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Abbreviations

BMI: Body mass index; ED: Energy density (kcal/100 g); EI: Energy intake (kcal); CF: Complementary feeding; LED: Low energy density; HED: High energy density; CEBQ-T: Child Eating Behaviour Questionnaire adapted for Toddlers; FR: Food responsiveness; EF: Enjoyment of food; SR: Satiety responsiveness; SE: Slowness in eating; FF: Food fussiness; spoonful-wt: Spoonful weight (g), dt: Time interval between two spoonfuls, (s), 'pace adaptation': Kendall correlation (τ) between dt(t) and spoonful-wt(t-1); 'decrease-wt': Difference in the spoonful-wt between the last and first thirds of the consumption session; 'increase-dt': Difference in dt between the last and first thirds of the consumption session.

Introduction

As theorized by Kral and colleagues (Kral et al., 2018), appetitive traits emerge early in infancy and persist over time. According to this theory, behavioural phenotypes related to obesity are underpinned by a strong food seeking trait (referring to a high responsiveness to external food cues, which results in overeating when surrounded by palatable foods) combined with poor self-regulation of energy intake (referring to a low sensitivity to internal cues of hunger and/or satiation, which results in a poor ability to adjust eating). Caloric compensation is defined as the adjustment of energy intake in response to the ingestion of a food preload and reflects a subject's sensitivity to internal satiation cues (Blundell et al., 2010). We recently showed that caloric compensation ability decreases between the ages of 11 and 15 months (Brugaillères, Issanchou, Nicklaus, Chabanet, & Schwartz, 2019). Additionally, this decrease was associated with a larger increase in weight status from 11 to 15 months of age and a higher weight status at 2 years of age (Brugaillères et al., 2019).

Appetite traits may be associated with eating behaviours and anthropometrics. For example, a recent longitudinal study with children seen at 4.5 and later at 6-year-old revealed significant associations between appetitive traits (evaluated by the mothers through the Child Eating Behaviour Questionnaire (CEBQ) (Wardle, Guthrie, Sanderson, & Rapoport, 2001)) and observed oral processing behaviour (e.g., eating rate, chew rate, bite size, and oral exposure time) during an *ad libitum* meal in the laboratory (Fogel et al., 2018). At 4.5 years of age, children who were perceived by their mothers as being slow eaters had lower observed eating and chew rates. At 6 years of age, children who were perceived by their mother as more attracted by food (i.e., higher score for the 'food enjoyment' dimension and lower scores for the 'satiety responsiveness', 'slowness in eating', and 'food fussiness' dimensions) showed higher eating rates and greater energy intakes. Moreover, studies have demonstrated that a higher eating rate promotes higher energy intake and is associated with increased bodyweight in children (Berkowitz et al., 2010; Fogel et al., 2017; He, Ding, Fong, & Karlberg, 2000). In a prospective cohort study which followed the infants from 30 to 42 months, the mothers evaluated their infant's eating rate on a 5-point scale ranging from 'very slow' to 'very fast' (Okubo, Miyake, Sasaki, Tanaka, & Hirota, 2017). The perceived eating rate at 30 months was positively associated with infant body mass index (BMI) at 30 and 42 months.

The main feature of mealtime episodes during complementary feeding (CF) is that feeding occurs through an interaction between the infant and a caregiver; generally the mother (Dupuy, 2017). Thus, the course of the meal is strongly linked to the mother-infant mealtime interaction (McNally et al., 2016; Pesch & Lumeng, 2017). The concept of responsive feeding reflects the reciprocity between the caregiver and the infant during the feeding process. This process requires that the infant emits hunger and satiation cues clear enough and that the caregiver can interpret the infant's signals and respond to them in an appropriate and prompt manner (Black & Aboud, 2011; Pérez-Escamilla, Segura-Pérez, & Lott, 2017). Depending on the degree of responsiveness in feeding – and the extent to which the mother is child-centred during the meal – the child will eat in response to hunger or will be overfed/underfed. For example, in an experimental study (Ventura & Mennella, 2016), in a mother-led feeding condition, the mothers were given instructions to feed their infants as they typically would, whereas in an infant-led condition, the experimenter ensured that feeding began when the infants signalled hunger (e.g., based on cues such as mouthing, rooting, and fussing) and ended when the infants signalled satiation by rejecting the bottle on three consecutive occasions. The infants in the mother-led condition appeared to consume significantly more formula than the infants in the infant-led condition.

According to DiSantis and colleagues (DiSantis, Hodges, Johnson, & Fisher, 2011), a discordant feeding interaction can result in increases in the amount and/or frequency of feeding and thus alter the infant's appetite control ability, leading to accelerated infant weight gain. Such evidence was also highlighted by Hurley and colleagues in their review (Hurley, Cross, & Hughes, 2011). An in-home observational study revealed that infants whose mothers were less sensitive to their infant's satiation cues gained significantly more weight from 6 to 12 months of age than infants of more sensitive mothers (Worobey, Islas Lopez, & Hoffman, 2009). Satiation cues may appear slowly over the course of a meal (e.g., looking away and tray pounding) and are communicated more strongly with age (Shloim, Shafiq, Blundell-Birtill, & Hetherington, 2018). In adults, the emergence of satiation during consumption may result in a decelerating food intake curve (Westerterp-Plantenga, 2000). However, this deceleration is not observed when the process of satiation is altered, for example in dietary restrained adults (Lindgren et al., 2000) or in adolescents with Prader-Willis syndrome (Westerterp-Plantenga, 2000). Certainly, in the case of meals of complementary-fed infants, the caregiver plays a role in the extent to which this deceleration is likely to happen. This deceleration can be due to a decrease of the spoonful pace and/or a decrease of the spoonful weight. Thereby, the deceleration in eating might be underpinned by the extent to which the parent adapts the pace of feeding and/or the weight of the spoonful offered to the infant's pace of eating. All of this considered, these feeding adaptations may reflect the quality of the caregiver-infant interaction during the meal, and thus, may reflect one facet of responsive feeding. Considering that responsive feeding is a key dimension in the development of healthy eating habits in infancy (Pérez-Escamilla et al., 2017), we emphasize that it is important to investigate these feeding adaptations as a mirror of the degree of responsive feeding. To our knowledge, these feeding adaptations have not yet been investigated and warrant further study, as far as possible through longitudinal observational studies evaluating the mother-child interaction during mealtimes (Bergmeier, Skouteris, & Hetherington, 2015).

Therefore, in the present study, we first aimed to relate the inter-individual variation in infant caloric compensation ability at 11 and 15 months of age to caregiver-infant interaction during meals when the caloric compensation ability was assessed. To this end, we investigated whether dyadic adaptation occurred; for example, we examined whether the spoonful pace (corresponding to the feeding pace) was associated with the spoonful weight. Second, at 11 and 15 months of age, we investigated the relationships between infant caloric compensation ability and the infants' appetitive traits at these ages, as evaluated by the caregiver. We hypothesized that infants who were perceived as more satiety responsive would have a more accurate caloric compensation ability. Third, as we reported previously that the caloric compensation ability decreased from 11 to 15 months (Brugaillères et al., 2019), we assessed the relationships between this decrease and the infants' appetitive traits. No hypothesis was formulated concerning the latter.

Methods

Participants

Recruitment was conducted in Dijon, France, from May 2015 to December 2016 using leaflets distributed to health professionals' consultation rooms, our internal database (the ChemoSens Platform's PanelSens database, Commission Nationale de l'Informatique et des Libertés (CNIL) n° 1148039) and the help of a recruitment agency. Sixty-nine caregiver-infant dyads were enrolled in the present study. Among these dyads, 29 previously participated in another separate study that aimed to evaluate the acceptance of fat added to the first purees around the onset of CF (when the infants were ≈ 5 months old): the results have been presented elsewhere (Schwartz et al., 2018) and will not be considered in the present paper. The infant inclusion criteria were as follows: no chronic health problems or food allergies, gestational age ≥ 37 weeks, birth weight ≥ 2.5 kg, no history of being tube fed and no history of being fed a hydrolysate formula. Infants of mothers with diabetes or celiac disease and infants of minor parents (< 18 years old) were excluded.

This study was conducted according to the guidelines established in the Declaration of Helsinki and was approved by the local ethics committee (Comité de Protection des Personnes Est I Bourgogne, 2015-A000014-45). Written informed consent was obtained from both parents. The participants received a 60 € voucher for completing the measures described in this paper.

Measures

The measures were conducted from December 2015 to July 2017. When the infants were 11 and 15 months old, we performed a laboratory-based assessment of the infants' caloric compensation ability. This measure required two visits to the laboratory on two non-consecutive days (mean delay between the two visits: 5.4 ± 3.2 d) at the infants' usual lunch time (94 %) or dinner time (between 6 and 6:30 pm) (6 %). The parents were asked not to feed their infants for 1.5 h before the visit. The mothers were present for 93 % of the visits (the father was present for 6 % of visits, and the grandmother was present for 1 % of visits when the mother was unavailable to come to the laboratory). The measure of caloric compensation consisted of offering the infant a food preload either low or high in energy density (ED), followed by an *ad libitum* meal (details below). The test meals took place in a study room dedicated to infant feeding: the infant was seated in a high chair in front of his or her caregiver (which corresponds to the usual feeding situation in France) and was fed by his or her caregiver, who generally used her/his own spoon. All *ad libitum* meals were recorded by using a connected weighing scale that continuously recorded the weight of the bowl (details below). At each studied age, the caregiver also completed the Child Eating Behaviour Questionnaire adapted for Toddlers (CEBQ-T) (Herle, Fildes, van Jaarsveld, Rijsdijk, & Llewellyn, 2016), which is a modified version of the validated CEBQ (Wardle et al., 2001).

Infant caloric compensation ability

The infants' caloric compensation ability was measured by adapting the preload paradigm that was developed by Birch & Deysher (Birch & Deysher, 1985) and previously used in children (Remy, Issanchou, Chabanet, Boggio, & Nicklaus, 2015) and adults (Almiron-roig et al., 2012). This measure reflects infant short-term responsiveness to variations in ED. The procedure is detailed in our previous report (Brugaillères et al., 2019). The principles were as follows. On the first visit at 11 and 15 months of age, the infants received a fixed amount of a food preload (67 g of carrot puree) that was either low or high in ED (LED = 22 kcal/67 g, HED = 65 kcal/67 g). The HED preload was made by adding vegetable oil. The order was counterbalanced across infants. Each infant was randomly assigned to a specific order group (LED/HED or HED/LED), and this order was the same at the two different ages. A minimal preload consumption of 85% (i.e., at least 57 g of 67 g) was required to assess the infant's caloric compensation ability. To facilitate the preload consumption, the caregivers were free to encourage eating and to use toys as distractions when necessary; in any case without using pressure. After a 25-min play period, the infants were served an *ad libitum* meal composed of 300 g of a vegetable-meat or a vegetable-fish puree followed by 195 g of a fruit puree. To respect the infants' food preferences, the food items were chosen by the caregiver among a preselection of 4 vegetable-meat or vegetable-fish purees (with similar EDs ranging from 62 to 65 kcal/100 g) and 3 fruit purees (with similar EDs ranging from 49 to 52 kcal/100 g). Each infant was offered the same *ad libitum* meal (the same food items) at each studied age. To ensure *ad libitum* consumption of the meal, the caregivers received precise instructions to stop feeding each food when the infant exhibited 2 consecutive refusals (e.g., the infant refused to open his/her mouth, pushed the spoon away or shook his/her head). The caregivers were instructed to feed the infants without encouraging or restricting consumption, but they remained free to interact as usually with their infants (e.g., talking, laughing, touching). The foods were also served in large opaque bowls so that the caregivers could not obtain an accurate idea of the offered quantities. To assess the weight intake (g), the experimenter weighed each bowl, as well as the infant's bib, before and after consumption (Soehnle, 1 g). Then, for each food (i.e., preload, vegetable-meat or vegetable-fish puree and fruit puree), the energy intake (EI) was calculated according to ED information from the manufacturer.

From the EI data, a caloric compensation score (COMPX [%]) was calculated at 11 and 15 months of age by using the following equation: COMPX = 100 × [(meal calories after LED preload – meal calories after HED preload) / (HED preload calories – LED preload calories)] (Johnson & Birch, 1994). A COMPX of 100 % reflects perfect caloric compensation. A COMPX higher than 100 % indicates overcompensation, whereas a COMPX lower than 100 % indicates under-compensation.

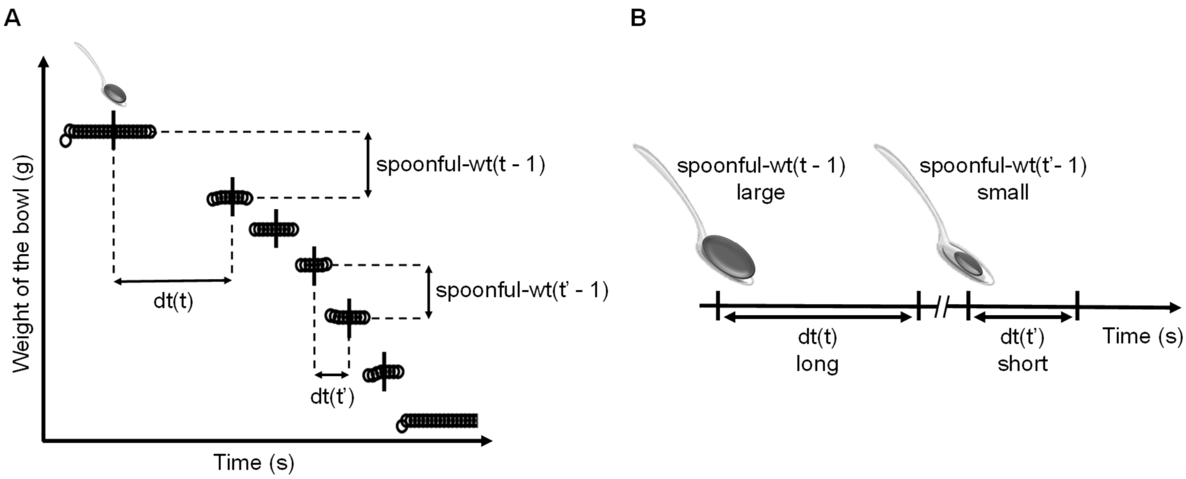
Caregiver-infant mealtime interaction

During each food consumption session of the *ad libitum* meal, the bowl containing the food was placed on a digital weighing scale with a sensitivity of 0.1 g (Adam® PGL-12001 or NBL-4602e depending on the study room) that was connected to a computer that recorded the weight of the bowl every second. Hence, the caregivers were asked to manipulate the spoon without handling the bowl. The experimenter started and stopped the recording manually for each food.

The first output variable describing the meal was the consumption duration (min). R functions were developed to automatically extract the total number of spoonfuls offered to the infant, the weight of each spoonful (spoonful-wt) and the time interval between two spoonfuls (dt). The details about the connected weighing scale and the reliability of the developed R functions, which were validated through a combined approach with video coding, are available elsewhere (Brugaillères, Chabanet, Issanchou, & Schwartz, 2018). To assess the degree of responsive feeding, we calculated three other variables called herein 'pace adaptation', 'decrease-wt' and 'increase-dt'. The variable 'pace adaptation' reflects the extent to which the spoonful pace is associated with the spoonful weight. This variable was operationalized by the Kendall correlation (τ value) between the time interval between two spoonfuls (dt(t)) and the weight of the previous spoonful (spoonful-wt(t-1)) (Figure 1). By definition, the higher (>0) the 'pace adaptation', the more strongly correlated the spoonful weight and the time interval until the next spoonful are. In order words, the larger the spoonful is, the longer the time interval until the next spoonful.

Figure 1: Representation of positive 'pace adaptation'.

Diagram A is a representation of a record from the connected weighing scale showing the weight of the bowl over time and how the following variables were extracted: spoonful-wt = spoonful weight (g), and dt = the time interval between two spoonfuls (s). Series of consecutive equal weight measurements (runs) correspond to periods during which the spoon was out of the bowl. The vertical lines in the middle of each run correspond to the extracted times at which each spoonful was supposed to be offered to the infant. Diagram B is another representation associated with diagram A. It shows a positive pace adaptation, namely, a longer dt following a larger spoonful-wt (Brugaillères et al., 2018).



The two variables 'decrease-wt' and 'increase-dt' were calculated to assess whether a deceleration occurred during the course of a food consumption session. The variable 'decrease-wt' reflects the extent to which the spoonful weight decreases over the course of the offered spoonfuls. The food consumption session was divided into three thirds based on the number of offered spoonfuls. The 'decrease-wt' variable corresponds to the difference between the average spoonful weight over the last third of the session and the average spoonful weight over the first third of the consumption session. This value was calculated only if the food consumption session was constituted by at least 10 spoonfuls. By definition, a negative 'decrease-wt' value indicates that the spoonful weight decreased between the first and the last third of the food consumption session. The variable 'increase-dt' was calculated in the same way. A positive 'increase-dt' value indicates that the time interval between two spoonfuls increased between the first and the last third of the food consumption session. Over the course of the consumption of a food, a deceleration of the eating rate can result in a decrease in the spoonful-wt and/or an increase in the dt.

Infant appetitive traits

At 11 and 15 months of age, the caregivers completed the CEBQ-T. This questionnaire is a modified version of the validated CEBQ, which measures appetitive traits. We used the French version of the CEBQ-T, which was previously used in the Habeat European project (Caton et al., 2014) and is detailed in Supplemental Table 1. According to our objectives and based on Kral's theory, five dimensions were analysed: two dimensions referring to food approach, i.e., 'food responsiveness' (FR) (e.g., 'my child is always asking for food', 'if allowed to, my child would eat too much') and 'enjoyment of food' (EF) (e.g., 'my child loves food', 'my child enjoys eating') and three dimensions referring to food avoidance, i.e., 'satiety responsiveness' (SR) (e.g., 'my child gets full up easily', 'my child gets full before his/her meal is finished'), 'slowness in eating' (SE) (e.g., 'my child eats more slowly during the course of a meal', 'my child eats slowly') and 'food fussiness' (FF) (e.g., 'my child refuses new foods at first', 'my child is difficult to please with meals'). The majority of the items composing these five dimensions are identical between the CEBQ and the CEBQ-T. However, the item '*if given the chance, my child would always have food in his/her mouth*' is omitted from the FR dimension of the CEBQ-T, and the item '*my child refuses to eat certain types of food (e.g., vegetables, meat)*' is added to the FF dimension of the CEBQ-T. In the original version, the items are scored on a 5-point Likert scale ranging from 'never' to 'always'. In our study, we added the option 'I do not know', given that some items could not be assessed by some caregivers because they had never encountered the described situation. At each studied age, the questionnaire was retrospective, with answers covering the past 3 months and the past 4 months when completed at 11 and 15 months of age, respectively. Thereby, the two evaluations covered the infant's life from 8 to 15 months.

The score for each dimension of the CEBQ-T is the mean of the different items and by definition it ranges from 1 to 5. At 11 months of age, due to a high number of missing values (57 % no response or 'I do not know'), the item '*my child could not eat a meal if s/he has had a snack just before'* was not included in the calculation of the SR dimension. This item was therefore also excluded at 15 months of age to ensure consistency when calculating this dimension at the two ages. The SR dimension was thus calculated based on four items instead of five. Mean scores for each dimension were only calculated if a minimum number of items was rated (3/4 for FR, EF, SR, and SE and 6/7 for FF). The score for each dimension was calculated for each infant at 11 and 15 months of age (FR_{11}, EF_{11}, SR_{11}, SE_{11}, and FF_{11} and FR_{15}, EF_{15}, SR_{15}, SE_{15}, and FF_{15}). Reliability analysis demonstrated good Cronbach's α values for the five dimensions, which ranged from 0.67 to 0.87 at 11 months of age and from 0.72 to 0.90 at 15 months of age for our longitudinal sample (i.e., the subjects for whom we calculated the dimensions at both studied ages).

Statistical analysis

R software for Windows version 3.4.0 was used to analyse the data. Significance was set at $p < 0.05$. The results are reported as the mean ± SD. The COMPX score was calculated for each infant at 11 and 15 months of age ($COMPX_{11}$ and $COMPX_{15}$, respectively). We then calculated the change in the COMPX score between these ages ($\Delta COMPX = COMPX_{15} - COMPX_{11}$).

To describe caregiver-infant mealtime interaction, we focused on the consumption of the vegetable-meat or vegetable-fish puree (from now on, called 'puree') since it was the major part of the *ad libitum* meal (72% of the meal EI).

Meal-to-meal consistency at each age

At each age, we first tested the consistency across the LED/HED conditions for each variable (i.e., weight intake, consumption duration, number of offered spoonfuls, spoonful weight (spoonful-wt), time interval between two spoonfuls (dt), 'pace adaptation', 'decrease-wt', and 'increase-dt') by using Kendall correlations (unilateral tests).

Stability across ages

At each age, all eight variables were averaged over the LED and HED conditions. Regarding 'pace adaptation', 'decrease-wt' and 'increase-dt', the resulting value was either an average or a unique measurement if only one of the LED/HED values was available. To determine whether a global deceleration of consumption occurred over the course of the meal at 11 and 15 months of age, we compared the mean 'decrease-wt' and 'increase-dt' values to the 0 value by using Student's *t* tests. We then tested the stability and consistency of the five variables describing caregiver-infant mealtime interaction (i.e., spoonful-wt, dt, 'pace adaptation', 'decrease-wt', and 'increase-dt') between 11 and 15 months of age by using paired Student's *t* tests and Kendall correlations (unilateral tests), respectively.

Associations with the COMPX score and its change

At 11 and 15 months of age, unpaired Student's *t* tests were used to compare the mean COMPX scores after a median split for 'pace adaptation' (median splits = 0.04 and 0.07 at 11 and 15 months, respectively), 'decrease-wt' (median splits = -4.42 and -3.56 at 11 and 15 months, respectively) and 'increase-dt' (median splits = 1.60 and 2.19 at 11 and 15 months, respectively). Regarding infant appetitive traits, we assessed the relationships between the COMPX score and the FR, EF, SR, SE and FF dimensions of the CEBQ-T by using Kendall correlations at 11 and 15 months of age. Concerning the change in the scores of the dimensions of the CEBQ-T with age, we first tested the stability and consistency of these scores between 11 and 15 months of age by using paired Student's *t* tests and Kendall correlations, respectively. Then, we tested the relationships between the ΔCOMPX and the dimensions of the CEBQ-T completed at 15 months of age by using Kendall correlations. For all Kendall correlations of the caloric compensation scores ($COMPX_{11}$ or $COMPX_{15}$) or its change (ΔCOMPX) with the five dimensions of the CEBQ-T, we used a Bonferroni adjustment (alpha level of 0.01 = 0.05/5 per test).

Results

Among the 69 eligible caregiver-infant dyads, we calculated the COMPX score for 46 infants at 11 months of age (20 females; mean age = 10.6 ± 0.3 months) and for 35 infants at 15 months of age (15 females; mean age = 14.6 ± 0.2 months). The longitudinal sample was composed of 31 infants (12 females) for whom we calculated the COMPX score at both ages. The number of individuals included for each measure in the cross-sectional analyses and the longitudinal analysis is presented in Figure 2. Participants' characteristics of the longitudinal sample are presented in Table 1. The reported age at the start of CF (4.9 ± 1.0 months) was in line with the age reported in a French representative cohort study (Bournez et al., 2018). A majority of parents (*n* = 23/31) declared a rather high monthly household income of at least 2 500 €, which is above the French median income (Institut national de la statistique et des études économiques, 2017). The descriptions of the cross-sectional samples for which we obtained the COMPX score at 11 or 15 months of age (*n* = 46 and *n* = 35, respectively) are available in Supplemental Table 2. The three considered samples (the samples at 11 and 15 months of age and the longitudinal sample) show high similarity in terms of infant and parental characteristics.

Figure 2: Flowchart showing the number of individuals for each measure.

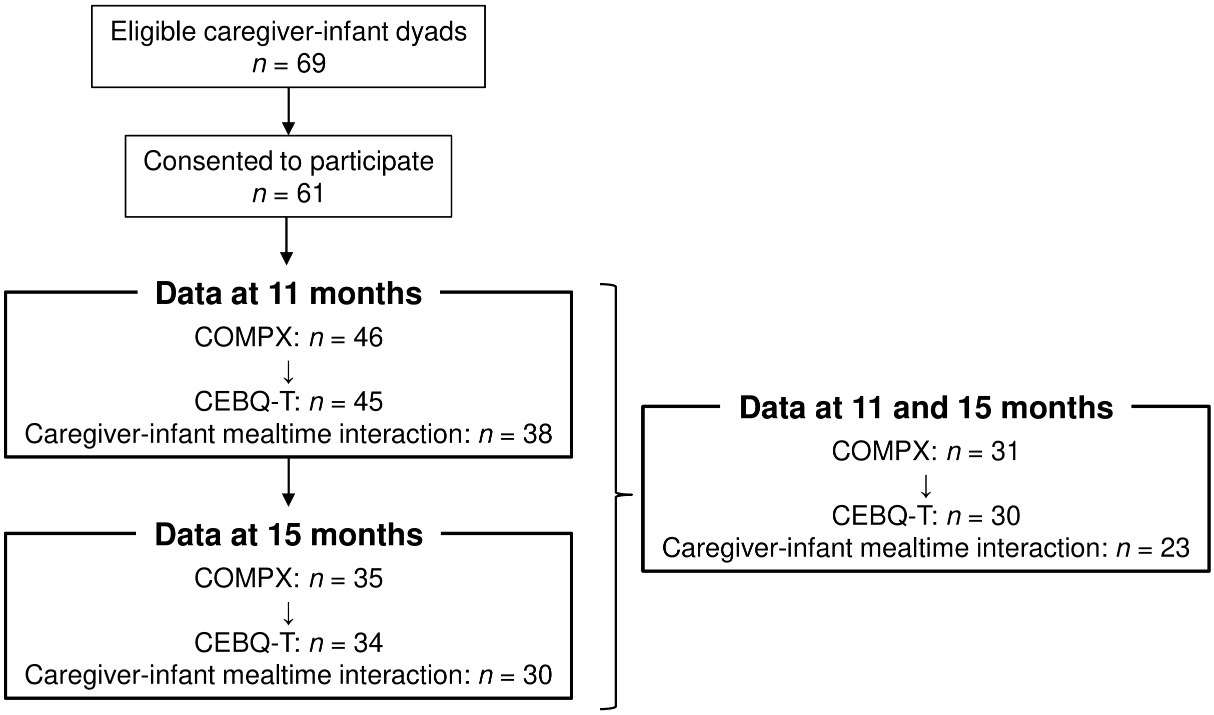


Table 1: Participants' characteristics: longitudinal sample, *n* = 31 (number or mean ± SD).

Infant characteristics:	
Sex, F/M	12/19
Gestational age (weeks)	39.6 ± 1.5
Birth weight (kg)	3.4 ± 0.4
Birth z-BMI score	0.3 ± 0.9
Duration of exclusive breastfeeding (weeks)	8.5 ± 9.3
Duration of total breastfeeding (weeks)	15.8 ± 20.3
Age at the start of CF[a] (months)	4.9 ± 1.0
Maternal/familial characteristics:	
Age at the start of the study (years)	31.8 ± 4.1
Pre-pregnancy BMI (kg/m^2) (*n*)	24.8 ± 5.7 (*30*)
Post-pregnancy BMI (kg/m^2) (*n*)	25.2 ± 4.6 (*30*)
Primiparous	16
At least high-school degree	24
Married or lived with a partner	30
Monthly household income [2500 – 4500 € [	23

[a] CF: complementary feeding

Caregiver-infant mealtime interaction

Cross-sectional analysis

As reported in our previous study (Brugaillères et al., 2019), the mean COMPX score was 44 ± 119 % at 11 months of age and -16 ± 151 % at 15 months of age. During the laboratory test meals, the infants consumed an average of 143 ± 67 g (Q1 = 95 g; Q3 = 200 g) of the puree at 11 months of age and 135 ± 56 g (Q1 = 97 g; Q3 = 172 g) of the puree at 15 months of age. The weight intake of the puree was consistent over the two meals at each age ($\tau = 0.49$, $p < 0.001$ and $\tau = 0.28$, $p = 0.009$ at 11 and 15 months, respectively). Table 2 reports the mean values and statistical tests for meal-to-meal consistency at 11 and 15 months of age for each variable. At 11 months of age, the consumption duration, the number of spoonfuls, the spoonful weight (spoonful-wt), the time interval between two spoonfuls (dt) and the 'decrease-wt' value were consistent over the two meals ($0.27 \leq \tau \leq 0.66$, all $p < 0.05$), whereas the 'pace adaptation' and 'increase-dt' values were not (all $p > 0.05$). At 15 months of age, only the consumption duration, the spoonful weight and the time interval between two spoonfuls were consistent ($0.40 \leq \tau \leq 0.62$, all $p < 0.05$). The decrease in the spoonful weight ('decrease-wt') over the course of the consumption session was significant at 11 months of age (t (28) = -7.72, $p < 0.001$) and at 15 months of age (t (22) = -7.14, $p < 0.001$). Similarly, the increase in the time interval between two spoonfuls ('increase-dt') was significant at 11 months of age (t (28) = 4.45, $p < 0.001$) and at 15 months of age (t (22) = 5.17, $p < 0.001$). Thus, at each age, a deceleration in eating occurred as illustrated by these variables.

Table 2: Caregiver-infant mealtime interaction at 11 and 15 months of age

	11 months						**15 months**					
				Meal-to-meal consistency						**Meal-to-meal consistency**		
	Mean	**SD**	***n***	τ^a	***p*-value**	***n***	**Mean**	**SD**	***n***	τ^a	***p*-value**	***n***
consumption duration (min)	6.68	2.35	*38*	0.27	**0.03**	*31*	6.20	3.75	*30*	0.40	**0.005**	*21*
nb of spoonful	31.75	13.32	*38*	0.43	**< 0.001**	*32*	29.12	12.12	*30*	0.24	0.07	*21*
spoonful-wt (g)	4.62	1.16	*38*	0.66	**< 0.001**	*32*	5.26	1.08	*30*	0.44	**0.002**	*21*
dt (s)	15.69	5.30	*38*	0.36	**0.004**	*32*	13.78	3.67	*30*	0.62	**< 0.001**	*21*
'pace adaptation'	0.02	0.15	*38*	0.05	0.36	*31*	0.05	0.14	*30*	0.20	0.11	*21*
'decrease-wt' (g)	-4.81	3.36	*29*	0.41	**0.03**	*13*	-3.98	2.67	*23*	0.24	0.16	*12*
'increase-dt' (s)	2.15	2.60	*29*	0.26	0.13	*13*	2.09	1.93	*23*	-0.12	0.73	*12*

spoonful-wt: spoonful weight; dt: time interval between two spoonfuls; 'pace adaptation': Kendall correlation (τ) between dt(t) and spoonful-wt(t-1); 'decrease-wt': difference in spoonful-wt between the last and the first thirds of the consumption session; 'increase-dt': difference in dt between the last and the first thirds of the consumption session. [a]Kendall correlation between the LED and HED conditions. *p*-values presented in bold are significant.

Longitudinal analysis

As shown in Table 3, between 11 and 15 months of age, the spoonful weight (spoonful-wt) increased (t (22) = 4.45, p < 0.001), and the time interval between two spoonfuls (dt) decreased (t (22) = -2.25, p = 0.035). Moreover, the 'decrease-wt' values increased, which means that the decrease in the spoonful weight over the course of consumption is reduced (t (11) = 2.71, p = 0.020). In other words, between 11 and 15 months of age, the spoonful pace increased (through an increase in the average spoonful weight and a decrease in the average time interval between two spoonfuls). This change was accompanied by a weaker deceleration in eating at 15 months of age than at 11 months of age (t (11) = 2.71, p = 0.020). Only the spoonful weight (spoonful-wt) (τ = 0.41, p = 0.003, n = 23) and the 'decrease-wt' value (τ = 0.55, p = 0.007, n = 12) were positively correlated between 11 and 15 months of age (Table 3).

Table 3: Developmental changes in caregiver-infant mealtime interaction.

	n	**11 months**		**15 months**		**Student *t*. test**[a]		**Kendall correlation**[b]	
		Mean	**SD**	**Mean**	**SD**	***t***	***p*-value**	***τ***	***p*-value**
spoonful-wt (g)	23	4.38	0.99	5.32	1.13	4.45	**<0.001**	0.41	**0.003**
dt (s)	23	16.73	5.86	14.03	3.55	-2.25	**0.035**	0.25	0.051
'pace adaptation'	23	-0.002	0.16	0.05	0.14	1.06	0.30	-0.08	0.72
'decrease-wt' (g)	12	-6.50	4.03	-4.33	3.22	2.71	**0.020**	0.55	**0.007**
'increase-dt' (s)	12	3.01	2.47	1.86	2.34	-1.08	0.30	-0.15	0.77

spoonful-wt: spoonful weight; dt: time interval between two spoonfuls; 'pace adaptation': Kendall correlation (τ) between dt(t) and spoonful-wt(t-1); 'decrease-wt': difference in spoonful-wt between the last and the first thirds of the consumption session; 'increase-dt': difference in dt between the last and the first thirds of the consumption session. [a] bilateral paired Student's t test, [b] unilateral Kendall correlation. p-values presented in bold are significant.

Caloric compensation ability and caregiver-infant mealtime interaction

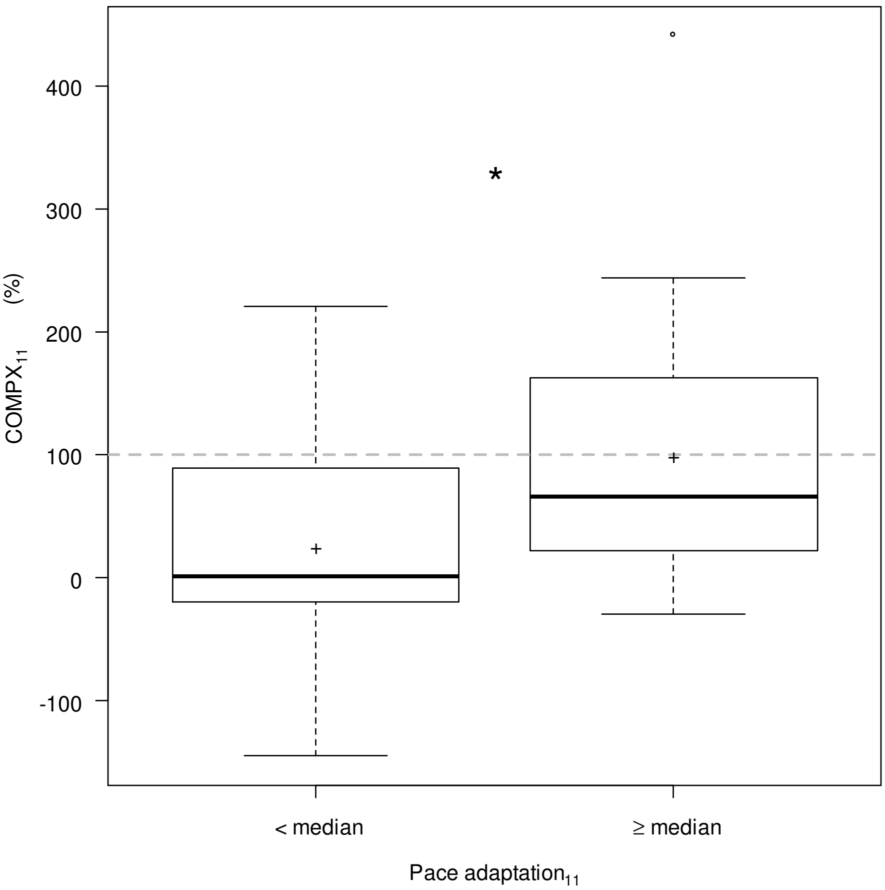
At 11 months of age, the mean COMPX score was 28 ± 100 % and 101 ± 116 % when the 'pace adaptation' value was below and above the median value, respectively (Table 4 and Figure 3). These values were significantly different (t (18) = -2.1, p = 0.04). Thus, at 11 months of age, the more the spoonful pace was positively associated with the spoonful weight, the better the infant's caloric adjustment ability. Yet, 101 ± 116 % reflects a perfect caloric compensation. This was not observed at 15 months of age. In addition, the COMPX scores were not different when the values of 'decrease-wt' or 'increase-dt' – the two variables reflecting the deceleration in eating over the consumption session – were below or above the median at either age (Table 4).

Table 4: COMPX scores according to 'pace adaptation', 'decrease-wt', 'increase-dt' at 11 and 15 months of age.

	COMPX (%)						**Student *t*.test**	
	'pace adaptation' < median			**'pace adaptation' ≥ median**			***t***	***p*-value**
	n	Mean	SD	*n*	Mean	SD		
11 months	*19*	28	100	*19*	101	116	-2.1	**0.04**
15 months	*15*	-11	168	*15*	-32	161	0.3	0.73
	'decrease-wt' < median			**'decrease-wt' ≥ median**				
	n	Mean	SD	*n*	Mean	SD		
11 months	*14*	59	111	*15*	26	85	0.91	0.37
15 months	*11*	-54	138	*12*	11	208	-0.89	0.39
	'increase-dt' < median			**'increase-dt' ≥ median**				
	n	Mean	SD	*n*	Mean	SD		
11 months	*14*	21	90	*15*	62	104	-1.15	0.26
15 months	*11*	41	168	*12*	-77	172	1.66	0.11

Unpaired Student's t test. The p-value presented in bold is significant.

Figure 3: COMPX scores according to ‘pace adaptation’ at 11 months of age.
‘pace adaptation’: Kendall correlation (τ) between dt(t) and spoonful-wt(t-1); in each boxplot, the mean COMPX score is indicated by a cross (+). The horizontal dotted line indicates the 100 % value corresponding to perfect caloric compensation. For each boxplot, the bottom and top of the box indicate the 25th and 75th percentiles, respectively, and the line within the box indicates the median. The whiskers extend from the box as far as the data extend, to a maximum distance of 1.5 × the interquartile range. Any values more extreme than this limit are marked by a small circle (°). *Unpaired *t* test, $p = 0.04$.



Infant appetitive traits

The mean values obtained at 11 and 15 months of age for all dimensions of the CEBQ-T are reported in Table 5. The changes in the dimensions of the CEBQ-T between 11 and 15 months of age are presented in Table 6. All values reported for the cross-sectional analyses were close to those reported for the longitudinal sample (Table 5 and Table 6). All five dimensions were positively correlated between 11 and 15 months of age (Table 6) (all $p < 0.05$). Moreover, the mean scores of the FR dimension and the FF dimension significantly increased between 11 and 15 months (all $p \leq 0.01$). Thus, infants were perceived as more responsive to food and more food fussy at 15 months of age than at 11 months of age.

Table 5: Dimensions of the CEBQ-T at 11 and 15 months of age.

	11 months			**15 months**		
	Mean	**SD**	***n***	**Mean**	**SD**	***n***
FR	2.13	0.82	*42*	2.35	0.85	*32*
EF	4.20	0.58	*45*	4.15	0.61	*34*
SR	2.70	0.65	*44*	2.66	0.68	*34*
SE	2.12	0.61	*45*	2.25	0.78	*34*
FF	1.58	0.55	*45*	1.83	0.78	*34*

FR: Food responsiveness; EF: Enjoyment of food; SR: Satiety responsiveness; SE: Slowness in eating; FF: Food fussiness.

Table 6: Developmental changes in the dimensions of the CEBQ-T.

	n	**11 months**		**15 months**		**Student *t*. test**		**Kendall correlation**	
		Mean	**SD**	**Mean**	**SD**	***t*** [a]	***p*-value**	***τ*** [b]	***p*-value**
FR	*28*	2.14	0.82	2.35	0.90	2.18	**0.04**	0.67	**<0.001**
EF	*30*	4.27	0.59	4.18	0.61	-1.00	0.33	0.55	**<0.001**
SR	*30*	2.65	0.68	2.63	0.65	-0.12	0.90	0.37	**0.004**
SE	*30*	2.11	0.59	2.22	0.75	1.12	0.27	0.52	**<0.001**
FF	*30*	1.53	0.50	1.83	0.76	2.69	**0.01**	0.42	**0.001**

FR: Food responsiveness; EF: Enjoyment of food; SR: Satiety responsiveness; SE: Slowness in eating; FF: Food fussiness. [a] bilateral paired Student's *t* test, [b] unilateral Kendall correlation. *p*-values presented in bold are significant.

Caloric compensation ability and infant appetitive traits

No correlations appeared significant between the COMPX scores at 11 and 15 months of age and the dimensions of the CEBQ-T at each corresponding age (all $p > 0.01$) (Table 7).

As reported in our previous work (Brugaillères et al., 2019), for the longitudinal sample composed of 31 infants, the mean COMPX score significantly decreased between 11 and 15 months of age (ΔCOMPX = -67 ± 190 %, unilateral *t* test, t (30) = -1.95, p = 0.03). The change in the COMPX score between 11 and 15 months of age was negatively associated with the FR dimension at 15 months of age (Table 7 and Figure 4). Thus, the more the COMPX decreased between 11 and 15 months of age, the more the infants were perceived as food responsive during this period. No other associations with the decrease in the COMPX score were significant (Table 7).

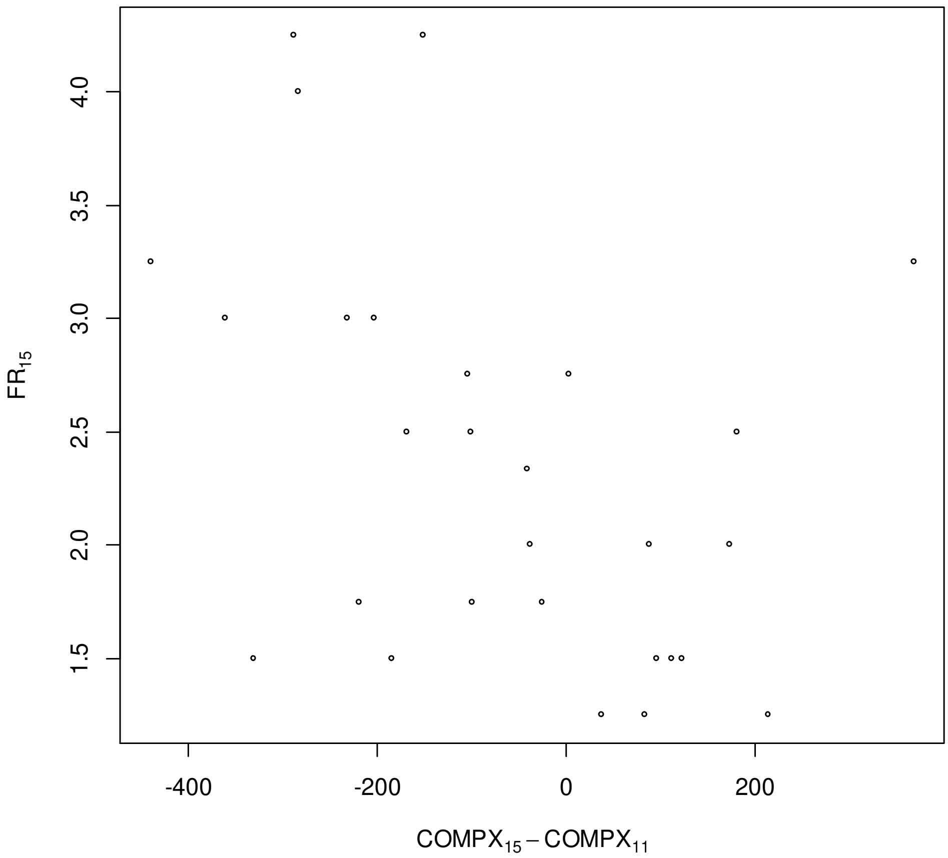
Table 7: Associations of COMPX scores and ΔCOMPX with the dimensions of the CEBQ-T.

	$COMPX_{11}$				$COMPX_{15}$				ΔCOMPX		
	n	**Kendall *τ***	***p*-value**		***n***	**Kendall *τ***	***p*-value**		***n***	**Kendall *τ***	***p*-value**
$\mathbf{FR_{11}}$	42	-0.10	0.38	$\mathbf{FR_{15}}$	32	-0.22	0.09	$\mathbf{FR_{15}}$	28	-0.36	**0.01**
$\mathbf{EF_{11}}$	45	-0.08	0.48	$\mathbf{EF_{15}}$	34	-0.17	0.17	$\mathbf{EF_{15}}$	30	-0.18	0.17
$\mathbf{SR_{11}}$	44	-0.001	0.99	$\mathbf{SR_{15}}$	34	0.10	0.45	$\mathbf{SR_{15}}$	30	0.17	0.21
$\mathbf{SE_{11}}$	45	-0.07	0.53	$\mathbf{SE_{15}}$	34	0.02	0.86	$\mathbf{SE_{15}}$	30	0.16	0.23
$\mathbf{FF_{11}}$	45	0.01	0.93	$\mathbf{FF_{15}}$	34	0.25	0.04	$\mathbf{FF_{15}}$	30	0.27	0.04

FR: Food responsiveness; EF: Enjoyment of food; SR: Satiety responsiveness; SE: Slowness in eating; FF: Food fussiness. ΔCOMPX = $COMPX_{15}$ – $COMPX_{11}$. Unadjusted *p*-values. The *p*-value presented in bold is significant after Bonferroni adjustment (α = 0.01).

Figure 4: Association between food responsiveness at 15 months of age and COMPX change between 11 and 15 months of age.

Kendall correlation, τ = -0.36, p = 0.01, n = 28.



Discussion

This study aimed to relate the inter-individual variation in infants' caloric compensation ability at 11 and 15 months of age and its decrease between these ages to both caregiver-infant interaction during laboratory test meals and infant appetitive traits. Contrary to our hypothesis, the infants who were perceived as more satiety responsive did not exhibit more accurate caloric compensation ability at either age. However, we showed that the more the caloric compensation ability decreased between 11 and 15 months of age, the more the infants were perceived as food responsive (e.g., 'my child is always asking for food', 'if allowed to, my child would eat too much') during the same period. We also showed that at 11 months of age, when the spoonful weight was more positively associated with the time interval between two spoonfuls (meaning that the larger the spoonful weight was, the longer the time interval until the next spoonful), the infants exhibited a better caloric compensation ability. This study provides new evidence regarding the importance of a responsive feeding style by suggesting that adapting the feeding pace to the spoonful weight could be a favourable practice associated with better caloric compensation ability by the end of the first year. Certainly, this feeding pace adaptation corresponds to a favourable practice because it allows the infant to have more time to chew and swallow the food in his/her mouth when larger quantities are offered. Hence, this feeding pace adaptation might promote a longer oral-sensory exposure time, leading to a better evaluation of the caloric content and a stronger satiation response (de Graaf, 2012). There is some evidence in adults that foods consumed in smaller bite size with longer oral-sensory exposure time confer a higher expected satiation (Forde, Van Kuijk, Thaler, De Graaf, & Martin, 2013). An observational study conducted on 4.5-year-old children revealed that 'slow eaters' (characterized by a long oral exposure time per gram) had lower EI during an *ad libitum* meal and lower BMI z-scores and adiposity than 'fast eaters' (Fogel et al., 2017). At 15 months of age, however, we observed that caloric compensation was not better when the pace adaptation was more favourable. Yet, as we demonstrated previously (Brugaillères et al., 2019), at 15 months of age, the infants exhibited a volumetric adjustment rather than a caloric adjustment. As the CF process progresses, the caregiver, the child or both may have increasing expectations regarding the volume of food to eat independently of the ED cues. Thus, the volume of the eaten food had prevailed over the ED cues; these cues being maybe mainly conveyed by sensory signals (de Graaf, 2012) and more specifically by the fat sensation that is quite well correlated with energy density (Lease, Hendrie, Poelman, Delahunty, & Cox, 2016; Martin & Issanchou, 2019; Teo et al., 2018). The description of caregiver-infant mealtime interaction at 11 and 15 months of age revealed meal-to-meal consistency for the majority of the variables (i.e., weight intake, consumption duration, spoonful weight and time interval between two spoonfuls). Parkinson & Drewett (2001) also reported meal-to-meal consistency for weight intake and meal duration in infants from the same age range (12-14 months) for meals at home. A kind of routine seems to settle over the progression of CF, probably until the child is able to self-feed. In addition, at both studied ages, we observed a global deceleration (as indicated by a decrease in the spoonful weight and a decrease in the spoonful pace) over the course of consumption. To some extent, our result is in line with observational studies in older children (10-15 years old), which reported a deceleration of eating rate (g/min) at home (Llewellyn, Van Jaarsveld, Boniface, Carnell, & Wardle, 2008) or in the laboratory (Zandian et al., 2012). Nevertheless, in our study, the caloric compensation ability was not better when the deceleration of eating was greater. Given that no comparable measurements are reported in the literature for the same age range, we cannot speculate whether this association does not exist or is modest. Not surprisingly, the spoonful pace and the spoonful weight increased between 11 and 15 months of age. Interestingly, we also know that the infant's feeding cues are more strongly communicated with age (Shloim et al., 2018) and, thus, more easily interpreted by the caregiver (Hodges et al., 2013). The fact that the 'pace adaptation' and 'increase-dt' values were not consistent between 11 and 15 months of age indicates that these parameters of caregiver-infant mealtime interaction evolve at different rates for different dyads. In contrast, the average spoonful weight and 'decrease-wt' values were consistent between 11 and 15 months of age. These results suggest that the caregivers' decision regarding the spoonful weight is quite stable over time and is maybe more caregiver-centered. More research is needed to understand how changes in the interaction between an infant and his/her caregiver while feeding over time affect infant food intake.

Regarding appetitive traits, the infants with better caloric compensation ability were not perceived as more satiety responsive by their caregivers, regardless of age. However, the item

"My child could not eat a meal if s/he has had a snack just before" was excluded from the calculation of the SR dimension even though this item reflects a situation similar to our caloric compensation paradigm. A complementary analysis revealed that the SR dimension was negatively associated with weight intake and the number of offered spoonfuls at 11 and 15 months of age and with the consumption duration at 15 months of age (Supplemental Table 3). Thus, we suggest that the SR dimension refers to the notion of having a large or small appetite. In a longitudinal cohort study, mothers rated their infants' appetites on a 5-point scale ranging from 'very poor' to 'very good' at 6 weeks, at 12 months and in early childhood at 5-6 years and their children's appetitive traits at 5-6 years (CEBQ) (Kathryn N. Parkinson, Drewett, Le Couteur, & Adamson, 2010). The infants reported having a good appetite at 6 weeks, 12 months and 5-6 years and were also reported to score lower on SR at 5-6 years. Moreover, having a large or a small appetite does not rule out the possibility of having good self-regulation. The FR trait pertains to the food approach tendency, and the caloric compensation score reflects the ability to adjust EI. A novel interesting finding is that the more the caloric compensation ability decreased between 11 and 15 months of age, the more the infants were perceived as food responsive between these ages. This result is in line with Kral's theory framework (Kral et al., 2018) which states that the behavioural phenotype for obesity is underpinned by the coexistence of a weak self-regulation system and strong food seeking.

By automatically recording the weight of the bowl over the course of the meal, the connected weighing scale allowed us to objectively describe the microstructure of the mealtime episode and to describe the interaction between a caregiver and an infant in this way for the first time and thus evaluate one facet of responsive feeding linked to the pace of feeding. This tool enabled the extraction of variables such as the weight of each spoonful or the time interval between spoonfuls, thus providing unique insights into the fine dynamics of caregiver-infant interaction during the meal. Indeed, studies conducted in children aged 4 to 13 years used average parameters and did not enable the exploration of temporality with a fine-grained methodology (Fogel et al., 2017; Lindgren et al., 2000; Llewellyn et al., 2008; Zandian et al., 2012). Moreover, herein, some significant associations that were observed between the dimensions of the CEBQ-T and the variables describing caregiver-infant mealtime interaction (detailed results in Supplemental Table 3) give us confidence regarding the relevance of our methodology using the connected weighing scale. For example, at 11 and 15 months of age, the weight intake was negatively correlated with the SR dimension. The weight intake was also positively correlated with the EF dimension at 15 months of age. To some extent, our results are in line with those reported by Carnell and colleagues (Carnell & Wardle, 2007) when they validated some dimensions of the CEBQ against behavioural measures of eating in 4- to 5-year-old children. The authors reported that EI was negatively correlated with the SR dimension but positively correlated with the EF dimension. Here, at 11 months of age, the SE dimension was negatively associated with the consumption duration. In addition, the SE dimension was negatively associated with weight intake and the number of spoonfuls. Together, these results suggest that the number of spoonfuls offered to the infant could be a more salient cue for the caregivers than the consumption duration *per se* when they assess the infant's eating rate. This observation provides new insights about the way the caregivers may perceive the mealtime episode. It should be noted that in our study, the caregiver was mainly the mother (involved in 93% of the recorded interactions). In fact, in France, the mother appears to be still the main caregiver in charge of infant feeding (Dupuy, 2017). The longitudinal approach is another strength of our study.

Some potential limitations of our study should be noted. The first limitation concerns the sample size. Due to the difficulty of performing the caloric compensation measurement, our initial sample was highly reduced, as discussed elsewhere (Brugaillères et al., 2019). The automatic extraction of the data obtained through the connected weighing scale also required the removal of all non-exploitable records (for more details, see (Brugaillères et al., 2018)), thus leading to a loss of subjects for the description of caregiver-infant mealtime interaction. The second limitation concerns the focus on the feeding behaviour while infants consumed the vegetable-meat or vegetable-fish puree solely (without considering the fruit puree) when assessing the caregiver-infant interaction. This is due to the weaker consumption of the fruit puree because the infants were already quite satiated after consuming the vegetable-meat or vegetable-fish puree. Some variables were not calculable for the fruit puree since the number of spoonful was generally too small. However, given that a meal-to meal consistency was observed for the majority of the variables describing the caregiver-infant interaction, this lets us suggest that the pattern of interaction may be relatively stable for a dyad and may not be different according to the type of the offered food. Some limitations concerning the laboratory-based paradigm could also be pointed out: first, it is possible that all the infants were not in a comparable state of hunger before starting the preload consumption. However, we tried to limit this by asking parents not to feed their infants 1.30 h before coming to the laboratory and analyzing the data only if a minimal preload consumption of 85% was achieved. Second, it is possible that the stop feeding criterion of two consecutive refusals for the ad libitum meal was not a usual situation for some dyads. At home, for some dyads the usual cessation of the meal could also be driven by other aspects than the infants' refusal signals (e.g. the meal duration). However, by setting this stop feeding criterion, we placed all the caregiver-infant dyads in a comparable situation and we favoured the cessation of the meal based on the infants' satiation signalling. Nevertheless, we maintained a natural situation by allowing free interactions between the caregivers and the infants sat down face to face. Finally, we focused only on some facets of responsive feeding that were linked to the cessation of the meal. Indeed, to be responsive in feeding also means initiating the meal when the infant is hungry and not offering food to soothe the infant (Black & Aboud, 2011; Pérez-Escamilla et al., 2017). In addition, in future works, it would be interesting to combine our approach with other methodologies, such as evaluating the frequencies of different infant cues, particularly the infant gaze towards the food (McNally et al., 2019). This area represents an avenue for further research.

Conclusions

This study provides new evidence regarding the importance of a responsive feeding style to the development of a healthy infant eating style. Through an innovative method involving a connected weighing scale, we showed that at 11 months of age, when the time interval between two spoonfuls was adapted to the spoonful weight offered, the infants exhibited a better caloric compensation ability. To date, most interventional studies on the impact of feeding guidelines concerning responsive feeding have based their evaluations on questionnaires and mainly focused on teaching parents to correctly interpret their infants' hunger and satiation cues (Pérez-Escamilla et al., 2017). Our approach provides new insights for evaluating feeding recommendations concerning responsive feeding. In addition, the content of feeding guidelines could include the notion of adapting the feeding pace. This study also revealed that the more the caloric compensation ability decreased between 11 and 15 months of age, the more the infants were perceived as food responsive between these ages. Exploring the causality of this relationship is important for future works.

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