Original Article

On the positive association between candy and fruit gum consumption and hyperactivity in children and adolescents with ADHD

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Abstract: *Objective:* The purpose of the present study was the analysis of the association between consumption of candy and fruit gums, diagnosis of attention deficit hyperactivity disorder (ADHD), and behavioural problems. *Methods:* In total, 1,187 children and adolescents of the German Health Interview and Examination Survey for Children and Adolescents (KiGGS) were analyzed. *Results:* It was observed that children and adolescents with ADHD as compared to healthy controls (HC) reported to consume more frequently and higher amounts of candy and fruit gums and that hyperactivity was associated with frequent candy and fruit gum consumption. *Conclusions:* Because with the present design no conclusions on causality or directionality of the found associations could be drawn, results are discussed quite broadly in the light of several previously published interpretations, also to serve as a generator for further research. One more innovative speculation is that children and adolescents with ADHD may consume more frequently candy and fruit gums in order i) to compensate for their higher needs of energy resulting from hyperactive behaviour and/or ii) to compensate for the ADHD-typical deficits in the "reward cascade".

Keywords: ADHD, nutrition, hyperactivity, children, adolescents

Über den positiven Zusammenhang zwischen Süßigkeiten- und Fruchtgummi-Konsum sowie Hyperaktivität bei Kindern und Jugendlichen mit ADHS

Zusammenfassung: *Fragestellung:* In der vorliegenden Studie wurde die Assoziation zwischen dem Konsum von Bonbons und Fruchtgummis, der Diagnose einer Aufmerksamkeits-Hyperaktivitäts-Störung (ADHS) und Verhaltensauffälligkeiten untersucht. *Methode:* Aus der Basiserhebung des „Kinder- und Jugendgesundheitssurvey" (KiGGS) wurden insgesamt 1187 Kinder und Jugendliche analysiert. *Ergebnis:* Kinder und Jugendliche mit ADHS konsumieren häufiger und mehr Bonbons und Fruchtgummis als gesunde Kontrollen. Zusätzlich wurde mittels Regressionsanalysen eine positive Assoziation zwischen Hyperaktivität, häufigem Konsum von Bonbons und Fruchtgummis, jungem Alter und ADHS ermittelt. *Schlussfolgerung:* Da das Design keine Schlussfolgerungen hinsichtlich kausaler Beziehungen und deren möglicher Richtung erlaubt, werden die Ergebnisse unter Berücksichtigung mehrerer bereits publizierter Interpretationen breit diskutiert – auch um zukünftige Forschung auf diesem Gebiet zu stimulieren. In diesem Zusammenhang postuliert eine eher innovative Hypothese, dass Kinder und Jugendliche mit ADHS häufiger Bonbons und Fruchtgummis konsumieren, um i) ihren höheren Energiebedarf, resultierend aus dem hyperaktiven Verhalten, zu kompensieren und/oder, ii) um für ADHS-typische Defizite in der sogenannten „Belohungskaskade" zu kompensieren.

Schlüsselwörter: ADHS, Ernähung, Hyperaktivität, Kinder, Jugendliche

Children show strong preferences for sweet tastes from birth on (Desor, Maller, & Turner, 1973). However, even if this preference and the associated consumption of food containing high amounts of sugar in infants has been considered as a suitable capacity to facilitate rapid postnatal growth and development (Johnston & Foreyt, 2014), the maintenance of high sugar intake has been considered to be unfavourable for several reasons such as dental health (Rossow, Kjaernes, & Holst, 1990), increase of body mass index (BMI, Ludwig, Peterson, & Gortmaker, 2001) or even development of cardiovascular diseases (Kosova, Auinger, & Bremer, 2013).

In addition to somatic effects, sugar has also been described as having adverse effects on children's behaviour, especially in those with a predisposition to hyperactive behaviour (Canadian Sugar Institute, 1989). Behavioural consequences, like restlessness or hyperactivity, from the intake of particular foods including those containing large amounts of sugar have already been described in 1922 by Shannon and were later attributed to a primary allergic behaviour, the so-called allergic tension-fatigue syndrome (Speer, 1958). In their meta-analytic review, Heilskov Rytter and colleagues (2014) reported that further studies investigating the role of dietary changes on the treatment of ADHD arised in the 1970s focussing on food colours and mega-dose vitamins. Thereafter, at the end of the 70s and in the early 1980s, several studies revisited the suggested association between sugar intake and hyperactivity (for more details see Heilskov Rytter et al., 2014; Wolraich, Milich, Stumbo, & Schultz, 1985). Interestingly, although most studies failed to support the hypothesis (Gross, 1984; Milich, 1986; Wolraich et al., 1985), speculations about the association persist to date particularly due to parents' and teachers' reports or believes that behavioural consequences of sugar intake can be observed (Comisarow, 1996; Cormier & Elder, 2007). One explanation, why many studies failed to show a possible association between foods high in sugar and behaviour might be that many studies had only few participants and therefore possibly have missed small associations, that may be more prominent only in children with special dietary behaviours (Heilskov Rytter et al., 2014). Another explanation was that studies did not assess the effects of foods high in sugar in daily life but compared sucrose with other placebo sweeteners such as aspartame, which are all dissolved in water, and subsequently evaluated behavioural ratings filled out by parents in a well-defined experimental design and not after long-term exposure (Heilskov Rytter et al., 2014). This might be problematic since, on the one hand, children and adolescents frequently consume high sugar foods during their daily life, like for instance candy and fruit gums (Mensink, Kleiser, & Richter, 2007), e.g. at home, during school, while visiting relatives and friends or while traveling (Schneider, Jerusalem, Mente, & De Bock, 2013), and, on the other hand, there are several confounders such as total energy intake (Willett, Howe, & Kushi, 1997), consumption of caffeinated beverages as well as diet components (e.g. fish consumption) assumed to be associated with ADHD, that were underrepresented or not represented at all in those experimental studies (for a review see Heilskov Rytter et al., 2014; Prinz, Roberts, & Hantman, 1980; Wender & Solanto, 1991). Altogether, it therefore appears more relevant to analyze a possible association between the abovementioned foods (i.e. candy and fruit gums) and children's and adolescents' behaviour in observations of daily life food intake. Prinz and colleagues (1980) found an association of daily life sugar consumption (recorded via parental records of a seven-day dietary record) with four to seven-year old children (N = 28) in videotaped playtime scenarios, fulfilling attention deficit hyperactivity disorder (ADHD) diagnostic criteria (note: in 1980 ADHD diagnostic criteria were less elaborated and established) as compared to healthy control children (HC). Their observational study was double-blinded and children's behaviour was rated by the Werry-Weiss-Peters Activity Scale (Werry, 1968). Interstingly, both children with ADHD and HC consumed similar amounts of sugar-containing products (327 g/day vs. 331 g/day); however, the authors found a positive association with consumption of sugar-containing foods for destructive-aggressive and restless behaviour only in children with ADHD, while in HC no corresponding effect was observed.

Another study (Wender & Solanto, 1991) compared five to seven-year old children with ADHD (N = 17) vs. HC (N = 9), assessing cognitive attention and aggressive behaviour but not hyperactivity immediately after ingestion of sugar (by a drink including sucrose in combination with a high carbohydrate breakfast). Behaviour was assessed via observations of playtime and via a computer based go/nogo performance test. While they observed no effect on aggressive behaviour, neither in the ADHD nor in the HC group, they reported an increase of inattention assessed by computer based tests in the ADHD group only. Moreover, a recent study investigated not only a possible association of the intake of a particular food, including those with high sugar content, and (hyperactive) behaviour but also, whether the adherence to a mediterranean diet was associated with a reduced prevalence of an ADHD diagnosis (Ríos-Hernández et al, 2017). The findings confirmed the assumed association inasmuch as: i) lower adherence to a mediterranean diet, ii) high frequency of skipping breakfast and of eating at fast-food restaurants, iii) a high consumption of sugar, candy, sweetened beverages (i.e. soft-drinks) as well as iv) low consumption of fatty fish (containing high amounts of omega-3 fatty acids) were associated with an increased likelihood of an ADHD diagnosis.

In summary, most former studies as well as explanatory approaches from parents, teachers, and physicians often argued in one direction, namely that intake of foods high in sugar increases ADHD symptoms and that "sugar reduction" might have benefical effects (Bennett & Sherman, 1983; Cormier & Elder, 2007; Varley, 1984).

Nevertheless, since causality and/or directionality cannot be deducted from correlational analyses, some authors discussed the validity of the mentioned causality and/or directionality of such an association. For example, Prinz and colleagues (1980) interpreted their findings with caution and argued that intake of foods high in sugar and its

possible effect on the behaviour of hyperactive children need to be further investigated. Thus, from time to time the question arose wether the intake of foods high in sugar and the association with hyperactivity could also indicate that children and adolescents suffering from (increased) ADHD symptoms consume more sugar.

Possible explanations were considered to underline the link between hyperactivity and the intake of foods high in sugar. To mention but a few: i) the clinical picture of ADHD goes along with impulsivity traits, emotional distress as well as reward difficulties, which may lead to unfavourable dietary choices (Ríos-Hernández, Alda, Farran-Codina, Ferreira-García, & Izquierdo-Pulido, 2017) and ii) with respect to reward difficulties, dysfunctions in the "brain reward cascade" (Blum et al., 2008). Against the background that in two-thirds of all households, sweets are used as as a reward (Schneider et al., 2013) both points seem to be highly relevant when analyzing the association between foods high in sugar like candy or fruit gums and behaviour.

Aims of the study

To the best of our knowledge, most studies conducted so far, did not assess the possible association of an intake of foods high in sugar and behaviour in a large epidemiological sample including ADHD vs. healthy control children and adolescents. This might explain i.a. why these studies failed to show a positive association between the intake of foods high in sugar and hyperactive behaviour. Therefore, we chose a large epidemiological data set (KiGGS baseline study, see also section "methods"), which depicts health and nutrition-related information that are representative for the average German population. With this data set, we aim to analyze the often hypothesized positive association between the intake of foods high in sugar and children's and adolescents' behaviour. In detail, we analyze the effect of candy and fruit gum consumption in the "food frequency questionnaire" (FFQ), which is part of the total KiGGS survey. We focus on candy and fruit gum consumption, since both are, if assessed over a time range of one day, the most often consumed kind of sweets in children and adolescents (Mensink et al., 2007). In addition, they contain, nearly solely sugar (or more specifically sucrose), which was shown to be positively associated with mental health problems, like for example reduced memory capacity and structural changes in the hippocampus (Lim et al., 2016).

Although the cross-sectional nature of the study design involves some methological limitations, e.g. prevents the evaluation of potential causal relationships and directionality (see also limitation section), it allows to analyze several health and nutrition-related information in a large sample that is representative for the average German population. Further, the likelihood to identify also small associations, which may occur more prominently in children and adolescents with special dietary behaviour or after long-term sugar exposure, increases. Finally, this study aims also to develop hypotheses on underlying neural and/or environmental mechanisms, which should be tested in future work, as they may have long-term implications into adulthood.

Methods

Participants

From May 2003 to May 2006, a total of 17,641 children and adolescents aged 0–17 years participated in the "German Health Interview and Examination Survey for Children and Adolescents" known as the KiGGS study (more detailed KiGGS baseline study, for further details see Kurth (2008). The study fully complies with the Declaration of Helsinki and was ethically approved by the ethics committee at the University Hospital – Charité in Berlin (Germany) as well as the Federal Office for the Protection of the Data. Written informed consent was obtained from the primary caregivers of all participants as well as from participants older than 14 years.

For the purpose of the present study 1,187 participants of the KiGGS data set were analyzed (see Figure 1). We included participants if they met the following criteria: a) presence of ADHD diagnosis and b) the completion of the KiGGS questionnaire on eating habits including questions on candy and fruit gum consumption (frequency and amount). In addition, we included an age-matched control group without ADHD diagnosis, which completed the eating habits questionnaire as well (see Figure 1). All participants were randomly selected out of the total sample using the SPSS function "select cases randomly". In sum, we analyzed 1,187 participants (50 % ADHD, 62.3 % male) aged between four to six years (8.6 %), seven to10 years (34.3 %), 11 to 13 years (27.9 %), and 14 to 17 years (28.9 %). Divided into social classes (Winkler & Stolzenberg, 1999), 27.0 % of the participants are part of low social class, 48.4 % of middle, and 23.7 % of high social class.

ADHD diagnosis

Following the methodology of the KiGGs study algorithm, participants were allocated to the ADHD group, if they had ever been diagnosed with ADHD. For this purpose, parents were asked, whether their child was diagnosed with ADHD. If they answered "yes", it was further speci-

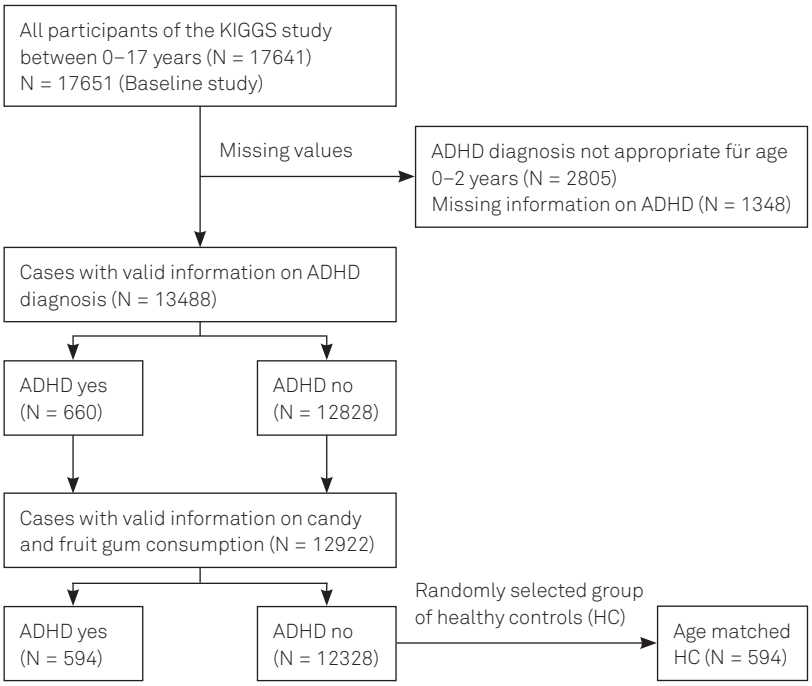


Figure 1. Study sample constitution.
Note. Sample Constitution. Description of how the analyzed sample is constituted. ADHD: Attention deficit hyperactivity disorder, KiGGS study: German Health Interview and Examination Survey for Children and Adolescents; N: number of participants.

fied whether ADHD was diagnosed by a physician or psychologist. For an estimation of the validity of the parental answer, symptomatic information was correlated with the scale "hyperactivity" of the strengths and difficulties questionnaire (SDQ, Cronbach's α = .78) (Schlack, Hölling, Kurth, & Huss, 2007). In addition, a ROC analysis with the hyperactivity scale of the SDQ as explanatory variable and the diagnosis question as criterion was applied and revealed an AUC (area under the curve) of = .86 (Schlack et al., 2007). However, it has to be kept in mind that this ROC analysis was not applied as a validiation method. Rather it is possible, to show with the help of this analysis a correspondence between answers given in the SDQ and answers given to the question, whether a child has been diagnosed with ADHD. This indicates that the applied methods in KiGGS to obtain an ADHD diagnosis seems to represent an appropriate approach.

SDQ

The SDQ (R Goodman, Meltzer, & Bailey, 1998; Robert Goodman, 1997) is a well-established and reliable screening tool (with mean Cronbach α: .73, mean cross-informant correlation: $M = 0.34$, mean retest stability after four to six months, $M = 0.62$ (Robert Goodman, 2001), including 25 items which are divided into five subscales: emotional problems, conduct/behavioural problems, hyperactivity, peer problems and prosocial behaviour. The SDQ was applied to identify potential behavioural differences between the two groups (ADHD and HC, see Table 1).

Consumption of candy and fruit gums

Information on candy and fruit gum consumption was obtained with the "food frequency questionnaire" (FFQ) as part of the KiGGS survey. Within this questionnaire the average food frequency and portion size was obtained (for more details see (Mensink et al., 2007; Truthmann, Mensink, & Richter, 2011). It has been shown that the FFQ is suitable for the collection of dietary data in large representative samples and that the relative validity of the KiGGS FFQ is comparable to other versions of FFQ in literature (Truthmann et al., 2011). For the purpose of our study, we focused on candy and fruit gums" (the question was "How often have you consumed candy and fruit gums?", "If you consume candy and fruit gums, how much candy and fruit gums do you eat?"). We analyzed both the frequency (ranging in the FFQ from 1–10, with 1 indicating "never" and 10 "more often than five times a day") and the amount (ranging in case of candy and fruit gum consumption in the FFQ from 1–6, with obe indicating "one piece" and six "at least 21 pieces or more"). For the purpose of the present study we analyzed the continuous variables (ranging from 1–10, 1–6).

Control variables

Since diet behaviour (Darmon & Drewnowski, 2008) as well as ADHD (Russell, Ford, Rosenberg, & Kelly, 2014) seems to be associated with socioeconomic status, we controlled the data with the Winkler Social Class Index scores (Winkler & Stolzenberg, 1999). The social class, according to Winkler, defines three categories: low, middle, and high. The social class is measured based on information provided by children's and adolescents' parents regarding their education, work status, and the net monthly income per household. Furthermore, since ADHD and hyperacticity seem to be associated with age (Biederman, Mick, & Faraone, 2000) and sex (Gershon & Gershon, 2002), we controlled the data additionally for age and sex. Finally, since diet behaviour is also associated with the body mass index (BMI), we controlled for BMI as well.

Statistical analysis

Statistical analyses were conducted with SPSS 22 (SPSS, Inc., Chicago, Il, U.S.A.). In a first step, we analyzed via chi-squared tests whether groups (ADHD vs. HC) differ with respect to sociodemographic data (age, sex, social class) and via t-tests whether they differ with respect to analyzed questionnaires (SDQ, candy and fruit gum consumption see also Table 1). Via linear as well as multiple regression analyses, we estimated and analyzed general (single and multiple) effects of candy and fruit gum con-

Table 1. Sample description.

	ADHD Group			Healthy Controls			Chi²-Test
	N = 594			N = 594			
Social Class	Low	Middle	High	Low	Middle	High	
N	181	295	113	142	281	169	
%	30.7 %	50.1 %	19.2 %	23.9 %	47.5 %	28.6 %	$\chi 2\ (2) = 16.43, p < .001$
Gender	Female		Male	Female		Male	
N	122		472	323		271	
%	20.5 %		79.5 %	54.5 %		45.5 %	$\chi 2\ (1) = 145.78, p > .001$
							t-Test
Age (years)	11.24 (± 3.43)			11.05 (± 3.59)			$t(1185) = .941, p = .347$
SDQ							
Total problems	14.82 (± 5.99)			7.61 (± 4.92)			$t(1185) = 22.77, p < .001$
Emotional problems	3.00 (± 2.19)			1.60 (± 1.68)			$t(1185) = 12.34, p < .001$
Conduct problems	3.15 (± 1.96)			1.85 (± 1.57)			$t(1185) = 12.61, p < .001$
Hyperactivity	6.21 (± 2.23)			2.81 (± 2.15)			$t(1185) = 26.74, p < .001$
Peer problems	2.48 (± 2.13)			1.36 (± 1.53)			$t(1185) = 10.36, p < .001$
Prosocial behaviour	7.24 (± 1.89)			7.77 (± 1.71)			$t(1185) = -5.13, p < .001$
Candy and fruit gum consumption							
Frequency	4.78 (± 1.73)			4.53 (± 1.67)			$t(1185) = 3.49, p < .001$
Amount	5.59 (± 1.03)			2.81 (± 1.11)			$t(1185) = 2.54, p < .001$
BMI (kg/qm)	19.38 (± 4.17)			18.63 (± 3.81)			$t(1178) = 3.21, p < .001$

Note. Upper part: Number (N) and percentages; Lower part: Means (M) ± standard deviation (SD). ADHD: Attention deficit hyperactivity disorder, SDQ: Strengths and Difficulties Questionnaire[19], BMI: Body mass index.

sumption (frequency and amount), age, sex, social class, and ADHD on hyperactive behaviour, which was set as dependent variable.

Results

Sample Characteristics (see Table 1)

Chi-squared tests analyzing the association between the "participant group" (ADHD, HC) and "sex" revealed a difference between groups ($\chi 2 = 145.78$, df = 1, $p > .001$), indicating lower percentage of females within the ADHD group (20.5%) as compared to HC (54.5%). In addition, a similar analysis on "social class" (low, middle, and high) and "participant group" revealed a difference between groups ($\chi 2 = 16.43$, df = 2, $p > .001$), indicating that a higher percentage of participants with ADHD vs. HC can be assigned to a low "social class" (30.7% vs. 23.9%), while a lower percentage of the ADHD group vs. HC can be assigned to a high "social class" (19.2% vs. 28.6%). Chi-squared tests on age-group revealed no effect ($p > .05$).

Candy and fruit-gum consumption

(FFQ, see Table 1, Figure 2)

Pairwise t-tests on the continuous variables "frequency of candy and fruit-gum consumption" and "amount of candy and fruit-gum consumption" revealed that participants with ADHD vs. HC consume both more often and higher amounts of candy and fruit gums.

Candy and fruit gum consumption and behaviour in children and adolescents with ADHD

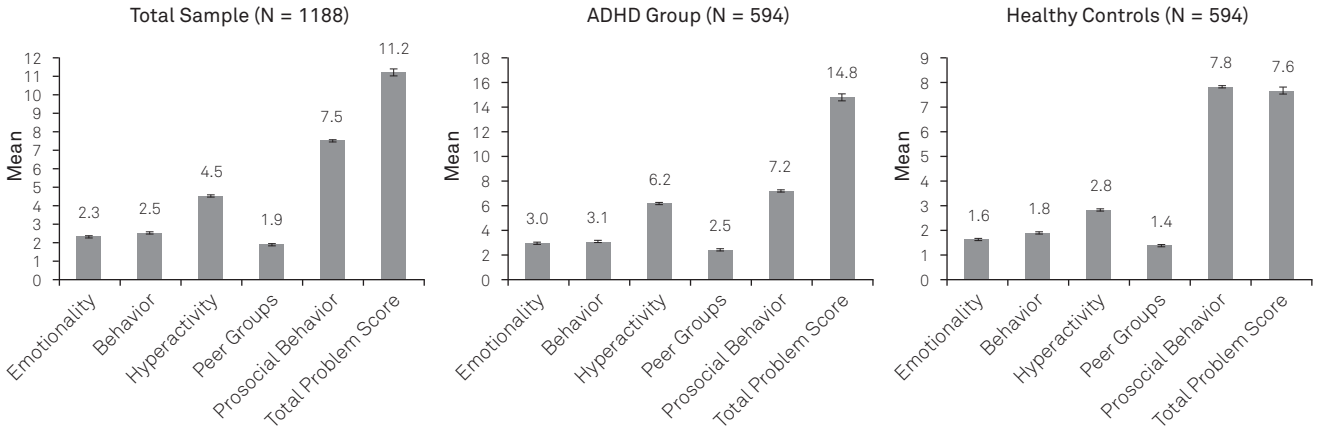
(see Figure 2, Table 2 and 3)

To analyze whether candy and fruit gum consumption is associated with hyperactive behaviour, we conducted a linear regression analysis. For this analysis, we determined hyperactivity as predictor variable and included sex, social class, age, ADHD, BMI, amount as well as frequency of candy and fruit gum consumption in the analysis. The analysis revealed that "ADHD" ($\beta = -.62$, $t(134) = -25.63$, $p < .001$), "age" ($\beta = -.20$, $t(018) = -8.74$, $p < .001$), and "frequency of candy and fruit gum consumption" ($\beta = .05$, $t(37) = 2.28$, $p = .023$) predict hyperactivity scores ($R^2 = .43$, $F[7,1170] = 123.55$, $p < .001$), while "amount of candy and fruit gum consumption", "social class", "sex", and "BMI" had no influence (all $p > .079$, see Table 3).

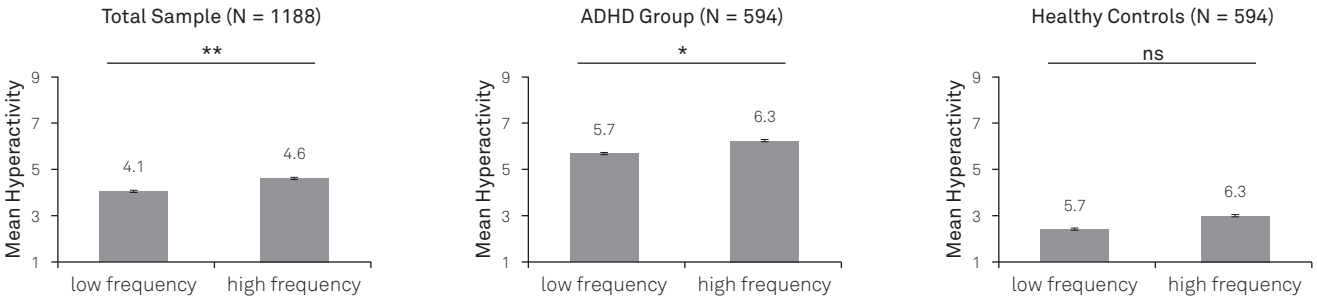
Discussion

The present study investigated the assumed association between candy and fruit gum consumption – both containing high amounts of sugar – and hyperactive behaviour as measured with the SDQ in children and adolescents with ADHD vs. HC in a large epidemiological data set that depicts several health and nutrition-related information representative for the daily life of the average German population. In addition, the possible influence of age, sex, social class, and BMI on this assumed association was analyzed. We observed that children and adolescents with ADHD consumed more (frequency and amount) candy and fruit gums compared to HC. Morover, the regression analysis specified the results and revealed that hyperactivity values rely on frequent candy and fruit gum consumption, ADHD diagnosis, and young age, indicating that hyperactivity values are highest especially in those children, who are diagnosed with ADHD, consume candy and fruit gums frequently and are of a young age. However, since causality and directionality cannot be deducted from our analyses, several hypothetical explanations can be made. Firstly, it can be speculated that hyperactive children and adolescents, and here particularly those crossing the threshold of a categorical ADHD diagnosis, consume candy and fruit gums more frequently to compensate for their higher energy needs due to hyperactivity particularly by food high in sugar. This speculation refers on the function of glucose, which is known to be the primary fuel source for brain and body (Marty, Dallaporta, & Thorens, 2007). In the brain, it is known i.a. to influence cortical regulation of feeding behaviour (Page et al., 2011). It was observed that even modest reductions in circulating glucose influences the control of attention (Ernst et al., 1994) and decreases prefrontal cortical inhibitory control (which are both core dysfunctions in ADHD). These effects may promote higher glucose intake (Page et al., 2011). Alternatively, the more frequent consumption of candy and fruit gums could also be seen as a consequence of the well-known dysfunctions in the "brain reward cascade" in ADHD (Blum et al., 2008). Since children with ADHD are observed to have dysfunctions in the opioid and dopamine system (Fusar-Poli, Rubia, Rossi, Sartori, & Balottin, 2012; Love, Stohler, & Zubieta, 2009; Modesto-Lowe, Chaplin, Soovajian, & Meyer, 2013) leading to ADHD specific symptoms (e.g. abnormal functions of reward and motivation (Modesto-Lowe et al., 2013) or impulsive behaviour (Love et al., 2009), it can also be speculated that inadequate dopaminergic activity in the brain may lead to the increased consumption of carbohydrates (i.e. sugar containing food, like candy and fruit gums). It can thus be speculated that children and adolescents with ADHD consume candy and fruit gums more frequently, since they have a more immediate reward dependence.

A: Strengths and Difficulties Questionnaire (SDQ) Values



B: Frequency of Candy and Fruit gum Consumption vs. Hyperactivity Values



C: Amount of Candy and Fruit gum Consumption vs. Hyperactivity Values

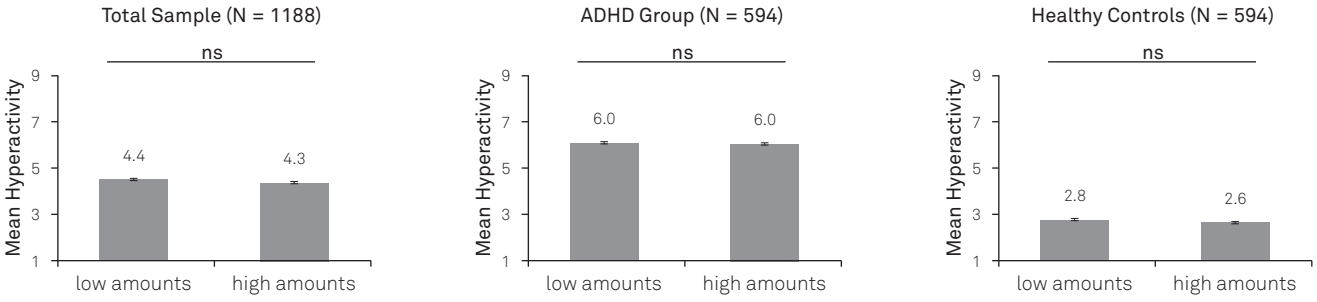


Figure 2. Relation between behavior and sweets consumption.

Note. Relation between behavior and sweets consumption. (A) Shows the means of the strength and difficulties questionnaire (SDQ), on the left side: in the total sample, in the middle: in children and adolescents with attention deficit hyperactivity disorder (ADHD), on the right side: in healthy controls (HC); (B) shows the means of the subscale "hyperactivity" of the SDQ in relation to the frequency of candy and fruit gum consumption; on the left side: in the total sample, in the middle: in ADHD, on the right side: in HC; (C) shows the means of the subscale "hyperactivity" of the SDQ in relation to the amount of candy and fruit gum consumption, on the left side: in the total sample, in the middle: in ADHD, on the right side: in HC; One asterisk represent a significant difference on the $p < .05$ level, two asterisks represent a significant difference on the $p < .01$ level. Error bars depict standard error of the mean (SEM).

However, here, two mechanisms have to be taken into account: (i) children and adolescents with ADHD tend to get attention only when they are doing something wrong. Therefore, cognitive behavioural therapy (CBT) with the Token-Economy (TE) technique is often administered in ADHD. Here, at least sweets are used not only as back-up reinforcers, but also directly as "tokens" in contingency management systems to systematically award appropriate behaviour. Due to the well known dysfunctions in the "brain reward cascade" in ADHD (Blum et al., 2008) these children and adolescents require and thus receive more often food high in sugar, like for example candy and fruit gums for reinforcement. As a consequence of that, they may also have learnt that consumption of candy and fruit gums on their own helps to reward themselves. Thus, (ii) the self-stimulation of the dopamine system by the con-

Table 2. Regression analysis for the relevant control variables predicting hyperactivity (N = 1.188), single model analysis.

Predictor		Single Model				
		B	SE B	ß	R^2	*F* and p for change in R^2
Age	4–17years	–.149	.023	–.188	.035	**$F = 43.57, p < .001$**
Sex	1 = male 2 = female	–1.156	.163	–.202	.041	**$F = 50.45, p < .001$**
Social economic status	1 = low 2 = middle 3 = high	–.462	.112	–.119	.014	**$F = 17.02, p < .001$**
Group	1 = ADHD 2 = HC	–3.40	.127	–.613	.376	**$F = 715.18, p < .001$**
Amounts of candy and fruit gum consumption	1–6	.169	.075	.066	.004	**$F = 5.14, p = .024$**
Frequency of candy and fruit gum consumption	1–10	.205	.047	.126	.016	**$F = 19.27, p < .001$**
BMI	12.29–44.57	.031	.020	.044	.002	$F = 2.29, p = .130$

Note. ADHD: Attention deficit hyperactivity disorder; HC: healthy controls; BMI: body mass index.

Table 3. Regression analysis for the relevant control variables predicting hyperactivity (N = 1.188), multiple model analysis.

Predictor		Multiple Model			
		B	SE B	ß	t and p
Age	4–17years	–.157	.018	–.198	**$t = -8.74, p < .001$**
Sex	1 = male 2 = female	.119	.136	.021	$t = .873, p = .383$
Social economic status	1 = low 2 = middle 3 = high	–.154	.087	–.039	$t = -1.76, p = .079$
Group	1 = ADHD 2 = HC	–3.43	.134	–.619	**$t = -25.63, p < .001$**
Amounts of Candy and fruit gum consumption	1–6	.052	.060	.020	$t = .866, p = .387$
Frequency of candy and fruit gum consumption	1–10	.085	.037	.052	**$t = 2.28, p = .023$**
BMI	12.29–44.57	–.014	.016	–.020	$t = -.89, p = .374$
R^2	.426				
F	**$F = 123.55, p < .001$**				

Note. ADHD: Attention deficit hyperactivity disorder; HC: healthy controls; BMI: body mass index.

sumption of foods high in sugar (Pepino et al., 2016) could alternatively explain our findings, i.e. children with ADHD will more frequently use candy and fruit gums to reward themselves. For example, it has been observed that the consumption of large quantities of sweets ("carbohydrate bingeing") stimulates not only circulating glucose levels but also the brains production and utilization of dopamine (Blum et al., 2008). Cruicially, however, the stimulation of the dopamine system may also result in some extent in addictive behaviour, similarily to other addictions that are associated with the stimulation of the dopamine systeme, like the consumption of alcohol, cocaine or the abuse of nicotine (Blum et al., 2008). In this vein, it has also been described that children with ADHD have an increased risk for the pediatric loss of control eating syndrome (Reinblatt et al., 2015) and obesity (Güngör, Celiloğlu, Raif, Özcan, & Selimoğlu, 2016), pointing to the dependency risk, which is evoked by an increased stimulation of the dopamine system. Last but not least neither the "other direction of causality" (more frequent consumption of food high in sugar increases hyperactive and/or impulsive behaviour) can be proven by our findings (see introduction). In view of the unresolved questions of causality and directionality as well as underlying mechanisms, it is also impossible to draw the recommendation from our findings that candy and fruit gums should be less frequently consumed, since younger, more hyperactive children could benefit from an increased consumption.

Limitations

The KiGGS study has a broad thematic focus. Therefore, it appears unlikely that children, adolescents, and parents could answer in terms of social desirability within all questionnaires. Nevertheless, it appears very unlikely that raters would be aware of a relationship between the SDQ and the nutrition questionnaires, which are used as two independent measures among numerous others. However, this potential strength could also be seen as a weakness, since candy and fruit gum consumption was not experimentally manipulated and we cannot investigate possible effects on the time course, such as a possible enhancement of disturbed behaviour rapidly following ingestion of sugar (Milich, 1986). Moreover, we are not able to analyze glucose concentration in the brain using the present data set. But it appears promising for further research to analyze glucose concentrations in children and adolescents with ADHD in comparison to HC and link them to core symptoms of ADHD, like hyperactivity and inattention as well as food habits. Since, we were not able to specify the exact ingredients or kind of candy and fruit gums which are consumed by children, it seems also to be relevant to further define the exact influence of specific ingredients of sweets like for example various types of sugar and artificial sweeteners on the observed effects of increased hyperactivity values. In line with these limiting factors, we have no information regarding total sugar or nutrient intake of the analyzed KiGGS sample – a fact which has to be rated as a major limitation, since it has been observed that adjustment for total energy intake is of high importance in epidemiologic studies to control for confounding effects, to reduce extraneous variation, and to predict the effect of dietary interventions more precisely (Willett et al., 1997). Moreover we are aware of the fact that the ADHD diagnoses were obtained several years ago implying that the nomenclature and diagnostic criteria have changed since then. Unfortunately, we do not know whether children and adolescents included in the present study belong to a specific subtype. Although congruency between reported ADHD diagnosis and observed SDQ values point towards reliable measurements in the KiGGS survey, it has to be stated that answers from these measurements are given by the parents.

Finally, we do not have information on comorbidities such as conduct disorder or opposotional defiant disorder, since the KiGGS database represents general information regarding health of children and adolescents of the German population and does not focus on psychiatric disoders per se. Nevertheless, we think that the advances of the large epidemiological data set, which i.e. depicts several health and nutrition related habits representative for the daily life of the average German population, outweighs the limitations to come to further evidence about this often parent-reported phenomenon.

Conclusions

We observed an association between hyperactivity and frequent consumption of candy and fruit gums, but have no evidence for causality or directionality. Therefore it could only be speculated about possible interpretations. One more innovative explanation could be that the higher demand of energy due to hyperactive traits results in more consumption of candy and fruit gums as an adaptation mechanism of the organism. An alternative interpretation are the negative consequences of an underlying inadequate dopaminergic activity in ADHD children's and adolescents' brain on reward, which may lead to the parent- or self-triggered increased consumption of candies and fruit gums. However, these assumptions are post-hoc interpretations. In addition, with the present design no conclusions on causal relationships could be drawn and further studies, analyzing the observed association with an experimental design are urgently needed.

Summary

The positive association between foods high in sugar and hyperactivity reported by parents and some clinicians has been widely discussed. However, experimental studies are rare and assessments are often biased, resulting in a small and heterogeneous base of evidence. Using a large epidemiological sample, we observed a positive association between frequent candy, fruit gum consumption, hyperactivity, and ADHD. In reference to the present results and since an excessive consumption of candy and fruit gums may also raise important issues for mental and physical health of children and adolescents with and without ADHD, we emphasize that further studies on underlying causal mechanisms are urgently required.

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