However, the sweet taste is already liked at birth, despite individual differences (Mennella et al., 2014; Steiner, 1979), and may therefore be harder to manipulate. This could be linked to a person's phenotype as well. Recent research suggests that children show greater variability in their response to sweet foods based on whether they classify as 'sweet liker' or 'sweet disliker' phenotypes. The latter shows a decreasing preference for increasing sweetness intensities (Armitage, Iatridi, & Yeomans, 2021). This may help explain why the effectiveness of repeated exposure on increased liking and intake is mainly demonstrated for initially disliked foods such as bitter vegetables (Anzman-Frasca et al., 2012; Barends et al., 2019; de Wild, de Graaf, & Jager, 2017; Hausner et al., 2012; Issanchou & Consortium, 2017; Lanigan, Bailey, Alexandra Malia Timpson, & Shea, 2019; Sullivan & Birch, 1994; Zeinstra et al., 2018).

Our results confirmed the hypothesis that children's habitual sweet taste exposure would be positively linked to parents' habitual sweet taste exposure. This is in line with previous research, where parents' free sugar intake was linked to that of adolescents (Zhang et al., 2022). Other studies have also shown that a child's home food environment plays a crucial role in moderating their sugar intake. When more fruits and vegetables were available at home, 3- to 6-year-olds consumed fewer sweets/confectionary than when fewer fruits and vegetables were available at home (Vepsäläinen et al., 2018). That this was caused by a lower sweetness preference/liking is unlikely as children in those households consumed more fruits than children who ate more free sugar products and therefore still consumed sweet-tasting foods. This finding might rather be linked to lower friction (i.e. less effort) to choose and consume fruits over sweets. The concept of friction is often used to describe the ease or difficulty of making choices. Lower friction is generally linked to an increased probability of enacting a certain behavior and implies that there are fewer obstacles in making the (healthier) choice (Verplanken & Orbell, 2022). Thus, children's food choices can be strongly influenced by their parents' taste preferences and the home food environments (Mahmood et al., 2021; Prada et al., 2021; Scaglioni et al., 2008). Those factors may have a greater impact on children's sugar consumption than their sweetness preferences and liking.

The present study had several strengths, including a stratified random sampling design which ensured that the three study groups were comparable for age, sex, weight, and height distributions. At baseline, the groups did not differ in sweetness preference or hedonic liking for the products used in the study. Further, a unique strength of the current approach compared to previous research (Beauchamp & Moran, 1982, 1984; Liem & de Graaf, 2004) was that we tested potential changes in sweetness preferences using a different flavor than the one used during the exposure intervention. This provided a better picture of general sweetness preference as the results cannot be traced back to familiarity effects. Another strength of the study was the follow-up test which enabled the assessment of sweetness preference two months after the exposure period to investigate the longer-term impact of the intervention. Further, children's sweetness preferences were correlated between all three time points, underpinning the reliability of the method used. We were able to assess whether a potential effect on sweetness preference was caused by sucrose content or sweet taste by including the sour exposure group and keeping the sucrose content of the sweet and sour groups the same. Lastly, home testing allowed us to include families living in different parts of the Netherlands and ensured the children were at ease in a familiar environment.

Yet, conducting the study at the child's home also resulted in a less controlled implementation of the taste intervention which may have been a limitation. Another limitation is that we did not measure children's daily intake of sweet products during the intervention. Although this would have given a more nuanced picture, we judged 14 daily food recalls a too high burden for the parents. Instead, we conducted a food frequency questionnaire at baseline and checked in the post-intervention survey whether children consumed more, less, or roughly the same amount of sweet-tasting products during the intervention. Both items were taken into account in our analyses. Yet, future studies should consider including several 24-h recalls during the intervention period as part of their research designs. The recipe of the strawberry syrup used for the hedonic liking test and the intervention drink was adapted by the producer halfway through the study. However, the change in the recipe only resulted in a difference of 0.5 g of sucrose in the test/intervention drinks. This marginal difference was not detectable in taste tests by independent researchers and was therefore considered negligible. Further, the intervention may have been too short to cause an effect on sweetness preference and liking in terms of duration and daily exposure. One study drink per day may not have been sufficient to shift dietary sweetness exposure and create distinct groups of lower and higher sweetness exposures. Future studies should aim to manipulate the whole diet over a longer study period to create more distinct study groups. So far, only one study in progress follows such a research design in adults (Čad et al., 2023). To the author's knowledge, this has never been done in children where ethical guidelines are even stricter than in adults. Additionally, measuring liking in foods with lower liking scores at baselines could have been a meaningful addition to the study design to avoid ceiling effects. For that, future studies should consider including sweet and sweet-sour (unfamiliar) foods or fruits in the liking measurements. Further, the majority of parents included in our sample had a medium or high education level, despite our efforts to recruit a representative sample across the Netherlands. Hence, our findings are less applicable to children from lower educated families. Finally, the inclusion of sibling pairs in the study may have led to nested results due to the shared home environment. We attempted to account for this by distributing the sibling pairs evenly across the study groups and controlling for whether children belonged to one of the sibling pairs in the analyses.

In conclusion, this study found no effect of a 14-day exposure to a sweet or sour-tasting, sucrose-containing strawberry-flavored drink on 4-7-year-olds' sweetness preference or hedonic liking for sweet or sweet-sour yogurts, candies, and strawberry-flavored drinks. We found that hedonic liking was stable over the 2.5-month study period, while sweetness preference increased across all study groups from baseline to post-intervention and remained heightened in the follow-up. Future research is needed to validate results from the current trial and better understand the relationship between repeated sweetness exposure and our observed increase in sweetness liking. The assumption that a reduction in children's dietary exposure to sweet taste will lead to lower preferred sweetness levels, thereby supporting the transition to a lower sugar intake reflects an attractive but unlikely narrative. Findings from the current study raise questions regarding the potential effectiveness of altering children's sweetness preference and liking through sweetness exposure. If the ultimate goal is to limit children's free sugar consumption, other approaches, such as making use of covert restrictions (Mueller et al., 2023) to limit exposure to sugar-containing products, and creating healthier food environments, for example through reducing sugar levels in products, may be more promising and direct in accomplishing this.

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Ethical statement

This study was conducted according to the guidelines laid down in the Declaration of Helsinki. The protocol was pre-registered at https://doi.org/10.17605/OSF.IO/PGMHU and the hypotheses were specified prior to data collection. The study protocol was exempted from review by the medical ethics committee of Wageningen University & Research (METC-WU). Informed consent was obtained from the parents at the beginning of the study.

CRediT authorship contribution statement

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

Declaration of competing interest

None.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.appet.2024.107277.

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