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Original Research

A matter of the metric? Sugar content overestimation is less pronounced in sugar cubes versus grams

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ABSTRACT

To make healthy food choices, consumers need to be aware of the sugar content of foods. Units act as an environmental cue that might influence sugar content estimation accuracy. The present study (1) tested whether estimations of sugar content are more accurate in sugar cubes vs grams, (2) compared accuracy of sugar content to estimations of the foods' weight and energy content, and (3) investigated gender, education, and body mass index as potential correlates. A sample of 886 adults was randomly assigned to estimating the sugar content of 10 common foods in grams or cubes. Estimations of sugar content diverged considerably from actual values in both groups ($0.22 \leq$ Cohen's $ds_{\text{grams}} \leq 1.20$; $0.20 \leq$ Cohen's $ds_{\text{cubes}} \leq 1.10$), but were more pronounced for sugar content estimations in grams in 7 out of 10 foods ($ts \geq 4.04$, $Ps < .001$, Cohen's $ds \geq 0.14$). Sugar content misestimation was somewhat more pronounced than misestimation of weight ($0.05 \leq$ Cohen's $ds \leq 1.43$) and energy content ($0.04 \leq$ Cohen's $ds \leq 1.19$). Relationships between sugar content misestimation and gender ($0.00 \leq$ Cohen's $ds \leq 0.33$), education ($-0.07 \leq r \leq 0.11$), and body mass index ($-0.08 \leq r \leq 0.06$) were mostly negligible. Although sugar content estimations were somewhat more accurate in sugar cubes vs grams, estimation accuracy is generally low. In addition to promoting consumers' knowledge through labeling and education, additional avenues for interventions might need to be explored for sizeable effects on food choices.

1. Introduction

Sugar consumption is related to a range of health risks including dental caries and overweight, which is in turn related to a range of noncommunicable diseases such as cardiovascular diseases [1,2]. Accordingly, the World Health Organization recommends to limit intake of free sugars, that is, monosaccharides and disaccharides added to foods and beverages, and sugars naturally present in honey, syrups, fruit juices, and

Abbreviation: BMI, body mass index.

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fruit juice concentrates, to 10% of daily energy intake [3]. This amounts to approx. 50 grams of sugar per day. Actual sugar consumption in the population exceeds those recommendations in many countries [4–6]. In Germany, for instance, average consumption of free sugars amounts to 61 grams in women and 78 grams in men [7]. Sugar consumption should thus be reduced to reduce health risks.

To promote healthier food choices, many countries have introduced nutritional labeling. Indeed, nutritional labeling reduces the amount of sugar in food purchases [8]. However, nutritional labeling is typically only available on packaged foods in supermarket settings. In other circumstances, for example, when buying loose and unwrapped produce, or when eating in restaurants or cafeterias, labeling is often unavailable, which requires consumers to rely on their knowledge to choose healthier options. This includes the ability to correctly estimate the foods' nutrients to be able to adhere to public health recommendations.

Previous research suggests that consumers struggle to estimate the sugar content of foods correctly. Three recent studies showed considerable deviations of estimates from actual sugar content and great variation in sugar content estimates provided by consumers [9–11]. The studies, however, diverge in the conclusions drawn regarding the direction of misestimation. Dallacker et al. [10] showed that the majority of participants underestimated the sugar content of four out of six presented food items. Specifically, sugar content of orange juice, cola, frozen pizza, and fruit yoghurt was underestimated by the majority of the sample, while the sugar content of a granola bar and ketchup was predominantly overestimated. König et al. [9], on the other hand, reported that sugar content was overestimated for all seven presented foods (quiche, sandwich, vegetable sticks, yoghurt-herb sauce, chocolate mousse, fruit skewers, muffin; see also Ehrecke et al. [11] for similar results). Although similar conclusions may result from the studies, such as amounts of sugar not being a suitable cue to guide food choices, the question remains how the diverging findings can be consolidated.

They may be explained by the different measures used to quantify sugar content estimation. Dallacker et al. [10] asked participants to provide estimations in sugar cubes. In many Western countries including Germany, where the present study was conducted, sugar cubes are often used in educational materials, public health communication, and the media to illustrate the amount of sugar contained in foods (e.g., [12,13]). König et al. [9] and Ehrecke et al. [11], however, asked for estimations in grams. The two measures might trigger differential anchors [14]. Sugar cubes are typically used in small quantities, for example, one or two cubes in a cup of coffee. This effect might have been further amplified through the unit bias, which postulates that small estimation units may induce the expectation that a small amount of these units is sufficient [15]. Together, this may lead to sugar content in sugar cubes to be underestimated. Grams of sugar, on the other hand, is a continuous measure without predefined units. Furthermore, grams of sugar are typically used in larger amounts, for example, 150 grams in a cake recipe. According to the anchor effect, this may induce overestimation of sugar content in grams. Finally, people tend to round to the next multiple of 10 or 100 or their half-way points [16], which might further amplify overestimation especially when sugar content is comparably low, as is typically the case in single portions of food.

The present study's first aim thus was to test whether the choice of the estimation measure for sugar content influences the conclusions drawn about estimation accuracy, measured as absolute and relative deviation from the actual values. It used the 10 foods used in previous research [9,10] and compared sugar content estimations in sugar cubes and grams using a between-subjects design. It was specifically tested whether estimation accuracy was higher for sugar cubes vs grams. Second, the study aimed to compare the magnitude of sugar content misestimation to misestimation of the foods' weight and energy content, which are more commonly explored in the literature (e.g., [17,18]) to test the generalizability. Third, the study aimed to test whether gender, level of education, and body mass index (BMI) are related to estimation accuracy since they have been linked to preoccupation with food, nutrition knowledge, or healthy literacy, which in turn is hypothesized to be linked to sugar, energy content and portion size estimation accuracy [19–22].

2. Methods and materials

2.1. *Design and procedure*

Healthy, adult participants were recruited within the framework of the Konstanz Life Study, an ongoing longitudinal cohort study that was launched in spring 2012 with 1321 participants (for more details, see [23–28]). The overarching aim of the study is to investigate psychological influences on eating behavior, physical activity, and health within the general population across time [25]. The study is part of the SMARTACT research project funded by the German Federal Ministry of Education and Research. Further points of measurement 2 to 6 took place in autumn 2012 and spring 2013/2016/2017/2019, respectively. For each point of measurement, participants were recruited via flyers, posters, and newspaper articles. Additionally, participants of the preceding points of measurement were reinvited via email and phone calls. People aged 18 and older without acute infectious diseases were eligible for participation. The measurements included the collection of fasting blood samples, questionnaires, as well as a standardized check-up including anthropometric measures and cognitive and physical fitness tests. As compensation for participation, participants received feedback about their objective health status referenced to current norms. This paper presents data from the sixth point of measurement (spring 2019).

After having filled in the main study questionnaire, participants were asked to fill in a second questionnaire either on site or at home, which contained the estimation task. If participants decided to fill out the questionnaire at home, they were asked to send it back to the study team and were provided with a stamped addressed envelope. Participants were randomly allocated to estimating the sugar content in grams or in sugar cubes by receiving the top questionnaire from a stack of shuffled questionnaires. Since this analysis uses a convenience sample recruited within a larger framework, no a-priori sample size calculation was conducted.

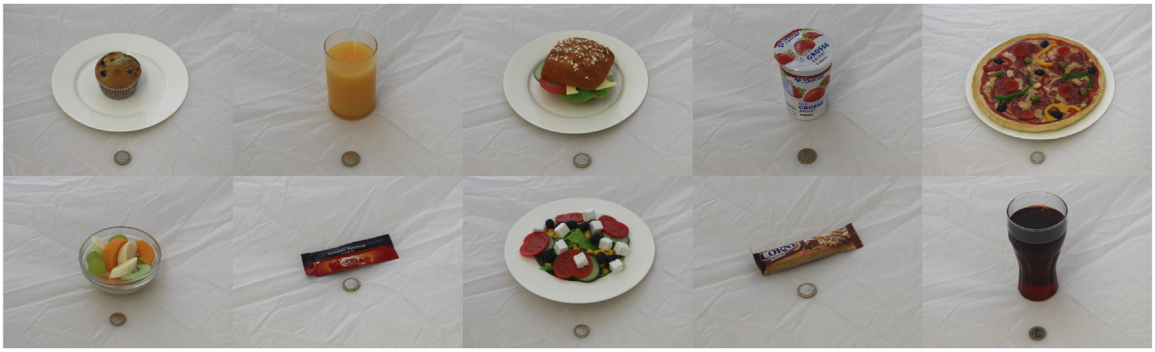

Fig. 1 – Foods used in the estimation task.

2.2. Ethics

For data processing and security, a register of processing operations was developed in cooperation with and approved by ZENDAS in 2012 and reviewed in 2016 (Zentrale Datenschutzstelle der Baden-Württembergischen Universitäten/Center for Data Protection of the Universities in Baden-Württemberg) and reviewed by the Landesdatenschutz-Beauftragte, Baden-Württemberg (Commissioner for Data Protection in Baden-Württemberg). All participants gave written informed consent prior to participation. The study adhered to the guidelines of the German Psychological Society (Deutsche Gesellschaft für Psychologie; see http://www.dgps.de/index.php?id=96422, paragraph C.III) and the Declaration of Helsinki and was conducted in compliance with relevant laws and institutional guidelines. The study protocol was approved by the University of Konstanz ethics committee (approval number 10/2016).

2.3. Materials and measures

2.3.1. Food items

Ten foods were chosen based on two previous studies on sugar estimation [9,10]: Orange juice, cola, cheese sandwich, pizza, mixed salad, tomato ketchup, strawberry yoghurt, fruit salad, granola bar, muffin. All foods were presented in typical serving sizes and next to a 1€ coin that served as a size reference. For the ketchup, the yoghurt, the granola bar, and the muffin, a picture was taken of real food items. For the remaining food items, a picture was taken from realistic food replicas (see Fig. 1). Food labeling on the packaged foods (yoghurt, granola bar, ketchup) was not visible to participants during the estimation task.

The weight of the food was determined based on the weight identified on the food packaging (yoghurt, granola bar, ketchup), by weighing the food (muffin) or by converting the weight of the fake food items into weight of real food based on a conversion factor (c.f., Sproesser et al. [29]). The weight was entered into the software OptiDiet Basic version 5.1.0.042 (GOE mbH, Linden) using which the sugar and energy content was determined based on the German Nutrient Database version 3.01 (Max Rubner-Institut, Karlsruhe). To determine the number of sugar cubes, which typically weigh 3 grams, sugar content in grams was divided by 3 and rounded to the next whole number. These values are further referred to as *actual* sugar content/weight/energy content (see Table 1).

2.3.2. Estimation task

For each food depicted in the questionnaire, participants were asked to give estimates of sugar content (in grams or sugar cubes) as well as weight and energy content in kilocalories (kcal). These values are further referred to as *estimated* sugar content/weight/energy content. Foods were presented in a fixed order since questionnaires were paper-based: (1) Muffin, (2) orange juice, (3) sandwich, (4) yoghurt, (5) pizza, (6) fruit salad, (7) ketchup, (8) salad, (9) granola bar, (10) cola. Participants were asked to complete the questionnaire individually and without any aids or support.

The deviation in percent from the actual value was computed as follows: $(\frac{estimation - actual\ value}{actual\ value}) * 100$. Based on this relative deviation, underestimation was defined as a relative deviation lower than 0, while overestimation was defined as a relative deviation greater than 0 (c.f. [9,10]). Estimations were accurate if relative deviation equaled 0. Absolute deviation in percent was determined by taking the absolute values.

2.3.3. Demographic and anthropometric variables

Participants were asked to indicate their age and gender (female or male). They furthermore reported their level of education which was converted into years of education.

BMI was calculated from height and weight measured by trained research staff following a standardized procedure. Participants wore light indoor clothing and were asked to take off their shoes. Height was measured using a wall-mounted stadiometer, and weight was measured using a digital scale (SECA mBCA 515).

2.4. Statistical analysis

Analyses were conducted with IBM SPSS 29. Missing values ranged from 0.3% for gender and BMI to 5.2% for the energy content of the granola bar (see Table S1 in the supplementary material for a breakdown by variable).

Implausible values were checked for estimations of sugar content. Values were declared implausible if the amount of

Table 1 – Estimation accuracy by food item and estimation measure as provided by the adult participants

Food item	Actual value (Ref.)	Estimated value					
		M	*SD*	*t*	*df*	*P*	Cohen's *d*
Orange juice							
Sugar content (grams)	18.2	36.78	33.71	11.65	446	<.001	0.55
Sugar content (sugar cubes)	6	7.54	7.51	4.22	421	<.001	0.21
Weight (grams)	215	201.26	58.36	–6.97	874	<.001	0.24
Energy content (kcal)	93	149.56	112.79	14.59	845	<.001	0.50
Cola							
Sugar content (grams)	33.5	78.04	58.95	15.94	444	<.001	0.75
Sugar content (sugar cubes)	11	16.01	13.70	7.45	416	<.001	0.36
Weight (grams)	309	236.85	74.79	–28.60	876	<.001	0.97
Energy content (kcal)	145	253.72	188.27	16.82	847	<.001	0.54
Sandwich							
Sugar content (grams)	1.3	22.66	26.45	17.00	442	<.001	0.81
Sugar content (sugar cubes)	0	4.25	5.73	15.28	424	<.001	0.74
Weight (grams)	107	204.58	90.34	31.92	872	<.001	1.08
Energy content (kcal)	192	268.52	169.51	13.09	840	<.001	0.45
Pizza							
Sugar content (grams)	2.9	58.73	56.28	20.86	441	<.001	0.99
Sugar content (sugar cubes)	1	11.70	13.56	16.21	421	<.001	0.79
Weight (grams)	370	386.70	136.00	3.63	872	<.001	0.12
Energy content (kcal)	874	654.36	348.50	–18.29	841	<.001	0.63
Salad							
Sugar content (grams)	3	21.23	26.76	14.42	447	<.001	0.68
Sugar content (sugar cubes)	1	3.77	6.02	9.49	424	<.001	0.46
Weight (grams)	268	274.05	110.69	1.62	875	.106	0.05
Energy content (kcal)	255	198.70	135.55	–12.09	846	<.001	0.42
Ketchup							
Sugar content (grams)	4.7	11.62	11.16	12.88	431	<.001	0.61
Sugar content (sugar cubes)	2	3.77	3.26	10.47	370	<.001	0.48
Weight (grams)	20	25.37	20.12	7.89	872	<.001	0.27
Energy content (kcal)	22	79.37	82.78	20.10	840	<.001	0.69
Yoghurt							
Sugar content (grams)	32.3	39.44	31.11	4.86	447	<.001	0.23
Sugar content (sugar cubes)	11	9.19	9.22	–4.02	419	<.001	0.20
Weight (grams)	250	194.20	63.67	–25.95	876	<.001	0.88
Energy content (kcal)	233	208.29	130.27	–5.52	846	<.001	0.19
Fruit salad							
Sugar content (grams)	28.4	35.54	33.08	4.56	445	<.001	0.22
Sugar content (sugar cubes)	9	6.01	6.53	–9.37	417	<.001	0.46
Weight (grams)	174	148.67	67.05	–11.17	874	<.001	0.38
Energy content (kcal)	135	139.26	106.91	1.16	847	.246	0.04
Granola bar							
Sugar content (grams)	8.5	27.34	23.19	16.86	430	<.001	0.80
Sugar content (sugar cubes)	3	6.93	5.36	14.63	397	<.001	0.73
Weight (grams)	25	65.86	38.19	31.58	870	<.001	1.07
Energy content (kcal)	114	197.63	186.07	13.03	839	<.001	0.46
Muffin							
Sugar content (grams)	4.4	31.96	22.90	25.36	443	<.001	1.20
Sugar content (sugar cubes)	1	7.71	6.07	22.38	409	<.001	1.10
Weight (grams)	37	110.85	57.85	37.64	868	<.001	1.43
Energy content (kcal)	103	262.59	153.06	30.22	839	<.001	1.19

sugar exceeded the weight estimated by the participant. Implausible values were replaced with a missing value. For sugar estimated in grams, $n = 3$ entries were replaced for the muffin, $n = 3$ entries were replaced for the pizza, $n = 1$ entry was replaced for the fruit salad, $n = 13$ entries were replaced for the ketchup, $n = 11$ entries were replaced for the granola bar, and $n = 3$ entries were replaced for the cola. For estimation in sugar cubes, $n = 15$ entries were replaced for the muffin, $n = 4$ entries were replaced for the orange juice, $n = 3$ entries were replaced for the sandwich, $n = 6$ entries were replaced for the yoghurt, $n = 6$ entries were replaced for the pizza, $n = 9$ entries were replaced for the fruit salad, $n = 56$ entries were replaced for the ketchup, $n = 1$ entry was replaced for the salad, $n = 26$ entries were replaced for the granola bar, and $n = 13$ entries were replaced for the cola.

Data were analyzed using one sample or independent sample *t* tests and bivariate Pearson correlations.

3. Results

3.1. Sample

In total, $N = 1321$ participants were recruited, of which $N = 886$ completed the questionnaire that contained the sugar estimation task. Participants (65.6% female) had a mean age of 44.60 ($SD = 18.41$) years and a mean BMI of 23.96 ($SD = 3.47$). The majority of the sample (71.8%) had a university entrance diploma, and 56.3% completed tertiary education, accumulating to a mean of 15.98 years of education ($SD = 2.40$). Compared to participants who did not fill out the questionnaire, the sample was older ($t(1300) = 2.02$, $P = .044$; $M_{dropout} = 42.42$, $SD_{dropout} = 17.91$) and comprised a greater proportion of females ($\chi^2(df = 1) = 12.63$, $P < .001$, Cramer $v = 0.10$; dropout: 54.9% females). There were no differences in BMI ($t(1301) = –0.20$, $P = .838$) or years of education ($t(1275) = 2.02$, $P = .943$).

Through randomization, $n = 453$ participants were allocated to estimation in grams and $n = 433$ participants were allocated to estimation in sugar cubes. Groups did not differ in age, BMI, years of education (ts($df \geq 852.23$) ≤ 1.39, Ps $\geq .167$), or gender ($\chi^2(df = 1) = 0.00$, $P = .975$).

3.2. Accuracy of sugar content, energy, and weight estimations

Table 1 depicts the actual values for the 10 food items and the average estimation values provided by the participants. One-sample *t* tests were conducted to test the accuracy of the estimations, using the respective actual value as a reference. Overall, the largest effect sizes were found for the estimated sugar content in grams ($0.22 \leq d \leq 1.20$), however, also sugar content estimation in sugar cubes and estimation of weight and energy content showed large effects according to Cohen [30] for some food items.

As Table 2 shows, sugar content in grams was overestimated by the majority of participants in eight out of 10 foods (orange juice, cola, sandwich, pizza, salad, ketchup, granola bar, muffin). For the other three estimation measures, the pattern of over- and underestimation was somewhat less consistent. When estimating the sugar content in sugar cubes, sugar content was overestimated by the majority of the sample in six out of 10 foods (sandwich, pizza, salad, ketchup, granola bar, muffin). Similarly, energy content was overestimated by the majority of participants in 6 out of 10 foods (orange juice, cola, sandwich, ketchup, granola bar, muffin). Weight was overestimated by the majority of the sample in three out of 10 foods (sandwich, granola bar, muffin).

In terms of the degree of estimation errors, the mean deviance in percent indicates that estimated sugar content in grams had the largest mean overestimation for 8 of the 10 food items (see Table 2). For example, all participants overestimated the sugar content of the pizza in grams, and they misperceived it on average by 1925.24%. The degree of overestimation was higher than the degree of underestimation for all four estimation measures. Furthermore, the degree of overestimation was the highest for sugar content estimated in grams for most foods (e.g., ketchup: $M_{sugar\ cubes} = 160.81$; $M_{sugar\ in\ grams} = 180.61$).

In addition, correlations between relative deviations of estimation measures were calculated per food item to evaluate their interrelation. Correlations ranged from $r = –0.06$ to $r = 0.72$ for sugar content estimated in grams and weight; from $r = 0.02$ to $r = 0.63$ for sugar content estimated in sugar cubes and weight; from $r = 0.06$ to $r = 0.37$ for sugar content estimated in grams and energy content; from $r = 0.02$ to $r = 0.25$ for sugar content estimated in sugar cubes and energy content; and from $r = 0.01$ to $r = 0.37$ for weight and energy content (see Table S2 in the supplementary material for details). Correlations between sugar content misestimation (both in grams and sugar cubes) and weight misestimation were descriptively larger than with energy content misestimation. Most correlations, however, were small [30].

3.3. Comparison of sugar content estimations in grams and sugar cubes

Absolute deviation from actual sugar content was compared between estimation in grams and sugar cubes using an independent samples *t* test. Significant differences emerged for seven of 10 comparisons (ts ≥ 4.04, Ps $< .001$, Cohen's ds ≥ 0.14). For all seven significant comparisons, deviations from the actual values were smaller for estimation in sugar cubes compared to estimations in grams (see Table 3). Effects were small to medium [30].

3.4. Relationships with gender, BMI, and years of education

Some significant gender differences were found (ts $\leq |3.55|$, Ps $\geq .001$, Cohen's ds ≤ 0.33). However, effects were mostly small to very small [30], and there was no coherent pattern for one gender to be more accurate than the other (see Table S3 in the Supplementary Material). Similarly, BMI and years of education were only weakly linked to absolute estimation accuracy (BMI: rs $\leq |0.09|$, Ps $\geq .008$; years of education: rs $\leq |0.11|$, Ps $\geq .011$; see Table S4 in the Supplementary Material).

3.5. Post-hoc exploratory analyses

Based on the identified pattern of results that indicate that certain characteristics of the presented food items might have influenced the results, two sets of exploratory analyses were conducted.

3.5.1. Comparison of fruit-based foods and foods without fruits

For this analysis, the mean relative deviation of sugar content estimations was calculated for fruit-based foods (i.e., fruit yoghurt, orange juice, fruit salad) and foods without fruits (i.e., cola, sandwich, pizza, salad, ketchup, granola bar, muffin). Separate paired samples *t* tests were computed for the sugar content estimation in grams and in sugar cubes. Both yielded significant differences between the two groups of foods. Differences were somewhat more pronounced for

Table 2 – Frequency (%) and degree (M, SD) of estimation errors by food type and estimation measure, as provided by the adult participants

Food item	Underestimation		Correct	Overestimation	
	N (%)	M[a] (SD)	N (%)	N (%)	M[b] (SD)
Sugar content (in grams)					
Orange juice	123 (27.5)	–40.74 (20.76)	0 (0.0)	324 (72.5)	156.29 (191.05)
Cola	121 (27.2)	–32.70 (21.24)	0 (0.0)	324 (72.8)	194.80 (168.17)
Sandwich	12 (2.7)	–83.97 (30.50)	0 (0.0)	431 (97.3)	1690.81 (2041.81)
Pizza	-	-	0 (0.0)	442 (100.0)	1925.24 (1940.52)
Salad	42 (9.4)	–67.06 (30.46)	23 (5.1)	383 (85.5)	718.28 (919.88)
Ketchup	66 (15.3)	–38.23 (23.01)	0 (0.0)	366 (84.7)	180.61 (243.18)
Yoghurt	257 (57.4)	–36.39 (22.90)	0 (0.0)	191 (42.6)	100.80 (101.29)
Fruit salad	228 (51.1)	–46.25 (22.72)	0 (0.0)	218 (48.9)	99.80 (127.75)
Granola bar	42 (9.7)	–29.27 (22.86)	2 (0.5)	387 (89.8)	249.96 (273.78)
Muffin	3 (0.7)	–39.39 (26.24)	0 (0.0)	441 (99.3)	630.86 (519.25)
Sugar content (in sugar cubes)					
Orange juice	219 (51.9)	–48.14 (23.58)	32 (7.6)	171 (40.5)	125.05 (144.92)
Cola	205 (49.4)	–30.93 (21.70)	4 (1.0)	206 (49.6)	122.51 (137.97)
Sandwich	0 (0.0)	-	25 (5.9)	400 (94.1)	451.40 (580.65)
Pizza	2 (0.5)	–75.00 (35.36)	7 (1.7)	413 (97.9)	1093.83 (1361.42)
Salad	71 (16.7)	–87.11 (22.08)	83 (19.5)	271 (63.8)	457.38 (691.27)
Ketchup	55 (14.8)	–51.55 (12.93)	94 (25.3)	222 (59.8)	160.81 (175.85)
Yoghurt	321 (76.4)	–47.75 (24.28)	6 (1.4)	93 (22.1)	90.47 (122.41)
Fruit salad	338 (80.9)	–59.40 (23.79)	1 (0.2)	79 (18.9)	78.06 (100.96)
Granola bar	47 (11.8)	–39.18 (13.34)	40 (10.1)	311 (78.1)	173.47 (180.02)
Muffin	0 (0.0)	-	7 (1.7)	403 (98.3)	682.46 (605.63)
Weight (in grams)					
Orange juice	645 (73.7)	–17.76 (17.70)	0 (0.0)	230 (26.3)	25.48 (23.40)
Cola	817 (93.2)	–27.64 (16.69)	0 (0.0)	60 (6.8)	35.02 (33.56)
Sandwich	136 (15.6)	–20.86 (17.69)	0 (0.0)	737 (84.4)	111.87 (75.10)
Pizza	469 (53.7)	–19.88 (14.00)	4 (0.5)	400 (45.8)	33.16 (34.65)
Salad	447 (51.0)	–26.30 (17.54)	0 (0.0)	429 (49.0)	32.02 (37.78)
Ketchup	239 (27.4)	–45.40 (16.08)	320 (36.7)	314 (36.0)	109.25 (128.27)
Yoghurt	611 (69.7)	–34.54 (15.58)	231 (26.3)	35 (4.0)	43.71 (42.43)
Fruit salad	618 (70.6)	–34.08 (19.78)	0 (0.0)	257 (29.4)	32.40 (31.51)
Granola bar	38 (4.4)	–24.42 (9.47)	48 (5.5)	785 (90.1)	182.54 (148.91)
Muffin	54 (6.2)	–31.08 (18.40)	0 (0.0)	815 (93.8)	214.88 (149.26)
Energy content (in kcal)					
Orange juice	233 (27.5)	–36.22 (24.67)	0 (0.0)	613 (72.5)	97.70 (123.01)
Cola	192 (22.6)	–34.31 (20.16)	0 (0.0)	656 (77.4)	106.96 (130.98)
Sandwich	235 (27.9)	–36.01 (22.94)	0 (0.0)	606 (72.1)	69.27 (86.70)
Pizza	697 (82.8)	–36.91 (22.13)	0 (0.0)	145 (17.2)	31.48 (54.96)
Salad	656 (77.4)	–43.08 (26.62)	0 (0.0)	191 (22.6)	50.05 (58.19)
Ketchup	105 (12.5)	–31.04 (27.90)	0 (0.0)	736 (87.5)	302.41 (384.43)
Yoghurt	581 (68.6)	–36.83 (21.99)	0 (0.0)	266 (31.4)	46.68 (64.17)
Fruit salad	508 (59.9)	–40.57 (21.56)	0 (0.0)	340 (40.1)	68.49 (88.48)
Granola bar	222 (26.4)	–31.12 (23.49)	0 (0.0)	618 (73.6)	110.89 (175.19)
Muffin	100 (11.9)	–28.80 (29.92)	0 (0.0)	740 (88.1)	179.77 (140.59)

[a] Mean deviation in percent for participants who underestimated the food item.
[b] Mean deviation in percent for participants who overestimated the food item.

the estimation in grams ($t[449] = -24.12$, $P < .001$, Cohen's $d = -1.14$; $M_{fruit} = 49.70$, $SD_{fruit} = 110.92$, $M_{no\ fruit} = 769.02$, $SD_{no\ fruit} = 711.35$) than for the estimation in sugar cubes ($t[428] = -18.13$, $P < .001$, Cohen's $d = -0.88$; $M_{fruit} = -4.72$, $SD_{fruit} = 92.18$, $M_{no\ fruit} = 434.01$, $SD_{no\ fruit} = 570.14$), but effects were both large [30].

3.5.2. *Comparison of foods high and low in carbohydrates*

Another analysis compared foods high and low in carbohydrates not classified as mono- or disaccharides. For this analysis, the mean relative deviation of sugar content estimation was calculated for high (i.e., pizza, sandwich) and low carbohydrate foods (i.e., orange juice, cola, salad, ketchup, yoghurt, fruit salad, granola bar, muffin). Separate paired samples *t* tests were computed for the sugar content estimation in grams and in sugar cubes. Again, differences were somewhat more pronounced for the estimation in grams ($t[445] = 20.57$, $P < .001$, Cohen's $d = 0.97$; $M_{high} = 1780.64$, $SD_{high} = 1758.19$, $M_{low} = 236.39$, $SD_{low} = 240.75$) than for the estimation in sugar cubes ($t[427] = 15.94$, $P < .001$, Cohen's $d = 0.77$; $M_{high} = 756.26$, $SD_{high} = 920.76$, $M_{low} = 155.49$, $SD_{low} = 208.05$), but effects were both large [30].

Table 3 – Results of independent samples *t* tests comparing absolute deviation for sugar content estimations in grams and in sugar cubes, as provided by the adult participants

Food item	Sugar in grams		Sugar cubes		Comparison			
	M	SD	*M*	SD	*t*	df	*P*	Cohen's *d*
Orange juice	124.56	171.13	75.71	103.01	5.13	737.14[a]	<.001	0.17
Cola	150.46	161.01	76.16	108.73	7.96	779.87[a]	<.001	0.27
Sandwich	1650.87	2031.67	425.38	573.80	12.19	513.69[a]	<.001	0.41
Pizza	1929.44	1940.71	1073.16	1356.56	7.54	789.10[a]	<.001	0.26
Salad	621.59	883.78	306.80	588.25	6.22	780.41[a]	<.001	0.21
Ketchup	159.21	229.91	104.02	153.89	4.04	755.91[a]	<.001	0.14
Yoghurt	63.85	75.50	56.51	64.11	1.54	854.41[a]	.123	0.05
Fruit salad	72.38	94.65	62.75	49.32	1.89	677.82[a]	.059	0.06
Granola bar	228.14	268.43	140.53	171.48	5.63	734.37[a]	<.001	0.20
Muffin	628.15	519.63	664.04	586.46	–0.95	894	.344	0.03

[a] Corrected for heterogeneity of variances, as indicated by the Levene test.

4. Discussion

In line with previous research [9,11], the present study indicates that sugar content of foods is mostly overestimated by consumers. Using an experimental between-subjects design, the magnitude of misestimation was compared between estimations in grams and estimations in sugar cubes. While sugar content was mostly overestimated using both measures, overestimation was less pronounced when sugar content was estimated using sugar cubes. Discrepancies in the results of prior studies as to a general under- [10] vs overestimation [9,11] of the content of foods thus cannot be explained by the choice of estimation measure.

Although estimation in sugar cubes does not lead to accurate estimations, they at least help consumers to form somewhat more accurate expectations of a food's sugar content. One potential reason for this might be increased familiarity with sugar cubes compared to loose sugar, for example, when sweetening coffee of tea. This might lead to a more accurate perception of the sweetness of a certain amount of sugar in cubes, which can then be compared to the sweetness of the presented food. Furthermore, it might indicate some success of public information campaigns that use sugar cubes to indicate the amount of sugar in selected foods [13]. On the other hand, one could argue that the range of reasonable estimations is smaller when estimating in cubes (as indicated by values ranging from 0 to 11 in this study) than when estimating in grams (with values ranging from 1.3 to 33.5 grams in this study), which reduces the variance in the potential estimations.

Another study has previously reported that sugar content of foods was largely underestimated [10]. Although this conclusion might seem at odds with the results of the present study, it is important to note that, on the level of individual foods, the present study was able to replicate most findings. Both Dallacker et al. [10] and the present study show that consumers tend to underestimate the sugar content of cola, fruit yoghurt, and orange juice while they tend to overestimate the sugar content of granola bars and ketchup. Indeed, orange juice and fruit yoghurt might be perceived to be healthier than they actually are since they both are made from fruit, which is prototypically healthy. This notion was also confirmed by an exploratory analysis conducted on the present dataset, which indicated that misestimation was more pronounced for foods that are not fruit-based compared to fruit-based foods. Underestimation of sugar content may thus indicate a health halo effect [31,32]. Interestingly, no such effect was observed for the granola bar, which might indicate that consumers have gained a better understanding of the ingredients of granola bars and subsequently might judge them as less healthy and containing more sugar [33]. Thus, the observed differences might be at least partially explained by the different foods presented to participants in prior research.

Independent of the estimations in sugar cubes or grams, largest overestimations occurred for savory foods that are high in carbohydrates, that is, the pizza and the sandwich, which was also confirmed in another exploratory analysis. This might indicate that many consumers are unable to differentiate between carbohydrates and sugars. This might be due to the increasing popularity of "low carb" diets [34] which are frequently discussed in the media [35] and which may lead consumers to perceive all carbohydrates as unhealthy. However, since the present study did not assess estimations of carbohydrate content, it is unclear whether the pronounced overestimation of sugar in these foods is actually due to a negative image of carbohydrates promoted by "low carb" diets and equalizing all carbohydrates with sugars. Future studies thus need to explore estimations of carbohydrate content in addition to estimations of sugar content to shed light on this issue.

Second, the present study aimed to compare the misestimation of sugar content to misestimation of the foods' weight and energy content. Again replicating previous research [9], the misestimation of weight and energy content was somewhat less pronounced than the misestimation of sugar content, as indicated by smaller effect sizes. Moreover, there was no general overestimation for weight and energy content. Contrary to previous research [18,36], calorie content was overestimated for the majority of the foods; however, this might be explained by the comparably small portion sizes used in the present study, which have been linked to a lesser degree of underestimation in previous research [18].

Lastly, the present study investigated relationships between the degree of misestimation of sugar content, weight and energy content, and participants' gender, level of education, and BMI. Replicating previous findings (e.g., [32,36,37]), only very weak associations were found. Even though gender and level of education may be associated with nutrition knowledge or preoccupation with food (e.g., [19]), nutrition expertise seems to be unrelated to accuracy of portion size, energy, or nutrient content estimations [32,38]. Similarly, BMI seems to be unrelated to estimation accuracy (c.f. [9,10]); however, since the relationship was assessed cross-sectionally in this study, this relationship warrants further investigation using longitudinal designs to rule out any causal relationships.

The results of the present study have implications for promoting healthier food choices. Misestimations especially of sugar content were considerable and mostly unrelated to education, which raises the question whether consumers should indeed be encouraged to rely on their estimations of macronutrient or energy content when making food choices. The present study suggest that the effectiveness of nutrition education programs might be limited, at least as long as they rely on energy or macronutrient content alone. This numerical information might be difficult to understand and apply in everyday life. More intuitive cues for food choice thus might need to be used. This is supported by the presented results showing that using sugar cubes instead of grams improved estimations. Accordingly, it could be recommended to display the amount of sugar contained in a product in sugar cubes instead of grams to reduce consumption of energy-dense foods [39]. Alternatively, a recent study suggests that providing consumers with reference values for representative foods within a category improves estimations [40]. However, since research on the links between sugar content misestimation and actual food intake is lacking, it is unclear whether overestimation of sugar content is actually protective by reducing consumption of foods that are perceived to be especially high in sugar. More research is thus needed to test potential backfire effects of interventions correcting sugar content misestimations.

Another avenue could be to use alternative measures for indicating appropriate or "healthy" portion sizes that can be used when labeling is unavailable. For instance, a hand-measure estimation aid could be used, which has been shown to lead to more accurate estimations [9]. Moreover, interventions on the individual level might need to be complemented by interventions targeting the choice architecture to increase availability of healthier options [41], for example, by providing fruits and vegetables in schools [42].

A strength of the present study is its comparably large sample. Furthermore, the sample was representative of the German population regarding mean age [43]. However, generalizability of the results might still be limited since the sample comprised more females [44] and its mean BMI was lower than in the general population [45]. Furthermore, the sample was comparably well-educated [46]. Women and more highly educated individuals are more interested in and know more about nutrition [19]; it thus cannot be ruled out that individuals with very low levels of education might misestimate nutrient content even more strongly, although the present study suggest that effects are likely to be small. Moreover, only a small number of foods were presented, and those foods were typical for a Western diet. Future studies thus need to replicate the findings using a greater variety of foods and, since diet is heavily influenced by culture [47], among non-Western samples. Similarly, the study focused on grams; generalizability to imperial units need to be explored. Moreover, foods were presented in fixed order since we used pen-and-paper questionnaires; we thus cannot rule out order effects. Finally, in line with prior research [9–11], accurate estimation was defined as participants exactly indicating the correct amount, which could be seen as a strict evaluation criterion. Yet, it is difficult to make assumptions about which degree of misestimation can still be regarded as "sufficiently accurate," and it is likely that the appropriate degree, amongst others, depends on typical serving sizes and nutrient density. Further research would thus benefit from (theoretically or empirically) determining tolerance ranges to develop new evaluation criteria for correct energy and nutrient content estimation.

5. Conclusions

Consumers struggle to estimate sugar content of foods correctly. Sugar cubes improve estimation accuracy to some extent and thus might be better suited for labeling and educational efforts. Yet, sugar content is largely overestimated independent of the unit of estimation. Also the weight and energy content of foods is often misestimated, indicating that numerical cues might generally be unsuitable for guiding food choices. To promote adherence to dietary guidelines, alternative cues for healthy food choices need to be explored.

Author Declarations

The authors declare no competing interests.

CRediT authorship contribution statement

Laura M. König: Writing – original draft, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Harald T. Schupp:** Writing – review & editing, Resources, Project administration, Methodology, Funding acquisition, Conceptualization. **Britta Renner:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization.

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Supplementary materials

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