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Social media and children's and adolescents' diets - a systematic review of the underlying social and physiological mechanisms

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Abbreviations: SM- social media, BMI- body mass index, dmPFC- dorsomedial prefrontal cortex, dlPFC- dorsolateral prefrontal cortex, ED food- energy dense foods, EI- energy intake, fMRI- functional magnetic resonance imaging; FFM: fat free mass; FM- fat mass, HFSS foods: foods high in fat, salt, and sugar; mPFC- medial prefrontal cortex, IFG- inferior frontal gyrus, OFC- orbitofrontal cortex, PS- portion size, PPHG- parahippocampal gyri, RCT- randomized controlled trials; SSB- sugar-sweetened beverages, vmPFC- ventromedial prefrontal cortex, WHO- World Health Organization.

Abstract

The association between social media (SM) and children's and adolescents' diet is poorly understood. This systematic literature review aims to explore the role of SM in children's and adolescents' diets and related behaviours considering also the underlying mechanisms. We searched Medline, Scopus and CINAHL (2008-December 2021) for studies assessing the relationship of SM exposure with food intake, food preference, dietary behaviours and the underlying mechanisms (e.g. brain activation to digital food images- as proxy for SM food images) among healthy children and adolescents aged 2-18 years. The protocol was registered in PROSPERO (number: CRD42020213977). A total of 35 articles were included. Of four studies, one found that exposure to peers' videos on healthy eating, but not SM-influencers', increased vegetable intake. Most studies reported that SM was associated with skipping breakfast, increased intake of unhealthy snacks and sugar-sweetened beverages, and lower fruit and vegetable intake, independent of age. Children and adolescents exposed to unhealthy vs. healthy digital food images showed increased brain response in reward- and attention-related regions. The mechanisms underpinning the abovementioned associations were: i) physiological (appetitive state, increased neural response to portion size and energy density of food depicted), and ii) social (food advertising via SM-influencers and peers). SM exposure leads to unfavourable eating patterns both in children and adolescents. The identified mechanisms may help to tailor future health interventions. Down-regulating SM advertising and limiting SM exposure to children and adolescents may improve food intake and subsequent health outcomes.

Keywords: eating habits, fMRI, food advertising, social media, Instagram, Facebook, neural activity, Influencer marketing, children, adolescents

Teaser Text: This review is the first to examine the role exposure to social media has on children's and adolescents' diets, considering developmental differences. We identified the underlying social and physiological mechanisms which will serve to tailor future health interventions.

Introduction

The prevalence of overweight and obesity among children aged 5-19 years has increased worldwide, from 4% in 1975 to 18% in 2016 (1). Eating behaviors driven by obesogenic environments, including the high availability, affordability, and the omnipresent marketing of energy-dense (ED) foods, especially in the digital environment, contribute to a poorer health status of children and adolescents. Prolonged television viewing (TV) is a well-documented factor associated with obesity risk (2), as it predominantly associates with unfavorable eating behaviors: increased consumption frequency of unhealthy foods, reduced consumption frequency of vegetables and fruits (3), high sweet and fat intake (4), and breakfast skipping (5).

With emerging technological developments, TV has been displaced by the use of smartphones. Their technological features facilitate ubiquitous access to internet and social media (SM) platforms (e.g. YouTube, Facebook, Instagram, etc.) (6, 7). Thus, children's smartphone use is more difficult for parents to control (8). The urge to constantly check highly entertaining online content and the upcoming notifications (i.e. from the SM applications) can influence children's and adolescents' attention span (6). This effect is especially worrisome in the eating environment as mindless eating when in front of screens is associated with overeating, potentially leading to overweight and obesity (9). The Global Kids Online Report (2019) showed that smartphones were the most popular devices children used to go online (10). According to the Common Sense Census (2020), nearly all (96%) 5-8 year old children in the United States, spent on average one hour daily using mobile devices (11). Moreover, 70% of US adolescents reported using the internet - notably via smartphones - to access Instagram, while 50% reported being online "almost constantly" (12). Research shows that despite the age restrictions of these SM platforms (≥13 years), 72% of US children aged ≤8 years use smartphones to watch videos on SM (11), while 9-11 year old European children visit their SM account every day, ranging from 11% in Germany to 45% in Serbia (13).

The ubiquitous presence of SM in children's and adolescents' lives represents a powerful tool for companies to advertise their junk food products through paid partnerships with bloggers (i.e. SM influencers) who are attractive role models for children and adolescents (14). The SM influencers may shape their followers' opinions by endorsing brand products in their SM posts (e.g. highly curated videos and images) (15). Increasingly, influencers also provide nutrition and weight management information, although they lack evidence-based features and the involvement of health care experts, questioning their validity and safety (16).

Studies examining advertisement exposure on SM platforms among Canadian children aged 7–16 years, found that they watch weekly almost 200 food/beverage advertisements (17), predominantly promoting unhealthy foods. Similar findings were observed in Australian and Belgian children and adolescents (18, 19). Children are particularly susceptible to marketing messages, as their cognitive development and the ability to recognize the selling, persuasive intent of advertisements is limited (20, 21). Food and beverage advertisements enhance brand recognition and may alter preferences for the advertised (mainly ultra-processed) foods (21). Moreover, SM has rendered the presence of highly appetizing and digitally-enhanced (unhealthy) food images ubiquitous (22). Image- and video-based SM platforms (Instagram, YouTube, TikTok) are indeed the platforms with highest use among children and adolescents (11, 12). Exposure to appetizing food images increases attention and neural activation in visual-processing and reward related brain areas in humans (22). Moreover, eye-tracking research showed that images of unhealthy foods are processed differently (i.e. higher gaze duration) compared to images of healthy foods and non-edible products (e.g. sunscreen), and can be remembered regardless of the amount of visual attention that children allocate to them (23). Further, our innate preference for sweet and fat taste has been reported (24) and consumption of sugar-sweetened beverages (SSB), for example, is associated with TV use (2). Thus, analyzing the role of food marketing in the SM environment is important for understanding the impact of brand-related SM posts on food preference and food choice.

A previous cross-sectional study reported that SM exposure was associated with higher odds of skipping breakfast and consuming SSB (25). Moreover, influencer marketing of unhealthy foods increased children's immediate intake of these foods, whereas the equivalent marketing of healthy foods showed no effect (26). The mechanisms behind these associations remain unknown.

These observations suggest that exposure to SM content might influence children's and adolescents' diets and eating behaviors. Prior reviews in this area have been focused on the role of advergames, where advertising content is embedded in the video-game (27), and in the effectiveness of using SM for nutrition interventions in adolescents and young adults (28). However, no systematic review has synthetized the evidence on the role of SM in children’s and adolescents’ diets, accounting for developmental differences such as age, brain maturation and puberty. Hence, we aim to identify, appraise, and synthetize the current body of evidence and to address two main research gaps: i) to determine how exposure to SM influences children's and adolescents' diets, including food intake (consumption frequency and quantity of unhealthy, high-energy vs. healthy, low-energy foods), food preference and/or liking of healthy vs. unhealthy foods, related behaviors (breakfast consumption), and nutrition literacy, and ii) to identify the underlying explanatory mechanisms (e.g. brain response to food images) and technological features of SM such as advertising disclosure that may shape children’s eating behaviors.

Methodology

This systematic review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (29). The protocol was registered with the International Prospective Register of Systematic Review (PROSPERO; registration number: CRD42020213977).

Search strategy

Three literature databases - MEDLINE (via PubMed), Scopus and CINAHL (via EBSCO) - were searched from 2008 to December 2021. As Facebook was publicly launched in 2006 and in 2008 the first iPhone entered the market, we set 2008 as the beginning year in our search strategy. However, studies evaluating the use of SM for research purposes were not published until 5-6 years later (30, 31). No restrictions on language, study design or publication type were imposed. Search terms were combined to identify articles targeting:

i) healthy children and adolescents aged 2-18 years at any context;
ii) an association with food intake (unhealthy vs. healthy food intake, junk food intake, fruit/vegetable intake, SSB intake), food preference/liking, nutrition literacy (or diet literacy) and related behaviors (breakfast skipping or breakfast consumption);
iii) SM use ((or social networking sites or Facebook, Instagram, Snapchat, TikTok, YouTube), or online SM food marketing/advertisement or influencers' marketing)); or proxies such as internet and smartphone use, exposure to food images or food videos.

The rationale for the inclusion of internet and smartphone use is based on recent findings which show that children and adolescents mainly use their smartphone and internet to access SM, share content from their everyday activities (including food images) and have (online) social interactions with their peers and SM followers (11, 12). Exposure to digital food images/videos was included as a proxy exposure for highly saturated and palatable food images in the SM context, which can shape children's and adolescents' food preferences and choices (23, 26, 32). Using electro-encephalography, Ohla and colleagues (33) showed that the mere exposure to images of energy-dense (ED) foods could enhance hedonic taste evaluation. After exposure to high vs. low calorie food images, participants reported the hedonically neutral electric taste signal as more pleasant, with effects being stronger in the reward processing (insula) and decision-making (orbitofrontal cortex) brain areas.

Studies conducted in diseased children (e.g., those having obesity, diabetes, eating disorders or neurological disorders), in children aged <2 years or >18 years, lacking an SM component, or not measuring diet-related outcomes were excluded. Studies primarily targeting parents and/or families and those where the main exposure was computer, television, advergames or mobile applications other than SM applications were also excluded. The complete search strategy for Medline is presented in **Supplementary table 1**.

Study selection and synthesis of the results

Articles identified in each database were downloaded to EndNote X9. ES removed duplicates and exported articles to the online Rayyan QCRI app (34). First, articles were screened based on title/abstract by ES and three independent reviewers (blind screening - in pairs), all with strong Public Health background and in a second step, based on full-texts. At both stages, disagreements were resolved by consensus or adjudicated by two additional reviewers (AH/DB). References of included studies and relevant review articles were manually searched for citations. For missing full texts, the respective authors were contacted by e-mail (ES). For the eligible articles, the four initial reviewers independently extracted the data and disagreements were resolved by mutual consensus. A concluding decision for the final extract was made by ES and AH. The extracted data were recorded in a predefined data extraction template including: 1) study details: title, authors, year, country, study design and SM exposure (type of platform and/or food image/video, frequency/duration of use), 2) participant information: age (mean and range), sex, sample size, parental SES, ethnicity/migration background; 3) outcomes investigated, main primary and secondary findings. The results were synthetized narratively and key findings - clustered by age group (children: <12 years; adolescents ≥12 years) - were categorized as: 1) SM exposure and unhealthy food intake (i.e. consumption frequency and quantity) and dietary behaviors (e.g., breakfast skipping), 2) SM exposure and healthy food intake (e.g., fruit and vegetable intake) and nutrition literacy, 3) smartphone use, food intake and dietary behaviors (e.g., breakfast consumption), 4) exposure to digital food images and patterns of brain activation, and 5) differences in the abovementioned associations by sex.

Risk of bias and assessment of study quality

The quality and risk of bias of the selected publications was assessed by two independent reviewers. For cohort studies, the Newcastle-Ottawa Scale was used (35), while the Joanna Briggs Institute appraisal tool (36) and the revised Cochrane risk of bias (RoB 2.0) tool were respectively used for assessing cross-sectional studies and randomized clinical trials (RCTs) (37). Further information on the specific domains/items of each appraisal tool is provided in the **Supplementary methods**. An aggregate quality rating was given to each study, and for all discrepancies, consensus was achieved via further discussions among ES and the three reviewers or by consulting an additional reviewer (AH/DB). We did not exclude studies based on their quality rating.

Results

Our database search identified a total of 5518 articles and an additional 4 articles were identified via manual search. After 1725 duplicates were removed, the remaining 3797 references went through title and abstract screening. Of these, 237 articles met our criteria for full-text screening.

At this stage, 202 studies were removed, with reasons outlined in **Figure 1** (29). The majority of studies were excluded because they did not include a SM component. A total of 35 studies were included in our review (**Table 1** and **Supplementary table 2**).

Study characteristics

The majority of the studies were conducted in North America (25, 38-48) and Europe (26, 49-61). A minority were conducted in Australia (19, 62, 63), Brazil (64), and Asia (65-69). The sample size ranged from 11 to 54,603 participants. SM platforms examined were Instagram (26, 50, 51, 56, 59), YouTube (19, 55), Facebook (25, 58) and WhatsApp (67), while four studies focused on smartphone or internet use (57, 62, 64, 65, 68, 69). Food and beverage SM marketing was investigated in ten studies; four of them focused on peer (51) and influencer marketing (26, 50, 56, 59). In the observational studies, SM exposure (frequency and duration) was self-reported, whereas RCTs pre-defined the exposure duration to SM. Among RCTs, 12 were fMRI-based studies (functional Magnetic Resonance Imaging) which measured the exposure to unhealthy digital food images, while one of them considered food video commercials (hereinafter food advertisements) (44). Detailed characteristics of the included studies are described in **Supplementary table 2**.

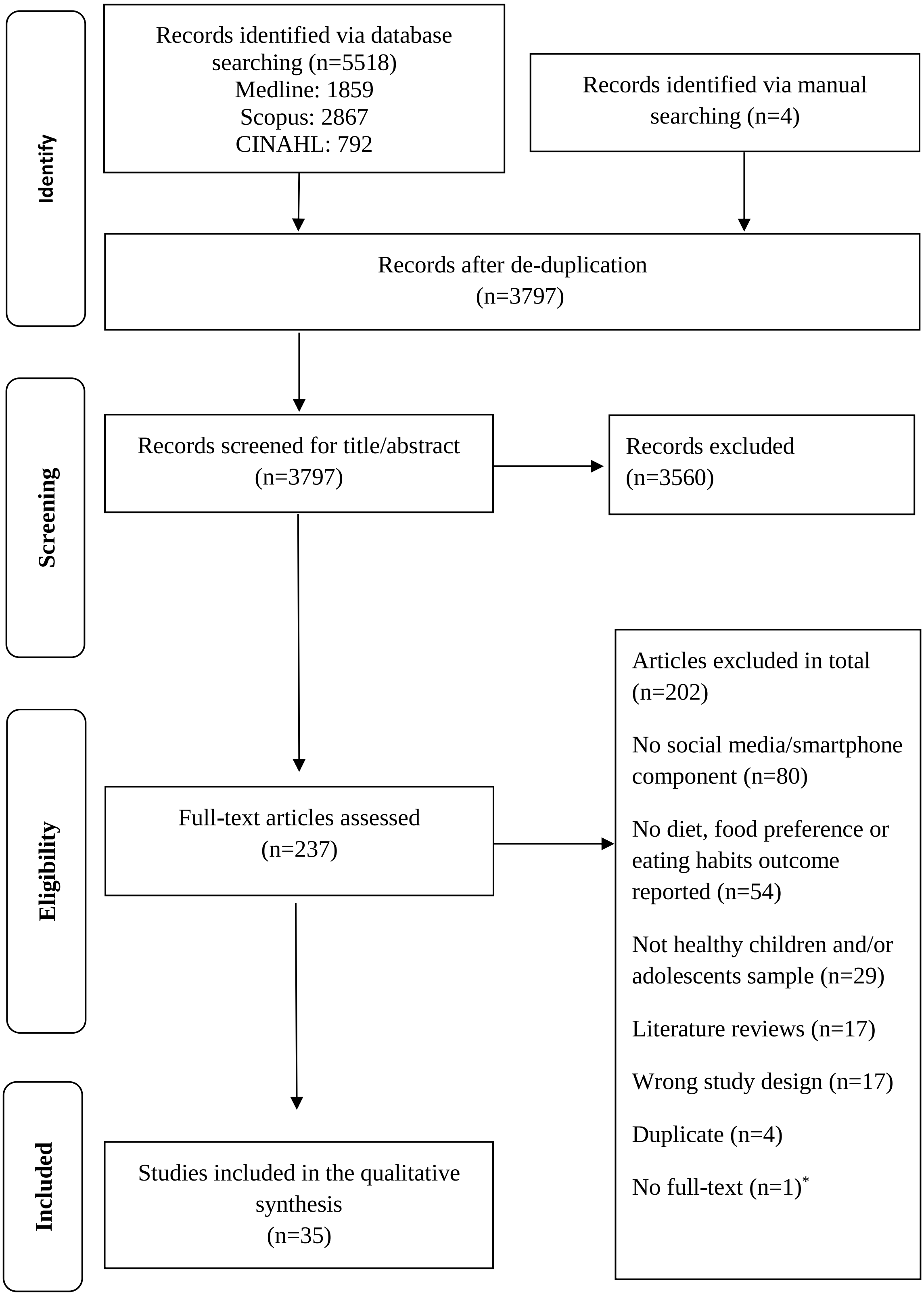

Figure 1. PRISMA flow diagram illustrating the selection process of the eligible studies

*The authors were contacted, but we did not receive an answer from them.

Quality Assessment

Over half of the included studies were interventional studies (i.e. RCTs: n=23) (26, 39-54, 56, 58-60, 62, 67) whereas twelve studies were observational, of which one and eleven studies were respectively longitudinal (55) and cross-sectional (19, 25, 38, 57, 61, 63-66, 68, 69). Among the RCTs, one was rated high quality (i.e. low risk of bias) (70), three medium quality (26, 50, 59) and nineteen low quality (39-49, 51-54, 56, 58, 60, 67) (**Table 1** and **Supplementary table 3**). The only longitudinal study included was rated low quality (55) (**Supplementary table 4**). Among the cross-sectional studies, seven were rated high quality (38, 57, 61, 63, 64, 68, 69) while four were rated medium quality (19, 25, 65, 66) (**Supplementary table 5**).

1) Social media exposure and unhealthy food intake and dietary behaviors

Of the included studies, eight investigated the association between SM and unhealthy diet intake (**Table 1**).

In adolescents, three cross-sectional studies reported a dose-response relationship between SM exposure and daily intake of sugar and caffeine (38), the consumption frequency of SSB, sweets and fried foods (61), as well as a higher likelihood of skipping breakfast (25). In a RCT, Teo et al (67) investigated the messaging feature of WhatsApp where participants were assigned to engage in texting with friends, while the control group was asked to read an online article. Adolescents in the WhatsApp messaging group consumed 58% more snacks (corn puffs) than those of the control group (67). Watching online videos was cross-sectionally associated with higher fast food preference among Chinese adolescents, while those living in rural areas had higher frequency of eating at fast food restaurants (65). Another RCT showed that watching SM culinary videos influenced food choice among Flemish adolescents (60). Exposure to a sweet snack video reduced the liking of fruits and vegetables and the likelihood of choosing a fruit over a cookie, which was mediated by intentions to eat sweet snacks. By contrast, the fruit and vegetable video did not influence food choice, but resulted in higher intentions to prepare healthy snacks (60).

In children, the frequency of watching YouTube video-blogs significantly predicted unhealthy beverage consumption amount two years later (55). In a cross-sectional sample of Indonesian children, Lwin et al. (66) observed that SM exposure was related to fast food consumption frequency in suburban, but not in urban areas. However, active parental mediation strategy (discussing and advising) significantly lowered fast food consumption frequency and increased nutrition knowledge for suburban children, but not for urban children (66).

Seven studies investigated the role of SM and SM-influencers' marketing in children's and adolescents' unhealthy food intake.

In children, SM influencer's marketing led to unhealthy food intake. Coates et al (26) revealed in a RCT that children exposed to a one-minute influencer's advertising segment (during a five-minute video on Instagram) of unhealthy food images consumed more energy overall and from unhealthy snacks compared to those exposed to healthy food images and non-food images. In a second study, they investigated the influencers' marketing of branded vs. unbranded unhealthy snacks with or without an advertising disclosure (50). Overall, children consumed more energy from the branded than the unbranded snack. When exposed to food marketing with vs. without a disclosure, they consumed more from the marketed snack compared to the alternative, indicating no interaction between food marketing with an advertising disclosure and children's awareness of advertising on energy intake. Masterson et al. (44) showed that exposure to advertisements (food vs. non-food) was not associated with children's subsequent total energy intake. A cross-sectional study including children and adolescents aged 10-16 years in Australia, showed that watching branded food videos on YouTube increased unhealthy food and beverage consumption, independent of age (19).

Among adolescents, exposure to branded food and beverage marketing on SM was cross-sectionally associated with increased intake of unhealthy drinks (fruit juice, sports and soft drinks) (63) and with increased preference for ED foods (sweets and fried foods) (61). Adolescents who engaged with food marketing posts on SM (liked, shared) had increased frequency intake of unhealthy foods and drinks, indicating that engagement with food marketing might have stronger effects on adolescents' diets than exposure per se (63). In fact, exposure to peers' Instagram images of energy-dense snacks and SSB had no effect on their respective consumption (51). In a RCT by Murphy et al (58), adolescents had longer gaze duration to advertisements for unhealthy compared to healthy foods. Fixation duration was higher for unhealthy foods when posted by peers but higher for healthy foods when posted by celebrities. Nevertheless, participants could recall and recognize unhealthy food brands more than healthy ones when coming from celebrities and companies, but not peers, especially among older adolescents (58).

2) Social media exposure, healthy food intake and nutrition literacy

Only five studies investigated the role of SM in healthy food intake (n=3) and nutrition literacy (n=2, **Table 1**) among children and adolescents.

In children, greater exposure to SM was not associated with better knowledge about nutrition, but broadcast media instead influenced nutrition literacy (66). Two RCTs showed that Instagram influencer marketing of healthy snacks (e.g. banana) did not influence children's subsequent intake of these foods (26), even when promoted by an athletic compared to a sedentary influencer (59). However, exposure to unhealthy foods (donuts) promoted by the sedentary SM influencer led to an increased choice for healthy snacks (strawberries) (59).

In adolescents, Folkvord et al. (56) reported findings comparable to those observed in children (26), but due to methodological concerns the results will not be explained in detail here (56).

Remarkably, adolescents who were exposed to a blog on healthy nutrition and to videos of peers addressing barriers to healthy eating (i.e. role models), reported eating ≥3 servings of vegetables/day compared to those not exposed to videos of peers (39). Flemish adolescents frequently exposed to SM healthy food messages (e.g. fruits and vegetables, mainly posted by peers, celebrities or influencers) had an increased intake of healthy foods and this association was mediated by higher food literacy (61). However, in that cross-sectional study, food literacy was not a mediator for the association between exposure to ED foods and ED food intake (e.g. sweets and fried foods).

3) ***Smartphone use, food intake and dietary behaviors***

Four cross-sectional studies and one RCT evaluated the role of smartphone and internet use in food intake, exclusively conducted in adolescents (**Table 1**). Prolonged smartphone use (>2 hours/day) was associated with higher consumption frequency of sweets (64) and fast food and increased likelihood of skipping breakfast (69). When distinguishing between patterns of smartphone use, Kim et al. (69) showed that Korean adolescents who used smartphones for communication vs. educational purposes had higher odds for fast food consumption (69). Prolonged use of multiple devices was associated with increased consumption frequency of fried foods, sweets and snacks in Brazilian adolescents, independent of age, sex and SES (64). Prolonged and compulsive internet use was associated with poor nutritional behaviors including low frequency intake of fruits and vegetables, lower frequency of eating breakfast, high frequency intake of SSBs, fast food and unhealthy snacks (68), especially in girls using multiple devices (57). Similar unfavorable nutritional behaviors were also observed among Korean adolescents with prolonged internet use during leisure time, independent of age, obesity and physical activity levels (68). Prolonged study-time internet use was positively associated with increased intake of unhealthy snacks, but inversely associated with low intake of fruits and vegetables (68). In an RCT, Marsh et al. (62) evaluated the distractive effect of multi-screening (simultaneous use of TV, iPad, smartphone) on food intake and observed that total energy intake did not differ between multi-screen vs. single-screen (TV only) users. Additionally, energy intake from and appetite for healthy relative to unhealthy foods were comparable between multi-screen vs. single-screen users.

4) Exposure to digital food images, patterns of brain activation

4.1. Food vs. non-food images

Three interventional studies investigated the neural responses to food compared to non-food images in children and adolescents (**Table 1**).

In children, an increased activation was observed in the visual cortex (associated with attention and visual processing) (45), the left and right posterior para-hippocampal gyri (PPHG- related to declarative memory functions), and the dorsomedial prefrontal cortex (social cognition, information processing, decision-making and response control) (45) when exposed to food vs. non-food images. Comparing healthy children's neural responses to food stimuli after exposure to food vs. toy advertisements, Masterson et al. (44) observed reduced brain response to high vs. low ED food images in the left fusiform gyrus, left supra-marginal gyrus and left orbitofrontal cortex.

In adolescents, increased activation was observed in the insula and operculum (gustation, food and reward) (49) when exposed to food vs. non-food images. Adolescents of parents with greater restrictive access on unhealthy foods showed greater activity in visual posterior regions: the left occipital pole, left lateral occipital cortex and right temporal occipital fusiform (49) upon exposure to food vs. non-food images.

4.2. Healthy, unhealthy vs. non-food images

Nine interventional studies examined the neural responses to healthy food, unhealthy food and non-food images (Table 1).

In children, Van Meer et al (54) observed an increased response to unhealthy vs. healthy food images in the right temporal/occipital gyri (visual attention), left precentral gyrus (reward) and left hippocampus (memory-related processes, **Table 1**). Exposure to high vs. low calorie food images in hungry compared to satiated state increased activation in the dorsomedial and medial prefrontal cortex (dmPFC) and right dorsolateral prefrontal cortex (dlPFC), respectively involved in reward and self-control during food choices (53) both in children and adolescents - and in the left thalamus (sensory perception and processing) among children only (42). On the other hand, high ED food images reduced activation in the left hypothalamus (appetite regulation) even after adjusting for pre-scan fullness (i.e. satiation) in children (40), and they also increased activation in the caudate, cingulate, and precentral gyrus (regions involved in reward and taste processing) (41). A neural activation was positively associated with child's fat free mass (FFM) index, but not fat mass in the right substantia nigra (reward) when exposed to high vs. low ED food images (42).

In adolescents, Watson and colleagues (52) did not observe differences in their motivation towards unhealthy vs. healthy foods after exposure to the respective images. When evaluating the ideomotor mechanism (response priming effects), they observed that adolescents responded faster to unhealthy compared to healthy food images both in direct (instrumental) and indirect (Pavlovian) response priming, independent of impulsivity traits. Adolescents with greater appetite for palatable foods showed reduced response in the dlPFC, medial prefrontal cortex (mPFC) and the right inferior parietal lobule (all regions associated with inhibitory control) for high relative to low ED foods (43). Adolescents at high vs. low risk for obesity by virtue of parental obesity, showed greater activation in reward related regions (i.e. the right caudate, right frontal operculum, and left parietal operculum) during palatable food (milkshake) receipt -

following exposure to milkshake images - relative to tasteless solution receipt (46). However, no significant differences emerged in response to the unpaired cue (i.e. only viewing food images and not consuming them) and monetary reward (46). Moreover, repeated exposure to milkshake images was associated with greater response in the caudate and posterior cingulate cortex (48). A significant effect of paternal, but not maternal obesity, was observed in the caudate response after repeated exposure to milkshake cues (48).

4.3. Food images varying in energy density and portion size vs. non-food images and food intake

Three interventional studies examined the neural responses to food images varying in energy-density and portion size (PS), focusing on children only. In two different fMRI studies with the same children, English and colleagues investigated neural responses to images of large compared to small PS food. First, activation was observed in the right inferior frontal gyrus (IFG) (40), a region involved in inhibition and information processing. In a second study, reduced response in the bilateral IFG was observed (41). Although contradictory, these effects were no longer significant after adjustment for either pre-scan fullness or hedonic liking of foods (41). Increased activation was found in the left IFG in response to large PS compared to scrambled images (40), while reduced activation was found in the right OFC in response to small PS vs. scrambled images. A PS x ED interaction was observed in the superior temporal gyrus (multimodal semantic processing and functionally related to the primary gustatory cortex). Children exposed to large vs. small PS food images had increased activation in the left vmPFC (decision making) and left OFC (salience and associative learning), which was associated with increased food intake from baseline compared to children with low activation (**Table 1**) (47). Children exposed to large vs. small PS images of high ED foods had activation in right IFG (inhibitory control) and right caudate (reward), which was negatively associated with intake of high ED foods with increasing PS. In contrast, activation in the left OFC was associated with increased food intake from baseline. Children's exposure to images of large vs. small PS of low ED foods did not show a brain response-food intake interaction for low ED foods in increasing portions (47).

5) Differences by sex

Data on differences by sex were limited (**Table 1**). No significant differences in attention related eye-tracking measures (fixation duration and count) were observed between sexes in response to unhealthy vs. healthy Facebook food advertisements (58). However, exposure to food/beverage marketing on SM was cross-sectionally associated with unhealthy beverage intake in males, but not in females (63). Watson et al (52) reported that females responded faster to high relative to low calorie foods during the Pavlovian priming phase, whereas no differences were observed in males. Females with excessive internet use cross-sectionally showed 87% higher odds for poor nutritional behaviours (low frequency of eating breakfast and fruits and vegetables) when considering multi-screen use, while no significant association was observed for males, indicating a potential effect modification due to the clustering of the screen-time behaviours in males (57). When distinguishing between internet use for leisure and study purposes, Byun et al. (68) reported deteriorated dietary outcomes both in females and males, including increased intake of instant noodles and chips/crackers and low intake of fruit and vegetables.

Table 1: Characteristics, quality assessment and main results of the included studies (n=35) by age group; distinguishing between RCTs, longitudinal studies (*shaded in gray*) and cross-sectional studies based on quality assessment [1,2]

Author (year, country), study design	Population (age range) N	Exposure	Outcome	Key primary results	Key secondary results	Quality assessment
		Social media exposure, unhealthy food intake and dietary behaviors, by age group (interventional study)				
De Jans et al. (2021, Belgium) (59) RCT- in between subject study design	Children (8-12 years) N=190	Instagram profiles of 2 fictious lifestyle influencers (sedentary vs. athletic): exposure to unhealthy (donuts) vs. healthy (strawberries) snack food images	1)Ad-libitum healthy food choice (healthy vs. unhealthy food)	- The ad libitum healthy food choice did not differ after exposure to healthy food promoted by athletic vs. sedentary influencer (β=0.28, p=0.60) -Exposure to unhealthy food promoted by sedentary compared to athletic influencer led to higher choice of healthy snacks (β=-1.31, p=0.02)	The interaction effect of influencer lifestyle and snack type were not significant in relation to source credibility (β=0.24, p=0.27), influencer admiration (β=0.19, p=0.52) or parasocial interaction (β=0.22, p=0.46)	medium
Coates et al. (2019a, UK) (26) RCT- in between subject study design	Children (9-11 years) N=186	Instagram profiles of 2 popular YouTube vloggers: exposure to unhealthy (cookies) vs. healthy (banana) food images vs. branded non-food pictures (sneakers)	1) Caloric intake ad libitum from a selection of snack foods 2) Caloric intake from unhealthy foods and healthy foods	- Children exposed to unhealthy foods on Instagram consumed 26% more energy (mean = 448 ± 141 kcal/d) compared to the control group (mean = 357 ± 147kcal/d; P = .001) and 15% more than children exposed to healthy foods on Instagram (mean =389 ± 146 kcal/d; p =.05), after adjusting for hunger, previous influencer exposure, and liking of Instagram profiles	- Children in the unhealthy condition consumed 32% more energy from unhealthy snacks (mean=385±141 kcal/d) vs. control (mean= 292 ± 147 kcal/d; P=.001) and 20% more than the healthy group (mean=320 ± 144 kcal/d; p=.03) - No effect of Instagram on energy intake from healthy snacks	medium
Coates et al. (2019b, UK) (50) RCT- in between subject study design	Children (9-11 years) N=151	Exposure to YouTube vloggers featuring influencer marketing of: branded non-food product (i-Phone 8) or	1) Unhealthy snack intake ad libitum 2) Total energy intake of snacks branded and unbranded	- Children exposed to food advertising with (P<.001, d=1.40) and without (P<.001, d=1.07) a disclosure consumed more energy from the advertised snack vs. the	- Children who viewed food advertising with a disclosure (and not those without) consumed 41% more of the	medium

		branded unhealthy snack (McVitie's chocolate digestives) either (a) with or (b) without an advertising disclosure.	3) Energy intake of snacks in the groups with advertising disclosure vs without	alternative, independently of age, sex and hunger; the control did not differ (p=0.186, d=0.45) - Children consumed more energy from the branded snack than the alternative (unbranded snack)	advertised snack (p=0.004, ηp2=.06), than the control. - No interaction between marketing with advertising disclosure and children's awareness of advertising (no awareness vs. awareness) on energy intake	
Ngqangashe et al. (2021, Belgium) (60) RCT	Adolescents (aged 12-14 years) N=126	Buzzfed's Tasty culinary videos on YouTube on preparation of snacks: 1)fruit and vegetable 2) sweets (unhealthy)	1) Food choice (fruit vs cookie) 2) Food liking (fruits and vegetables vs. sweets)	- Exposure to the fruit and vegetable video did not influence food choice (β=-0.11, p=0.83), but resulted in higher intentions to prepare healthy snacks and reduced liking of sweets	-Exposure to the sweet snack video reduced the liking of fruits and vegetables and reduced the likelihood of choosing a fruit over a cookie, mediated by intentions to eat sweet snacks.	low
Marsh et al. (2015, New Zealand) (62) Randomized 2-arm parallel trial[3]	Adolescents (13-18 years) N=78	Multiscreen use (simultaneous use of television, iPad, smartphone) vs. single screen (television)	1a) Total energy intake (EI) for foods/drinks. 1b) EI for high vs. low energy-density (ED) foods 2) Appetite changes	a) Total EI did not differ between multi-screen (758 kcal/d, SE=75) vs. single-screen group (681 kcal/d, SE=75; difference=77 kcal/d; 95%CI=-166 to +320), after adjusting for age, sex BMI and appetite at baseline b) EI from healthy vs. unhealthy foods did not differ between groups	- Change from baseline in appetite scores did not differ significantly between the multi- and single-screen groups (-1.0; 95% CI=-7.0 to +5.0).	high
Sharps et al. (2019, UK) (51) RCT	Adolescents (13-16 years) N=144	Peers' Instagram images of high energy dense snacks and SSB	1) Changes in desired portion sizes 2) Changes in consumption and liking of snacks and SSB	- No significant main effect of condition, no main effect of time and no interactions (p>.05) for changes in desired portion sizes of high ED snacks or SSBs, after adjusting for age, sex and BMI.	- There were no main effects or interactions for frequency of consumption or liking of snacks and SSB	low
Teo et al. (2018, Singapore) (67) RCT	7^{th}-10^{th} grade (mean age= 14.6 years) N= 50	Intervention group: WhatsApp use/ texting Control group: reading a neutral article	Food intake (corn puff snacks)	Participants in the WhatsApp group consumed 58% more snacks (mean increase of 29-73 kcals) than in the control group	NA	low
		Exposure to food images and brain activation, by age group (interventional study)				

Sadler et al. (2021, USA) (48) within-subjects, repeated measures crossover design; fMRI study	Adolescents (aged 14-17 years) of high vs. low risk for obesity (of obese vs. lean parents) N=154	1) Food stimuli: images of milkshake and water glasses that signalled the delivery of a chocolate milkshake or a tasteless solution (TS).	1) Brain activation to food stimuli by: a) unpaired milkshake vs. tasteless cue b) milkshake vs. tasteless receipt c) after repeated exposure to respective milkshake cues 2) Role of parental obesity	a) Exposure to unpaired milkshake cues vs. tasteless cue increased response in the bilateral caudate, the occipital fusiform cortex and the anterior cingulate cortex. - This activation remained after repeated exposure (in the bilateral posterior cingulate cortex and the bilateral caudate.) b) Increased activation emerged in the bilateral pre/postcentral gyrus in response to the milkshake receipt vs. tasteless receipt. - After repeated exposure, activation remained in the bilateral oral somatosensory cortex (pre/post central gyrus)	- After repeated exposure: High vs. low risk participants showed greater activation the right caudate, independent of time. Exploratory analyses showed a significant effect of paternal but not maternal obesity in the right caudate after repeated exposure to milkshake cues.	low
Masterson et al., (2019, USA) (44) within-subjects, repeated measures crossover design; fMRI study	Children (7-9 years) N=25	**1**) Advertisements for food vs. toy vs. no exposure. 2) Images of low vs. high ED foods *control*: blurred images	1) Total meal energy intake 2) Brain response as mediator	- Meal intake did not differ between advertisement condition in healthy children, after adjusting for sex, BMI z-score, parental education, SES, time of meals and pre-meal fullness	- Food vs. toy advertisements reduced brain response to high vs. low ED food images in the left fusiform gyrus, left supramarginal gyrus and one region of left OFC	low
Keller et al., (2018, USA) (47) within-subjects, repeated measures crossover design; fMRI study	Children (7-11 years) N=39	Food images of varying ED and PS**:** i) Large PS High ED, ii) Small PS High ED, iii) Large PS Low ED, iv)Small PS Low ED *Control conditions*: (furniture and scrambled images).	1) Brain response to large vs. small PS food images in association with total food intake 2a) Brain response to large vs. small PS high ED foods 2b) Brain response to large vs. small PS low ED foods	- Large vs. Small PS: Activation in the left vmPFC and left OFC was associated with increased intake from baseline (32% more) than children with low activation, after adjusting for age, sex, BMI z-score, test-meal food liking and pre-meal fullness level - Children who had high vmPFC and OFC activation also reached peak consumption at smaller PS than children with low activation.	a) Activation in right IFG and caudate was negatively associated with high-ED food intake (87% less from baseline) with increasing PS. Activation in left OFC was associated with increased food intake from baseline. b) None of regions tested was associated with children's intake of low-ED foods in increasing PS	low
Charbonnier et al., (2018, The Netherlands,	Children (8-10 years); Adolescents (13-17 years)	Food images: high-ED foods, low ED foods, non-food images	1) Brain activation between and across hungry vs. sated conditions	- Brain activation to high vs. low calorie food image viewing was greater in the hungry compared to sated state in the dorsomedial and	- No significant main effect of hunger state on food vs. non-food image viewing related-brain activation.	low

Scotland and Greece) (53) within subject, crossover trial fMRI study	N=55		2) liking of high vs. low calorie foods	medial prefrontal cortex (dmPFC) and right dl PFC, after adjusting for age, country and scan order. - Higher liking for high vs. low ED foods both in children and teens	- Food vs. non-food image viewing: no differences in brain activation between children and adolescents	
Samara et al., (2018, USA) (45) RCT; fMRI study	Children (8-10 years) N=11	High calorie food images vs. non-food images	Brain activation	- Increased activation in the visual cortex, left and right PPHG and the dmPFC in response to food vs. non-food images	NA	low
English et al., (2017, USA) (41) RCT fMRI study	Children (7-10 years) N=36	Food images varying in ED and PS i) Large PS/High ED, ii) Small PS/High ED, iii) Large PS/Low ED, iv) Small PS/Low ED.	1) Brain activation across conditions (varying in PS and ED) 2) Brain response and: a) food intake in response to food images varying in PS b) appetitive traits	- Large vs. small PS: decreased activation in the bilateral IFG. A PS x ED interaction was shown in the superior temporal gyrus, but no longer significant after adjusting for pre-fMRI fullness or food liking - High vs. low ED: Increased activation in the caudate, cingulate, and precentral gyrus; and decreased activation in the insula and superior temporal gyrus, after adjusting for BMI z-score	a) Activation to high vs. low ED cues in the declive interacted with PS to influence energy intake. b) Activation to high vs. low ED was negatively correlated with scores on the enjoyment of food subscale in the anterior insula and with food-responsiveness scores in the declive (cognitive processing)	low
Fearnbach et al., (2016, USA) (42) RCT fMRI study	Children (7-10 years) N=36	Food images varying in ED: high ED, low ED, vs. control	1) Brain activation across conditions 2) Mediating role of fat free mass (i.e. body composition)	- High vs. low ED foods elicited greater activation in the left thalamus.	- Neural activation was positively associated with child FFM in the right substantia nigra to high vs. low ED food images, after adjusting for BMI z-score and food liking	low
English et al., (2016, USA) (40) RCT fMRI study	Children (7-10 years) N=36	Food images varying in ED and PS: Large PS/High ED, Small PS/High ED, Large PS/Low ED, and Small PS Low ED. *control stimuli:* Furniture, Scrambled images	1) Brain activation across conditions (varying in PS and ED) 2) Brain response to food vs. non-food images 3) Liking and wanting of high vs. low ED foods	- Large vs. small PS: Increased activation in the right and left IFG; no longer significant after adjusting for pre-scan fullness and food liking - High vs. low ED: decreased activation in the left hypothalamus, after adjusting for fullness, but no longer significant after adjusting for both fullness and food image liking	- Higher mean liking and wanting ratings for high ED vs. low ED	low

Van Meer et al., (2016, The Netherlands) (54) RCT fMRI study	Children (10-12 years) N=27	Unhealthy vs. healthy food images	1) Brain responses to unhealthy vs. healthy food images 2) Role of BMI	- Higher response to unhealthy vs. healthy food images in the right temporal/occipital gyri and left precentral gyrus and left hippocampus, independent of age and sex	- Negative correlation between BMI and the brain response to unhealthy vs. healthy food images in the bilateral dlPFC.	low
Murphy et al. (2020, Ireland) (58) RCT	Adolescents: **Study 1:** 13-14 years; N=72 **Study 2:** 13-17 years N=79	1)Advertising content: Exposure to Facebook unhealthy, healthy vs. non-food advertising 2)Source of advertisement: peer, celebrity, company	**Study 1:** 1) Recall & brand recognition 2)Social responses to healthy vs. unhealthy foods (post sharing) **Study 2:** Eye-tracking measures of attention: 1)Attention to advertising (fixation duration and count) 2) Fixation duration by ads source	**Study 1:** - Participants could recall and recognize unhealthy food brands more than healthy posts (5x), when coming from celebrities and companies, but not peers, after adjusting for age, sex, product type and internet use. **Study 2:** - adolescents looked at ads for unhealthy foods for longer (fixation duration) vs. healthy foods - Fixation count and duration to posts overall was greater for older adolescents	**Study 1:** - Adolescents responded more positively to unhealthy food brands, compared to healthy and non-foods in terms of social attitudes: post-sharing **Study 2:** - Fixation duration was higher for unhealthy foods when posted by peers; but higher for healthy foods when posted by celebrities, after adjusting for sex, age, internet use.	low
Allen et al., (2016, UK) (49) RCT fMRI study	Adolescents (12-18 years) N=21	**Food images** high fat, high sugar (e.g. cake); high fat, low sugar (e.g. fried chicken) low fat, high sugar (e.g. sweets, apples); low fat, low sugar (e.g. carrots). **Control**: non-food	1a) appeal of food 1b) brain activation 2) Mediator: parental feeding practices	a) Participants rated high fat/high sugar and low fat/high sugar foods as more appealing compared to high fat/ low sugar and low fat/low sugar foods, independent of age and sex. b) Participants showed heightened activation to food compared to non-food images in the insula and operculum (gustation and reward)	- Food images related to restrictive feeding: Greater activity in visual regions (posterior) including the left occipital pole, left lateral occipital cortex, right temporal occipital fusiform)	low
Jensen et al., (2016, USA) (43) RCT fMRI study	Adolescents (14-20 years) N=12	Food images: high energy foods (e.g., SSB, fried potatoes); low-energy foods (e.g., fresh fruits, vegetables) control non-food objects (e.g. flowers)	1) Neural activation depending on Power of Food Score- i) food available; ii) food present, but not tasted; iii) food tasted - as a measure of appetite and food motivational reward	- For high energy foods, higher PFS decreased brain response in the dlPFC, mPFC and right inferior parietal lobule (inhibitory control), but not for low-energy foods, after controlling for age and BMI	- No differences were observed in brain activation depending on food proximity (i.e., available, present, or tasted)	low

Watson et al. (2015, The Netherlands) (52) RCT	Adolescents Study 1: (12-15 years) N=62 Study 2: (12-16 years) N=111	Food images: unhealthy (chocolate, potato crisps) vs. healthy (cucumber, tomato)	1) Motivation (desire to eat) to unhealthy vs. healthy food images 2) Response priming to unhealthy vs. healthy food: a) Direct(instrumental) b) Indirect (Pavlovian) response priming	- No significant difference between the reported desire (motivation) to eat high-calorie foods vs. low-calorie foods; - Participants responded faster (1131(399) ms) for high-calorie vs. low-calorie food images (1271 (640); t (61) = 2, p=0.05) in direct and in indirect (Pavlovian) response priming	- No association was observed between self-reported impulsivity and response priming for high calorie snacks. - Females performed better on high relative to low calorie trials (p=0.004) during the Pavlovian training; In males no differences were observed	low
Stice et al., (2011, USA) (46) RCT fMRI study	Adolescents of high vs. low risk of overweight (of obese vs. lean parents) N=60	1) Food stimuli: images of milkshake and water glasses that signalled the delivery of a chocolate milkshake or a tasteless solution (TS). 2) Monetary reward: three coin images	1) Brain activation to food stimuli by: a) milkshake vs. tasteless receipt or b) unpaired milkshake vs. tasteless cue 2) Brain activation to the monetary reward	a) High vs. low risk adolescents showed greater activation in the right caudate, right frontal operculum, and left parietal operculum during milkshake vs. tasteless solution receipt. b) No differences emerged in response to the unpaired cue.	- Monetary reward paradigm: High vs. low risk participants showed greater activation the right putamen, left putamen, right OFC, and left caudate boundary.	low
		Social media exposure, unhealthy food intake and dietary behaviors, by age group (observational study)				
Smit et al. (2020, The Netherlands) (55) Longitudinal study	Children (8-12 years) N= 453	Exposure to YouTube vlogers	Consumption of: 1) unhealthy beverages (SSB) and 2) high ED snacks	- Frequency of watching vlogs significantly predicted unhealthy beverages consumptions at two years later, after adjusting for BMI and family affluence (as proxy for SES)	- No association between frequency of watching vlogs and unhealthy snack intake at 1 and 2 years later	low
Quettina et al. (2021, Belgium) (61) Cross-sectional study	Adolescents (11-19 years) N=1002	Exposure to 1)food messages posted by peers, influencers, celebrities on SM 2)branded food marketing	1)Frequency intake and preference for a) high ED foods (sweets and fast food) b) healthy foods (fruits and vegetables) 2) food literacy	a) Exposure to SM high ED food messages was positively associated with preference and frequency intake of those food (Z=3.63, p<0.000), after controlling for age, sex, BMI-for-age, self-regulated autonomy and food literacy b) Exposure to SM food marketing of high ED foods was associated with higher preference for high ED foods (Z=3.38, p>0.000)	- Adolescents with lower exposure to high ED food messages on SM demonstrated increased food literacy (Z=-5.39, p<0.000) - Food literacy mediated the association between healthy food messages/ marketing exposure and increased healthy food intake, but not the relationship between	high

					exposure to high ED food posts and intake of ED foods.	
Byun et al. (2021, Republic of Korea) (68) Cross-sectional study[3]	Adolescents (12-18 years) N=54.416	1)Total internet duration 2)Internet use for leisure purposes 3) Internet use for study purposes	1)Single dietary behaviours: breakfast skipping, low intake of fruits and vegetables, high intake of instant noodles, fast food, chips/crackers and SSBs 2) Composite dietary risk indicator (≥3 dietary risk factors vs. <3 factors)	- Longer total internet use (≥301 min/day) was associated with higher prevalence of frequent breakfast skipping (OR=1.16, 95%CI=1.08-1.24), low intake of vegetables, high intakes of instant noodles, fast food and SSBs (1.61, 95%CI=1.50-1.72) and the composite dietary risk indicator (OR=1.67, 95%CI=1.55-1.80). - Prolonged internet use during leisure time (≥241 min/day vs. 1-60 min/day) was associated with higher prevalence of all seven individual dietary risk factors and the composite dietary risk indicator (OR=2.00, 95%CI=1.85-2.15).	- Prolonged study time internet use (≥121 min/day vs. 1-60 min/day) was inversely associated with prevalence of low fruit and vegetable intake (OR=0.91, 95%CI=0.85-0.98), and positively associated with intake of instant noodles (OR=1.10, 95%CI=1.03-1.19), and chips/crackers (OR=1.13, 95%CI=1.04-1.23). Similar results were observed in the analyses stratified by sex, school grade, region, household income, physical activity and obesity status.	high
Gascoyne et al. (2021, Australia) (63) Cross-sectional study	Adolescents (12-17 years) N=8708	1) Exposure to food marketing on SM 2) Engagement with food marketing on SM (liked or shared post)	1)Frequency intake of: a) unhealthy foods b)unhealthy drinks (fruit juice, soft, and sports drinks) 2)Differences by SES and sex	-Exposure to food marketing on SM was not associated with unhealthy food intake, but was positively associated with frequency intake of unhealthy drinks (daily/almost daily: OR=1.57, 95%CI=1.30-1.90) - Stratified analyses showed that associations persisted across SES and in males (daily/almost daily: OR=1.88, 95%CI=1.46-2.43), but not in females (p>0.20)	-Engagement (liking or sharing) with food marketing posts on SM was associated with higher intake of unhealthy foods (daily/almost daily: OR=5.26, 95%CI=3.97-7.01) and drinks (daily/almost daily: OR=4.14, 95%CI=3.09-5.55), independent of age, sex with only slight variations by SES.	high
Kim et al. (2020, Republic of Korea) (69) Cross-sectional study[3]	Adolescents (12-18 years) N=54.603	1)Total smartphone use (hours/day) 2) Smartphone use for educational vs. communication purposes	1) Breakfast skipping 2) Frequency of eating fast food	- Smartphone use was associated with frequent breakfast skipping (≥5 times/week) and higher consumption frequency of fast food (≥3 times/week) in a dose-response manner, after adjusting for sex, school year, place of residence, parental education level etc.	- Smartphone use for communication vs. educational purposes was associated with fast food consumption frequency for ≥3 times/week (OR=1.37, 95%CI=1.25-1.50), after adjusting for covariates.	high

Lwin et al. (2017, Indonesia) (66) Cross-sectional study	Children (mean age= 9.4 years) N= 394	Online and SM use duration	1) Fast food consumption between a) suburban vs. urban children and b)Parental mediation strategies (active vs. restrictive) 2) Nutrition knowledge	-a) Children's exposure to online and SM was positively related to fast food consumption in sub-urban areas (p=0.02), but not in urban areas. Greater SM use was not associated with nutrition knowledge; instead broadcast media influenced nutrition knowledge.	- b) Active parental mediation significantly lowered fast food consumption and increased nutrition knowledge for the suburban children, but not for urban children	medium
Bradbury et al. (2019, USA) (38) Cross-sectional study	Adolescents (14-16 years) N= 32,418	Social media use (hours/day)	1) Daily intake of sugar and caffeine 2) Likelihood of exceeding the WHO recommendation on sugar and caffeine intake	- Daily sugar intake was 1.65g (95%CI =1.13-2.14; p< 0.001) higher for each additional hour of SM use - Caffeine intake was 5.21mg (95%CI=3.51-6.99; p< 0.001) higher per one additional hour of SM, after adjusting for grade, sex, parental education, hours unattended at home	The odds of exceeding the sugar intake recommendation was 7% higher (95%CI=1.05-1.09) with each hour of SM and 9% higher (95%CI= 1.06-1.11) for caffeine intake, independent of covariates	high
Delfino et al. (2018,Brazil) (64) Cross-sectional study[3]	Children and adolescents (10-17 years) N= 1011	Smartphone use duration: high vs. low (cut-off : ≥2 h/day)	Food intake: fruit & vegetables, sweet foods, soft drinks, diary, fried foods, grains	- High use of smartphones was associated with high consumption frequency of sweets, independent of age, sex and SES, but not with healthy food intake (fruits and vegetables)	High use of 3 to 4 devices was associated with higher consumption frequency of fried foods, sweets and snacks	high
Busch et al. (2013, The Netherlands) (57) Cross-sectional study[3]	Children and adolescents (11-18 years) N= 2425	1) Excessive internet use duration (>2h/week) 2) Compulsive internet use	Nutritional behaviour: composite score of eating breakfast and fruits/vegetables at least 5 times/week	Excessive internet use was associated with poor nutritional behaviours (males: OR=1.36; 95%CI=1.00-1.86, females: OR=2.09, 95%CI=1.57-2.78). When considering multiscreen use, this association remained significant only in females (OR=1.87, 95%CI=1.22-2.86)	- Compulsive internet use was associated with poor nutritional behaviours in all children (OR=5.35, 95%CI=2.54-11.27)	high
Baldwin et al. (2018, Australia) (19) Cross-sectional study	Children and adolescents (10-16 years) N= 417	Use of Facebook and Youtube	1) Unhealthy food and beverages frequency intake	- Children who watched branded videos on YouTube had food scores 0.46 (SD=0.18) points higher (P=0.01), drink scores 0.34 (SD=0.13) points higher (p=0.01)	- Seeing favourite food & beverage brands on SM increased unhealthy food score with 0.63 points (SD=0.25, p=0.01), and the	medium

			2) exposure to unhealthy food marketing	and combined scores 0.80 (SD=0.27) points higher (p=0.003) on average than children who did not, after adjusting for age, sex and SES	combined score with 0.86 points (SD=0.35) (p=0.015) - Purchasing food online was associated with higher unhealthy food score	
Hansstein et al. (2017,China) (65) Cross-sectional study	Children and adolescents (6-18 years) N=1815	1) Watching videos and movies online (hours/week), 2) Internet use (hours/week)	1) Fast food frequency consumption in a fast food restaurant, 2) liked/did not like fast food restaurants and whether liked high ED foods (salty snack, energy drinks)	- Children and adolescents in rural areas watching online videos ($p<0.01$) and surfing the Internet ($p<0.05$) had higher odds of eating at fast food restaurants	- Adolescents who watched online videos were more likely to like fast food - Children living in urban areas liked fast foods, salty snacks and sugary drinks more than the rural sub-sample.	medium
Sampasa-Kanyinga et al. (2015, Canada) (25) Cross-sectional study	7th to 12th grade students (mean age= 15.2 years) N= 9858	Social media use (Facebook, MySpace, Instagram, Twitter) in hours/day	1) Consumption of SSB 2) Skipping breakfast frequency	- SM was positively associated with SSB intake(<1 h/day: OR=1.67, 2 h/day: OR= 1.90 and >5 h/day: OR=3.29), after adjusting for age, sex, ethnicity, SES, parental education level, BMI, and tobacco, alcohol and cannabis use	-SM was associated with increased odds of skipping breakfast in a dose–response manner after adjusting for same covariates.	medium
		Social media exposure, healthy food intake and nutrition literacy (interventional study)				
Folkvord et al. (2020, The Netherlands) (56) RCT- in between subject study design	Adolescents (13-16 years) N=132	Instagram influencer exposure: vegetables (red peppers) or energy-dense snacks (finger foods) vs. control non-food product (sunglasses)	1) Vegetable intake (red peppers, cherry tomatoes, cucumbers) Mediators: 2a) Persuasion knowledge 2b) Para-social interaction	- No significant effect of type of Instagram post on vegetable intake ($p>0.05$, $\eta 2= 0.02$). - No significant effect of type of Instagram post on the three individual vegetable intake ($p>0.05$). No adjustment for confounders was conducted.	a) No interaction effect of Instagram post and persuasion knowledge on vegetable intake ($p>0.05$, $\eta 2=0.20$); b) No interaction effect of Instagram post and para-social interaction on vegetable intake ($p>0.05$, $\eta 2=0.19$)	low
Cullen et al. (2013, USA) (39) RCT	Adolescents (12-17 years) N=291	Intervention group: 1) Blog and website on healthy nutrition 2) Videos of peers (as role models) which address barriers on healthy eating; Control group: no access to role model videos	1) Intake of fruit & vegetables, milk and less sweetened beverages 2) Self-efficacy and home-availability as mediator	-The percentage of intervention group (18% of adolescents) who reported eating ≥3 servings of vegetables/day in the past week was higher in the treatment group at post-intervention compared with the control group (5%) ($P<0.05$), independent of sex, age, SES, ethnicity and TV availability in child's bedroom.	- A significant group-by-time effect was reported for home-availability for both fruit/juice ($p<0.05$) and whole milk ($p<0.01$) in the control group only. - No significant group-by-time effect for self-efficacy for any of the groups.	low

[1] The quality rating is aggregated as low, medium and high according to the respective appraisal tools. For RCTs, high quality refers to a low risk of bias across the 5 domains of the Cochrane risk assessment tool. For longitudinal studies, a medium quality is reached with two stars in the selection domain and 1 or 2 stars in the comparability domain and 2 or 3 stars in the outcome/exposure domain. For cross-sectional studies, a low quality refers to high risk of bias - if a score ≤4/8 is reached. Detailed information on the quality rating has been summarized in the Supplementary material. [2] Abbreviations: SM- social media, BMI- body mass index, dmPFC- dorsomedial prefrontal cortex, dlPFC- dorsolateral prefrontal cortex, ED food- energy dense foods, EI- energy intake, fMRI- functional magnetic resonance imaging; FFM: fat free mass; mPFC- medial prefrontal cortex, NA- not applicable, IFG- inferior frontal gyrus, OFC- orbitofrontal cortex, PS- portion size, PPHG- parahippocampal gyri, RCT- randomized clinical trials; SSB- sugar-sweetened beverages, UK- the United Kingdom, USA- the United States of America, vmPFC- ventromedial prefrontal cortex**.** [3] In these studies, the main exposure was smartphone and internet use, as proxy for SM exposure in children and adolescents.

Discussion

This review examined the role exposure to SM content has on healthy children's and adolescents' diets and related behaviours, and identified potential mechanisms underlying the pathway of these associations. SM exposure was associated with increased consumption frequency of unhealthy snacks, fast food and SSB; daily caffeine and sugar intake; fast food preference, and higher odds of skipping breakfast. These associations were observed both in children and adolescents, with those living in rural and suburban areas being at higher risk. We did not find evidence for the role of SM influencer marketing of healthy foods on the actual healthy food intake and nutrition literacy among children and adolescents. A number of mechanisms which may explain the abovementioned associations were identified.

1) Peer influence (among adolescents) and parental influence (among children) on social media

Peer influence, i.e. peers acting as role models on SM, may shape preferences and change food intake among adolescents. Although the mere exposure to images of peers with high ED snacks and SSB had no effect on intake of these foods (51), eye-tracking research showed that adolescents look at unhealthy food pictures longer when posted by peers compared to celebrities or companies (58), suggesting that food cues are processed differently depending on the source of the exposure. However, adolescents exposed to peers' videos on SM addressing barriers on healthy eating, increased daily vegetable intake, indicating that peers might have a higher potential for promoting healthy eating compared to influencers (39). In fact, peers are considered the most powerful source in shaping consumption-related decision making (71), and the screen-time behaviors in early adolescence (72). Further, peers might be a more trusted source compared to celebrities and influencers, as electronic recommendations from them (eWord of Mouth) are believed to be highly trustworthy because no commercial interest is involved (73).

Parents of younger children seemed to have positive influence over their children fast food consumption frequency and nutrition knowledge via active parental mediation strategy such as discussing and advising (66). On the other hand, adolescents of parents who place many restrictions on unhealthy foods showed in fMRI measurements a greater activity in visual regions (e.g. left lateral occipital cortex) when exposed to food images, indicating an attentional weight (saliency) for restricted food rather than the reward per se (49). This supports previous evidence suggesting that parents are important drivers of children's eating behaviors, which diminishes in adolescence, due to adolescents' ambition for autonomy and other socio-cultural factors (74). Future SM interventions should carefully consider the source of marketing of healthy foods - respectively parents and peers - in order to motivate children and adolescents to make healthy food choices.

2) Food and influencer marketing targeting children and adolescents on social media

The child-directed marketing of branded snacks and unhealthy beverages embedded in images and videos on Instagram (26) and YouTube led to increased preference (61) and intake of those foods (60), even 2 years later (55). Food marketing may interfere with children's neural processing of food cues, as exposure to food vs. toy advertisements elicited different response to high relative to low ED food images (44). In adolescents, unhealthy food brands were recalled and recognized more often than healthy foods in SM posts when coming from celebrities and companies but not peers (58). These findings reinforce the powerful use of SM influencer marketing by food companies to promote junk products on SM. These results are in line with a previous systematic review on digital advertising, which showed that exposure to advergames led to higher energy intake in children and adolescents of a similar age range to our review (75). Consumer protection acts have enacted stricter guidelines for the disclosure of paid influencer content on SM, as a "protective" tool against deceptive advertisements and to increase audience's knowledge of persuasion mechanisms (76). However, our review shows that there is no interaction between food marketing with an advertising disclosure and children's awareness of advertising on energy intake, suggesting that SM marketing deteriorates children’s and adolescents’ food intake, independent of using advertising disclosures (50). A possible explanation could be that children and adolescents trust and/or feel a familiarity with SM influencers who are often also the same age group. They may perceive an advertising disclosure as honest and/or an act of fairness, which may lead to a positive attitude towards influencers and enhanced advertising effects (71). Another explanation could be that disclosures are too small and misplaced within the SM post, underpinning hidden and misleading marketing messages as the advertising content is usually mixed with social and cultural user-generated content, hence enabling direct exhortations to children and adolescents (77). Nevertheless, it has been suggested that unhealthy, but not healthy food marketing may lead to healthy food intake in children, when promoted by a sedentary vs. an athletic influencer (59). This indicates that the lifestyle of the influencer may impact children’s food choice. This supports the Healthy Food Promotion Model, emphasizing the role of message and situational factors on children’s susceptibility to food cues (78). Future health interventions should take into consideration the type of message and the contextual factors when using SM influencers for promoting healthy food intake in children and adolescents.

3) Ubiquitous access to social media via smartphones and food intake

Adolescents’ prolonged smartphone use as the main device used to access SM and internet was associated with lower intake of fruits and vegetables but increased intake of sweets, fast food and SSB (68), especially among those using several screens and for leisure purposes (68, 69). This suggests that exposure to marketing via different digital channels simultaneously might have an accelerating effect on deteriorating adolescent's dietary patterns. Although studies evaluating smartphone use and food intake were conducted only in adolescents, similar results could be expected in children as well. Sina et al. (79) observed that in European children and adolescents, prolonged smartphone and internet use were associated with an increased preference for sweet, salty and fatty tasting foods (taste sensations of unhealthy, highly processed foods), but were negatively associated with bitter taste preference (the taste of healthy foods). This sheds light on a further potential mechanism by which exposure to online content accessed via smartphones (i.e. SM) may affect food intake, leading to overweight and obesity. Furthermore, the capacity of smartphones to offer various services (i.e. SM, videogames, camera/pictures, texting) means a higher potential to influence children's and adolescents' attention span and act as distractors (64, 67, 80). Additionally, smartphone and SM use were associated with a lower frequency of eating breakfast in adolescents (25, 69). Shifts in circadian rhythmicity, towards a later midpoint of sleep in adolescence, may explain this relationship. It is noteworthy that other types of digital media might moderate the association between SM and diets. Recent literature suggests that children and adolescents engage in media multi-tasking behaviours by using several devices (e.g. smartphone, TV, PC) in parallel. Media multi-tasking may affect children's and adolescents' self-regulation and cognitive processes, which in turn are also associated with unhealthy snack consumption and obesity (81, 82). In our review, only one study examined the role of media multi-tasking in adolescents' food intake and did not find any significant difference between multi-screen and single screen users (62). More studies are needed to elucidate the long-term role of media multi-tasking also in combination with other non-screen activities in children's and adolescents' eating behaviours.

4) Food images on social media may elicit brain responses related to attention, memory and reward in both children and adolescents

The fMRI-based studies evaluating the neural correlates to digital food images as a proxy to food images embedded in SM revealed that healthy children and adolescents have heightened responses towards food images (53), independent of age. The areas with increased activation included those related to gustation and reward in adolescents (insula and operculum) (49), attention and visual processing (visual cortex) (45), memory (PPHG), and information processing in children (dmPFC). These findings suggest that when children and adolescents view food images on SM feeds, their brain processes them differently compared to non-food images, leading to higher attention, memory and reward, especially when exposed to unhealthy palatable foods (54) and even after repeated exposure (48).

4.1. Appetite and brain response to unhealthy food images

The appetitive state (hungry vs. satiated) also plays a role in the manner healthy vs. unhealthy food images are processed in the brain. Children and adolescents in fasting state showed increased response in areas related to reward (dlPFC) (53), sensory perception and processing (the left thalamus) (42). Adolescents have reported that they use SM as soon as they wake up, i.e. in a fasting state (83). Exposure to unhealthy food images on SM in a hungry state might lead to poor food choices for breakfast and the rest of day, including buying decisions, as motivation towards palatable foods has also shown to reduce response in regions associated with inhibitory control (dlPFC, mPFC) after exposure to high ED food images (43). These findings indicate that children and adolescents with high motivation (i.e. appetite) for high ED foods available in the environment have lower executive control, which makes them vulnerable to consuming higher quantities of these foods. Furthermore, a neural activation in the right substantia nigra (reward) was positively associated with child FFM index when exposed to high vs. low ED food images (42), supporting the notion of FFM (i.e. lean mass) as an appetitive driver. The dopamine receptors of the substantia nigra respond to signals of leptin, insulin and ghrelin, subsequently influencing the dopamine signaling (84).

4.2. Food portion size in social media images

Food portion size depicted in SM images is another mechanism which might interfere with brain activation and food intake. Children exposed to large PS food images had increased activation in areas related to decision making (left vmPFC), salience and associative learning (left OFC), which in turn was associated with increased food intake (47). Previous evidence has suggested that SM influencers offering nutritional advice on healthy eating, most often show food pictures of large PS, with high fat, salt and sugar content, undermining their followers' efforts to eat a healthy diet (85). However, the appetitive state and the energy density of foods seem to lie in the pathway of how children's brain processes information about portion size (41). Children exposed to large vs. small PS images of high ED foods had activation in inhibitory control regions (right IFG) which was negatively associated with intake of high ED foods with increasing PS (47). These findings may indicate an increased conflict and more information processing related to social judgment and subsequently reduced food intake. Nevertheless, the role of food PS was examined only in children. Future studies are warranted to elucidate neural and developmental differences between children and adolescents in response to increasing PS of food images.

Strengths and limitations

To our best knowledge, this review is the first to identify and summarize studies examining the association between SM exposure and dietary behaviors in both children and adolescents, while identifying the underlying mechanisms. The strengths of our review include the rigorous and comprehensive search strategy applied across three databases, the adherence to the PRISMA guidelines (29), use of a pre-tested and standardized data extraction template, and data extraction and quality assessment by two independent reviewers. Also, the wide age span we included (2-18 years) enabled us to evaluate SM use habits and their associations with dietary habits from childhood to adolescence, considering developmental differences in age and brain maturation. The inclusion of different study designs: observational studies, RCTs and studies based on fMRI and eye-tracking methods, allowed us to better understand the possible mechanisms explaining how SM influences the diets of children and adolescents.

Limitations of the review

This review has limitations. Due to the heterogeneity of study designs and measurements used across the included studies, a meta-analysis was not feasible. We included studies with digital food images as a proxy-variable for SM-related food images. Evidence indicates that adolescents are not able to distinguish between food images originating from traditional sources (print) vs. Instagram and they rate their advertisement features similarly (86). However, adolescents rated Instagram food pictures as trendier. Hence, the effect of digital food images on the neural response and the actual food intake and preference might be different in the SM context. Other factors might also influence children's and adolescents' brain response, such as influencer or peer endorsement, post engagement (liking, sharing), or SM technological features (e.g. filters, animations). Similarly, the use of smartphone and internet as proxy for SM exposure is another limitation of this review. The multi-tasking and other technological features of smartphones might have effects that go beyond SM alone. However, as literature suggests, smartphones are mainly used to access SM and for communication and leisure purposes, all of which were associated with unfavorable eating behaviors. It is thus difficult to distinguish between smartphone and SM use, especially with regard to daily duration and frequency of use. Future studies should use other methods such as Ecological Momentary Assessment or log-on data from SM applications, for a more comprehensive assessment of duration and context of SM exposure.

Limitations of the included studies

Among the interventional studies, the majority assessed exposures (SM) at one time point only; hence, future RCTs with repeated measurements are warranted. Only one of the RCTs blinded the researchers from knowing the participants' allocation groups. This was also the only RCT assessed at a low risk of bias (62). The majority of the RCTs were rated low quality due to high risk of bias arising from the domains “deviations from intended interventions” and “measurement of the outcome”. This is due to the fact that those delivering the interventions and assessing the outcomes were not blinded to the participants’ assigned intervention. Methodological concerns were also identified in the RCT conducted by Folkvord et al. (56). First, the authors did not take into account sex differences in the exposure, as they included only a male SM influencer. Second, although evaluating the role of influencer’s marketing of healthy and unhealthy foods, at post-intervention they measured only healthy food intake. The results might have differed if both healthy (vegetables) and unhealthy snack intake were considered post-intervention. Third, the authors did not report adjustments for confounders; hence, the findings should be interpreted with caution (56). Moreover, Teo et al. (67) did not consider sex differences as they included only male adolescents in their study. Among the observational studies, the majority was cross-sectional; hence causality cannot be inferred from the observed associations. SM exposure and diet-related outcomes were mostly self-reported, thus results might be limited due to recall and social-desirability bias (87). Moreover, a number of these studies did not report whether the questionnaires used for measuring SM exposure were evaluated for validity and reproducibility (19, 38, 61, 63-65). Although only five studies reported full information on SES (19, 25, 39, 47, 57), the majority of children came from a high SES background, which might affect generalizability of findings to children from a low SES. Another key limitation is residual confounding in the included studies, as some of them did not adjust for ethnicity and SES, which may be key drivers of food choices (88). Future longitudinal studies with adequate follow-up of participants and with objectively measured SM exposure (e.g. log on data from smartphones) and food intake in children from different SES backgrounds are thus needed to examine the long-term impact of SM on their diets. It is noteworthy that five studies were based on data from the same analytic sample (40-42, 44, 47). The type of control images presented in the fMRI studies varied, including cars, toys and landscapes, which might have translated into different neural patterns based on their perceived arousal. Hence, use of standardized control images compared with food cues in fMRI-based studies is warranted.

Conclusion

This systematic review elucidates that SM exposure influences children's and adolescents' diets by increasing intake of unhealthy snacks and SSB and decreasing intake of fruits/vegetables, independent of age. Exposure to unhealthy food images increased neural response in brain areas related to memory, reward, attention, and decision-making, relative to healthy or non-food images. Food portion size, its energy density, and children's appetitive state play a role on how healthy and unhealthy food images are processed and the subsequent food intake. No evidence on the impact of SM on improving children's and adolescents' diet quality and nutrition literacy was found. However, peers seem to have a higher potential to improve vegetable intake among adolescents compared to influencers while parents posed a higher influence among children. Future health interventions should take into account the identified mechanisms (e.g. food portion size, peer influence) in order to yield effective outcomes. These findings ask for further actions by health authorities on regulating SM exposure and SM marketing to minimize unhealthy dietary habits in children and adolescents and subsequent adverse health outcomes.

Conflict of Interest Statement

The authors declare no potential conflict of interest.

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Author’s contribution

ES, WA and AH developed the concept and scope for this review. ES, AH and DB conducted the research. ES and LC were involved in literature research. ES wrote the paper. ES and AH had primary responsibility for the final content. All authors have read and approved the final manuscript.

Data sharing

The data described in the manuscript will be made available upon request from the corresponding author.

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Supplementary Methods

Risk of bias assessment

The Newcastle-Ottawa Scale used for assessing risk of bias of cohort studies is based in a 'star system' in which a study is judged on three broad perspectives: the selection of the study groups; the comparability of the groups; and the ascertainment of either the exposure or outcome of interest with a total maximum of 10 points(1). A fair (i.e. medium) quality is reached with two stars in the selection domain, and 1 or 2 stars in comparability domain, and 2 or 3 stars in the outcome/exposure domain. The RoB 2.0 tool used for assessment of RCTs, addresses five domains: 1) bias arising from the randomisation process; 2) bias due to deviations from intended interventions; 3) bias due to missing outcome data; 4) bias in measurement of the outcome; and 5) bias in selection of the reported result. An overall summary 'Risk of bias' judgement: low (i.e. high quality); some concerns (i.e. medium quality); and high (i.e. low quality) for each specific domain was derived, whereby the overall RoB for each study was determined by the highest RoB level in any of the domains that were assessed.(2) For cross-sectional studies, the Joanna Brigs Institute appraisal tool(3) was used to evaluate: 1) whether the samples were representative and whether they were chosen randomly or not; 2) whether the sampling was justified and satisfactory; 3) whether the exposure tool was valid and objective; 4) whether confounding factors were controlled; 5) the method of assessing the outcome and 6) whether the statistical test used was clearly described and appropriate. The tools were used by two reviewers independently, recording supporting information and justifications for judgements of risk of bias for each domain. Discrepancies were resolved by further discussion and a concluding decision was made by ES and AH/DB.

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Supplementary Table 1. Search strategy for Medline (via PubMed) conducted on the 3rd December 2021

Search ID	Search Item
1	child[MeSH Terms] OR adolescent[MeSH Terms]
2	child*[Title/Abstract] OR adolescent*[Title/Abstract] OR youth*[Title/Abstract] OR teen*[Title/Abstract] OR "pre teen*"[Title/Abstract] OR "preteen*"[Title/Abstract] OR "preschool*"[Title/Abstract] OR "pre school*"[Title/Abstract] OR kid[Title/Abstract] OR kids[Title/Abstract]
3	1 OR 2
4	diet[MeSH Terms] OR food and beverages[MeSH Terms] OR diet habits[MeSH Terms] OR food preferences[MeSH Terms] OR taste perception[MeSH Terms] OR vegan diet[MeSH Terms] OR diet, vegan[MeSH Terms] OR diet, vegetarian[MeSH Terms]
5	"sugar sweetened beverage*" [Title/Abstract] OR "eating behaviour*" [Title/Abstract] OR "eating behavior*" [Title/Abstract] OR "eating pattern*" [Title/Abstract] OR "dietary pattern*" [Title/Abstract] OR "diet pattern*" [Title/Abstract] OR "dietary behavior*" [Title/Abstract] OR "dietary behaviour*" [Title/Abstract] OR "eating breakfast" [Title/Abstract] OR "skipping breakfast"[Title/Abstract] OR "food choice" [Title/Abstract] OR "food intake" [Title/Abstract] OR "unhealthy food*" [Title/Abstract] OR "healthy food*" [Title/Abstract] OR "junk food*" [Title/Abstract] OR snack* [Title/Abstract] OR "night eating*" [Title/Abstract] OR "night snacking" [Title/Abstract] OR "taste preference" [Title/Abstract] OR fruit* [Title/Abstract] OR vegetable* [Title/Abstract] OR "nutrition education"[Title/Abstract] OR "nutrition literacy" [Title/Abstract] OR "water intake"[Title/Abstract]
6	4 OR 5
7	internet[MeSH Terms] OR social media[MeSH Terms] OR online social networking[MeSH Terms] OR blogging[MeSH Terms] OR smartphone[MeSH Terms] OR mobile phone[MeSH Terms]
8	influencer* [Title/Abstract] OR facebook [Title/Abstract] OR instagram* [Title/Abstract] OR youtube* [Title/Abstract] OR snapchat [Title/Abstract] OR tiktok[Title/Abstract] OR "social media marketing" [Title/Abstract] OR "digital food marketing"[Title/Abstract] OR "social media advertising*"[Title/Abstract] OR "social media advertisement"[Title/Abstract] OR "social media"[Title/Abstract])) OR "food picture*"[Title/Abstract] OR "food image*"[Title/Abstract] OR "food cue*"[Title/Abstract]

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9	7 OR 8
10	3 AND 6 AND 9
11	Limit 10 from 2008 to 3rd December 2021

Supplementary Table 2. Characteristics of studies included in the qualitative analysis[1]

Author (Year, Country)	Study design	Sample size	Age range (years)	Mean age (SD)	Sex	Ethnicity/ migration background	SES
De Jans et al. (2021, Belgium) (4)	RCT- in between subject	190	8-12	10 (0.9)	52% females, 48% males	NR	NR
Coates et al. (2019a,UK)(5)	RCT- in between subject	176	9-11	10.5 (0.7)	60% females, 40% males	NR	NR
Coates et al. (2019b, UK)(6)	RCT- in between subject	151	9-11	10.3 (0.6)	53% females 47% males	NR	NR
Ngqangashe et al. (2021, Belgium)(7)	**RCT**	126	12-14	13.9 (1.2)	62% females, 38 % males	NR	NR
Marsh et al. (2015, New Zealand)(8)	Randomized 2-arm parallel trial	78	13-18	15.1 (0.3)	62% females, 38% males	73% European New Zealander	NR
Sharps et al. (2019, UK)(9)	RCT	44	Intervention 2: 13-16	14.4 (1.1)	70% females, 30% males	NR	NR
Teo et al. (2018, Singapore) (10)	RCT	50	7th to 10th grade	14.6 (0.8)	100% male	Chinese (84%), Indian (8%), Malay (4%), Other (4%)	NR
Sadler et al. (2021, USA)(11)	within-subjects, repeated measures crossover design; fMRI study	154	14-17 years	15.2 (2.02)	51% females, 49% males	Ethnicity: Hispanic (12%), Non-Hispanic (87%) Race: (White 84%)	NR
Masterson et al. (2019, USA)(12)	within-subjects, repeated measures crossover design; fMRI study	25	7-9	7.9 (0.7)	54% females, 46% males	83% Caucasian, 10% Black, 5% Asian, 2% Hispanic	NR

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Author (Year, Country)	**Study design**	**Sample size**	**Age range (years)**	**Mean age (SD)**	**Sex**	**Ethnicity/ migration background**	**SES**
Keller et al. (2018, USA)(13)	within-subjects, repeated measures crossover design; fMRI study	39 (healthy weight)	7-11	8.9 (1,2)	53% females, 47% males	94% Caucasian	84% high
Charbonnier et al. (2018, The Netherlands, Scotland, and Greece) (14)	RCT- within-subjects, crossover design; fMRI study	55	Children: 8-10 Teens: 13-17	Children: 9.6 (0.9), teens: 15.5 (1.7)	Children: 45% females, 55% males Teens: 80% males, 20% females	NR	NR
Samara et al. (2018, USA)(15)	RCT- within-subjects; fMRI study	11	8-10	9.7 (0.7)	50% females, 50% males	NR	NR
English et al. (2017, USA)(16)	within-subjects, repeated measures crossover design; fMRI study	36	7-10	8.9 (1.2)	50% females, 50% males	92% Caucasian, 8% other	NR
Fearnbach et al. (2016, USA)(17)	RCT- within-subjects; fMRI study	36	7-10	8.9 (1.2)	50% females, 50% males	92% Caucasian, 8% other	NR
English et al. (2016 , USA)(18)	within-subjects, repeated measures crossover design; fMRI study	36	7-10	8.9 (1.2)	50% females, 50% males	92% Caucasian, 8% other	NR
Van Meer et al. (2016, The Netherlands)(19)	RCT - within-subjects; fMRI study	27	10-12	10.9 (0.8)	NR	NR	NR
Murphy et al. (2020, Ireland)(20)	RCT	Study 1: 72 Study 2: 79	Study 1: 13-14 Study 2: 13 – 17	Study 1: 13.6 (0.5) Study 2: 15.4 (1.4)	Study 1: 63% females Study 2: 62% females	Irish students	NR
Allen et al. (2016, UK)(21)	RCT- within-subjects fMRI study	21	12-18	NR	77% females, 23% males	NR	NR
Jensen et al. (2016, USA)(22)	RCT – within-subjects; fMRI study	12	14-20	18.7 (0.5)	100% females	82% Non-Hispanic White	NR

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Author (Year, Country)	**Study design**	**Sample size**	**Age range (years)**	**Mean age (SD)**	**Sex**	**Ethnicity/ migration background**	**SES**
Watson et al. (2016, The Netherlands)(23)	RCT- within-subjects ;	Study 1: 62 Study 2: 111	Study 1: 12-15 Study 2: 12-16	Study 1: 13.3 (0.7) Study 2: 13.9 (0.7)	Study 1: 40% males, 60% females Study 2: 54% males, 46% females	NR	NR
Stice et al. (2011, USA)(24)	RCT - within-subjects; fMRI study	60	NR	15 (2.9)	50% females, 50% males	85% European Americans, 5% Hispanic, 2% Asian, 3% African Americans, and 5% Native American	NR
Smit et al. (2020, The Netherlands)(25)	Longitudinal	453	8-12	10.1 (0.9)	53% females, 47% males	Dutch origin (90%)	NR
Qutteina et al (2021, Belgium)(26)	Cross-sectional	1002	11-19	15 (2.1)	58% females, 42% males	NR	NR
Byun et al. (2021, Republic of Korea)(27)	Cross-sectional	54416	12-18	15.1 (NR)	47% females, 53% males	NR	8% high, 75% medium 17% low
Gascoyne et al. (2021, Australia) (28)	Cross-sectional	8708	12-17	NR	53% females 47% males	NR	25% high, 46% medium 29% low
Kim et al. (2020, Republic of Korea)(29)	Cross-sectional	54603	12-18	NR	51% females, 49% males	NR	40% high, 46% medium 14% low
Lwin et al. (2017, Indonesia)(30)	Cross-sectional	394	NR	9.4 (NR)	47% males, 53% females	NR	38% high
Bradbury et al. (2019, USA)(31)	Cross-sectional	32,418	14-16	NR	48% males, 52% females	14% Black, 65% White, 21% Hispanic	NR
Delfino et al. (2018, Brazil)(32)	Cross-sectional	1011	10-17	13.2 (2.3)	55% females 45% males,	NR	NR
Busch et al. (2013, The Netherlands)(33)	Cross-sectional	2425	11-18	13.8 (NR)	45% males, 55% females	NR	82% high, 18% low-medium
Baldwin et al.	Cross-	417	10-16	NR	47% male,	NR	27%

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Author (Year, Country)	**Study design**	**Sample size**	**Age range (years)**	**Mean age (SD)**	**Sex**	**Ethnicity/ migration background**	**SES**
(2018, Australia)(34)	sectional				53% female		high, 28% low
Hansstein et al. (2017, China)(35)	Cross-sectional	1815	6-18	NR	NR	NR	NR
Sampasa-Kanyinga et al. (2015, Canada)(36)	Cross-sectional	9858	7th to 12th grade	15.2 (1.9)	55% females, 45% males	60% white 6% black 10% South East Asia, 11% South Asian	30% low, 70% high
Folkvord et al. (2020, The Netherlands)(37)	RCT- in between subject	132	13-16	14.1 (0.96)	46%females, 55% males	NR	NR
Cullen et al. (2013, USA)(38)	RCT	291	12-17	NR	46% males, 54% females	38% white, 13% Latino/Hispanic, 38 % Black	62% high

[1]fMRI- functional magnetic resonance imaging; NR- not reported, RCT- randomized controlled trials; SD- standard deviation; USA- the United States of America; UK- the United Kingdom

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Supplementary Table 3. Quality assessment of the randomized controlled trials according to the Cochrane risk of bias (RoB2) appraisal tool

Author, year, country, study design	**Domain 1 (Randomization Process)**	**Domain S[1]**	**Domain 2 (Deviations from intended interventions)**	**Domain 3 (Missing outcome data)**	**Domain 4 (Measurement of outcome)**	**Domain 5 (Selection of reported results)**	**Overall risk of bias**	**Overall quality**
Marsh et al. (2015, New Zealand) Randomized 2-arm parallel trial	Low		Low	Low	Low	Low	Low	High
De Jans et al. (2021, Belgium) (4) RCT- in between subject study design	Some concerns		Low	Low	Some concerns	Low	Some concerns	Medium
Coates et al. (2019a, UK) (5) RCT- in between subject study design	Some concerns		Low	Low	Some concerns	Some concerns	Some concerns	Medium
Coates et al. (2019b, UK) (6) RCT- in between subject study design	Some concerns		Low	Low	Some concerns	Some concerns	Some concerns	Medium
Folkvord et al. (2020, The Netherlands) (37) RCT- in between subject study design	Some concerns		High	Low	High	High	High	Low
Sharps et al. (2019, UK)(9) RCT	Some concerns		High	Low	High	Some concerns	High	Low
Teo et al. (2018, Singapore)(10)	Some concerns		Some concerns	Low	Low	High	High	Low

RCT								
Cullen et al. (2013, USA)(38) RCT	Some concerns		High	High	High	Some concerns	High	Low
Murphy et al. (2020, Ireland)(20) RCT	Some concerns		High	High	High	High	High	Low
Sadler et al. (2021, USA)(11) within subject, crossover trial	Some concerns	Some concerns	Low	Low	High	High	High	Low
Ngqangashe et al. (2021, Belgium)(7) RCT	High		High	Low	High	Low	High	Low
Masterson et al. (2019, USA)(12) within subject, crossover trial	Some concerns	Some concerns	High	Low	High	Some concerns	High	Low
Keller et al. (2018, USA)(13) within subject, crossover trial	Some concerns	High	High	Low	High	High	High	Low
Charbonnier et al. (2018, The Netherlands, Scotland and Greece)(14) within subject, crossover trial	Some concerns	Some concerns	High	Low	High	Some concerns	High	Low
Samara et al. (2018, USA)(15) RCT	Some concerns		High	Low	High	Some concerns	High	Low
English et al. (2017, USA)(16) within subject, crossover trial	Some concerns	High	High	Low	High	High	High	Low
Allen et al. (2016, UK)(21)	Some concerns		High	Low	High	High	High	Low

RCT								
Fearnbach et al. **(**2016, USA)(17) RCT	Some concerns		High	Low	High	High	High	Low
English et al. (2016, USA)(18) within subject, crossover trial	Some concerns	High	High	Low	High	Some concerns	High	Low
Jensen et al. (2016, USA)(22) RCT	Some concerns		High	Low	High	Some concerns	High	Low
Van Meer et al. **(**2016, The Netherlands)(19) RCT	Some concerns		High	Low	High	Some concerns	High	Low
Watson et al. **(**2015, The Netherlands) (23) RCT	Some concerns		High	High	High	Some concerns	High	Low
Stice et al. (2011, USA)(24) RCT	Some concerns		High	Low	High	Some concerns	High	Low

[1] Domain S is a specific addition in the RoB 2 tool evaluating the risk of bias due to carryover effects for cross-over trials(2)

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Supplementary Table 4. Quality assessment of the longitudinal studies according to the Newcastle-Ottawa Scale appraisal tool

	Selection			**Comparability**		**Outcome**			
Author, year, country	**Representativeness of the exposed cohort**	**Representativeness of the non-exposed cohort**	**Ascertainment of exposure**	**Outcome not present at start**	**Design or confounders**	**Assessment of outcome**	**Follow-up long enough**	**Adequacy of follow-up**	**Overall quality**
Smit et al. (2020, The Netherlands) (25)	0 star	1 star	0 stars	0 stars	1 star	0 stars	1 star (follow-up: 3 years)	0 star	low quality

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Supplementary Table 5. Quality assessment of the cross-sectional studies included according to the Joanna Briggs Institute appraisal tool

Author, year, country	**Inclusion criteria well defined**	**Subjects and setting well described**	**Exposure measured in valid way**	**Objective criteria for condition measurement**	**Confounders identified**	**Strategies to deal with confounders**	**Outcome measured in valid way**	**Appropriate statistical analysis**	**Overall quality assessment**
Quettina et al (2021, Belgium)(26)	1	1	0.5	1	1	1	1	1	7.5 (high quality)
Byun et al. (2021, Republic of Korea)(27)	1	1	1	1	1	1	0.5	1	7.5 (high quality)
Gascoyne et al. (2021, Australia) (28)	1	0.5	0.5	1	1	1	0.5	1	6.5 (high quality)
Kim et al. (2020, Republic of Korea)(29)	1	0.5	1	0.5	1	1	0.5	1	6.5 (high quality)
Bradbury et al. (2019, USA) (31)	0.5	1	0.5.	1	1	1	0.5	1	6.5 (high quality)
Delfino et al. (2018,Brazil)(32)	1	1	0.5.	1	1	1	0.5	1	7 (high quality)
Busch et al. (2013, The Netherlands)(39)	1	1	1	1	1	1	1	1	8 (high quality)
Baldwin et al. (2018, Australia)(34)	1	1	0.5	0.5	1	1	0	1	6 (medium quality)
Lwin et al. (2017, Indonesia)(30)	0.5	0.5	1	1	0.5	0.5	1	0.5	5.5 (medium quality)

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Sampasa-Kanyinga et al. (2015, Canada)(36)	0	1	0	1	1	1	0.5	1	5.5 (medium quality)
Hansstein et al. (2017,China)(35)	0.5	0.5	0.5	1	0.5	0.5	0.5	0.5	4.5 (medium quality)

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Online Supplementary Material

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