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Factors associated with eating rate: a systematic review and narrative synthesis informed by socio-ecological model

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Abstract

Accumulating evidence shows associations between rapid eating and overweight. Modifying eating rate might be a potential weight management strategy without imposing additional dietary restrictions. A comprehensive understanding of factors associated with eating speed will help with designing effective interventions. The aim of this review was to synthesise the current state of knowledge on the factors associated with eating rate. The socio-ecological model (SEM) was utilised to scaffold the identified factors. A comprehensive literature search of eleven databases was conducted to identify factors associated with eating rate. The 104 studies that met the inclusion criteria were heterogeneous in design and methods of eating rate measurement. We identified thirty-nine factors that were independently linked to eating speed and mapped them onto the individual, social and environmental levels of the SEM. The majority of the reported factors pertained to the individual characteristics ($n = 20$) including demographics, cognitive/psychological factors and habitual food oral processing behaviours. Social factors ($n = 11$) included eating companions, social and cultural norms, and family structure. Environmental factors ($n = 8$) included food texture and presentation, methods of consumption or background sounds. Measures of body weight, food form and characteristics, food oral processing behaviours and gender, age and ethnicity were the most researched and consistent factors associated with eating rate. A number of other novel and underresearched factors emerged, but these require replication and further research. We highlight directions for further research in this space and potential evidence-based candidates for interventions targeting eating rate.

Keywords: Eating rate: Eating speed: Eating behaviour: Oral processing behaviour: Eating microstructure

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Introduction

According to the recent estimates, the global prevalence of overweight and obesity will reach approximately 20% by year 2025 if the current trends continue[1]. This is alarming because obesity has been linked to a number of adverse health outcomes including diabetes mellitus, cardiovascular issues, fatty liver disease and poor mental health among others, posing a substantial economic burden for the global healthcare systems[2]. Preventive and therapeutic efforts focus on improving diets and/or promoting greater physical activity. Programmes specifically focused on dietary intakes predominantly target 'What'[3] (food types, macronutrients), 'How much'[4] (portion size guidance) and 'When' people eat[5] (snacking behaviour). A growing body of evidence shows that eating rate, which characterises 'How' people eat[6], is also an important predictor of body weight and may potentially be a novel avenue for weight management programmes.

Accumulating evidence demonstrates positive associations between eating rate (i.e. the amount of food consumed per unit of time) and weight status across various age groups (from childhood to advanced age)[7,8], demographics (gender, education and income levels)[9,10] and cultural backgrounds (i.e. European, Asian and American samples)[11,12], in general and clinical (e.g. with obesity or underweight) populations. However, the mechanisms underlying these associations are not well understood. Eating at a slower rate extends the oral exposure time of food, and has been linked with increased glucose response, higher postprandial level of anorexigenic gut peptide YY, greater satiation (earlier meal termination), longer inter-meal satiety[13–15], greater ghrelin suppression, greater reported post-meal fullness, more accurate portion size memory and reduced inter-meal snack consumption[16]. Faster eaters may experience less satiety and eat more, which over time can lead to sustained positive energy balance and, in consequence, obesity[6]. Eating rate is considered to be habitual, as it shows good-to-excellent within-individual consistency and stability across the meals, independently of the food type[17]. Still, eating rate changes depending on, for example, food texture[18,19] or eating location[20] and shows individual differences between genders[21], ethnicities[22] or age groups[11], pointing to the complex interaction between individual and environmental

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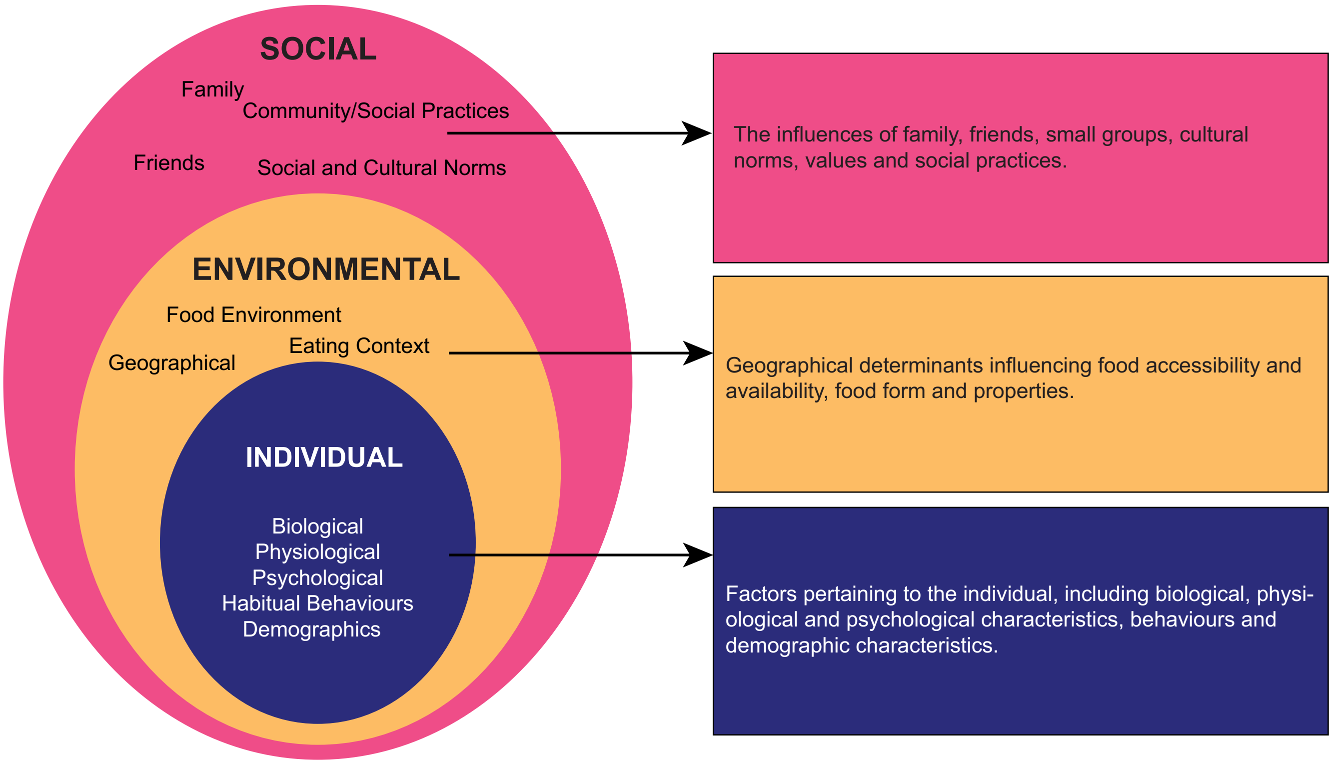

Fig. 1. Socio-ecological model for eating rate. *Note*: The adaptation includes merging of community/policy level with group, culture, organisation level to represent 'Social level'. Individual and Environmental levels remain unchanged.

factors that have not been systematically summarised to date, and are currently poorly understood.

Considering the diversity of factors associated with eating rate, it is necessary to gain a holistic understanding of the variety of individual differences and environmental influences on eating rate, as well as how these factors interact to develop effective and evidence-based interventions that target eating rate. To our knowledge, a systematic review of the factors associated with eating rate has not been conducted to date. The objectives of this systematic review were to: (i) identify factors associated with eating rate; (ii) evaluate the strength and direction of the associations between the identified factors and eating rate; and (iii) to conduct a narrative synthesis of the identified factors, accounting for the strength of the reported associations.

Given the diversity of the factors associated with eating rate, the adapted socio-ecological model (SEM)[23,24] was applied to scaffold the identified variables for the purpose of the narrative synthesis. The SEM construct of health posits that internal individual factors interact with the external social and environmental factors to affect health and health-related behaviours[25,26], which was deemed an appropriate framework for the current research question. The adaptation of the SEM for the purpose of the current study included clustering together two levels (community/policy level with group, culture, organisation level to represent 'Social level') that were considered separate in the original publication[23] (Fig. 1). No other adaptations were made. This multi-level integrative framework will allow the transfer of research evidence into translation and implementation guidelines. This study will contribute to identify existing gaps, and guide further multi-disciplinary research directions to develop engaging and well-informed solutions to optimise eating rate.

Methodology

Search strategy

A systematic search of eleven databases (CINAHL, EMBASE, IEEExplore, MEDLINE, PAIS, PsycINFO, PubMed, Science Direct, Scopus, Web of Science and ACM Digital Library) was conducted following with Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) standards[27] and registered with the PROSPERO database[28] (International Prospective Register of Systematic Reviews: no. CRD42021236498). A list of keywords, including general terms related to eating rate and other related factors were used for each database: ('eating rate' OR 'eating speed' OR 'slow eating' OR 'eating time' OR 'fast eating' OR 'quick eating' OR 'rapid eating' OR 'slow chewing' OR 'fast chewing' OR 'eating pace' OR 'oral-process rate' OR 'eating slowly' OR 'eating too fast') AND ('factor*' OR 'cause*' OR 'influence*' OR 'reason*' OR 'determinant*'). For an example search strategy adapted for the Web of Science, see Supplementary 1. Forward and backward reference list searches of all included articles were also conducted through Publish or Perish™ to ensure a comprehensive search. The search covered all the relevant studies in the past five decades (1971–2022) to reflect studies in the contemporary eating environment.

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Study eligibility and selection

Following the initial search, Rayyan, an online software system developed for conducting systematic reviews, was used for title and abstract screening[29]. Both abstracts and full texts were independently screened by two reviewers, based on a set of predefined eligibility criteria. Any discrepancies were resolved through discussion until a unanimous decision was reached. Papers were included if the report was a peer-review publication published in English. As this review was predominantly focused on identifying factors associated with eating rate, there was no restriction on study design to ensure a broader coverage of relevant research. Studies were excluded if: (i) the paper was an abstract, dissertation, book, book chapter, demo, review or meta-analysis; (ii) the paper described devices or novel technologies for intake monitoring or eating pattern detection; or the study (iii) reported relevant factors such as bite/sip size and frequency, number of chews and meal time, but did not directly relate to eating rate; (iv) was a randomised control trial that reported eating rate, but did not report factors associated with eating rate; (v) investigated the associations between eating speed and measures of body composition or body weight other than body mass index (BMI)[30,31], waist circumference (WC) or waist-to-height ratio (WHtR)[32–34] (these indices of body weight/body composition were selected as the most commonly reported to streamline the search process and subsequent data synthesis); (vi) investigated the factors linked only with drinking behaviour (i.e. alcoholic/non-alcoholic beverages) and not with food-related behaviours; (vii) included subjects that were non-human animals; (viii) investigated the effect of pharmacological therapy on eating rate (e.g. fluoxetine-induced eating behaviour change); (ix) investigated participants with eating disorders including dysphagia, anorexia nervosa, binge-eating disorder, and other eating difficulties or impairments; and (x) investigated participants who need assisted eating, such as infants who require parental feeding and individuals with physical or mental disabilities, who have difficulties in manipulating food in the mouth.

Data extraction and quality assessment

The following essential information was extracted from each eligible study by two researchers, if reported: first author, year of publication, country, abbreviated aim(s) of the study, study characteristic (study design), participant characteristic (age, gender, BMI, ethnicity), sample characteristic (size, sampling method, population), data collection and analysis, outcome and factors identified to be associated with eating rate with statistical evidence. All data were compiled into a standard Microsoft Excel template for further synthesis. Any disagreements were resolved in a discussion. Effect sizes for each identified factor were extracted and/or calculated on the basis of the available data, when the factor of interest was significantly associated with eating rate at the statistical threshold level pre-specified by the study authors (this was $p < 0{\cdot}05$ for all of the identified studies) to evaluate the strength of the relationship between eating rate and the individual factors. When the data necessary for the effect size calculation (e.g. standard deviation) were not provided, one of the researchers contacted the corresponding author to obtain the additional information.

The quality of the manuscripts was assessed using standard quality assessment criteria[35]. This quality assessment checklist contained fourteen items, including clarification of the research question, study design, method, participants, intervention and random allocation justification, investigator and/or subject blinding (if possible), justification of outcome methods, appropriateness of sample size, control of confounding variables, and sufficient detail in the results, with conclusions supported by results. Each item was scored ('yes' = 2, 'partial' = 1, 'no' = 0) based on the degree to which the specific criterion was met. The summary score for each paper was calculated by dividing the total sum of points by the total possible score and ranged from 0 to 1. The quality assessment was performed by two researchers independently with a strong level of agreement ($\kappa = 0{\cdot}93$). Note that the critical appraisal was used only to assess the quality of studies and no papers were excluded on the basis of their quality score.

Data synthesis

Due to significant heterogeneity in study designs, population characteristics, outcome measurement methods and analytical approaches, a meta-analysis was not considered[36]. This decision was based on the expert opinion of the Investigator team familiar with the high heterogeneity of methodologies within the eating rate literature and later confirmed by conducting preliminary searches across the databases, prior to commencing the full systematic search and prior to study registration. A narrative synthesis was conducted to provide qualitative evaluations of the available evidence. Two independent reviewers identified factors and synthesised them inductively, and a third reviewer resolved disagreements.

Considering the multifaceted nature of factors associated with eating rate, the socio-ecological model (SEM) was used to synthesise the complex data[37]. SEM assumes that individual behaviour is shaped and influenced by social and ecological environments, which was considered an appropriate approach given the available evidence on the factors associated with eating rate. Using this approach, a wide range of potential factors were nested under three hierarchical levels: individual (e.g. gender, habits, attitude), social (e.g. family, peers) and environmental (e.g. eating surroundings, food). Social factors, in principle, are also environmental specifically involving other people. Note that, in this review, the differentiation between these factors was highlighted due to the implied degree of their modifiability (social factors are more difficult to modify as they are typically outside of one's control or deeply engrained). Therefore, in the current study all the environmental factors that involve other people will be referred to as social factors, and all the external factors, excluding the social ones, will be referred to as environmental factors. All the identified factors were described in terms of the direction of the association (i.e. significant and positive, significant and negative, and non-significant), with effect sizes as an indication of their magnitude.

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Various indices of effect size were either extracted or if not reported, they were calculated by the Investigator team on the basis of the study design, inferential statistics reported and available data. These included Cohen's *d* for *t*-tests, *r* for correlation coefficients, η^2, R^2, and Cohen's *f* for analyses of variance (ANOVAs). As examples, Cohen's *d* is based on the difference between observations, divided by the standard deviation of these observations while η^2 was calculated from the sum of squares for the effect divided by the sums of squares for other factors in the design[38,39]. Three different types of effect size were reported for the studies that conducted ANOVAs, depending on the effect size reported by the authors or, if the effect size was not reported, depending on what data were available. The effect size was interpreted as small, medium or large based on the benchmarks suggested for each effect size measure[40,41]. Further information is provided in the footnote to Table 1.

Results

General study characteristics

A flowchart outlining the literature search is summarised in Fig. 2. Of the 4932 studies, 337 were included during the initial screening. Major reasons for exclusion were: 109 studies did not investigate eating rate (i.e. most studies focused on eating behaviours other than eating rate), 65 did not identify factors associated with eating rate, 23 were interventions that did not identify factors associated with eating rate, and 41 reported associations body weight/body composition and eating rate but reported measures of body weight/body composition other than BMI, WC or WHtR. To ensure sufficient coverage of all relevant papers, a follow-up citation tracking[42] was employed. Specifically, the reference lists of the 100 eligible papers were scrutinised to identify any further pertinent articles for inclusion. Consequently, this process yielded 4 additional papers that satisfied the predetermined inclusion criteria, resulting in a total of 104 manuscripts that were included in this systematic review.

An overview of the study characteristic and key findings of the included studies are outlined in Supplementary 2. Among the included studies, forty-five (43%) were conducted in Europe, thirty-nine (38%) in Asia, seventeen (16%) in North America, two (2%) in New Zealand and one (1%) in Australia. The study populations consisted of various ethnicities, and five studies[11,22,43–45]specifically examined ethnic differences in eating rate. Among the different types of study design, the majority ($n = 47$; 45%) had cross-sectional design, thirty-six (35%) were (crossover) randomised controlled trials, fifteen (14%) came from cohort studies and the remaining six (6%) had case–control design. Most studies ($n = 99$; 95%) reported effect sizes; however, five studies[46–50] (5%) failed to provide sufficient data for computing the effect sizes. Corresponding authors of these studies were contacted to obtain data for effect size computation, though none of the authors replied within the stipulated time period. The sample sizes of the reviewed studies varied greatly, ranging from 10[50] to 197 825[51] participants. Similarly, participants from various age groups were included, with age ranging from 4 years[52,53] to 87[54] years. Most studies ($n = 76$; 73%) included adults between 18 and 65 years old, a number of studies ($n = 21$; 20%)[7,43,46,47,52,53,55–69] explicitly explored eating rate among children or adolescents, and seven studies[8,11,22,44,54,70,71] (7%) investigated older adults. The majority of the studies ($n = 82$; 79%) included both males and females; however, nine studies (8%)[72–80] investigated females only, and six (6%) recruited only males[18,81–85]. Only seven studies (7%)[7,10,20,86–89] had a balanced male/female ratio. Most studies ($n = 42$; 40%) examined participants with a healthy weight status, and thirty-seven studies (36%) did not provide inclusion or exclusion criteria based on body weight, body composition or adiposity. Four studies (4%) focused only on people with overweight and obesity[68,72,73,77] defined by ethnicity-specific cut-off values[90–92], whereas two (2%) studies involved lean Asian young men[85] and lean Asian children[71]. The study quality scores are summarised in Supplementary 3, ranging from 0 (poor quality) to 1 (high quality). In general, study quality was moderate (mean 0·78, median 0·82), with scores ranging from 0·41[93] to 1[7,67,94]. Four papers[59,73,78,93] received low ratings (using 0·5 as the cut point[35]).

Definition and measurement of eating rate

There was no consensus on the definition of eating rate across the studies. In 53 of 104 (51%) papers (Table 2), eating rate was defined using a pre-specified formula. Among these, the majority ($n = 37$; 70%) calculated eating rate by dividing the grams consumed by the total meal duration (i.e. from the start of the first bite to the swallow of the last bite). One study[52] (1%) defined eating rate as total energy intake (i.e. kilocalories) divided by the meal duration (referred to as 'energy intake rate' in other studies[95,96]), and five studies[20,72,95,97,98] (9%) used both measures. In thirteen studies (25%) total oral exposure time (time food spent in mouth) rather than meal duration was used to compute eating rate (e.g. Fogel *et al.*[43] investigated the association between faster eating rates and higher BMI among 4·5-year-old children). Two studies[46,55] (4%) defined eating rate as number of bites per minute. Other studies ($n = 32$, 31%) measured eating rate using questionnaires (e.g. Sakata's Eating Behaviour Questionnaire (SEBQ)[81]) and defined it according to the questionnaire definition (e.g. one study[99] using mealtime duration as a numerical measure) or did not define eating rate at all (e.g. question[100] such as 'compared to other people, is your eating speed quicker').

Due to the heterogeneous definitions and study designs, methodologies used to determine eating rate varied between the studies (Table 3). In general, these can be divided into two categories: (1) objective measurements ($n = 69$; 66%) using video analysis, universal eating monitors (UEM)[101], Mandometer®[102], electromyography (EMG) sensors and others; (2) and subjective measures ($n = 32$; 31%) from self-reported questionnaires, which were mostly used in studies with large sample sizes. Subjectively measured eating rate often utilised Sakata's Eating Behaviour Questionnaire (SEBQ)[81] in studies with adults, Children's Eating Behavior Questionnaire (CEBQ)[53] for parental reports of children's eating rate and self-reports measured using direct questions in non-validated surveys (e.g. How fast is your eating speed?

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Table 1. A summary of factors and effect sizes# associated with eating rate that emerged from the review, narratively synthesised across the levels of the socio-ecological model

Theme	Factor	Description	Positive association (with effect size)#	Negative association (with effect size)#	No association#
Individual					
Food oral processing behaviours	Number of chews per mouthful/bite	Faster eating rate achieved through larger average bite size (g), fewer chews per gram, shorter pauses between bites, and shorter oral exposure time per bite (s)		44 8 43 73 74 108 171 118 48	8 Difference between 200% and 150% of habitual number of chews
	Bite size		44 11 43 74 113 117 118 119		
	Oral exposure time (per bite)			44 119 18 108 117	
	Inter-bite interval		74		
Eating habits	Snacking behaviour	Snacking behaviours linked with faster eating	51		
	Irregular diet	Erratic eating (e.g. skipping breakfast) linked with faster eating	51		
	Food-to-mealtime context incongruity	Eating rate increased from breakfast time to lunch time for pasta, but did not change for porridge	111 For Pasta		111 For Porridge
	Food palatability	Greater perceived palatability linked with a faster eating rate	113 75 79 87 50		
	Perceived hunger or satiation	Higher subjective hunger linked with faster eating rate	113 60 75 93		50 120
Demographics	Age	Older age linked with slower eating. *Young adults as baseline		51 11 22 44 70 46	
	Gender	Faster eating linked with male gender. *Female as baseline	51 63 68 113 10 11 20 22 57 86 87 120		21 46 60 124
	Ethnicity	Caucasian Dutch and/or other Asian ethnic groups (Malay, Indian) have faster eating rate than Chinese. *Asian-Chinese ethnicity as baseline	11 22 43 44 45		
Body characteristic	Measures of adiposity	Rapid eating linked with larger BMI, larger WC or WHtR	45 63 69 71 93 103 126 127 WC in female 51 52 54 60 61 64 66 83 97 105 113 128 129 130 55 58 62 80 81 82 86 94 99 100 131 132 133 134 48		56 104 127 WC in male
	Measures of oral physiology	Rapid eating associated with mastication performance and dental status (i.e. number of teeth)	44		
		Rapid eating is positively associated with tongue thickness	11		
	Oral cavity volume	A decrease in volume of oral cavity is associated with an increased eating rate		44	
Cognitive/psychological	Inhibitory control	Lower inhibitory control is linked with faster eating rate		7 21	
	Addictive behaviours	Faster eating linked with addictive behaviours	45 94		82
	Mood disorders	Depressive symptoms linked with slower eating		137	
	Stress	Psychological stress response linked with faster eating	81		
	Mindfulness	Higher mindfulness linked with slower eating rate		98	
	Portion size effect	Higher perceived portion size is linked to slower eating rate (size mismatch)		138	
		Increased portion size linked with faster eating rate	77 138 7		

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Table 1. *(Continued)*

Theme	Factor	Description	Positive association (with effect size)[#]	Negative association (with effect size)[#]	No association[#]
Social					
Feeding practices	Pressure to eat	Associated with eating slowly		53	
	Monitoring			53	
	Restriction	Restrictive food practices not linked with child's eating rate			53
	Prompt to eat	Parental prompts to eat were associated with increased eating rate	52		
Family structure	Birth order	First-born children were more likely to have a faster eating rate	58		
	Parity	Children with siblings were more likely to have a faster eating rate	58		
Eating companion	Modelling influence	People tend to mimic their eating companion's eating pattern within 5 s	76 46 49Male fast eating model		49Female fast eating model
	Eating companion	Group eating linked with lower eating rate compared with eating alone. * Eating alone as baseline		72	
		Small or large group size (3 or 9) not linked to eating rate			65
	Parental influence	The presence of parents leads to faster eating rate for children with obesity	56		
Social and cultural norms	Social/cultural practice	Chinese eating culture (sharing food or using chopsticks) is linked to slower eating rate	112		
	Socially guided time available to consume foods	Sack lunch offered more time to eat than school lunches. *School lunch as baseline		59	
		As grade level increases, students have a decreased consumption time		59	
Environmental					
Food environment	Food processing	Cooking/food storage methods affected eating rate. Boiling, steaming or grilling linked with faster eating rate; sous-vide and raw linked with slower eating rate. *Sous-vide and raw as baseline	141 142 89 139 140		
		UPFs linked with faster eating. *Unprocessed food as baseline	95 96		
	Food form or texture	Texture properties (i.e. springiness, chewiness, resilience, high fracture stress and adhesiveness) linked to a slower eating rate		143 18 108 110 141 142	
		Increased food viscosity associated with slower eating		84 138 145 146	119
		Increased food hardness linked with slower eating		148 Luncheon meat 44 11 18 22 70 95 106 109 118 144	148Meat replacers and candy
	Mixture of foods	Condiments linked with faster eating	107 147		
		Addition of particles decreased the eating rate		70 110	
		Larger particle size linked to slower eating	124	119	
	Food presentation	Mashed food linked to faster eating. *Whole food as baseline	88		
		Food shape influences eating rate.	107 Carrot in cube 147Cracker in flat square	107 Carrot in juliene 147Cracker in finger square	
		Food served separately linked to slower eating. *Mixed food as baseline		78	

Table 1. (*Continued*)

Theme	Factor	Description	Positive association (with effect size)#	Negative association (with effect size)#	No association#
Eating environment	Cutlery	Larger cutlery size (i.e. chopsticks and spoon) linked to faster eating	85 114		
		Eating with chopsticks linked to slower eating. *Other methods (fingers, spoons) as baseline		112	
		Eating yoghurt with a straw linked to slower eating. *Spoon as baseline	149		
		Eating with spoon linked with faster eating. *Fork as baseline	131		
		The texture of spoon associated with eating rate			151
	Eating location	Eating in free-living conditions is slower than in lab conditions. *Lab as baseline	144 At home	72	
	Meal type	Eating at lunch faster than other meals (breakfast, dinner and snack). *Lunch as baseline	20		
	Eating atmosphere	Music is linked with slower eating. *Silence as baseline		152	
		Slower sound while eating (e.g. chewing sound, tempo legato) linked with slower eating	153	152	
		Excessive media use linked with faster eating rate	47		

Note: Numbers in the table refer to the relevant references;

* indicates the baseline condition. Any further remarks about the study findings are presented next to the references;

Effect size annotation: **small effect size** – black box outline, white background, black font **small**; **medium effect size** – black box outline, grey background, black font **medium**; **large effect size** – black box, white font **large**; when effect size was not computed, only the reference number is presented without an accompanying box. Effect size calculations based on the following values: small (Pearson *r* or correlation coefficient = ±0·1; coefficient of determination (r^2 or R^2) = 0·01; η^2 = 0·01; ω^2 = 0·01; Cohen's *f* = 0·1; Cohen's *d* = 0·2; odds ratio (OR) = 1·5; relative risk or risk ratio (RR) = 2); medium (Pearson *r* or correlation coefficient = ±0·3; coefficient of determination (r^2 or R^2) = 0·09; η^2 = 0·06; ω^2 = 0·06; Cohen's *f* = 0·25; Cohen's *d* = 0·5; odds ratio (OR) = 2; relative risk or risk ratio (RR) = 3); large (Pearson *r* or correlation coefficient = ±0·5; coefficient of determination (r^2 or R^2) = 0·25; η^2 = 0·14; ω^2 = 0·14; Cohen's *f* = 0·40; Cohen's *d* = 0·8; odds ratio (OR) = 3; relative risk or risk ratio (RR) = 4); NA indicates that there were not enough data provided for a effect size calculation; BMI, body mass index; WC, waist circumference; WHtR, waist-to-height ratio; UPF, ultra-processing food; detailed information about raw effect size is provided in Supplementary Material 2.

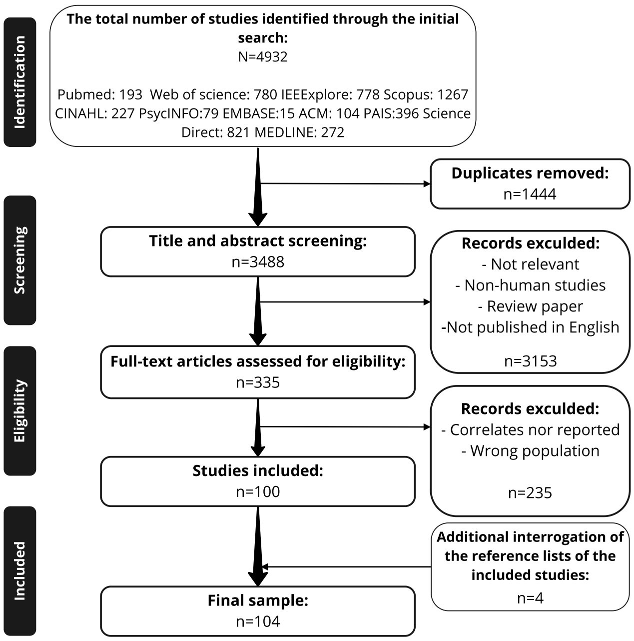

Fig. 2. Flow diagram of the literature search strategy.

How quickly do you eat in comparison with others?), with semi-qualitative responses (e.g. slow, average/medium, fast)[50], visual analogue scales[47,60,73,103,104] or other scoring methods[64]. Across the studies which used subjective measures of eating rate there was often poor distribution of scores[45], and in most cases (eight out of nine studies) the categories had to be combined (e.g. 'very slow' and 'slow' or 'fast' and 'very fast') to facilitate data analysis[105]. Only one study[99] explicitly benchmarked meal duration in units of time (e.g. <5 min per meal, ≤5 and ≤10 min per meal) as a proxy for asking the participant to determine their eating rate. For objective measurements, studies predominantly ($n = 34$; 49%) used video recordings to capture the eating process and code eating microstructure from the recordings. The oral processing behaviours such as oral processing time, number of chews, number of bites and number of swallows were subsequently computed from analysis of eating microstructure using behavioural annotation software. Among these, some studies ($n = 6$; 18%) additionally placed stickers on subjects' faces (e.g. nose tip, forehead and chin) as a reference point to extract more accurate microstructure parameters (i.e. bites, chews and swallows) during video analysis[11,22,44,106–108]. Similarly, participants in the three studies were instructed to indicate every moment of swallowing by raising their hands[70,109,110]. Sixteen studies (23%) only recorded total food consumption and mealtime with an electronic scale and/or stopper for eating rate calculation rather than measuring other eating oral processing behaviours, such as bite size and chewing rate. Other, less common methods, included the Universal Eating Monitor (UEM)[20,56,68,72,77,86,97,111], Mandometer[57], electromyography (EMG) sensors[10,50,112] and direct observation[49,75,79,85,93,113,114].

Table 2. Definition of eating rate provided in reviewed papers ($n = 53$)

Definition	Reference
Total intake divided by the duration of mealtime (g/min) or (g/s)	Thirty-seven studies [10,11,20,44,48–50,57,61,65,68,70,72,74,77,84–86,88,89,95–98,110–113,118,120,131,138,142,147,149,151]
Total energy intake by the duration of mealtime (kcal/min)	Six studies [20,52,72,95,97,98]
Total intake divided by the total oral exposure time (g/min) or (g/s)	Thirteen studies [18,22,43,95,106–108,117,119,143,145,146,153]
Total number of bites by the duration of mealtime (bite/min)	Two studies[46,55]

Note: Five studies[20,72,95,97,98] used both grams and kilocalories consumed divided by the unit of time (g/min) and (kcal/min) or (g/s) and (kcal/s).

Factors associated with eating rate: socio-ecological model

Individual factors. Of the 104 included studies, 66 (63%) investigated the relationship between eating rate and various individual-level factors. The factors were centred around five key themes including eating microstructure[115] (bites, chews, swallows) and/or food oral processing behaviour (e.g. chews per bite), eating habits, demographic factors, body characteristics and cognitive/psychological factors. For simplicity, we will refer only to oral processing behaviours rather than microstructure and/or oral processing behaviours throughout.

All the identified factors have been graphically presented in a word cloud in Fig. 3 created using open access software (Wordart). The word cloud summarises the identified factors using two dimensions: font size and font colour. Font size is a qualitative interpretation of the study findings representing the number of studies that investigated the given factor and their effect size, with larger font representing a larger number of studies, with stronger and/or more consistent effect sizes. Font size has been determined using the following formula created especially for the purpose of the current analysis: number of entries of the factor into the word cloud = ((number of studies with small effect size × 1) + (number of studies with medium effect size × 2) + (number of studies with large effect size × 3)) – (number of studies that found no association). Where the study reported a significant positive/negative association but the effect size was not provided and/or could not be computed, a small effect size was assumed and the factor was entered once. Different colours have been used to differentiate between levels of SEM.

Food oral processing behaviour. Food oral processing[116], which is the manipulation and degradation of food inside the mouth before swallowing, has been one of the most investigated ($n = 14$; 21%) individual factors. Despite the variety of food properties, individuals tend to exhibit consistent habitual oral processing behaviours[17] such as chews per bite, oral exposure time, bite size or inter-bite interval, all of which have been

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Table 3. Eating rate detection methods/tools provided in reviewed papers ($n = 101$)

Method	Description	Reference
Objective		
Video analysis	Naked eye observation of bites, chews and swallows from the video clips	Twenty-five studies [7,18,43,46,52,53,55,61,65,74,76,87,89,96,117–119,141–147,153]
	Stickers on the face of participants to extract oral processing parameter	Six studies [11,22,44,106–108]
	Indicate swallowing moment by raising a hand	Three studies [70,109,110]
Stopwatch and/or electronic scale	Stopwatch for mealtime calculations and electronic scale for measuring total portion consumed	Sixteen studies [8,48,59,78,84,88,98,120,131,138–140,148,149,151,152]
Universal eating monitor	A hidden scale that connects to a microcomputer to read weight continually	Eight studies [20,56,68,72,77,86,97,111]
Mandometer	A weighting scale and a custom-made computer with a touch screen to display the eating rate.	One study[57]
Observe directly	Record eating duration and oral processing behaviour (e.g. count the number of mouthfuls) directly	Seven studies [49,75,79,85,93,113,114]
EMG	Mastication parameters (e.g. number of chews per mouthful)	Three studies [10,50,112]
Subjective		
Self-report or parent report	SEBQ/CEBQ	Two studies [53,81]
	Dichotomous scale: not fast (slow and medium)/fast	Five studies [53,62,63,82,100]
	Slow, medium/average, fast	Nine studies [51,66,71,80,83,126,129,130,134]
	Four options: <5 min per meal/≤5 and ≤10 min per meal/≤10 and ≤15 min per meal/≥15 min per meal	One study[99]
	Never, quit, newly and continuous	One study[64]
	Five options: very slow, slow, medium, fast and very fast	Nine studies [21,45,54,69,94,127,128,132,133,137]
	Visual analogue scale	Five studies [47,60,73,103,104]

EMG, electromyography of the masticatory muscles; SEBQ, Sakata Eating Behaviour Questionnaire; CEBQ, Children's Eating Behavior Questionnaire.

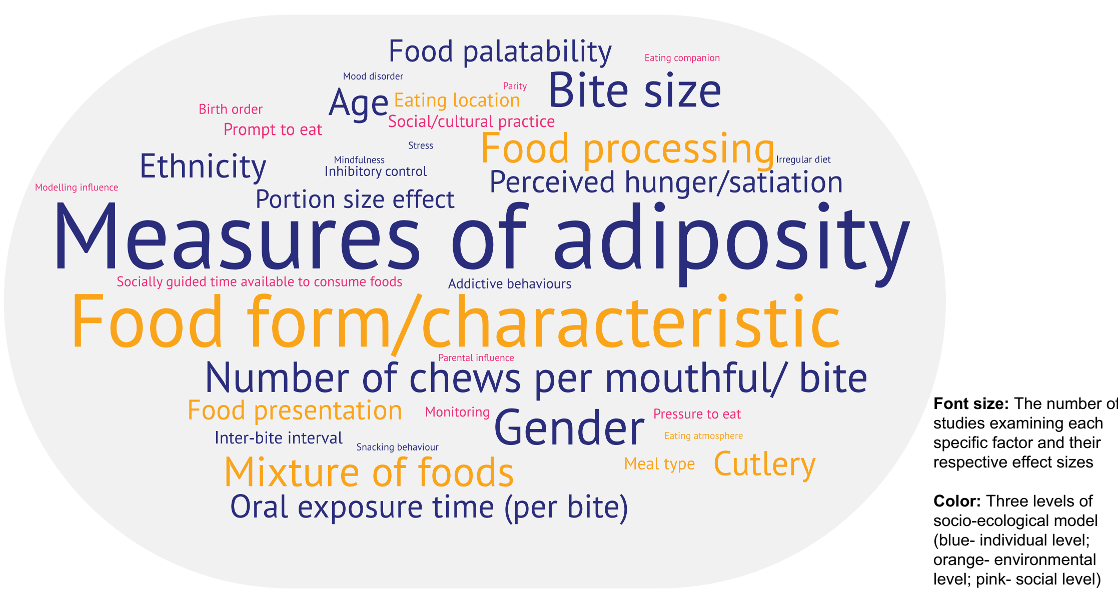

Fig. 3. A word cloud diagram depicting all factors associated with eating rate identified in the current study. *Note:* The font size varies depending on the number of studies that investigated the specific factor and the effect size, with larger font representing more studies and/or with larger effect sizes. Different colours have been used to differentiate between the different levels of socio-ecological model (blue, individual level; orange, environmental level; pink, social level). The following formula was created for the purpose of this analysis to determine the font size: ((number of studies with small effect size × 1) + (number of studies with medium effect size × 2) + (number of studies with large effect size × 3)) – number of studies that found no association) = number of entries of the factor to the word cloud. Where the study reported a significant positive/negative association but effect size could not be computed, a small effect size was assumed.

associated with eating rate. Among these, higher number of chews per bite[8,43,73,74,108,117,118] has shown strong associations with reduced eating rate, except one study showing a small effect size[44] and another study[48] that failed to provide sufficient data to calculate an effect size. Most studies have also consistently identified larger bite size[11,43,74,85,113,117–119] as a strong factor linked to faster eating rate among participants who differed in weight status (e.g. people with overweight[77]) or age groups (e.g. children[43], adults[113] and elderly[11]), with only one study showing a small effect size[44]. Other elements of food

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oral processing, such as oral exposure time per bite showed mixed associations with eating rate, with two studies[43,119] reporting a small effect, while three[18,108,117] reported a large effect size. In only one study, shorter intervals between mouthfuls[74] were associated with faster eating rate with a large effect size.

Eating habits. Eleven studies (16%) investigated elements of eating habits and eating rate. Various factors were considered, including snacking behaviour[51] and irregular diet[51], food-to-mealtime context[111], food palatability[50,75,79,87,113] and perceived hunger/satiety[50,60,75,93,113,120]. Small positive associations were shown between tendency to snack or irregular diet and faster eating rate, though these were investigated only in single studies. McLeod *et al.*[111] suggested that eating rate was slower and less food was consumed when food was presented at an unusual mealtime (i.e. pasta for breakfast) rather than the usual food-to-mealtime context (i.e. pasta at lunch; small positive effect size), though this has not been consistent across the foods (inconsistent results for a sweet porridge dish).

Food palatability and perceived satiation were two of the most investigated factors ($n = 8$) pertaining to the eating habits. Individuals who reported having greater food flavour preference or food palatability were more likely to consume food at a faster rate. Among the studies, three indicated a large effect size[75,79,87], one indicated a small effect size[113], while another[50] did not supply adequate data for effect size computation. Similarly, hungry subjects were observed to take less time per bite and had faster eating rate than non-hungry subjects[60,75,93,113] with small-to-medium effect size, though this association was not very consistent[50,120]. Studies differed in the methodologies, including duration of fast (15 h versus 4 h), diurnal versus nocturnal fasting, types of food served and meal context (e.g. an *ad libitum* buffet or fixed-portion meals). Generally, foods perceived to be more palatable were eaten faster, while perceived hunger/satiety showed less consistent associations.

Demographic characteristics. Out of the studies included in this review, twenty-one studies (31%) examined demographic factors in the context of the eating rate, including age, gender and ethnicity. Four[11,22,44,70] of the six studies reported a strong negative association, and one reported a weak negative association[51], between age and eating rate, suggesting that older adults (age range 70–85 years old) had lower eating rate compared with the younger participants (age range 18–30 years old). One study[121] investigating eating rate in families with adolescents indicated a marginally faster eating rate among adolescents compared with their parents (effect size could not be computed). No studies compared eating rate among various age groups in childhood (early, mid-, late childhood), or across various age groups in adulthood (e.g. early, mid-, late adulthood).

Of the sixteen studies that examined gender, twelve[10,11,20,22,51,57,63,86,87,120,122,123] reported that females have slower eating rate than males regardless of the type of food consumed and their age groups (e.g. children[43], school-going adolescents[57], and adults[22]), while the rest reported lack of association[21,46,60,124]. Gender-based differences could be partially mediated by physical differences in oral physiology[11] including larger oral cavity among males, as well as larger head height and width. The reported effect sizes varied across the studies, ranging from small[51,63] to medium[68,113] to large[10,11,20,22,57,86,87,120].

Consistent ethnic differences in eating rate were found[22,43–45] with medium-to-large effect sizes, though only limited cross-cultural comparions have been reported. Specifically, Asian Chinese participants tended to have better mastication performance[44] and lower eating rate characterized by more chews per bite and a smaller average bite size compared with Caucasian Dutch participants when consuming chewable foods (e.g. raw carrots, cheese and beef). Moreover, Chinese participants tended to have a relatively slow eating rate regardless of their age (children[43], adults[45]), when compared with other major Asian ethnic groups (e.g. Malay and Indian[43]). Notably, all the reported studies focused on cross-cultural comparisons between Asians and European Caucasians, and there was lack of evidence pertaining to any other ethno-cultural backgrounds (e.g. African, Middle Eastern ethnicities or Aboriginal cultures).

Body characteristics. The association between body weight status and eating rate has been extensively studied ($n = 39$ studies) and covered in other reviews[125]. In most studies ($n = 33$; 85%), BMI was used to estimate body weight status using ethnic specific cut-off values, further used to compare eating rates among participants with healthy weight and with overweight/obesity. Thirty-seven out of thirty-nine studies reported a positive association between higher body weight/overweight and eating rate, with effect size ranging from small[45,63,69,71,93,103,126,127] to medium[51,52,54,60,61,64,66,83,97,105,113,128–130] to large[55,58,62,80–82,86,94,99,100,131–134]. Among these, twenty-one were cross-sectional analyses, including eight studies specifically focusing on children and adolescents from various ethnicities, such as Japanese[69,71], Finnish[103], Chinese[62,66], Spanish[63], Swedish or Greek[61] and Multi-Asian[43]. In prospective analyses, five studies[52,55,60,64,129] focused only on children, while one study[82] assessed the relationship between 8-year weight change and eating rate for Japanese middle-aged male workers only. These findings support findings from the previous reviews[6,135,136] demonstrating consistent associations between faster eating and greater body weight. Three studies failed to find an association between body weight and eating rate[56,104]. Some mediators of this association have been investigated. One cross-sectional study[56] demonstrated that children with overweight ate significantly faster than children with normal weight only when the mother was present in the laboratory, suggesting that parental influence could be an important mediator. Another study[127] in Dutch adults reported that, while a positive association was found between BMI and eating rate in both genders, the positive association between eating rate and waist circumference was observed only in females. Two other studies investigated the associations between measures of oral physiology and oral cavity volume, demonstrating faster eating rate among participants with a greater number of teeth[44], smaller oral cavity[44] and thicker tongue[11].

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Cognitive/psychological factors. Cognitive/psychological factors including individual differences in inhibitory control[7,21], depressive symptoms[137] and mindfulness[98] consistently demonstrated negative associations with eating rate, whereas psychological stress[81] was positively associated with eating rate, all with small effect sizes. In two cross-sectional studies, one in a Japanese population[94] and one in a multi-Asian population[45], addictive behaviours (such as smoking, alcohol intake) showed weak associations with rapid eating, while one retrospective longitudinal study[82] conducted over an 8-year period failed to find statistically significant associations between addictive tendencies to exercising, smoking, habitual alcohol intake and eating rate.

The impact of portion size effect on eating rate has been examined in three studies[7,77,138], and results consistently indicated that greater meal sizes were associated with faster eating rate, with two of the studies showing a medium effect size. However, rather than a linear relationship between portion size and eating rate, one study[77] in women with overweight reported a threshold, approximately 15% greater than a reference portion size, beyond which eating rate began to decrease. Wilkinson *et al.*[138] explored the influence of the ongoing perceptual volume of food remaining (rather than the actual volume of food at the beginning) on eating rate. This interesting study showed that eating rate was faster when participants saw a small portion of soup (300 ml) but actually consumed a large portion (500 ml), compared with when participants saw 500 ml but in fact consumed a 300 ml food portion. Therefore, the eating rate may not be solely influenced by the portion size at the beginning of the meal, but also by the perceived portions of food available. However, this relationship did not persist when comparing the eating rate of custard with large portion size (500 ml) and small portion size (300 ml), indicating that the effect of portion size on eating rate is moderated by the food type and palatability, highlighting the complexity of these associations.

Social factors

Eleven studies (11%) investigated the relationships between eating rate and social factors such as caregiver feeding practices[52,53], family structure[58], eating with companions[46,49,65,72,76], parental influence[56], cultural and social eating norms[112] and socially determined time available for food consumption[59].

In a longitudinal study[53] that assessed bidirectional relationships between parental controlling feeding practices and children's eating rate, it was demonstrated that pressuring children to eat and monitoring of eating at age 4 years were positively associated with eating very slowly at age 7 years, and the same was observed in the opposite direction, with medium effect sizes. This association was not observed for other controlling feeding practices such as food restriction. Parental prompts to eat were also significantly associated with children's eating rate (kcal/min) in another longitudinal study[52] (with a large effect size), though bidirectional associations were not examined. Laessle *et al.*[56] found that children with overweight were particularly susceptible to maternal presence during mealtime and increased eating speed when mothers were present in the room. Similarly, Potter *et al.*[58] found that children with siblings tended to have a faster eating rate and consumed more food than children without siblings. During the sensitive period for development of eating behaviours, parental feeding practices and behaviours around the meal, as well as presence of other models including siblings, can influence the development of children's habitual eating rates. However, the behaviours of models are also, to some extent, a response to spontaneous eating behaviours of children that the models observe.

Contrary to studies conducted in children, in adults companionship during a meal was linked with a slower eating rate compared with eating alone[72], though this has been investigated in only a single study. Three studies have investigated the phenomenon of behavioural mimicry, where people unconsciously change their eating patterns in social conditions (only one study[76] provided data to compute an effect size). In the family eating context, participants (males and females) were more likely to speed up eating rate within 5 s following a bite by their eating partner[46]; this was, however, observed only for the subset of family members (nineteen of seventy-eight dyads). Among strangers, it was reported that participants (females) eating with a fast-eating confederate model consumed their lunch significantly faster than participants who ate with slow-eating models[49]. Gender differences were explored in experiment II in the same study[49], showing that female subjects ate more crackers in 7 min if the model confederate was a male who ate more crackers, and they ate less if the model was a female or if the model was a male who ate fewer crackers. A crossover study[65] which examined the influence of a group size (small group of three and large group of nine) on children's eating behaviour found no associations between eating rate and group size.

Two studies investigated elements that can be attributed to cultural influences on eating rate demonstrating moderate[59] to strong[112] relationships between eating speed and mealtime norms and practices[112] or socially guided time available for food consumption[59]. Lunch break times in schools as well as cultural/social practices with regard to lunch provisions affect time that pupils in schools have to consume food, which can further impact eating speed[59]. Furthermore, in Chinese culture it is typical to share food with others, as platters are always placed in the middle of the table and food is taken on plate individually, and this has been associated with a slower rate of consumption compared with consuming food mixed on the individual plates[78]. Similarly, cultural practices can influence other eating behaviours for example use of cutlery. Chopsticks, a frequently used cutlery in Chinese culinary culture, are known to reduce eating rate compared with other eating methods[112], such as spoons commonly used in Western cultures and fingers commonly used in South Asian or African cultures.

Environmental factors

Food environment. Thirty-two out of 104 studies investigated the role of food environment on eating rate and four factors emerged: food processing approaches[89,139–142], food characteristics including textural and mechanical properties[18,108,110,141–

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143), hardness[11,18,22,44,70,95,106,109,118,144] and viscosity[84,138,145,146], mixtures of food with various mechanical matrices[70,110,124] and food presentation[78,88,107,147].

Seven studies investigated the association between food processing approaches and eating rate (medium-to-large effect size). Among these, five[89,139–142] focused on the impact of different cooking methods on altering the mechanical properties of food, which in turn contributed to the changes in eating rate. In general, studies have reported that complex cooking methods (e.g. grilling, steaming, boiling), as compared with simple cooking methods (e.g., raw or sous-vide) could significantly alter the innate structure of food, contributing to less consumption effort and a faster eating rate. This has been observed in various foods, including potatoes[142], potherb mustard greens (Mizuna; *Brassica rapa*)[140] and wild boar ham[89]. One study[139] found that the storage condition of rice affected the eating rate. Specifically, cold-stored parboiled rice was found to have a more ordered structure compared with freshly cooked medium-grain rice, resulting in a longer chewing time and slower eating rate. The degree of food processing and its positive association with eating rate was examined in two studies[95,96]. In particular, highly processed foods defined by NOVA classification (a framework that classified foods into four groups based on the level of processing) as ultra-processing foods (UPFs), on average, were found to be associated with faster eating rate than unprocessed or minimally processed foods[96]. However, there was significant variability within each food category, suggesting that other factors (e.g. composition and texture) may also play a role in mediating the influence of processed foods on eating behaviour.

Six studies demonstrated that the physical–chemical, rheological and mechanical properties of food play a crucial role in influencing eating speed. In the study by Wee *et al.*[143], across fifty-nine solid commercial food products in Asian and Western cuisines, higher springiness, chewiness and resilience of food were related to slower eating rate as they required more chews to form a swallowable bolus. This has been supported by other studies consistently showing medium-to-large effect sizes[18,108,110,141,142]. Other textural properties such as hardness[11,18,22,44,70,95,106,109,118,144] and viscosity[84,138,145,146] were also quite consistently negatively associated with eating rate, with medium-to-large effect sizes. Specifically, chewable foods were consumed at the slowest rate, with the smallest bite size, the greatest chewing rate per bite and the longest consumption time, compared with drinkable and spoonable foods[106]. Additionally, stiffer solid foods and more viscous liquid and semi-solid foods were associated with slower eating rate. These results, however, were not consistent. For instance, in the study of Zijlstra *et al.*[148] the eating rate of hard luncheon meat was slower than that of soft luncheon meat, but this was not observed for alternative protein food and candy.

Apart from directly manipulating the texture of a single food, six studies[70,107,110,119,124,147] investigated the associations between eating rate and composite foods, in which two or more foods are combined. It has been consistently suggested[107,147] that the inclusion of condiments such as mayonnaise or cheese, which are frequently consumed with carrier foods such as bread or crackers, can speed up eating rate. For example, carrots with mayonnaise were consumed faster than plain carrots, presumably due to the condiment's lubricating effect on bolus particles, which reduces saliva incorporation and increases eating rate[107]. Alternatively, particle addition to certain foods[70,110,124], including granola and yogurt, may result in complicated textural properties that require greater oral manipulation skills that consequently slow down eating rate. This[70] may be exacerbated by particle hardness and particle number, which can slow down the eating rate even further. Another study assessed[119] the influence of particle size on eating rate and reported that yogurt with smaller granola particles (6 mm) was consumed slower than yogurts with large granola particles (12 mm). However, in the study that investigated candy particle size on oral behaviour[124], a single large candy led to a longer total oral processing time compared with eight small candy portions. The disparity is likely due to hard candy requiring not only chewing but also sucking to dissolve it with saliva. All the studies reported large effect sizes pointing to the saliency and consistency of this factor on eating rate.

In terms of food presentation, two studies have reported that consuming smaller food pieces can reduce the eating rate compared with the food served in larger sizes with a medium effect size. For instance, carrots presented in large cubes were found to cause lower mastication effort and require lower number of chews than carrots pre-cut into smaller pieces[107]. Moreover, carrots cut in julienne shape with a higher surface area triggered slower eating rate in comparison with carrots presented in cubes[107]. Similar effects were demonstrated in another study that investigated the shape of crackers on eating rate[147]. Other factors that may influence eating rate, including the serving format of Korean foods (separately or together)[78] and the presentation of potatoes (mashed or whole)[88], were examined in only a single study and warrant further investigation. It should be noted that food presentation can also change the texture of the food even though physical–rheological properties of the food due to, for example, thermal processing are unaffected. Mashed potatoes will therefore have a different texture to whole potatoes despite being cooked in the same way.

Eating environment. Eating environment and eating rate were assessed in twelve studies. Three of these reported consistent associations between eating methods[112,131,149] and eating rate, with two[112,131] indicating a large effect size and one[149] indicating a small effect. Specifically, eating with chopsticks was slower than eating with fingers or spoons[112], and eating with a fork has also been demonstrated to be slower than eating with a spoon[131]. These differences may be driven by the maximum permitted carrying volume. For example, a small spoon (teaspoon) resulted in a smaller bite size, longer mealtime duration and slower eating rate compared with a larger spoon (dessert spoon)[85]. This trend was also observed for straws[150] (thin or thick) and chopsticks (long or short)[114], with large effect sizes. One recent study[151] examined the effect of different 3D-printed textured spoons on eating rate, but no significant associations with eating rate were found. Participants' familiarity with certain eating tools, such as chopsticks, may also play a role

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pointing to the interaction between socio-cultural elements and physical eating environment.

The association between eating rate and eating location has not been reported consistently. One study[144] found that, compared with laboratory settings, eating rate was slower when food was consumed in free-living conditions (a large effect size). Conversely, another study[72] that explored the effect of test location (lab versus home) on sensory profile and eating behaviour found an opposite relationship, albeit with a small effect size.

The effect of auditory features of the eating environment on eating rate was examined in two studies. The findings showed that, compared with silence, listening to music while eating effectively prolonged the meal duration and thus modulated the eating speed (a large effect size)[152]. People also spent significantly more time eating when music was slower in tempo and with legato articulation. In the other study it was demonstrated that participants could slow down their eating rate without being aware they were doing so by just listening to their slower chewing sounds, although the effect size was small[153].

Other interesting findings include faster eating speed observed during lunch compared with other meals (breakfast, dinner, snack)[20], with a large effect size. Additionally, the impact of media usage[47] on eating rate among secondary school children was examined, demonstrating that 25% of children self-reported eating the meal faster at least once a week to be able to watch TV or play a computer game.

General discussion

The objective of the review was to examine and synthesize the current evidence on factors associated with eating rate. This review provides a comprehensive summary of the identified factors and a narrative synthesis with discussion of their effect size. Overall, 104 eligible studies were analysed and 40 factors were extracted and mapped onto the SEM, following qualitative evaluation. The majority were factors pertaining to the individual characteristics (20/39), followed by those related to social factors (11/39) and other environmental factors (8/39). Evidence suggests that individual factors such as food oral processing behaviour, gender, measures of body weight, and environmental factors such as food physical, rheological and mechanical properties are among the most frequently investigated factors with the most consistent associations with eating rate. The overall findings are summarised in Fig. 3.

Looking at the individual factors associated with eating rate, food oral processing behaviours including fewer chews per mouthful[8,43,73,74,108,117,118], a large bite size[11,43,74,85,113,117–119] and shorter oral exposure time[18,108,117] have consistently been identified as the primary drivers of rapid eating, with medium-to-large effect size.

Of the demographic factors considered, there was a consistent indication that eating rate decreases with age[11,22,44,46,51,70], with particularly strong evidence for slower eating among the older adults compared with younger adults. This could be attributed to the degradation of oral functionalities associated with ageing[154,155], such as lower biting force, less tongue pressure and fewer teeth, which may contribute to the longer consumption times and the increased number of chews before swallowing that the elderly take to compensate for their reduced mastication efficiency. Additionally, age-correlated anatomical alterations, including decrease in salivation[156] or oral cavity volume[44], might also impair the effectiveness of food oral processing behaviour, leading to a slower eating rate. Further research across the full age spectrum from childhood through adolescence and early, mid- and late adulthood is required to better understand age-related changes in masticatory efficiency and eating rate.

There was also a large body of evidence suggesting that males eat faster than females, though effect sizes varied considerably and several studies failed to find this association. This potential gender-based difference could be partially attributable to attitudes towards mealtime etiquette[157], impression management tactics[158] and oral physiology. For instance, research on consumption stereotypes[159] demonstrated that individuals who consume smaller meals and healthy diets are more feminine, less masculine, more physically attractive and more moral. Additionally, males normally have higher muscle strength, larger oral cavity, bite force, and salivary flow rate, resulting in shorter chewing cycle duration, larger bite sizes and faster eating rate[160]. The discrepancies in the identified effect sizes may be related to the textures of food served across the identified studies, or the heterogeneity in the methodology and/or sample size. Ketel *et al.*[106] reported gender differences in eating rate only for solid foods, with females eating chewable food at a slower rate than males, while that trend was not apparent for semi-solid and liquid foods.

Ethnic differences in eating rate have also been consistently reported[22,43,44], albeit within a very limited number of ethnicities that were investigated (typically European and Asian). Asian Chinese participants tended to eat more slowly than other Asian ethnicities and Caucasian Dutch. This could be attributed to differences in their oral physiology (e.g. oral cavity volume)[44], cultural/social practices[112,131] or other external factors such as different cutlery congruent with various cuisines[112].

Finally, one of the most researched and consistently reported individual factors was the association between faster eating and greater body weight[45,48,51,52,54,55,58,60–64,66,69,71,80–83,86,93,94,97,99,105,113,126,128–130,133], in line with other systematic reviews in this area published previously[6,135,136]. It should be noted that the directionality of this relationship is still under debate as it is at present unclear if higher body weight *causes* faster eating, or whether faster eating *leads to* greater body weight. Likely, this association is bidirectional[161].

Few studies examined cognitive/psychological factors associated with eating rate, including inhibition control[7,21], depressive symptoms[137], psychological stress[81] and mindfulness[98], or eating habits such as snacking behaviour or diet irregularity, which were examined in single studies, making it difficult to draw any conclusions regarding the significance, direction or strength of this association. More consistently, it has been reported that larger food portions may be linked to faster eating[7,77,138] in both children and adults[162–165]. Several mechanisms may be involved including visual references for

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meal termination[166], which provide indirect information to eaters regarding the amount consumed and large portions which stimulate increases in bite size[167]. Further research is needed to gain a clearer understanding of how portion size impacts eating rate. This includes investigating whether the effect is due to inability to accurately judge the amount of food served and/or if it relates to specific alterations in oral processing behaviours (i.e. bite size).

Interestingly, a number of social factors emerged as a result of our synthesis, though the support for these associations is rather weak and is often based on a single study in this area. Nevertheless, this emerging evidence is interesting as it offers insight into specific mechanisms through which eating rate is learnt or acquired during early development and provides context for potential implementation of interventions to reduce eating rate across cultures and populations. Several social factors, including feeding practices[53] (i.e. pressure to eat, monitoring), family structure[58] (i.e. birth order, parity) and socially guided time available to consume foods[59], were investigated in single studies, with small-to-medium effect sizes. The influence of other overarching factors such as social and cultural norms[112,131] can potentially help explain other individual-level factors such as previously discussed ethnic differences. The impact of social/cultural factors can also influence quantities or types of food consumed, using specific cutlery for certain meals, food-to-mealtime context incongruity or perception of the mealtime etiquette. Research on a wider variety of ethnical backgrounds and cultures is needed to better understand the impact of social/cultural norms on eating behaviours.

Unsurprisingly, of the environmental factors, food characteristics, such as textural and mechanical properties[18,108,110,141–143], hardness[11,18,22,44,70,95,106,109,118,144] and viscosity[84,138,145,146] of the food, were the most investigated factors associated with eating rate, with consistent medium-to-large effect sizes. Strong consistent[168] correlations between instrumental texture properties and oral processing behaviours, which then impact eating rate, have been well established. Importantly, research shows that people adopt their eating behaviour in response to the structural properties of foods they consume. An adhesive, chewy, less lubricated, hard-textured food may enable smaller bites and more chewing, which will result in a slower eating style, a phenomenon that is evident when it comes to foods of liquid, semisolid and solid form[169]. Supported by the previous findings, food texture modification can be accomplished through various food processing (i.e. minimal or ultra-processing[95,96]) and cooking approaches[89,139–142] (i.e. grilling, steaming), by destroying the innate structures of foods, which leads to the reformulation of food texture, or by changing food presentation methods (mashed versus whole potatoes). Aside from dramatic changes in the mechanical properties of food, changing food shape[107,147] to a high aspect ratio and large surface area (e.g. cutting vegetables into elongated, julienne particles) may also be an alternative method of prolonging mastication time and slowing down eating rate. Other approaches, such as adding condiments[107,147] or particles[70,110,119] to create a mixture of food with a variety of mechanical matrixes, demonstrated great efficacy in decreasing eating rate. Extrinsically introduced food texture manipulation could potentially alter other factors such as sensory perception and acceptability of food, thus impacting palatability[168]. Minor changes (i.e. food shape, addition of condiments or particles) that reduce the alterations to the eating experience may therefore be more desirable than dramatic changes to food texture. Further research is needed to determine whether food texture manipulation approaches could be applied across the foods and whether these would be acceptable to both producers and consumers. Several environmental attributes, such as food forms[78], meal types[20] (i.e. breakfast, dinner and snack), auditory features[152,153] and media usage[47] were examined in single studies, and as such, the findings, though promising, are still preliminary.

Given the complexity of eating rate, the SEM model was successful in outlining the various known factors associated with eating rate at different levels, differentiating between factors pertaining to the individual, the environment and the cultural–societal elements. Such presentation of individual factors can help steer future research efforts to explore the associated mechanisms or to study the effectiveness in manipulating eating rate in experimental designs. It is important to note that, although the factors here are listed separately for ease of navigation, they should be considered as inter-dependent. For example, food oral processing behaviours have been suggested to be highly modifiable and, as such, should be effective in slowing down or speeding up eating rate[168,170]. However, the effectiveness of such manipulation may vary depending on the individual differences such as age, gender, ethnicity or body weight, social factors including presence of siblings, duration of lunch breaks at school or work, cultural appropriateness of cutlery, and other environmental factors (e.g. media usage while eating).

Implication for future research

One interesting finding from this review was the heterogeneity in the definitions of eating rate and methods of measurement across the studies. To enhance replicability and the generalisability of the study findings, it is recommended that the definitions of eating rate and methods of measurement be more standardised across the studies, while accounting for the study design, population and objectives. For example, it is recommended that validated questionnaires be used for studies that rely on self-reports of eating rate, rather than self-reported eating rate based on a single question. Further research to establish and validate briefer versions of currently used questionnaires, appropriate for large population-based studies, is necessary. For laboratory-based studies that measure eating rate in grams per unit of time or kcal per unit of time, we recommend to provide both measures (e.g. g/min and kcal/min). It is worth noting that the discrepancies between self-reported eating rate and objectively measured eating rate have been extensively discussed[20,61,123,171]. These findings suggest that, while self-reports may be a viable options for population level studies, smaller experimental studies should strive for more objective methods of measurement[127].

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Despite its accuracy, manual video coding of eating microstructure is not cost-effective due to reliance on expert manpower and the time required, limiting its utility in real-life eating environments. Alternative methods such as automated video coding[172] may be more cost-effective and efficient; however, this method is prone to errors and may not be easily applied. Modern technological tools, such as audio sensors[173,174] for capturing chewing and swallowing behaviour, and inertial measurement unit (IMU) sensors[175–177] for recognising eating gestures can help improve the objectivity of eating rate assessment, though these methods are in early phases of development and are not yet widely available. We have been working on developing a smart eating tool capable of measuring eating rate in children (work in progress), for whom video-coding of eating rate is more difficult than for adults due to more movement during the meal and less mature eating behaviour. Our technology[178] also allows dynamic regulation of bite size during eating and showed promising early results among participants with healthy weight and with overweight.

Based on the factors identified in this systematic review, we suggest that, to optimise eating rate, interventions targeting eating rate should focus on modification of specific oral processing behaviours, that is, bite size, oral processing time and inter-bite interval. This can be achieved by manipulating the texture of food to promote smaller bites and/or more chewing, which has been shown to be effective in small laboratory-based studies[118]. Whether translation of such methods to real life is feasible requires further evidence. Using 3D food printing technologies[179,180] it is also possible to re-formulate the microstructure of food, though cost-effectiveness of this process today may be an important barrier. A challenge remains in understanding how to develop food products that reduce the potential for overconsumption of energy without compromising their sensory appeal[170]. Alternatively, or in addition, we can manipulate the type and size of eating cutlery to statically reduce the bite size, though sustainability and social acceptance of such methods may be problematic. It is also important to foster a supportive environment (in the school and workplace) where ample time is provided for eating.

Implementing effective interventions to improve eating behaviour is challenging due to its complex nature. Future interventions should prioritise identifying clear targets that are evidence-based, feasible and accessible for individuals and do not require a radical change in a person's lifestyle. It is important to note that, to optimise the effectiveness, interventions should not be treated as one-size-fits-all; rather, they may need to be tailored to specific circumstances. For example, food shape control is not feasible for vulnerable populations such as the elderly. In this instance, lubrication of food to accommodate physical conditions as well as to stimulate faster eating and greater energy intakes may be more desirable.

Strengths and limitation

This review provides a comprehensive synthesis of factors associated with eating rate mapped onto the socio-ecological model. This review highlights well-established factors across the individual, environmental and social levels, as well as emerging evidence in this area that shows promising findings that require further replication and/or research. By embracing an ecological perspective, we discuss the links and interactions between different factors providing clear directions for future research. This study had several limitations. Due to the methodological heterogeneity in eating rate definition and assessment methods, population characteristics and study designs, a meta-analysis was not feasible and was not considered. Several of the identified factors were supported by evidence from single studies; thus, their discussion in the broader context was not possible due to insufficient evidence. In addition, conclusions regarding specific factors that were drawn from a small number of studies are not generalisable and will not apply to other populations or circumstances. The discussion was instead focused on the most prevalent and researched factors, which were briefly discussed in the context of this emerging evidence. Moreover, we were unable to discuss the directionality of some of the factors due to the correlational designs of many of the studies, and as such, these findings and recommendations for future research and interventions need to be approached with caution. Finally, many of the factors that were mapped onto SEM could belong to more than one category (e.g. food presentation and texture), but were assigned on the basis of subjective interpretation of the study team.

Conclusions

This review provided an evidence-based synthesis of factors associated with the eating rate from multidisciplinary studies and mapped them to the socio-ecological model framework in a systematic way. The study highlighted heterogeneity in the definitions of eating rate across the studies, as well as a need for more standardised methods of measurement, appropriate for specific study designs, populations and objectives. Overall, we identified forty different factors associated with eating rate that were subsequently mapped onto the socio-ecological model, across individual, social and environmental levels. We identified some well-explored factors, which consistently showed strong associations with eating rate (i.e. oral processing behaviour, food texture, age), as well as many less explored factors such as eating habits, cognitive/psychological factors, feeding practices, eating companions and eating methods. These less explored factors are not yet well understood and require further investigation, but they may complement the development of effective strategies for eating rate modification and can enhance our understanding of the mechanisms involved. Based on the findings of this review, we propose further directions for research in this space as well as recommendations for feasible and evidence-based interventions to optimise eating rate.

Supplementary material

To view supplementary material for this article, please visit https://doi.org/10.1017/S0954422423000239

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Competing interests

There are no conflicts of interest.

References

1. Kelly T, Yang W, Chen C-S, *et al.* (2008) Global burden of obesity in 2005 and projections to 2030. *Int J Obes* **32**, 1431–1437.
2. Miller AA & Spencer SJ (2014) Obesity and neuroinflammation: a pathway to cognitive impairment. *Brain Behav Immun* **42**, 10–21.
3. Zobel EH, Hansen TW, Rossing P, *et al.* (2016) Global changes in food supply and the obesity epidemic. *Curr Obes Rep* **5**, 449–455.
4. Marteau TM, Hollands GJ, Shemilt I, *et al.* (2015) Downsizing: policy options to reduce portion sizes to help tackle obesity. *BMJ* 351, h5863.
5. Mielmann A & Brunner TA (2019) Consumers' snack choices: current factors contributing to obesity. *Br Food J* **121**, 347–358.
6. Ohkuma T, Hirakawa Y, Nakamura U, *et al.* (2015) Association between eating rate and obesity: a systematic review and meta-analysis. *Int J Obes* **39**, 1589–1596.
7. Fogel A, McCrickerd K, Goh AT, *et al.* (2019) Associations between inhibitory control, eating behaviours and adiposity in 6-year-old children. *Int J Obes* **43**, 1344–1353.
8. Zhu Y & Hollis JH (2014) Chewing thoroughly reduces eating rate and postprandial food palatability but does not influence meal size in older adults. *Physiol Behav* **123**, 62–66.
9. Sonoda C, Fukuda H, Kitamura M, *et al.* (2018) Associations among obesity, eating speed, and oral health. *Obes Facts* **11**, 165–175.
10. Park S & Shin WS (2015) Differences in eating behaviors and masticatory performances by gender and obesity status. *Physiol Behav* **138**, 69–74.
11. Ketel EC, de Wijk RA, de Graaf C, *et al.* (2020) Relating oral physiology and anatomy of consumers varying in age, gender and ethnicity to food oral processing behavior. *Physiol Behav* **215**, 112766.
12. Bellisle F (2017) Cultural resistance to an obesogenic world: infrequently examined differences in lifestyle between France and America. *Nutr Today* **52**, 5–9.
13. Kokkinos A, le Roux CW, Alexiadou K, *et al.* (2010) Eating slowly increases the postprandial response of the anorexigenic gut hormones, peptide YY and glucagon-like peptide-1. *J Clin Endocrinol Metab* **95**, 333–337.
14. Benelam B (2009) Satiation, satiety and their effects on eating behaviour. *Nutr Bull* **34**, 126–173.
15. Galhardo J, Hunt L, Lightman S, *et al.* (2012) Normalizing eating behavior reduces body weight and improves gastrointestinal hormonal secretion in obese adolescents. *J Clin Endocrinol Metab* **97**, E193–E201.
16. Hawton K, Ferriday D, Rogers P, *et al.* (2018) Slow down: behavioural and physiological effects of reducing eating rate. *Nutrients* **11**, 50.
17. McCrickerd K & Forde CG (2017) Consistency of eating rate, oral processing behaviours and energy intake across meals. *Nutrients* **9**, 891.
18. Choy JYM, Goh AT, Chatonidi G,*et al.* (2021) Impact of food texture modifications on oral processing behaviour, bolus properties and postprandial glucose responses. *Curr Res Food Sci* **4**, 891–899.
19. Koc H, Vinyard CJ, Essick GK, *et al.* (2013) Food oral processing: conversion of food structure to textural perception. *Annu Rev Food Sci Technol* **4**, 237–266.
20. Petty AJ, Melanson KJ & Greene GW (2013) Self-reported eating rate aligns with laboratory measured eating rate but not with free-living meals. *Appetite* **63**, 36–41.
21. Shiozawa K, Mototani Y, Suita K, *et al.* (2020) Gender differences in eating behavior and masticatory performance: an analysis of the three-factor-eating questionnaire and its association with body mass index in healthy subjects. *J Oral Biosci* **62**, 357–362.
22. Ketel EC, Aguayo-Mendoza MG, de Wijk RA, *et al.* (2019) Age, gender, ethnicity and eating capability influence oral processing behaviour of liquid, semi-solid and solid foods differently. *Food Res Int* **119**, 143–151.
23. Sallis JF, Owen N & Fisher E (2015) Ecological models of health behavior. *Health Behav* **5**, 43–64.
24. Golden SD & Earp JAL (2012) Social ecological approaches to individuals and their contexts: 20 years of health education & behavior health promotion interventions. *Health Educ Behav* **39**, 364–372.
25. Mahmudiono T, Segalita C & Rosenkranz RR (2019) Socio-ecological model of correlates of double burden of malnutrition in developing countries: a narrative review. *Int J Environ Res Public Health* **16**, 3730.
26. Kilanowski JF (2017) Breadth of the socio-ecological model. *J Agromedicine* **22**, 295–297.
27. Moher D, Liberati A, Tetzlaff J, *et al.* (2009) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Ann Intern Med* **151**, 264–269.
28. Chien PF, Khan KS & Siassakos D (2012) Registration of systematic reviews: PROSPERO. *BJOG* **119**, 903–905.
29. Ouzzani M, Hammady H, Fedorowicz Z, *et al.* (2016) Rayyan—a web and mobile app for systematic reviews. *Syst Rev* **5**, 1–10.
30. Seidell JC & Flegal KM (1997) Assessing obesity: classification and epidemiology. *Br Med Bull* **53**, 238–252.
31. Weir CB & Jan A (2019) BMI classification percentile and cut off points. https://europepmc.org/article/nbk/nbk541070 (accessed 15 May 2019)
32. American Diabetes Association (2022) Introduction: standards of medical care in diabetes—2022. *Diabetes Care* **45**, S1–S2.
33. Franz MJ, Powers MA, Leontos C, *et al.* (2010) The evidence for medical nutrition therapy for type 1 and type 2 diabetes in adults. *J Am Diet Assoc* **110**, 1852–1889.
34. Mukai N, Doi Y, Ninomiya T, *et al.* (2009) Impact of metabolic syndrome compared with impaired fasting glucose on the development of type 2 diabetes in a general Japanese population: the Hisayama study. *Diabetes Care* **32**, 2288–2293.
35. Kmet LM, Cook LS & Lee RC (2004) *Standard Quality Assessment Criteria for Evaluating Primary Research Papers from a Variety of Fields*. Edmonton: Alberta Heritage Foundation for Medical Research (AHFMR).
36. Walker E, Hernandez AV & Kattan MW (2008) Meta-analysis: its strengths and limitations. *Cleve Clin J Med* **75**, 431.
37. Glass TA & McAtee MJ (2006) Behavioral science at the crossroads in public health: extending horizons, envisioning the future. *Soc Sci Med* **62**, 1650–1671.
38. Higgins J & Deeks J (2011) Obtaining standard deviations from standard errors and confidence intervals for group means. In *Cochrane Handbook for Systematic Reviews of Interventions*,

https://doi.org/10.1017/S0954422423000239 Published online by Cambridge University Press

5th ed, pp. 7733. Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, Welch VA (Eds). Chichester: John Wiley & Sons.
39. Rosenthal R (1994) Parametric measures of effect size. In *The Handbook of Research Synthesis*, pp. 231–244. In Cooper H & Hedges L (Eds). New York: Russell Sage Foundation.
40. Leppink J, O'Sullivan P & Winston K (2016) Effect size—large, medium, and small. *Perspect Med Educ* **5**, 347–349.
41. Fritz CO, Morris PE & Richler JJ (2012) Effect size estimates: current use, calculations, and interpretation. *J Exp Psychol* **141**, 2.
42. Weightman AL, Morgan HE, Shepherd MA, *et al.* (2012) Social inequality and infant health in the UK: systematic review and meta-analyses. *BMJ Open* **2**, e000964.
43. Fogel A, Goh AT, Fries LR, *et al.* (2017) A description of an 'obesogenic' eating style that promotes higher energy intake and is associated with greater adiposity in 4.5 year-old children: Results from the GUSTO cohort. *Physiol Behav* **176**, 107–116.
44. Ketel EC, Zhang Y, Jia J, *et al.* (2021) Comparison of and relationships between oral physiology, anatomy and food oral processing behavior of Chinese (Asian) and Dutch (Caucasian) consumers differing in age. *Physiol Behav* **232**, 113284.
45. Teo PS, van Dam RM, Whitton C, *et al.* (2020) Association between self-reported eating rate, energy intake, and cardiovascular risk factors in a multi-ethnic Asian population. *Nutrients* **12**, 1080.
46. Bell BM, Spruijt-Metz D, Vega Yon GG, *et al.* (2019) Sensing eating mimicry among family members. *Transl Behav Med* **9**, 422–430.
47. Van den Bulck J & Eggermont S (2006) Media use as a reason for meal skipping and fast eating in secondary school children. *J Hum Nutr Diet* **19**, 91–100.
48. Zhu Y & Hollis JH (2014) Increasing the number of chews before swallowing reduces meal size in normal-weight, overweight, and obese adults. *J Acad Nutr Diet* **114**, 926–931.
49. Rosenthal B & McSweeney FK (1979) Modeling influences on eating behavior. *Addict Behav* **4**, 205–214.
50. Bellisle F, Lucas F, Amrani R, *et al.* (1984) Deprivation, palatability and the micro-structure of meals in human subjects. *Appetite* **5**, 85–94.
51. Kudo A, Asahi K, Satoh H, *et al.* (2019) Fast eating is a strong risk factor for new-onset diabetes among the Japanese general population. *Sci Rep* **9**, 8210.
52. Berkowitz RI, Moore RH, Faith MS, *et al.* (2010) Identification of an obese eating style in 4-year-old children born at high and low risk for obesity. *Obesity* **18**, 505–512.
53. Costa A, Severo M & Oliveira A (2021) Food parenting practices and eating behaviors in childhood: a cross-lagged approach within the generation XXI cohort. *Am J Clin Nutr* **114**, 101–108.
54. Nakamura T, Nakamura Y, Takashima N, *et al.* (2021) Eating slowly is associated with undernutrition among community-dwelling adult men and older adult women. *Nutrients* **14**, 54.
55. Llewellyn CH, van Jaarsveld CH, Boniface D, *et al.* (2008) Eating rate is a heritable phenotype related to weight in children. *Am J Clin Nutr* **88**, 1560–1566.
56. Laessle R, Uhl H, Lindel B, *et al.* (2001) Parental influences on laboratory eating behavior in obese and non-obese children. *Int J Obes* **25**, S60–S62.
57. Langlet B, Anvret A, Maramis C, *et al.* (2017) Objective measures of eating behaviour in a Swedish high school. *Behav Inf* **36**, 1005–1013.
58. Potter C, Gibson EL, Ferriday D, *et al.* (2021) Associations between number of siblings, birth order, eating rate and adiposity in children and adults. *Clin Obes* **11**, e12438.
59. Buergel NS, Bergman EA, Knutson AC, *et al.* (2002) Students consuming sack lunches devote more time to eating than those consuming school lunches. *J Am Diet Assoc* **102**, 1283–1286.
60. Slyper A, Shenker J & Israel A (2021) A questionnaire-based assessment of hunger, speed of eating and food intake in children with obesity. *Diabetes Metab Syndr Obes* **14**, 59–66.
61. Fagerberg P, Charmandari E, Diou C, *et al.* (2021) Fast eating is associated with increased BMI among high-school students. *Nutrients* **13**, 880.
62. Gong Q-H, Li S-X, Wang S-J, *et al.* (2022) Self-reported eating speed is associated with overweight among Chinese schoolchildren: a cross-sectional survey. *Eat Weight Disord* **27**, 1297–1302.
63. Gomez-Martinez S, Martinez-Gomez D, Perez de Heredia F, *et al.* (2012) Eating habits and total and abdominal fat in Spanish adolescents: influence of physical activity. The AVENA study. *J Adolesc Health* **50**, 403–409.
64. Yamagishi K, Sairenchi T, Sawada N, *et al.* (2018) Impact of speed-eating habit on subsequent body mass index and blood pressure among schoolchildren – the Ibaraki children's cohort study (IBACHIL). *Circ J* **82**, 419–422.
65. Lumeng JC & Hillman KH (2007) Eating in larger groups increases food consumption. *Arch Dis Child* **92**, 384–387.
66. Zeng X, Cai L, Ma J, *et al.* (2018) Eating fast is positively associated with general and abdominal obesity among Chinese children: a national survey. *Sci Rep* **8**, 14362.
67. Eloranta A, Lindi V, Schwab U, *et al.* (2012) Dietary factors associated with overweight and body adiposity in Finnish children aged 6–8 years: the PANIC study. *Int J Obes* **36**, 950–955.
68. Laessle R & Lehrke S (2012) Differences in laboratory eating behaviour between overweight boys and girls before treatment. *Eat Weight Disord* **17**, e137–e139.
69. Ochiai H, Shirasawa T, Nanri H, *et al.* (2016) Eating quickly is associated with waist-to-height ratio among Japanese adolescents: a cross-sectional survey. *Arch Public Health* **74**, 1–7.
70. Aguayo-Mendoza M, Santagiuliana M, Ong X, *et al.* (2020) How addition of peach gel particles to yogurt affects oral behavior, sensory perception and liking of consumers differing in age. *Food Res Int* **134**, 109213.
71. Okubo H, Murakami K, Masayasu S, *et al.* (2018) The relationship of eating rate and degree of chewing to body weight status among preschool children in Japan: a nationwide cross-sectional study. *Nutrients* **11**, 64.
72. Hordern K (2012) Impacts of social factors on free-living eating rate as assessed by multiple-pass, 24-h recalls. Master Thesis, University of Rhode Island.
73. Canterini CC, Gaubil-Kaladjian I, Vatin S, *et al.* (2018) Rapid eating is linked to emotional eating in obese women relieving from bariatric surgery. *Obes Surg* **28**, 526–531.
74. Ferriday D, Bosworth ML, Godinot N, *et al.* (2016) Variation in the oral processing of everyday meals is associated with fullness and meal size; a potential nudge to reduce energy intake? *Nutrients* **8**, 315.
75. Hodgson RJ & Greene JB (1980) The saliva priming effect, eating speed and the measurement of hunger. *Behav Res Ther* **18**, 243–247.
76. Hermans RC, Lichtwarck-Aschoff A, Bevelander KE, *et al.* (2012) Mimicry of food intake: the dynamic interplay between eating companions. *PLoS ONE* **7**, e31027.

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77. Almiron-Roig E, Tsiountsioura M, Lewis HB, *et al.* (2015) Large portion sizes increase bite size and eating rate in overweight women. *Physiol Behav* **139**, 297–302.
78. Suh HJ & Jung EY (2016) Effect of food service form on eating rate: meal served in a separated form might lower eating rate. *Asia Pac J Clin Nutr* **25**, 85–88.
79. Westerterp-Plantenga MS, Wouters L & ten Hoor F (1991) Restrained eating, obesity, and cumulative food intake curves during four-course meals. *Appetite* **16**, 149–158.
80. Hamada Y, Miyaji A, Hayashi Y, *et al.* (2017) Objective and subjective eating speeds are related to body composition and shape in female college students. *J Nutr Sci Vitaminol* **63**, 174–179.
81. Nishitani N, Sakakibara H & Akiyama I (2009) Eating behavior related to obesity and job stress in male Japanese workers. *Nutrition* **25**, 45–50.
82. Tanihara S, Imatoh T, Miyazaki M, *et al.* (2011) Retrospective longitudinal study on the relationship between 8-year weight change and current eating speed. *Appetite* **57**, 179–183.
83. Shin A, Lim SY, Sung J, *et al.* (2009) Dietary intake, eating habits, and metabolic syndrome in Korean men. *J Am Diet Assoc* **109**, 633–640.
84. Zhu Y, Hsu WH & Hollis JH (2013) The impact of food viscosity on eating rate, subjective appetite, glycemic response and gastric emptying rate. *PLoS ONE* **8**, e67482.
85. James LJ, Maher T, Biddle J, *et al.* (2018) Eating with a smaller spoon decreases bite size, eating rate and *ad libitum* food intake in healthy young males. *Br J Nutr* **120**, 830–837.
86. Barkeling B, Rossner S & Sjoberg A (1995) Methodological studies on single meal food-intake characteristics in normal-weight and obese men and women. *Int J Obes* **19**, 284–290.
87. Yeomans MR (1996) Palatability and the micro-structure of feeding in humans: the appetizer effect. *Appetite* **27**, 119–133.
88. Forde CG, van Kuijk N, Thaler T, *et al.* (2013) Texture and savoury taste influences on food intake in a realistic hot lunch time meal. *Appetite* **60**, 180–186.
89. Ilic J, Tomasevic I & Djekic I (2022) Influence of boiling, grilling, and sous-vide on mastication, bolus formation, and dynamic sensory perception of wild boar ham. *Meat Sci* **188**, 108805.
90. WHO (2022) *Noncommunicable Diseases Progress Monitor 2022*. Geneva: World Health Organization.
91. Deurenberg P (2001) Universal cut-off BMI points for obesity are not appropriate. *Br J Nutr* **85**, 135–136.
92. WHO (2000) *Obesity: Preventing and Managing the Global Epidemic*. Geneva: WHO.
93. Azrin NH, Kellen MJ, Brooks J, *et al.* (2008) Relationship between rate of eating and degree of satiation. *Child Fam Behav Ther* **30**, 355–364.
94. Ohkuma T, Fujii H, Iwase M, *et al.* (2013) Impact of eating rate on obesity and cardiovascular risk factors according to glucose tolerance status: the Fukuoka Diabetes Registry and the Hisayama Study. *Diabetologia* **56**, 70–77.
95. Teo PS, Lim AJ, Goh AT, *et al.* (2022) Texture-based differences in eating rate influence energy intake for minimally processed and ultra-processed meals. *Am J Clin Nutr* **116**, 244–254.
96. Forde CG, Mars M & de Graaf K (2020) Ultra-processing or oral processing? A role for energy density and eating rate in moderating energy intake from processed foods. *Curr Dev Nutr* **4**, nzaa019.
97. Laessle RG, Lehrke S & Duckers S (2007) Laboratory eating behavior in obesity. *Appetite* **49**, 399–404.
98. Rogers PJ, Drumgoole FDY, Quinlan E, *et al.* (2021) An analysis of sensory-specific satiation: food liking, food wanting, and the effects of distraction. *Learn Motiv* **73**, 11.
99. Lee KS, Kim DH, Jang JS, *et al.* (2013) Eating rate is associated with cardiometabolic risk factors in Korean adults. *Nutr Metab Cardiovasc Dis* **23**, 635–641.
100. Lee JS, Mishra G, Hayashi K, *et al.* (2016) Combined eating behaviors and overweight: Eating quickly, late evening meals, and skipping breakfast. *Eat Behav* **21**, 84–88.
101. Kissileff H & Guss J (2001) Microstructure of eating behavior in humans. *Appetite* **36**, 70–78.
102. The Mandometer®. *Mando Clinics, Stockholm Sweden*. https://mando.se/en/ (accessed August 2000)
103. Eloranta AM, Lindi V, Schwab U, *et al.* (2012) Dietary factors associated with overweight and body adiposity in Finnish children aged 6–8 years: the PANIC Study. *Int J Obes* **36**, 950–955.
104. Leong SL, Gray A & Horwath CC (2016) Speed of eating and 3-year BMI change: a nationwide prospective study of mid-age women. *Public Health Nutr* **19**, 463–469.
105. Yamane M, Ekuni D, Mizutani S, *et al.* (2014) Relationships between eating quickly and weight gain in Japanese university students: a longitudinal study. *Obesity* **22**, 2262–2266.
106. Aguayo-Mendoza MG, Ketel EC, van der Linden E, *et al.* (2019) Oral processing behavior of drinkable, spoonable and chewable foods is primarily determined by rheological and mechanical food properties. *Food Qual Prefer* **71**, 87–95.
107. van Eck A, Wijne C, Fogliano V,*et al.* (2019) Shape up! How shape, size and addition of condiments influence eating behavior towards vegetables. *Food Funct* **10**, 5739–5751.
108. Gonzalez-Estanol K, Libardi M, Biasioli F, *et al.* (2022) Oral processing behaviours of liquid, solid and composite foods are primarily driven by texture, mechanical and lubrication properties rather than by taste intensity. *Food Funct* **13**, 5011–5022.
109. Doyennette M, Aguayo-Mendoza MG, Williamson AM, *et al.* (2019) Capturing the impact of oral processing behaviour on consumption time and dynamic sensory perception of ice creams differing in hardness. *Food Qual Prefer* **78**, 103721.
110. Aguayo-Mendoza MG, Chatonidi G, Piqueras-Fiszman B, *et al.* (2021) Linking oral processing behavior to bolus properties and dynamic sensory perception of processed cheeses with bell pepper pieces. *Food Qual Prefer* **88**, 104084.
111. McLeod CJ, James LJ & Witcomb GL (2020) Eating rate and food intake are reduced when a food is presented in an 'unusual' meal context. *Appetite* **154**, 104799.
112. Sun LJ, Ranawana DV, Tan WJK, *et al.* (2015) The impact of eating methods on eating rate and glycemic response in healthy adults. *Physiol Behav* **139**, 505–510.
113. Hill SW & McCutcheon NB (1984) Contributions of obesity, gender, hunger, food preference, and body size to bite size, bite speed, and rate of eating. *Appetite* **5**, 73–83.
114. Lin HM, Lin CH & Hung HH (2015) Influence of chopstick size on taste evaluations. *Psychol Rep* **116**, 381–387.
115. Pearce AL, Cevallos MC, Romano O, *et al.* (2022) Child meal microstructure and eating behaviors: a systematic review. *Appetite* **168**, 105752.
116. Stieger M & van de Velde F (2013) Microstructure, texture and oral processing: new ways to reduce sugar and salt in foods. *Curr Opin Colloid Interface Sci* **18**, 334–348.
117. Forde CG, Leong C, Chia-Ming E, *et al.* (2017) Fast or slow-foods? Describing natural variations in oral processing characteristics across a wide range of Asian foods. *Food Funct* **8**, 595–606.

https://doi.org/10.1017/S0954422423000239 Published online by Cambridge University Press

118. Bolhuis DP, Forde CG, Cheng Y, *et al.* (2014) Slow food: sustained impact of harder foods on the reduction in energy intake over the course of the day. *PLoS ONE* **9**, e93370.
119. Mosca AC, Torres AP, Slob E, *et al.* (2019) Small food texture modifications can be used to change oral processing behaviour and to control *ad libitum* food intake. *Appetite* **142**, 104375.
120. Hinton EC, Leary SD, Comlek L, *et al.* (2021) How full am I? The effect of rating fullness during eating on food intake, eating speed and relationship with satiety responsiveness. *Appetite* **157**, 104998.
121. Bell BM, Spruijt-Metz D, Vega Yon GG, *et al.* (2019) Sensing eating mimicry among family members. *Transl Behav Med* **9**, 422–430.
122. Leong SL, Madden C, Gray A, *et al.* (2011) Faster self-reported speed of eating is related to higher body mass index in a nationwide survey of middle-aged women. *J Am Diet Assoc* **111**, 1192–1197.
123. Stubbs RJ, O'Reilly LM, Whybrow S, *et al.* (2014) Measuring the difference between actual and reported food intakes in the context of energy balance under laboratory conditions. *Br J Nutr* **111**, 2032–2043.
124. Rosenthal AJ & Philippe O (2020) Influence of candy particle size on oral behaviour. *Physiol Behav* **225**, 113089.
125. Robinson E, Almiron-Roig E, Rutters F, *et al.* (2014) A systematic review and meta-analysis examining the effect of eating rate on energy intake and hunger. *Am J Clin Nutr* **100**, 123–151.
126. Zhu B, Haruyama Y, Muto T, *et al.* (2015) Association between eating speed and metabolic syndrome in a 3-year population-based cohort study. *J Epidemiol* **25**, 332–336.
127. van den Boer JHW, Kranendonk J, van de Wiel A, *et al.* (2017) Self-reported eating rate is associated with weight status in a Dutch population: a validation study and a cross-sectional study. *Int J Behav Nutr Phys Act* **14**, 121.
128. Fujii H, Funakoshi S, Maeda T, *et al.* (2021) Eating speed and incidence of diabetes in a Japanese general population: ISSA-CKD. *J Clin Med* **10**, 1949.
129. Okubo H, Miyake Y, Sasaki S, *et al.* (2017) Rate of eating in early life is positively associated with current and later body mass index among young Japanese children: the Osaka maternal and child health study. *Nutr Res* **37**, 20–28.
130. Nagahama S, Kurotani K, Pham NM, *et al.* (2014) Self-reported eating rate and metabolic syndrome in Japanese people: cross-sectional study. *BMJ Open* **4**, e005241.
131. Bolhuis DP & Keast RSJ (2016) Assessment of eating rate and food intake in spoon versus fork users in a laboratory setting. *Food Qual Prefer* **49**, 66–69.
132. Nanri A, Miyaji N, Kochi T, *et al.* (2020) Eating speed and risk of metabolic syndrome among Japanese workers: the Furukawa nutrition and health study. *Nutrition* **78**, 110962.
133. Kang M, Joo M, Hong H *et al.* (2021) Eating speed, physical activity, and cardiorespiratory fitness are independent predictors of metabolic syndrome in korean university students. *Nutrients* **13**, 2420.
134. Wuren, Endoh K, Kuriki K, *et al.* (2019) Eating rate as risk for body mass index and waist circumference obesity with appropriate confounding factors: a cross-sectional analysis of the Shizuoka-Sakuragaoka J-MICC Study. *Asia Pac J Clin Nutr* **28**, 79–91.
135. Garcidueñas-Fimbres TE, Paz-Graniel I, Nishi SK, *et al.* (2021) Eating speed, eating frequency, and their relationships with diet quality, adiposity, and metabolic syndrome, or its components. *Nutrients* **13**, 1687.
136. Yuan S-Q, Liu Y-M, Liang W, *et al.* (2021) Association between eating speed and metabolic syndrome: a systematic review and meta-analysis. *Front Nutr* **8**, 700936.
137. Zhang L, Yin J, Cai X, *et al.* (2022) Association between eating behaviors and depressive symptoms in Chinese adults: a population-based cross-sectional study. *Psychol Health Med* **27**, 1176–1183.
138. Wilkinson LL, Ferriday D, Bosworth ML, *et al.* (2016) Keeping pace with your eating: visual feedback affects eating rate in humans. *PLoS ONE* **11**, e0147603.
139. Lu LW, Venn B, Lu J, *et al.* (2017) Effect of cold storage and reheating of parboiled rice on postprandial glycaemic response, satiety, palatability and chewed particle size distribution. *Nutrients* **9**, 475.
140. Zhou B, Yamanaka-Okumura H, Seki S, *et al.* (2014) What influences appetite more: eating approaches or cooking methods? *J Med Invest* **61**, 118–125.
141. Ilic J, Tomasevic I & Djekic I (2021) Influence of boiling, steaming, and sous-vide on oral processing parameters of celeriac (*Apium graveolens* var. *rapaceum*). *Int J Gastron Food Sci* **23**, 100308.
142. Ilic J, Tomasevic I & Djekic I (2021) Influence of water-based and contact heating preparation methods on potato mechanical properties, mastication, and sensory perception. *Int J Gastron Food Sci* **25**, 100401.
143. Wee MSM, Goh AT, Stieger M, *et al.* (2018) Correlation of instrumental texture properties from textural profile analysis (TPA) with eating behaviours and macronutrient composition for a wide range of solid foods. *Food Funct* **9**, 5301–5312.
144. De Wijk RA, Kaneko D, Dijksterhuis GB, *et al.* (2019) Food perception and emotion measured over time in-lab and in-home. *Food Qual Prefer* **75**, 170–178.
145. McCrickerd K, Lim CMH, Leong C, *et al.* (2017) Texture-based differences in eating rate reduce the impact of increased energy density and large portions on meal size in adults. *J Nutr* **147**, 1208–1217.
146. Oladiran DA, Emmambux MN & de Kock HL (2018) Extrusion cooking of cassava-soy flour with 200 g/kg wheat bran promotes slower oral processing during consumption of the instant porridge and higher derived satiety. *LWT* **97**, 778–786.
147. van Eck A, van Stratum A, Achlada D, *et al.* (2020) Cracker shape modifies *ad libitum* snack intake of crackers with cheese dip. *Br J Nutr* **124**, 988–997.
148. Zijlstra N, Mars M, Stafleu A, *et al.* (2010) The effect of texture differences on satiation in 3 pairs of solid foods. *Appetite* **55**, 490–497.
149. Hogenkamp PS, Mars M, Stafleu A, *et al.* (2010) Intake during repeated exposure to low- and high-energy-dense yogurts by different means of consumption. *Am J Clin Nutr* **91**, 841–847.
150. Lin H-M, Lo H-Y & Liao Y-S (2013) More than just a utensil: the influence of drinking straw size on perceived consumption. *Mark Lett* **24**, 381–386.
151. Smith MI & Dando R (2021) 3-D printed texture spoons for food flavor and satiety. *J Sens Stud* **36**, e12650.
152. Mathiesen SL, Mielby LA, Byrne DV, *et al.* (2020) Music to eat by: a systematic investigation of the relative importance of tempo and articulation on eating time. *Appetite* **155**, 104801.
153. Chen Y & Yen CC (2022) SLNOM: Exploring the sound of mastication as a behavioral change strategy for rapid eating regulation. In CHI Conference on Human Factors in Computing Systems Extended Abstracts, pp. 1–6.
154. Mioche L, Bourdiol P, Monier S, *et al.* (2004) Changes in jaw muscles activity with age: effects on food bolus properties. *Physiol Behav* **82**, 621–627.

155. Alsanei WA & Chen J (2014) Studies of the oral capabilities in relation to bolus manipulations and the ease of initiating bolus flow. *J Texture Stud* **45**, 1–12.
156. Affoo RH, Foley N, Garrick R, *et al.* (2015) Meta-analysis of salivary flow rates in young and older adults. *J Am Geriatr Soc* **63**, 2142–2151.
157. Rolls BJ, Fedoroff IC & Guthrie JF (1991) Gender differences in eating behavior and body weight regulation. *Health Psychol* **10**, 133.
158. Gilmore DC, Stevens CK, Harrell-Cook G, *et al.* (1999) Impression management tactics. In *The Employment Interview Handbook*, pp. 321–336 [RW Eder and MM Harris, editors]. Thousand Oakds, CA: Sage.
159. Vartanian LR, Herman CP & Polivy J (2007) Consumption stereotypes and impression management: how you are what you eat. *Appetite* **48**, 265–277.
160. Pereira L & Van der Bilt A (2016) The influence of oral processing, food perception and social aspects on food consumption: a review. *J Oral Rehabil* **43**, 630–648.
161. Henry CJ, Ponnalagu S, Bi X, *et al.* (2018) Does basal metabolic rate drive eating rate? *Physiol Behav* **189**, 74–77.
162. Fisher JO, Liu Y, Birch LL, *et al.* (2007) Effects of portion size and energy density on young children's intake at a meal. *Am J Clin Nutr* **86**, 174–179.
163. Jeffery RW, Rydell S, Dunn CL, *et al.* (2007) Effects of portion size on chronic energy intake. *Int J Behav Nutr Phys Act* **4**, 1–5.
164. Kral TV, Roe LS & Rolls BJ (2004) Combined effects of energy density and portion size on energy intake in women. *Am J Clin Nutr* **79**, 962–968.
165. Rolls BJ, Roe LS & Meengs JS (2006) Larger portion sizes lead to a sustained increase in energy intake over 2 d. *J Am Diet Assoc* **106**, 543–549.
166. Linné Y, Barkeling B, Rössner S, *et al.* (2002) Vision and eating behavior. *Obes Res* **10**, 92–95.
167. Fisher JO, Rolls BJ & Birch LL (2003) Children's bite size and intake of an entree are greater with large portions than with age-appropriate or self-selected portions. *Am J Clin Nutr* **77**, 1164–1170.
168. Forde C, Van Kuijk N, Thaler T, *et al.* (2013) Oral processing characteristics of solid savoury meal components, and relationship with food composition, sensory attributes and expected satiation. *Appetite* **60**, 208–219.
169. Zijlstra N, Mars M, de Wijk RA, *et al.* (2008) The effect of viscosity on *ad libitum* food intake. *Int J Obes* **32**, 676–683.
170. Bolhuis DP & Forde CG (2020) Application of food texture to moderate oral processing behaviors and energy intake. *Trends Food Sci Technol* **106**, 445–456.
171. Woodward E, Haszard J, Worsfold A, *et al.* (2020) Comparison of self-reported speed of eating with an objective measure of eating rate. *Nutrients* **12**, 599.
172. Lasschuijt MP, Brouwer-Brolsma E, Mars M, *et al.* (2021) Concept development and use of an automated food intake and eating behavior assessment method. *J Vis Exp* **168**, e62144.
173. Chen Y, Cui Z & Yen CC (2021) Chewpin: a wearable acoustic device for chewing detection. In Adjunct Proceedings of the 2021 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2021 ACM International Symposium on Wearable Computers, 11–12.
174. Papapanagiotou V, Diou C, Zhou L, *et al.* (2016) A novel chewing detection system based on ppg, audio, and accelerometry. *IEEE J Biomed Health Inform* **21**, 607–618.
175. Zhang S, Zhao Y, Nguyen DT, *et al.* (2020) Necksense: a multi-sensor necklace for detecting eating activities in free-living conditions. *Proc ACM Interact Mob Wearable Ubiquitous Technol* **4**, 1–26.
176. Bell BM, Alam R, Alshurafa N, *et al.* (2020) Automatic, wearable-based, in-field eating detection approaches for public health research: a scoping review. *NPJ Digit Med* **3**, 38.
177. Heydarian H, Adam M, Burrows T, *et al.* (2019) Assessing eating behaviour using upper limb mounted motion sensors: a systematic review. *Nutrients* **11**, 1168.
178. Chen Y, Fennedy K, Fogel A, *et al.* (2022) SSpoon: a shape-changing spoon that optimizes bite size for eating rate regulation. *Proc ACM Interact Mob Wearable Ubiquitous Technol* **6**, 1–32.
179. Zhang JY, Pandya JK, McClements DJ, *et al.* (2022) Advancements in 3D food printing: a comprehensive overview of properties and opportunities. *Crit Rev Food Sci Nutr* **62**, 4752–4768.
180. Mantihal S, Kobun R & Lee B-B (2020) 3D food printing of as the new way of preparing food: a review. *Int J Gastron Food Sci* **22**, 100260.

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