Complementary feeding practice during infancy and its relevance for dietary behaviour in infancy and childhood

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SUMMARY

Complementary feeding practice during infancy and its relevance for dietary behaviour in infancy and childhood

Emerging research indicates that besides innate taste preferences early sensory experiences in infancy via amniotic fluid, breast milk, and infant formula play a crucial role in the development of individual food preferences and dietary behaviour. With the introduction of complementary food (CF) during weaning, the spectrum of different flavours and textures increases further. However, the potential of CF's sensory properties – particularly with regards to its preparation type, i.e. homemade or commercial – in shaping later food preferences has not been extensively examined so far. Thus, the **overall aim** of this thesis was to determine existing trends in complementary feeding practice, and their relevance for later dietary behaviour. Three analyses (Studies I-III) were conducted using data from the German DOrtmund Nutritional and Anthropometric Longitudinally Designed (DONALD) Study, an ongoing, open cohort study.

Study I (n=366) revealed that commercial CF dominated infant feeding, especially in infants who were breast-fed for a shorter duration and whose mothers had a lower educational status. Both commercial and homemade CF showed opposing, nonlinear age trends; however, no time trends could be found during the observed study period (2004-2012). In **Study II** (n=281), a higher commercial CF proportion was associated with lower vegetable intake in infancy in both sexes. Prospectively, only boys showed an inverse association between a higher commercial CF proportion and a lower vegetable intake in preschool age as well as lower total fruit and vegetable intake in preschool and primary school age. For girls, no significant prospective association could be observed. With respect to fruit and vegetable variety, no distinct associations were found. **Study III** (n=288) indicated that infants with a high contribution of commercial CF had higher odds for a high consumption of added sugar from CF as well as a high total added sugar intake. Commercial CF consumption in infancy was also positively related to added sugar intake in preschool and primary school age.

In conclusion, this thesis highlights the constantly high and widespread consumption of commercial CF in today's infant nutrition and further provides first evidence of the preparation type of CF being a relevant modifiable factor shaping long-term dietary behaviour. Although the question, whether it is the early diet tracking through childhood or the sensory properties of CF imprinting later taste and food preferences cannot be conclusively answered, these results underline that the occasional provision of homemade CF can help infants to develop beneficial food preferences and contribute to a favourable dietary behaviour by means of increasing fruit and vegetable consumption as well as limiting added sugar intake in childhood.

ZUSAMMENFASSUNG

Fütterungspraktik von Beikost während des Säuglingsalters und deren Relevanz für das Ernährungsverhalten im Säuglings- und Kindesalter

Neben angeborenen Geschmackspräferenzen spielen auch die frühen sensorischen Erfahrungen im Säuglingsalter durch Fruchtwasser, Muttermilch und Säuglingsformula eine entscheidende Rolle bei der Entwicklung von individuellen Lebensmittelvorlieben und dem Ernährungsverhalten. Mit der Einführung von Beikost während des Abstillens steigt das Spektrum der verschiedenen erlebten Geschmäcker und Konsistenzen weiter an. Allerdings wurde dabei die Bedeutung der sensorischen Eigenschaften von Beikost – insbesondere im Hinblick auf die Herstellungsart, d.h. selbst gekocht oder kommerziell – für die Formung der späteren Lebensmittelpräferenzen bis jetzt noch nicht eingehend untersucht. Daher war es das übergeordnete **Ziel** dieser Arbeit, bestehende Trends in der Fütterungspraktik von Beikost sowie deren Relevanz für das spätere Ernährungsverhalten zu bestimmen. Es wurden dazu drei Analysen (Studien I-III) mit Daten der deutschen DOrtmund Nutritional and Anthropometric Longitudinally Designed (DONALD) Studie, einer fortlaufenden offenen Kohortenstudie, durchgeführt.

Studie I (n=366) zeigte, dass kommerzielle Beikost die Säuglingsernährung dominiert, besonders bei Säuglingen mit einer kürzeren Stilldauer und Müttern mit einem niedrigeren Bildungsstatus. Kommerzielle und selbst gekochte Beikost zeigten gegensätzliche nicht-lineare Alterstrends, allerdings konnten keine Zeittrends in dem betrachteten Studienzeitraum (2004-2012) gefunden werden. In **Studie II** (n=281) war ein höherer Anteil kommerzieller Beikost bei beiden Geschlechtern mit einem niedrigeren Gemüseverzehr im Säuglingsalter assoziiert. Prospektiv zeigten nur Jungen eine inverse Assoziation zwischen einem höheren kommerziellen Beikostanteil und einem niedrigeren Gemüseverzehr im Vorschul- sowie einem niedrigeren Gesamtobst- und Gemüseverzehr im Vor- und Grundschulalter. Bei Mädchen konnten keine signifikanten prospektiven Zusammenhänge beobachtet werden. Im Hinblick auf die Obst- und Gemüsevarietät wurden keine eindeutigen Zusammenhänge gefunden. **Studie III** (n=288) legte nahe, dass Säuglinge mit einem hohen Anteil kommerzieller Beikost eher eine hohe zugesetzte Zuckerzufuhr aus Beikost sowie eine insgesamt höhere zugesetzte Zuckerzufuhr aufwiesen. Der Verzehr kommerzieller Beikost war auch positiv mit der zugesetzten Zuckerzufuhr im Vor- und Grundschulalter assoziiert.

Zusammenfassend betont diese Arbeit den konstant hohen und weitverbreiteten Verzehr von kommerzieller Beikost in der heutigen Säuglingsernährung und liefert zudem erste Hinweise, dass die Herstellungsart von Beikost ein relevanter veränderbarer Einflussfaktor auf das langfristige Ernährungsverhalten ist. Auch wenn die Frage, ob die frühen Ernährungsmuster in der Kindheit beibehalten werden oder die sensorischen Eigenschaften der Beikost die späteren Geschmacks- und Lebensmittelvorlieben prägen, nicht abschließend beantwortet werden kann, unterstreichen diese Ergebnisse, dass das gelegentliche Anbieten von selbst gekochter Beikost Säuglingen helfen kann, vorteilhafte Lebensmittelvorlieben zu entwickeln und damit zu einem günstigen Ernährungsverhalten im Sinne eines höheren Obst- und Gemüseverzehrs sowie einer geringeren zugesetzten Zuckerzufuhr in der Kindheit beitragen kann.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

ABBREVIATIONS

BMI	Body Mass Index
CF	Complementary food
DONALD Study	Dortmund Nutritional and Anthropometric Longitudinally Designed Study
ESPGHAN	European Society for Paediatric Gastroenterology, Hepatology, and Nutrition
FFQ	Food frequency questionnaire
FKE	Research Institute of Child Nutrition (Forschungsinstitut für KinderErnährung)
FITS	Feeding Infants and Toddlers Study
IDEFICS	Identification and Prevention of Dietary- and Lifestyle-induced Health Effects in Children and Infants
LEBTAB	In-house food and nutrient database (LEBensmittelTABelle) of the DONALD Study
RQ	Research question
UK	United Kingdom
US	United States
WHO	World Health Organization

1 INTRODUCTION

There is no stage in life where the diet changes as rapidly as it does during infancy. In particular, complementary food (CF) has an important role in building the bridge between the exclusive milk feeding after birth and the introduction of solid foods. Thus, it is important to monitor early feeding practices and their influence on later dietary behaviour closely.

1.1 Complementary food

Definition

The European Society for Paediatric Gastroenterology, Hepatology, and Nutrition (ESPGHAN) defines CF as "all solid and liquid foods other than breast milk or infant formula and follow-on formula" [1]. The well-established schedule of the food-based dietary guidelines for the first year of life in Germany, developed by the Research Institute of Child Nutrition (FKE) that has been approved by different medical and scientific societies and institutions is also following this definition [2,3]. Contrarily, the World Health Organization (WHO) includes any nutrient-containing foods or liquids other than breast milk into their definition [4]. For practical purposes in the context of this thesis, CF is defined as any foods other than breast milk and infant formula that are fed during weaning. Weaning is defined here as the transition from a solely milk-based diet to a varied family diet with solid table foods through the gradual introduction of new foods; also referred to as complementary feeding. Thereby, providing sufficient energy and essential nutrients like iron is one of the key aims of weaning. Furthermore, also the relevance of weaning in facilitating infants' food acceptance has gained scientific and public interest during the last years.

Due to the economic and cultural circumstances in Western societies, there is a broad choice of different industrially produced CF products and meals that can be bought in retail. Thus, CF can be divided by its preparation type into homemade and commercial CF; the latter is also referred to as ready-to-eat, ready-made, or manufactured CF. Detailed definitions for the purpose of this thesis can be found in the published manuscripts (see chapter 3).

Recommendations

Table 1 gives an overview on CF recommendations in current national and international infant feeding guidelines from Europe and the United States (US). The choice of homemade or commercial CF is not mentioned in every guideline and even if both types are mentioned, there is not always an explicit recommendation for either choice.

Table 1: National and international recommendations on the use of homemade and commercial CF in selected current infant feeding guidelines

Country, Institution	Published	Recommendations on commercial and homemade CF [1]
Europe		
European Society for Paediatric Gastroenterology, Hepatology, and Nutrition (ESPGHAN) [1]	2008	Homemade or commercial CF not mentioned. *No explicit recommendation.*
Germany		
Netzwerk Gesund ins Leben – Netzwerk Junge Familie [Network Healthy Start – Young Family Network] [3]	2013	Infants can be fed either homemade or commercial CF. *No explicit recommendation.* Homemade CF: control over used ingredients; avoidance of added sugar and salt; broader range of different flavour, taste, and texture experiences Commercial CF: convenience; underlies high legal standards
Ernährungskommission der Deutschen Gesellschaft für Kinder- und Jugendmedizin [Committee on Nutrition of the German Society of Paediatrics and Adolescent Medicine] [5]	2014	Infants can be fed either homemade or commercial CF. *No explicit recommendation.* Homemade CF: broader range of different flavour and taste experiences Commercial CF: convenience; underlies high legal standards
Austria		
Österreichische Gesellschaft für Kinder- und Jugendheilkunde [Austrian Society of Paediatrics and Adolescent Medicine] [6]	2010	Homemade or commercial CF not mentioned. *No explicit recommendation.*
Switzerland		
Ernährungskommission der Schweizerischen Gesellschaft für Pädiatrie [Committee on Nutrition of the Swiss Society of Paediatrics] [7]	2009	Infants can be fed either homemade or commercial CF. *No explicit recommendation.*
Schweizerische Gesellschaft für Ernährung [Swiss Nutrition Society] [8]	2012	Infants can be fed either homemade or commercial CF. *Commercial CF should not be used solely.* Homemade CF: broader range of different flavour and taste experiences
United Kingdom (UK)		
British Dietetic Association [9]	2014	*Commercial CF should not be used solely.* Commercial CF: convenience; difficulties to accept family foods later on
Department of Health [10]	2014	*Homemade CF is favoured over commercial CF.* Homemade CF: control over used ingredients; avoidance of added sugar and salt; less expensive; broader range of different texture experiences Commercial CF: portions size can be too big; difficulties to accept family foods later on

[1] The recommendations have been aggregated and rated according to the following criteria: emphasis on and distinction between homemade and commercial CF, *recommendation on the use of either preparation type (in italics)*, separated pros and cons for homemade and commercial CF as stated in the respective guideline.

Table 1: National and international recommendations on the use of homemade and commercial CF in selected current infant feeding guidelines (continued)

Country, Institution	Published	Recommendations on commercial and homemade CF [1]
United Kingdom (UK)		*Commercial CF should not be used solely.*
British Nutrition Foundation [11]	2015	Homemade CF: less expensive; broader range of different texture experiences Commercial CF: convenience; portions size can be too big; added sugar should be avoided
Ireland		
Food Safety Authority of Ireland [12]	2012	*Homemade CF is favoured over commercial CF.* Homemade CF: control over used ingredients; broader range of different flavour and taste experiences; less expensive Commercial CF: convenience; savoury meals should be preferred to avoid added sugar (and fat)
United States (US)		
American Academy of Pediatrics Committee on Nutrition [13]	2009	*No explicit recommendation.* Homemade CF: energy and nutrient sufficiency needs to be ensured
US Department of Agriculture [14]	2009	Infants can be fed either homemade or commercial CF. *No explicit recommendation.* Homemade CF: less expensive; broader range of different flavour, taste, and texture experiences Commercial CF: safe and sanitary

[1] The recommendations have been aggregated and rated according to the following criteria: emphasis on and distinction between homemade and commercial CF, *recommendation on the use of either preparation type (in italics)*, separated pros and cons for homemade and commercial CF as stated in the respective guideline.

Although the ESPGHAN comments on the role of CF in the development of taste and food preferences, the contribution of either homemade or commercial CF is not mentioned in this regard [1]. In German-speaking countries, most institutions do not favour homemade CF over commercial CF. Only the Swiss Nutrition Society recommends to not solely feed commercial CF [8]. Although Austrian guidelines do not postulate which type of CF to choose [6], they provide detailed additional recommendations on how to select commercial CF, when self-preparation is not desired or possible [15]. Recommendations from different institutions in the UK and Ireland concordantly promote the use of homemade rather than commercial CF [9–12], while the US guidelines provide no clear recommendation [13,14].

Characteristics

As demonstrated above there is a slight tendency in current infant feeding recommendations to favour homemade CF over commercial CF or at least to not solely rely on commercial CF. The main rationale to prefer homemade CF is the exposition of the infant to a greater range of different flavours, tastes, and textures during weaning, although tangible scientific evidence is still pending. However, there are more diverging properties of homemade and commercial CF as stated in **Table 2**.

Table 2: Characteristics of homemade and commercial CF [adapted from 16]

Homemade CF	**Commercial CF**
Natural, original taste	Uniform, standardised taste
Varying textures	Standardised texture due to serial production
High variety of available ingredients (e.g. due to seasonality)	Low variety of available ingredients
Limited number of ingredients; avoidance of salt and sugar	High number of ingredients; use of redundant ingredients (e.g. salt, sugar)
Sufficient food safety provided by official food monitoring	Additional safety guaranteed through more intense screenings for food contaminants
Lower costs	Higher costs
Enjoyment of cooking	Less time-consuming and labour-intensive

Jarred commercial CF is manufactured by heat preserving, i.e. the ingredients are heated for a certain time period to specified high temperatures which are sufficient to kill microorganisms. However, heat preserving also affects the taste of the food as levels of aromatic substances are lowered during heating [17]. Commercial CF products containing meat might also suffer from an unpleasant warmed-over flavour [18]. Standardised production processes with the same predefined ingredients for each single product lead to rather uniform taste experiences, whereas homemade recipes are less standardised. Further, homemade CF provides a wider range of different textures since the puréeing process is not standardised as it is for commercial CF.

Only few qualitative studies shed some light on parents’ motives for choosing homemade CF. According to different non-representative focus group discussions homemade CF is often perceived superior to commercial CF in terms of its nutritional value or general quality [19–22], although this impression has never been confirmed scientifically. In general, besides the perceived better and more natural taste, parents value the fresh ingredients and having the choice of what ingredients are used [22,23]. Thus, homemade CF is chosen for either physiological (e.g. rich in vitamins, healthy ingredients) or safety reasons (e.g. certainty about ingredients and their amounts, food safety scandals); whereas convenience purposes (e.g. time-saving, handy on the go) as well as safety reasons (e.g. absence of pesticides) were mentioned most often for commercial CF [20,22,24].

Composition

Nutrient profiles as well as the composition of commercial and particularly homemade CF have been analysed only rarely. Most chemical analyses of commercial CF focus on minerals and trace elements [e.g. 25–29]. Macronutrient concentrations of eight meat- and vegetable-based commercial CF meals sold in the UK complied with regulatory requirements, although protein content differed significantly between both meal types [30]. While the nutrient content and composition of commercial CF is regulated by European law [31], the preparation and composition of homemade CF lies in the caregivers' responsibility. Although standard recipes at least for Germany exist [2], it remains inconclusive to what extent parents comply with those recommended recipes since the available studies rely on different methodological approaches and include only small (local) sample sizes.

An older UK study from 1995 analysed 265 samples of homemade CF and found some deficits regarding the nutrient composition. In this study, homemade CF showed a greater variation in energy density and nutrient content than commercial CF [32]. A Spanish study with 50 samples of homemade CF from the same period of time showed comparable results. Most nutrients differed significantly between homemade and commercial CF, also the relation of macronutrients as well as the energy density showed some shortcomings of homemade CF [19]. *García et al.* compared the declared nutritional information of 462 commercial infant foods from the UK market available in 2010-2011 with homemade family foods commonly given to infants in the UK. Nutrient density except for iron density was much lower in savoury commercial products compared to similar homemade meals [33]. In contrast, a recent comparison between German commercial and homemade CF meals eaten under true-to-life conditions during infancy did not reveal any serious discrepancies in energy or nutrient content [34], although a similar study from 2000 has shown a lower energy and fat content in commercial compared to homemade CF [35]. Overall, commercial CF is characterised by a lower variation of nutrient contents due to the legally regulated composition and standardised production.

Apart from the scarce and inconsistent data on energy and nutrient contents of both CF types, a German market survey provided a preliminary insight into the ingredients of commercial CF. Overall, vegetable variety was rather low; carrot was the main vegetable in more than half of the vegetable-containing CF meals followed by tomato. In total, only 16 different vegetables were available in commercial CF; whereas in homemade CF meals in the German Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) Study 26 different vegetables were used [36]. A survey of the UK market revealed similar results with an overall low variation of fruits and vegetables in commercial CF with carrots and apples being the most frequently used ingredients [37]. Further, in German commercial CF up to 6 different vegetables and in the UK even up to 11 fruits and vegetables were combined in a single meal masking the particular tastes of the individual fruits or vegetables [36,37].

Consumption

Besides the lack of detailed composition analyses, also dietary data on the consumption of homemade and commercial CF is lacking. Older German data from the 1990's showed the relevance of commercial CF in 3-12 months old participants of the DONALD Study. The consumption of commercial CF reached its peak with 62% in 6 month old infants [38]. In the UK Infant Feeding Survey from 2010, 4-6 months old infants were more likely to be fed commercial (38%) than homemade CF (28%). Yet, in older infants at 8-10 months, homemade food (70%) was more common than commercial CF (44%) [39]. Both preparation types were almost counterbalanced during the first 6 weeks of complementary feeding (49% homemade vs. 45% commercial CF) in infants from an Irish birth cohort study recruited in 2008-2012 [40]. For the US, a high relevance of commercial CF was shown in the representative 2002 Feeding Infants and Toddlers Study (FITS) with 73-95% of infants between 4-11 months of age having consumed commercial CF during the previous 24 hours [41]. In a cross-sectional telephone survey of US mothers receiving governmental benefits conducted in 2004-2005, 54% of infants younger than 6 months and 98% of 6-12 months old infants had consumed CF in the previous 24 hours, 60% and 81%, respectively, as commercial CF [42].

In conclusion, these numbers illustrate the generally high relevance of commercial CF in industrialised countries. But even though there seem to be essential differences between homemade and commercial CF, the current body of research does not allow drawing any final conclusion on what type of CF to choose or their possible influences on the development of individual food preferences.

1.2 Early development of taste and food preferences

Given that individual food preferences play a predominant role in determining children's food choice and dietary behaviour it is important to understand how these food preferences develop. Those preferences for specific flavours and foods are determined by an interplay of genetic (innate) and environmental (experiential) influences [43]. Every infant is born with characteristic inborn taste preferences. Sweet, umami, and salty tastes elicit positive reactions, whereas bitter and sour tastes are initially rejected by neonates [44,45]. However, taste perception differs between individuals, e.g. some showing a higher sensitivity to bitter tastes depending on their genotype which also affects their food preferences [45]. Further, early sensory experiences play a crucial role in shaping those innate preferences (**Figure 1**) given that the plasticity of individual flavour and food preferences is greatest in early years [44,46].

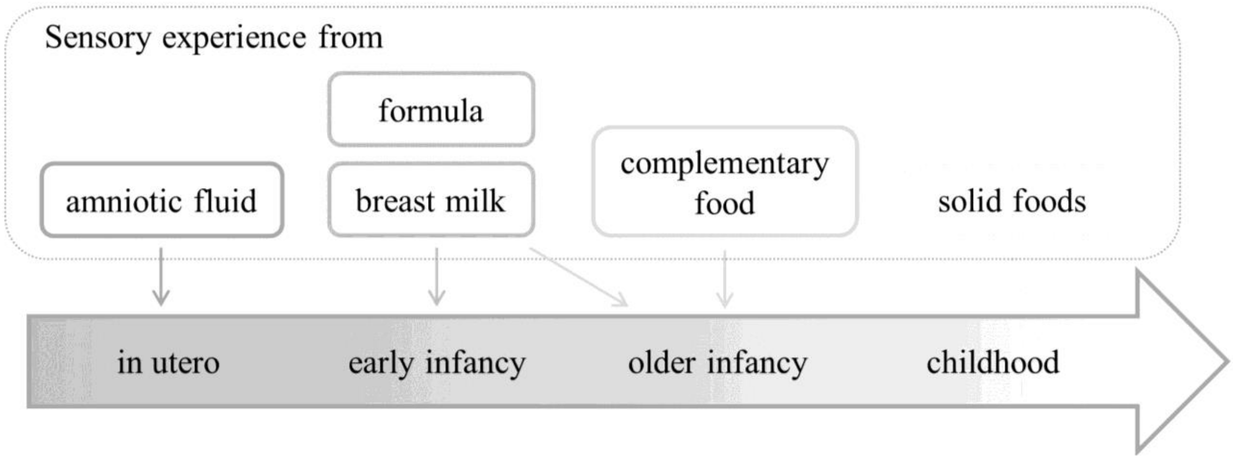

Figure 1: Role of exposure to different sensory experiences in the development of food preferences throughout early childhood [adapted from 46,47]

Already foetuses are repeatedly exposed to specific flavours in utero transmitted from the mother's diet to the amniotic fluid which is inhaled and swallowed by the foetus [48,49]. After birth, it is assumed that infants' flavour learning proceeds through breastfeeding and/or formula feeding with breastfed infants being exposed to greater variations and more diverse flavours in mother's milk than infants fed with formula [50,51]. However, recent studies challenge the assumption that food aromas from the mother's diet are equally transmitted to their breast milk. The transfer of different flavour compounds is time-dependent and selective [52] since at least the intake of herbal nursing tea and fish oil capsules does not significantly alter the odour or aroma profile of breast milk [53,54]. Still, other compounds of several flavours or foods like vanilla, garlic, or carrots seem to be transmitted into breast milk as they are recognised and accepted more easily by the breastfed infant [48]. In contrast to breast milk, infant formulas provide a constant monotonous flavour experience except for milk protein hydrolysate formulas that are characterised by a rather unpleasant bitter and sour taste and odour [49,55]. Infants who were repeatedly fed hydrolysate formula had a higher intake of bitter-, sour-, and savoury-tasting cereals during weaning compared to infants fed with breast milk or usual cow milk formula [56].

Taken together, those studies demonstrate that the recurring experiences with certain taste and flavour qualities from amniotic fluid, breast milk, and even formula are recognised by the infant during weaning and hence increase the infant's familiarity with the exposed flavours and tastes.

Early sensory experiences therefore have the potential to imprint preferences for specific foods during weaning since they enhance the acceptance and liking of foods containing these tastes and flavours [46,57]. Further, the exposure to the varying flavour profiles of amniotic fluid and breast milk both being directly influenced by the maternal diet facilitates the infant's acceptance not only of familiar flavours and foods but also of newly introduced solid foods during weaning. At least for breastfeeding, the latter seems to have a greater impact as shown in an experimental study by *Hausner et al.* suggesting that the acceptance of unknown foods is resulting from breastfeeding per se rather than the familiarisation to specific flavours via breast milk exposure [58].

Irrespective of early milk feeding choice, the infant's food preferences can still be modified during complementary feeding (**Figure 1**) since the development and shaping of food preferences is not completed yet [47,59]. Besides the indirect sensory experience of various flavours and foods via amniotic fluid and breast milk also the direct sensory experience from different foods fed during weaning has an impact on their acceptance. In particular fruits and vegetables, which are usually given as first CF in Germany [60], provide a broad range of different taste impressions, reaching from sweet over sour to bitter tastes. In addition, food preferences are not only a consequence of the taste and flavour of a specific food, but are also influenced by other sensory properties like smell, colour, and texture [61–63]. With the introduction of CF, the infant's exposure to a wide range of differing textures becomes more important since it increases the development of oral motor skills, facilitates food acceptance, and prevents infants from feeding difficulties [64–67]. In an experimental study by *Birch et al.*, infants consumed less of homemade CF prepared from a known fruit or vegetable compared to the commercially prepared versions due to the differing unfamiliar textural properties [68]. Given that infants generally prefer to eat familiar foods they accept more complex textures easier, if they are already used to varying textures in their diet [65,66].

Apart from those sensory properties of solid foods there are other weaning-related factors like the repeated exposure to certain foods as well as high dietary variety discussed to have an impact on later food preferences [61]. The repeated exposure to a particular food with recommended exposures varying between 8-10 [59] and 6-15 contacts [44] is one of the key determinants to increase food acceptance and liking for the exposed, but also for similar foods during weaning [61,68–70]. It is therefore suggested as the underlying mechanism in the concept of pre- and postnatal taste programming through amniotic fluid and breast milk [57]. Even differences between breast- and formula-fed infants' acceptance and intake of a initially disliked or unknown food disappeared after repeated exposure to the respective food [47,58,69]. Further, not only repeated exposure to single foods but also the exposure to a high variety of foods and flavours during complementary feeding increases acceptance of unknown foods and thus sets the foundation for a diverse diet later on [47,61]. The desired diversity of the weaning diet is best achieved by offering a high variety and frequent changes of foods and flavours between and within meals [47,62]. Since those repeated exposure and variety effects were predominately shown to increase the intake of certain fruits or vegetables, the current body of literature does not allow a definite conclusion on whether these effects can be shown only for similar foods within a food group or whether they can also be generalised to other food groups [61,71].

While the acceptance and liking of healthy foods like fruits and vegetables needs to be learned or at least enhanced during infancy, the infant's liking for sugar and sweet foods is evolutionary determined by their inborn preference for sweet tastes [72]. Already foetuses are exposed to sweet-tasting sugars like glucose and fructose through their first food, the amniotic fluid [73]. After birth the innate sweet preference attracts the infant to the sweet taste of breast milk determined by its high content of lactose [74]. The repeated exposure to sweet(ened) foods magnifies this preference even further during infancy and childhood [75–77]. Although in particular infancy has been highlighted as a sensitive period for the acceptance of new foods and the development of favourable food preferences, sensory experiences during childhood and beyond still have the potential to shape individual preferences (**Figure 1**). However, social influences like parental or peer modelling, the imitation of other role model's behaviour, or media gain impact with increasing age [45,78,79].

1.3 Early feeding experiences and their long-term influence on childhood dietary behaviour

The infant's food preferences are to a great extent shaped by repeated early pre- and postnatal sensory experiences, whether from amniotic fluid, breast milk, or formula as presented in the previous chapter. It remains unclear; however, whether any of these early experiences have the potential to also form long-term food preferences and dietary behaviour.

The few available studies focus on the long-term influence of breastfeeding on later dietary behaviour. According to a Canadian study, three or more months of exclusive breastfeeding predicted a higher vegetable consumption in preschool children [80]. Further, the duration of any breastfeeding (i.e. exclusive and partial breastfeeding) predicted fruit and vegetable intake in four European birth cohorts [81]. In two of those birth cohorts, never being breastfed or a short breastfeeding duration (<1 month) was also associated with lower variety scores of healthy foods in early childhood; the remaining two cohorts showed at least a trend in the same direction [82]. Consistently, duration of any breastfeeding was positively associated with fruit and vegetable variety as well as healthy core food variety at 2 years of age in Australian children [83]. Resuming these results, they support the hypothesis that flavour variations transmitted via breast milk not only facilitate infants' food acceptance but also improve children's food choice prospectively.

Given that breastfeeding seems to shape later dietary behaviour – most likely due to the provision of constant flavour changes and repeated exposure to novel flavours – one can hypothesize that differing sensory properties of homemade and commercial CF (i.e. taste, flavour, and texture) may also contribute to differences in later dietary behaviour. The much-noticed study by *Coulthard et al.* on early fruit and vegetable feeding practice showed a positive association between home-cooked fruits and vegetables fed in infancy and later fruit and vegetable consumption, whereas feeding ready-prepared fruits and vegetables was not related [84]. The later was ascribed to the rather homogenous taste and texture of commercial CF providing only a limited taste range compared to homemade CF.

Experimental data from *Maier et al.* showed further that a frequent change of fed vegetables during complementary feeding increased the subsequent acceptance of new foods more than the number of different vegetables fed. This effect was also shown to persist for several weeks [85]. Recent follow-up data suggest that children with exposure to a high vegetable variety during weaning ate and liked more vegetables with 15 months, 3 and 6 years of age than those children given no or low variety in infancy [86]. In terms of variety, homemade CF is commonly anticipated to provide higher sensory variation, although in practice at least vegetable variety in homemade CF is nearly as low as in commercial CF [36].

Based on these results the question arises, whether these prospective associations between CF and later dietary behaviour can also be shown not only for the preparation type of single CF components (i.e. fruits and vegetables) but also for commercial CF in general as part of the entire diet as well as for other dietary outcomes.

2 RESEARCH AIMS AND APPROACH

As outlined in the previous chapter, besides innate taste preferences, early sensory experiences in infancy via amniotic fluid, breast milk, and formula play a crucial role in the development of individual food preferences and dietary behaviour. However, the potential of CF's sensory properties in particular with regards to its preparation type in shaping later dietary behaviour has not been extensively examined so far.

Further, most existing studies investigating the associations between early feeding experiences and later dietary behaviour have been focusing on fruit and vegetable consumption, since promoting fruit and particularly vegetable acceptance and intake has been a major public health goal and hence an important research topic recently. The inborn taste preferences with the unlearned rejection of sour and bitter tastes characterising several fruits and vegetables in combination with the innate liking of sweet tastes characterising sugar and sweets stand in direct contrast to current dietary recommendations for children [87]. Given the results of representative nutrition surveys, fruit and particularly vegetable intake in German toddlers and children is below recommendations, whereas the intake of sugar and sweets is clearly higher than recommended [88,89]. Thus, it is of great public interest to identify modifiable determinants like the preparation type of CF in order to facilitate healthy dietary choices in children, i.e. increasing fruit and vegetable consumption as well as reducing added sugar intake.

Therefore, the overall aim of this thesis was to investigate the relevance of commercial CF consumption in infancy and its cross-sectional as well as prospective relation to dietary behaviour. To address this objective the following three research aims with their respective research questions (RQ) have been formulated for this thesis:

Research aim 1: to identify time and age trends in breastfeeding and weaning practices (Study I)

Hypothesis: Breastfeeding and weaning periods are sensitive time frames for the development of food preferences and dietary behaviour, but are subject to constant changes. Due to recent societal trends, e.g. higher proportion of working mothers, the relevance of commercial CF may play a continually increasing role in today's infant nutrition.

RQ 1.1: Has the full or total breastfeeding duration changed during the last decade?
RQ 1.2: What is the proportion of commercial CF in today's infant feeding practice and what characterises high consumers of commercial CF?

RQ 1.3: Has the consumption of commercial CF changed with age or time?

Research aim 2: to examine the association between commercial CF consumption and fruit and vegetable intake and variety cross-sectionally and prospectively (Study II)

Hypothesis: Sensory properties of commercial CF differ presumably from those of homemade CF by differences in flavour or texture experiences, due to the standardised production processes as well as a lower exposure to different fruits and vegetables or multiple combinations of flavours diluting the taste of individual fruits and vegetables. Thus, a high commercial CF consumption may affect fruit and vegetable consumption in infancy and childhood.

RQ 2.1: Is the consumption of commercial CF associated with the fruit and vegetable intake or variety in infancy?
RQ 2.2: Is the consumption of commercial CF in infancy associated with the fruit and vegetable intake or variety in preschool and primary school age?

Research aim 3: to examine the association between commercial CF consumption and added sugar intake cross-sectionally and prospectively (Study III)

Hypothesis: A high consumption of commercial CF and the concomitant early and frequent exposure to added sugar in infancy may further enhance the inborn preference for sweet taste and thus predispose to a high intake of added sugar later in life.

RQ 3.1: Is the consumption of commercial CF associated with the total added sugar intake or added sugar intake from CF during infancy?
RQ 3.2: Is the consumption of commercial CF in infancy associated with the total added sugar intake in preschool and primary school age?

A set of three consecutive analyses (Studies I-III) as summarised in **Figure 2** has been carried out. The resulting publications are presented in the following chapter 3.

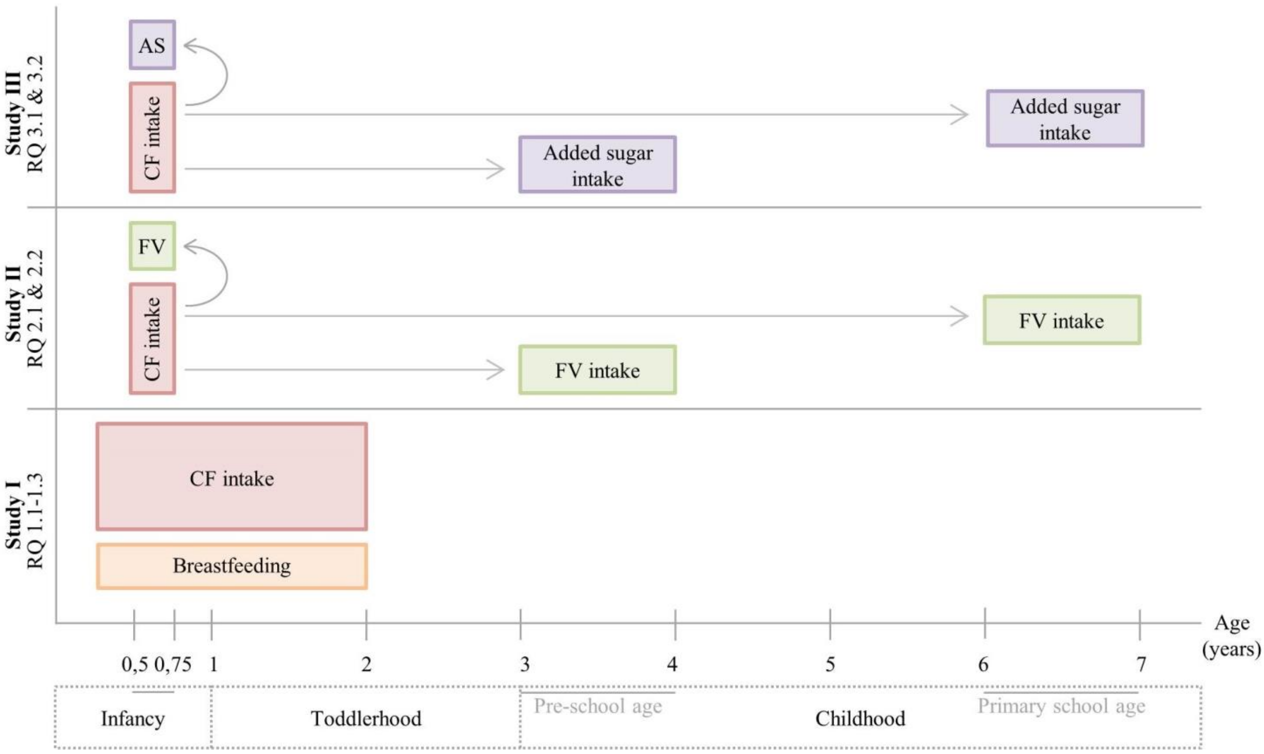

Figure 2: Scheme of research questions and the respective studies over the course of infancy and childhood. Solid lines mark the considered age groups. AS, added sugar; CF, complementary food; FV, fruit and vegetable; RQ research question

To address the formulated research questions, data from the longitudinal DONALD Study providing detailed repeated measurements of dietary intakes at several points of ages was used.

The DONALD Study is an ongoing open cohort study conducted at the DONALD Study centre (formerly FKE) in Dortmund. Since recruitment started in 1985, detailed data concerning diet, growth, development, and metabolism in healthy subjects between infancy and early adulthood have been collected. Every year, infants are newly recruited and first examined at the age of 3 months. Each child returns for up to three more visits in the first year, two in the second, and then annually until young adulthood. The non-invasive assessments include interviews on lifestyle, anthropometric measurements, a medical examination, and relevant for this thesis, detailed 3-day weighed dietary records (**Figure 3**). The study was approved by the ethics committee of the University of Bonn, and all of the examinations are performed with parental, and later on with the children’s written consent [90,91].

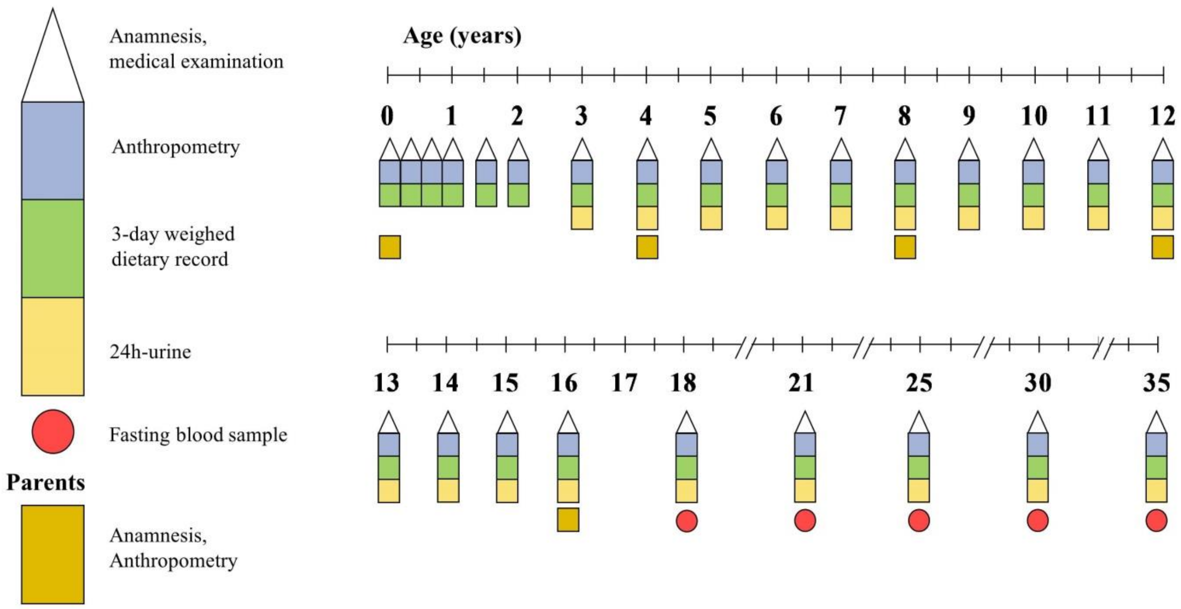

Figure 3: DONALD Study schedule [adapted from 90]

For the dietary records, the parents of each child are instructed to weigh and record all foods and beverages consumed by their child using electronic food scales (±1g) on three consecutive days. The participants choose the day of the beginning of dietary recording within a given period of time, usually around the child's birthday. The detailed dietary assessment also requests the recording of all recipes (ingredients and preparation) of homemade foods and meals as well as a detailed description including type and brand of commercial products. Subsequently, any recorded food or drink is entered into the continuously updated in-house food composition database LEBTAB, which incorporates information from standard nutrient tables [92]. If parents record new foods or commercial food products, those are added into the database. For commercial food products, energy and nutrient content is estimated using recipe simulation based on the labelled ingredients and nutrients. This unique feature of LEBTAB also allows the estimation of the composition of commercial CF products [92].

More detailed methodological information can be found in the published scientific papers (see chapter 3).

3 PUBLICATIONS

Research aim 1:

Foterek K, Hilbig A, Alexy U.

Breast-feeding and weaning practices in the DONALD Study: age and time trends.

Journal of Pediatric Gastroenterology and Nutrition 2014; 58(3):361–367

Accepted October 5, 2013

DOI: 10.1097/MPG.0000000000000202

Research aim 2:

Foterek K, Hilbig A, Alexy U.

Associations between commercial complementary food consumption and fruit and vegetable intake in children. Results of the DONALD Study.

Appetite 2015; 85; 84-90

Accepted November 11, 2014

DOI: 10.1016/j.appet.2014.11.015

Research aim 3:

Foterek K, Buyken AE, Bolzenius K, Hilbig A, Nöthlings U, Alexy U.

Commercial complementary food consumption is prospectively associated with added sugar intake in childhood.

British Journal of Nutrition 2015 [under review]

3.1

Breast-Feeding and Weaning Practices in the DONALD Study: Age and Time Trends

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ABSTRACT

Objectives: Besides influencing short- and long-term health status, infant feeding practices are known to have an effect on later food preferences. This study aimed to identify present trends in breast-feeding duration and weaning practices with special focus on preparation methods of complementary food (CF), that is, homemade and commercial CF.

Methods: In total, 1419 three-day weighed diet records collected between 2004 and 2012 from 366 children of the German DOrtmund Nutritional and Anthropometric Longitudinally Designed study ages 6 to 24 months were analysed. Full (n = 339) and total breast-feeding duration (n = 344) was collected by questionnaire. To investigate age and time trends, logistic regression and polynomial mixed regression models were used.

Results: Infants born between 2008 and 2012 were 3.3-fold less likely to be fully breast-fed for ≥4 months than those born before 2004 ($P < 0.0001$). Overall, 59.3% commercial, 21.1% homemade, and 19.6% combined CF was consumed by the study sample. Subjects with high commercial CF consumption (percentage of commercial CF > median 62%) were significantly older ($P < 0.0001$), showed shorter full and total breast-feeding duration ($P < 0.0001$), and were more likely to have mothers with a lower educational status ($P = 0.01$). Both commercial and homemade CF showed opposing, nonlinear age trends. No time trends could be found.

Conclusions: Decreasing duration of full breast-feeding should encourage health care providers to further promote longer breast-feeding duration. With the constantly high consumption of commercial CF at all ages, nutritional adequacy of both homemade and commercial CF needs to be investigated closer, as does their long-term influence on health and dietary habits, for example, fruit and vegetable intake.

Key Words: breast-feeding duration, commercial complementary food, homemade complementary food, infant feeding

(*JPGN* 2014;58: 361–367)

Infant feeding practices not only affect short- and long-term health status (1,2) but are also known to influence later taste and food preferences (3). Hence, infants' early food environment plays an important role in the development of their individual eating behaviour (4).

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Breast-feeding is one of the first opportunities for an early exposure to different flavours and can hence affect later food preferences in childhood (5,6). Undoubtedly, breast-feeding is also associated with several health benefits in infancy and adulthood (1,7). Therefore, exclusive breast-feeding (ie, breast milk only with no other food or drink) or full breast-feeding (ie, breast milk in combination with water or water-based drinks) for 4 to 6 months is recommended in Europe (8); however, breast-feeding patterns have been changing during the last few decades, for example, breast-feeding initiation rates have increased over time, presently reaching approximately 80% (9) to 90% (10,11).

In the representative cross-sectional German Health Interview and Examination Survey for Children and Adolescents (KiGGS), breast-feeding duration was questioned retrospectively. The average duration of full breast-feeding for infants born between 1986 and 2005 was 4.6 months and therefore in line with present recommendations; however, both full and total breast-feeding duration decreased in KiGGS from 2001 onwards (9). Overall, in comparison with other European countries, German breast-feeding rates are ranked somewhere in the middle (12).

In accordance with the recommendations on breast-feeding, complementary food (CF)—in Europe, usually given as semisolid, spoonable foods—should be introduced not more than 6 months of age and not less than 4 months (13). With the introduction of CF, the exposure to different flavours continues (3), although infants' flavour experiences vary with respect to the way in which the CF is prepared. The taste of jarred commercial CF differs from homemade CF because of the different cooking process during manufacturing.

Recent studies suggest that the method of preparation of CF is linked to diet quality and later eating behaviour (14,15); however, results are inconsistent: in a cross-sectional survey of families receiving governmental benefits, those infants fed commercial CF consumed a larger variety of fruits and vegetables (14). Within the prospective Avon Longitudinal Study of Parents and Children, participants who were fed home-cooked fruits and vegetables at 6 months were more likely to show an increased intake and variety of fruits and vegetables at 7 years (15). An association between consumption of commercial CF in infancy and lower intelligence quotient scores in childhood has also been discussed (16).

Although the American Academy of Pediatrics only recommends ensuring nutrient and energy sufficiency when preparing CF at home (17), UK infant feeding guidelines promote the use of homemade rather than commercial CF (18). There are no such recommendations in Germany; the German Research Institute of Child Nutrition (FKE) has stated that given their respective advantages and disadvantages, both homemade and commercial CF are equally acceptable alternatives for infant feeding (19). There is presently insufficient scientific evidence to make a more specific recommendation.

Extremely few studies exist on the consumption of commercial and homemade CF in industrialised countries. In Germany, the quantity of commercial CF products on sale increased between

2010 and 2012 from 276 to 309 jarred vegetable-potato-meat meals (Mesch et al, unpublished data). Moreover, there was a slight increase in sales, by 0.4%, for all commercial CF between 2010 and 2011 (20).

To determine existing trends in infant feeding practices, it is important to monitor these practices during this sensitive time frame. The aim of our study, therefore, was to identify present breast-feeding and weaning practices in German infants, with a special focus on the method of preparation of CF.

METHODS

Study Sample

The present analysis is based on data from the German DOrtmund Nutritional and Anthropometric Longitudinally Designed (DONALD) study, an ongoing open cohort study. Details of the study protocol have been published previously (21). Briefly, since 1985, detailed information concerning diet, growth, development, and metabolism in healthy subjects between infancy and early adulthood has been collected. Every year, infants are newly recruited and first examined at the age of 3 months. Each child returns for up to 3 more visits in the first year, 2 in the second, and then annually until young adulthood. The noninvasive assessments include 3-day weighed diet records, interviews on lifestyle, anthropometric measurements, and a medical examination. The study was approved by the ethics committee of the University of Bonn, and all of the examinations were performed with parental written consent.

For the purpose of this analysis, we considered data from 366 infants (194 boys, 172 girls) ages 6 to 24 months collected between 2004 and 2012. Each infant had to have completed at least one 3-day diet record. Subsamples were used for specific analyses depending on individual data availability.

Diet Records

All of the foods and beverages consumed by the infant were weighed and recorded by the parents using electronic food scales ($\pm$1 g) on 3 consecutive days. Breast milk intakes were determined by weighing the infant before and after each breast-feeding. Recipes of homemade CF as well as a detailed description including type and brand of commercial CF were also requested. If weighing was not possible, semiquantitative recording (eg, number of glasses, cups, spoons) was allowed. At the end of the 3-day recording period, a dietician visited the family and checked the record for completeness and accuracy.

Any food or drink consumed by the DONALD study participants was entered into the continuously updated in-house food composition database LEBTAB, which incorporates information from standard nutrient tables, product labels, or recipe simulation based on the labelled ingredients and nutrients (22). Dietary supplements and pharmaceuticals were recorded, but excluded from this analysis.

For this analysis, CF was defined as all semisolid, pureed, or mashed foods fed with a spoon during weaning. Snack foods intended for infants and toddlers (eg, biscuits, cereal bars) were not included in the definition of CF because they usually have a solid texture. Commercial CF was defined as all industrially processed, prepackaged CF (from jars or packets). Homemade CF was defined as all home-prepared, semisolid, pureed, or mashed foods made from fresh ingredients. Combined CF was defined as homemade CF that was mixed with commercial CF products in a single meal, for example, homemade vegetable puree in combination with commercial jarred baby meat.

Breast-Feeding Duration

In addition to the diet records, duration of breast-feeding from birth was questioned by the study paediatricians at each of the first visits at 3, 6, 9, 12, and 18 months until the infant was fully weaned. Moreover, the consumption of any additional liquids, formula, or food was questioned to distinguish between full and partial breast-feeding. For this analysis, breast-feeding definitions as provided by the World Health Organisation were used (23). Thus, full breast-feeding duration was defined as the number of weeks of both exclusive (breast milk only with no other food or drink) and predominant (breast milk in combination with water or water-based drinks) breast-feeding. Total breast-feeding duration was defined as the number of weeks of full and partial (breast milk in combination with formula or CF) breast-feeding. Data on total breast-feeding duration were available for a subsample of 344 participants, as well as on full breast-feeding duration for 339 participants.

Potentially Confounding Factors

On their child's admission to the study, parents were interviewed by the study paediatrician about family characteristics, and were weighed and measured by the study nurses. Information on the child's birth characteristics were abstracted from the "Mutterpass," a standardised document given to all the pregnant women in Germany.

For this analysis, the following characteristics were considered as potential covariates: total energy intake (kilocalories per day), maternal employment (yes/no), ongoing breast-feeding (yes/no), high maternal educational status ($\geq$12 years of schooling), household size, maternal age at birth (years), parental overweight (body mass index [BMI] $\geq$25 kg/m^2), and birth weight (g). For missing values (n = 2 for maternal employment, n = 20 for household size) the respective median of the total sample was used. Parental overweight was defined as a BMI >25 kg/m^2, calculated with maternal height and weight. If maternal data were missing (n = 45), paternal data were used. For the remaining missing values (n = 3), the median of the total sample was used.

Statistical Analyses

SAS procedures (version 9.1.3; SAS Institute, Cary, NC) were used for data analyses. Food and energy intake was calculated as the individual means of 3 recorded days using LEBTAB. Descriptive data were presented as frequencies, medians with an interquartile range (in the case of skewed data), or means with a standard deviation. $P < 0.05$ was considered as significant. Because there was no significant sex interaction, data from girls and boys were pooled for all of the analyses.

Because of the number of zero values and the resulting skewness of breast-feeding data, time trends in breast-feeding duration were analysed using logistic regression for ordinal-dependent variables (PROC LOGISTIC in SAS). For this purpose, the duration of full breast-feeding was categorised into 3 groups (<4 months, 4–<6 months, and $\geq$6 months), and the duration of total breast-feeding into 4 groups (<4 months, 4–<8 months, 8–<12 months, and $\geq$12 months). The birth years of the sample (2001–2012) were categorised into 3 strata (Table 2).

To determine differences in the characteristics of low and high commercial CF consumers, the study participants were split into 2 groups according to whether their average commercial CF intake was lower or higher than the median commercial CF consumption of 62% (median of all records where CF was consumed). Tests for differences were performed using the *t* test for normally distributed variables, Wilcoxon rank-sum test for non-normally distributed variables, and χ^2 test for categorical variables.

To analyse time and age trends in the methods of CF preparation (calculated as percentage of total CF intake), a polynomial mixed-effects regression model including both fixed and random effects was used (PROC MIXED in SAS). A repeated statement was used to account for the lack of independence that exists between repeated observations on the same person; a random statement accounted for the nested nature of our data (children within families).

Models were also adjusted for potential confounding factors. Only those variables that significantly modified regression coefficients in the basic models by ≥10%, had a significant, independent effect on the outcome variable, or led to an improvement of the Akaike Information Criterion (AIC) were considered in the final models (24).

RESULTS

Study Sample Characteristics

Between 1 (n = 31, 8.5% of total sample) and 5 (n = 183, 50.0%) 3-day weighed diet records were available per subject (mean 3.9), a total of 1419 records. Descriptive data on the study sample are presented in Table 1, stratified by age. Total energy intake increased with age, whereas the percentage of breast milk consumers and total breast milk intake decreased. More than two-thirds of the study sample was still being breast-fed at the age of 6 months, and one-fifth at the age of 12 months.

Breast-Feeding Practice

In the subsample with available questionnaire data on breast-feeding duration, the majority of mothers (96.2%) had breast-fed their infants for at least 1 week. Afterwards, breast-feeding rates declined continuously (Fig. 1). At 4 months of age, 60.5% of the infants were fully breast-fed, with a total breast-feeding rate of 79.1%. At 6 months of age, the rate of full breast-feeding was 24.5%, whereas the rate of total breast-feeding remained high (71.2%). The median duration of full breast-feeding in the DONALD sample was 21 weeks (interquartile range 7–25 weeks), and the median duration of total breast-feeding was 35 weeks (21–50 weeks, data not shown).

Table 2 shows time trends in the duration of full and total breast-feeding. The odds ratio for a short duration of full breast-feeding (<4 months) was higher for later-born infants in both the unadjusted ($P = 0.0004$) and the adjusted ($P < 0.0001$) models. Infants born between 2008 and 2012 had a 3.3-fold higher chance for a short duration of full breast-feeding than those born between 2001 and 2003; however, there was no significant difference in the likelihood for a long duration of total breast-feeding (≥12 months) for different birth year cohorts ($P = 0.140$). Breast-feeding duration did not differ between boys and girls.

Weaning Practice

In the present sample, CF was introduced in 29.4% of infants before the age of 4 months, and in 2.2% after 6 months (Fig. 1). Thus, two-thirds of the study sample (68.4%) was introduced to CF between the recommended ages of 4 to 6 months. The median age of introduction was 23 weeks (interquartile range 21–26, data not shown).

The number of CF consumers (99% of records) and CF intake (548 g/day) was highest at 9 months of age. At the age of 12 months, nearly all infants still consumed CF (96%), but intake was lower (428 g/day). Thereafter, consumer frequency and CF intake declined, but at the age of 18 months, almost two-thirds of the study sample still received CF, at least in small amounts (Table 1).

Preparation Method of CF

Overall, 59.3% of CF was commercially prepared, 21.1% was homemade, and 19.6% was a combination of both. (For detailed percentages of different methods of preparation by age, see Table 1.) Of all of the records in which CF was consumed (n = 1080), 354 records (32.8%) contained exclusively commercial CF, whereas homemade CF was eaten exclusively in 61 records (5.6%, data not shown).

TABLE 1. Study sample characteristics by age of DOrtmund Nutritional and Anthropometric Longitudinally Designed study participants, 2004–2012 (1419 records, 366 participants)

	Age, mo				
	6	9	12	18	24
Records, n (%)	288 (20.3)	300 (21.1)	298 (21.0)	276 (19.5)	257 (18.1)
Consumers, n (%)					
Breast milk consumers	204 (70.8)	130 (43.3)	62 (20.8)	23 (8.3)	6 (2.3)
Complementary food (CF)* consumers	241 (83.7)	296 (98.7)	286 (96.0)	172 (62.3)	85 (33.1)
Commercial CF* consumers	214 (74.3)	294 (98.0)	274 (91.9)	158 (57.2)	79 (30.7)
Intake, median (Q1–Q3)					
Total breast milk intake, g/day	515 (0–760)	0 (0–253)	0 (0–0)	0 (0–0)	0 (0–0)
Total CF* intake, g/day	165 (45–337)	548 (391–675)	428 (236–584)	73 (0–196)	0 (0–46)
Total energy intake, kcal/day	607 (531–670)	690 (613–758)	758 (686–856)	866 (789–970)	931 (812–1042)
Preparation method of CF,* mean (SD)					
Commercial CF† (% of total CF* intake)	60.8 (40.2)	54.2 (31.4)	55.3 (34.5)	65.8 (40.2)	73.8 (40.0)
Homemade CF‡ (% of total CF* intake)	22.7 (34.4)	20.9 (23.3)	24.7 (29.0)	18.3 (32.1)	10.5 (27.8)
Combined CF§ (% of total CF* intake)	16.5 (27.7)	24.9 (26.1)	20.0 (26.4)	15.9 (30.3)	15.6 (32.3)

CF = Complementary food; SD = standard deviation.
* CF was defined as all semisolid, pureed, or mashed foods fed with a spoon during weaning.
† Commercial CF was defined as all industrially processed, prepackaged CF (from jars or packets).
‡ Homemade CF was defined as all home-prepared, semisolid, pureed, or mashed foods made from fresh ingredients.
§ Combined CF was defined as homemade CF that was mixed with commercial CF products in a single meal.

TABLE 2. Time trends in duration of full and total breast-feeding of DOrtmund Nutritional and Anthropometric Longitudinally Designed study participants born in 2001–2012 (339, resp. 344 participants)

	Unadjusted			Adjusted*		
	OR	95% CI	P	OR	95% CI	P
Full breast-feeding† <4 mo, n = 339						
Birth years 2001–2003 (reference)	1.0		0.0004	1.0		<0.0001
Birth years 2004–2007	1.7	1.0–2.7		1.7	1.0–2.9	
Birth years 2008–2012	2.8	1.7–4.6		3.3	1.9–5.6	
Full breast-feeding† ≥6 mo, n = 339						
Birth years 2001–2003 (reference)	1.0		0.0004	1.0		<0.0001
Birth years 2004–2007	0.6	0.4–1.0		0.6	0.3–1.0	
Birth years 2008–2012	0.4	0.2–0.6		0.3	0.2–0.5	
Total breast-feeding‡ ≥12 mo, n = 344						
Birth years 2001–2004§ (reference)	1.0		0.592	1.0		0.140
Birth years 2005–2007§	1.1	0.6–1.7		1.2	0.7–2.0	
Birth years 2008–2012	0.8	0.5–1.3		0.8	0.5–1.2	

Significant differences between birth years were tested using logistic regression for ordinal dependent variables. CI = confidence interval; OR = odds ratio.
* Full breast-feeding was adjusted for high maternal educational status (yes/no), maternal age at birth (years), household size (n people), and parental overweight (yes/no). Total breast-feeding adjusted for high maternal educational status (yes/no), maternal age at birth (years), and parental overweight (yes/no).
† Full breast-feeding duration was defined as number of weeks of exclusive (breast milk only with no other food or drink) and predominant (breast milk in combination with water or water-based drinks) breast-feeding.
‡ Total breast-feeding duration was defined as number of weeks of full and partial (breast milk in combination with formula or CF) breast-feeding.
§ Deviating birth year strata were used to get most balanced strata sizes.

The differences between high (percentage of commercial CF > median) and low (percentage of commercial CF < median) commercial CF consumers are shown in Table 3. Subjects with high commercial CF consumption were significantly older ($P < 0.0001$) and showed a shorter duration of full ($P < 0.0001$) and total ($P < 0.0001$) breast-feeding. Those infants with lower commercial CF consumption were introduced to CF later than those with a high consumption ($P = 0.002$). Total CF ($P = 0.001$) and total food intake ($P < 0.0001$), as well as total energy intake ($P < 0.0001$), was higher in subjects with high commercial CF consumption. The differences persisted when calculated per kilogram body weight ($P < 0.0010$). Mothers of low commercial CF consumers had a significantly higher educational status ($P = 0.01$). No differences between low and high commercial CF consumers were seen with respect to sex, maternal age, birth weight, breast milk intake, and parental BMI.

Age and Time Trends in the Consumption of CF

Table 4 shows age and time trends for the different methods of preparation of CF, calculated as percentage of total CF intake. No significant time trends could be found for any method of preparation during the study period, neither in the unadjusted nor in the adjusted models.

Significant age trends were found for both commercial and homemade CF. For commercial CF, the model described a negative linear with a positive, U-shaped quadratic age trend. Thus, the percentage of commercial CF consumed showed a decrease, followed by an increase with increasing age. In contrast, a negative, U-shaped quadratic age trend could be found for homemade and combined CF, showing an initial increase followed by a decrease in the percentage of homemade and combined CF consumed with increasing age. For homemade CF, there was an additional positive linear age trend.

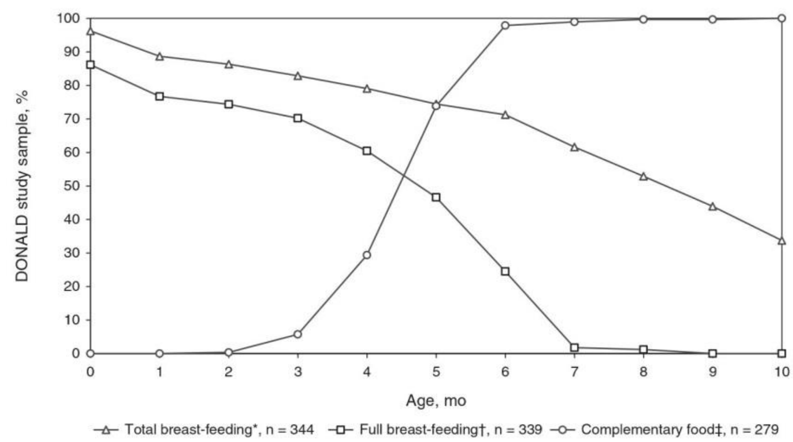

FIGURE 1. Breast-feeding rates (full and total breast-feeding) and rates of complementary food consumers of DOrtmund Nutritional and Anthropometric Longitudinally Designed (DONALD) study participants born in 2004–2012.

TABLE 3. Maternal and early-life characteristics according to low and high commercial CF intake of DOrtmund Nutritional and Anthropometric Longitudinally Designed (DONALD) study participants, 2004–2012 (CF consumers only, 350 participants)

Characteristics	Commercial CF consumption Low (<62.0%)	High (>62.0%)	
n = 350	175	175	*P*
Sex	53.7% boys	50.9% boys	0.593
Age, y*	0.67 (0.32)	0.93 (0.35)	<0.0001
Maternal age at birth, y	34.5 (4.0)	33.9 (4.1)	0.181
Birth weight, g	3499.7 (514.3)	3450.7 (445.5)	0.341
Duration of full breast-feeding,† wk, n = 299	19.4 (9.4)	13.6 (10.2)	<0.0001
Duration of total breast-feeding,‡ wk, n = 285	41.9 (22.5)	31.8 (25.7)	<0.0001
Breast milk intake,* g	110.5 (133.1)	121.0 (173.2)	0.27
Breast milk intake,* g/kg BW)	13.5 (15.8)	14.4 (20.3)	0.237
Age at introduction of CF, mo§ (n = 272)	5.5 (0.9)	5.2 (0.8)	0.002
Total CF§ intake,* g	258.1 (126.3)	306.0 (139.2)	0.001
Total CF§ intake,* g/kg BW	28.3 (14.3)	33.3 (15.6)	0.001
Total food intake without beverages,* g	593.8 (205.8)	748.0 (179.9)	<0.0001
Total food intake without beverages,* g/kg BW	65.0 (23.1)	80.6 (21.5)	<0.0001
Total energy intake,* kcal	507.0 (179.8)	667.8 (150.8)	<0.0001
Total energy intake,* kcal/kg BW	54.3 (18.6)	69.8 (13.6)	<0.0001
Parental BMI, kg/m^2	24.1 (4.0)	25.0 (5.2)	0.186
High maternal educational status (>12 y of schooling)	92.0%	82.9%	0.01
Maternal employment	17.1%	20.0%	0.492
Household size (n people)	3.3 (0.7)	3.4 (0.7)	0.892

Significant differences between low and high commercial CF consumption were tested using *t* test for normally distributed variables, Wilcoxon rank-sum test for non-normally distributed variables, and χ^2 test for categorical variables. BMI = body mass index; BW = body weight; CF = complementary food.

* Mean overall available diet records per person.

† Full breast-feeding duration was defined as number of weeks of exclusive (breast milk only with no other food or drink) and predominant (breast milk in combination with water or water-based drinks) breast-feeding.

‡ Total breast-feeding duration was defined as number of weeks of full and partial (breast milk in combination with formula or CF) breast-feeding.

§ CF was defined as all semisolid, pureed, or mashed foods fed with a spoon during weaning.

TABLE 4. Age and time trends of CF preparation methods from DOrtmund Nutritional and Anthropometric Longitudinally Designed study participants, 2004–2012 (CF consumers only, 1080 records, 350 participants)

	Age trend per year of age (6–24 mo)				Time trend per study year (2004–2012)			
	Age β (SE)	*P*	Age*age β (SE)	*P*	Time* β (SE)	*P*	Time* time β (SE)	*P*
Commercial CF* (% of total CF† intake)								
Unadjusted model	−29.7 (11.6)	0.011	15.8 (4.7)	0.001	0.3 (2.3)	0.904	0.0 (0.3)	0.923
Adjusted model‡	−30.3 (11.6)	0.009	16.0 (4.7)	0.001	−0.4 (2.3)	0.853	0.2 (0.3)	0.557
Homemade CF§ (% of total CF† intake)								
Unadjusted model	13.7 (9.5)	0.151	−7.9 (3.7)	0.035	−2.1 (1.7)	0.227	0.3 (0.2)	0.184
Adjusted model‖	22.4 (10.5)	0.033	−9.9 (3.9)	0.011	−1.7 (1.7)	0.319	0.2 (0.2)	0.286
Combined CF¶ (% of total CF† intake)								
Unadjusted model	9.7 (10.0)	0.333	−5.6 (4.1)	0.176	−1.7 (1.7)	0.322	−0.3 (0.2)	0.185
Adjusted model**	14.4 (10.8)	0.182	−8.8 (4.2)	0.036	1.4 (1.6)	0.372	−0.3 (0.2)	0.144

Age and time trends were tested using polynomial mixed effects regression models. CF = complementary food; SE = standard error.

* Commercial CF was defined as all industrially processed, prepackaged CF (from jars or packets).

† CF was defined as all semisolid, pureed, or mashed foods fed with a spoon during weaning.

‡ Adjusted for maternal employment (yes/no), high maternal educational status (yes/no), mother's age at birth (years), and parental overweight (yes/no).

§ Homemade CF was defined as all home-prepared, semisolid, pureed, or mashed foods made from fresh ingredients.

‖ Adjusted for total energy intake (kilocalorie), high maternal educational status (yes/no), breast-feeding (yes/no), and parental overweight (yes/no).

¶ Combined CF was defined as homemade CF that was mixed with commercial CF products in a single meal.

** Adjusted for total energy intake (kilocalorie), maternal employment (yes/no), high maternal educational status (yes/no), breast-feeding (yes/no), and parental overweight (yes/no).

DISCUSSION

Breast-feeding and weaning practices are important for short- and long-term health, as well as for the development of dietary habits and preferences. New data from the DONALD study illustrate a negative time trend in full breast-feeding duration in German infants born between 2001 and 2012. In addition, we could show the relevance of commercial CF in today's infant nutrition, especially in infants who were breast-fed for a shorter duration and whose mothers had a lower educational status. Both commercial and homemade CF showed opposing, nonlinear age trends; however, no time trends could be found during the observed study period, illustrating that, in the DONALD study, the majority of CF was consistently commercially prepared.

The strengths of our analysis include the well-characterised cohort, the detailed dietary assessment method with recurring 3-day weighed diet records, and the food composition database, which allows differentiation between commercial and homemade CF. In addition to the detailed dietary data, numerous early life and socioeconomic family characteristics were assessed and could be adjusted for.

The longitudinal design of the DONALD study allows analyses on age and time trends based on individual intake data from close-meshed measurements using consistent survey methods for several years; however, the way in which CF is prepared has only been recorded since 2004. The time period considered in this analysis, therefore, may be too short to detect any underlying time trends, compared with previous trend analyses using DONALD study data (25,26). A comparison of data from the last 2 cross-sectional Infant Feeding Surveys in the United Kingdom, carried out in 2005 and 2010, showed that the proportion of mothers giving homemade CF remained about the same, whereas fewer infants were given commercial CF in 2010 than in 2005 (27,28).

The generalisability of our results may be limited because the participants in the DONALD study are characterised by a relatively high educational and socioeconomic status (21). Consequential differences in food expenses, health consciousness, or maternal employment could influence the choice of CF preparation methods (29,30). Thus, women who are better educated are more likely to go back to work sooner after birth (31), which could lead to an overestimation of the importance of commercial CF in this population, it being the more convenient and time-saving option.

Our finding of a slight downward trend in the rate of full breast-feeding is in accordance with the findings of the KiGGS survey, which also showed a decrease in full and total breast-feeding duration for infants born after 2001 (9). The reason for this observed decline in full breast-feeding duration is unknown. Although continuous breast-feeding promotion in Germany has led to a higher initial breast-feeding prevalence, our data show no success with respect to breast-feeding duration. Therefore, more effort should be made to achieve at least 4 months of exclusive or full breast-feeding in Germany.

Regarding the method of preparation of CF, our study sample illustrates the importance of commercial CF in Germany, given that 94.4% of the 3-day diet records included at least 1 commercial CF product. There are extremely few studies on the consumption of commercial versus homemade CF, possibly because of inconsistent or missing information on the different methods of preparation. In line with our data, the Feeding Infants and Toddlers study showed that 73% to 95% of US infants between the ages of 4 and 11 months had consumed commercially prepared baby foods during the previous 24 hours (32). In a cross-sectional telephone survey of US mothers receiving benefits as part of the Special Supplemental Nutrition Program for Women, Infants, and Children, a governmental nutrition programme, 54% of infants younger than 6 months and 98% of infants ages 6 to 12 months had consumed baby foods in the previous 24 hours, 60% and 81%, respectively, as commercial baby food (14). In the UK Infant Feeding Survey from 2010, mothers were more likely to give their 4- to 6-month-old infants commercial CF (38%) than homemade food (28%). Yet, at 8 to 10 months, homemade food (70%) was more common than commercial CF (44%) (27). Taken together, these studies illustrate the generally high, but also age-dependent, usage of commercially produced CF in industrialised countries.

Although the percentage of commercial CF consumed decreased initially and then rose from 12 months onwards, the percentage of homemade and combined CF consumed showed an opposing trend in our data. A possible explanation is that parents become more experienced and confident in the preparation of CF toward the end of their child's first year of life. Nevertheless, at every age between 6 and 24 months, commercially produced CF accounted for a larger proportion of the CF consumed than homemade CF. When considering the noticeably higher proportion of commercial CF consumed in the second year of life, one should keep in mind the smaller number of consumers and therefore the lower absolute amount of CF consumed at this age. In addition, the ever increasing quantity and variety of commercial CF and toddler foods on sale could also influence the dietary habits described above.

Given these results, the question arises as to whether commercial or homemade CF is nutritionally more favourable for infants. Although the nutrient content and composition of commercial CF are regulated by an EC directive (38), the composition of homemade CF or the extent to which parents abide by the recommended recipes for cooking homemade CF remains unclear. Two older studies on the composition of homemade and commercial CF in Spain and the United Kingdom showed that homemade CF contained on average a broader nutrient range and a less favourable nutrient composition (39,40). In 2 recent studies, Zand et al showed that the macronutrient content and composition of commercial ''ready-to-feed'' CF in the United Kingdom were within the regulatory requirements, whereas the content of some essential and trace elements did not meet the recommended intakes (41,42). Another cross-sectional UK survey found infant commercial weaning foods to be generally less nutrient dense than homemade family weaning foods (43). Dietary pattern analysis from the ALSPAC study also points to some contrary differences in nutrient intake between homemade and commercial CF, although the nutrient profiles of both patterns were not consistent in themselves between 6 to 8 and 15 to 18 months (44). A European focus group discussion showed that taste is an important deciding factor for parents when preparing infant food at home (33). Although reliable data on possible differences between commercial and homemade CF with regards to taste and texture are missing, some infant feeding guidelines encourage the use of homemade CF because this offers the infant a wider range of different tastes and textures (34,35), which is known to increase food acceptance later in life (36,37).

In addition to those short-term effects, the preparation method of CF may have an influence on the later development of eating behaviour and diet quality (14,15). In view of the fact that in Germany commercial CF does not incorporate a great variety of vegetables (Mesch et al, unpublished data), a possible association between commercial CF and fruit and vegetable variety later in life needs to be considered in future studies.

CONCLUSIONS

The development of healthy dietary habits should start early in life with favourable breast-feeding and weaning practices. With respect to breast-feeding, the decreasing trend in full breast-feeding duration observed here should encourage health care providers and public health authorities to further promote adequate full breast-feeding duration through greater maternal encouragement as well as extended professional information and education. In addition, national breast-feeding monitoring needs to be established to provide representative data periodically. Although the constantly high and widespread consumption of commercial CF may have some advantages given that its composition is closely monitored in the EU, there are still concerns related to its long-term influence on dietary habits, in particular on fruit and vegetable intake and variety. Parents choosing to prepare CF at home need to be advised carefully on appropriate ingredients and recipes.

REFERENCES

1. Robinson S, Fall C. Infant nutrition and later health: a review of current evidence. *Nutrients* 2012;4:859–74.
2. Przyrembel H. Timing of introduction of complementary food: short- and long-term health consequences. *Ann Nutr Metabol* 2012;60 (suppl 2): 8–20.
3. Mennella JA, Trabulsi JC. Complementary foods and flavor experiences: setting the foundation. *Ann Nutr Metab* 2012;60 (suppl 2):40–50.
4. Scaglioni S, Arrizza C, Vecchi F, et al. Determinants of children's eating behavior. *Am J Clin Nutr* 2012;94 (6 suppl):S2006–11.
5. Mennella JA, Jagnow CP, Beauchamp GK. Prenatal and postnatal flavor learning by human infants. *Pediatrics* 2001;107:e88.
6. Forestell CA, Mennella JA. Early determinants of fruit and vegetable acceptance. *Pediatrics* 2007;120:1247–54.
7. World Health Organization. *Infant and Young Child Feeding*. Geneva: WHO; 2009.
8. Agostoni C, Braegger C, Decsi T, et al. Breast-feeding: a commentary by the ESPGHAN Committee on Nutrition. *J Pediatr Gastroenterol Nutr* 2009;49:112–25.
9. Lange C, Schenk L, Bergmann R. Verbreitung, Dauer und zeitlicher Trend des Stillens in Deutschland. Ergebnisse des Kinder- und Jugendgesundheitssurveys (KiGGS) [Distribution, duration and temporal trend of breastfeeding in Germany. Results of the German Health Interview and Examination Survey for Children and Adolescents (KiGGS)]. *Bundesgesundheitsbl Gesundheitsforsch Gesundheitsschutz* 2007;50:624–33.
10. Kohlhuber M, Rebhan B, Schwegler U, et al. Breastfeeding rates and duration in Germany: a Bavarian cohort study. *Br J Nutr* 2008;99:1127–32.
11. Kersting M, Dulon M. Assessment of breast-feeding promotion in hospitals and follow-up survey of mother-infant pairs in Germany: the SuSe Study. *Public Health Nutr* 2002;5:547–52.
12. Cattaneo A, Burmaz T, Arendt M, et al. Protection, promotion and support of breast-feeding in Europe: progress from 2002 to 2007. *Public Health Nutr* 2010;13:751–9.
13. Agostoni C, Decsi T, Fewtrell M, et al. Complementary feeding: a commentary by the ESPGHAN Committee on Nutrition. *J Pediatr Gastroenterol Nutr* 2008;46:99–110.
14. Hurley KM, Black MM. Commercial baby food consumption and dietary variety in a statewide sample of infants receiving benefits from the special supplemental nutrition program for women, infants, and children. *J Am Diet Assoc* 2010;110:1537–41.
15. Coulthard H, Harris G, Emmett P. Long-term consequences of early fruit and vegetable feeding practices in the United Kingdom. *Public Health Nutr* 2010;13:2044–51.
16. Smithers LG, Golley RK, Mittinty MN, et al. Dietary patterns at 6, 15 and 24 months of age are associated with IQ at 8 years of age. *Eur J Epidemiol* 2012;27:525–35.
17. Kleinman RE. *Pediatric Nutrition Handbook*. 6th ed. Chicago: American Academy of Pediatrics; 2009.
18. Department of Health. Introducing solid foods: giving your baby a better start in life. *http://www.dh.gov.uk/prod_consum_dh/groups/dh_digitalassets/documents/digitalasset/dh_125828.pdf*. Published April 5, 2011. Accessed September 20, 2012.
19. Alexy U. Die Ernährung des gesunden Säuglings nach dem "Ernährungsplan für das 1. Lebensjahr" [Feeding healthy infants according to the "Dietary schedule for the first year of life"]. *Ern Umschau* 2007;54:588–94.
20. Manns K-J. Marktentwicklung Babynahrung: Wieder gewachsen [Market development baby food: grown again]. *Lebensmittelzeitung* 2011;47:36.
21. Kroke A, Manz F, Kersting M, et al., The DONALD Study. History, current status and future perspectives. *Eur J Nutr* 2004;43:45–54.
22. Sichert-Hellert W, Kersting M, Chahda C, et al. German food composition database for dietary evaluations in children and adolescents. *J Food Compos Anal* 2007;20:63–70.
23. World Health Organization, Division of Child Health and Development Indicators for assessing breastfeeding practices. *http://whqlibdoc.who.int/hq/1991/WHO_CDD_SER_91.14.pdf*. Published 1991. Accessed February 15, 2013.
24. Maldonado G, Greenland S. Simulation study of confounder-selection strategies. *Am J Epidemiol* 1993;138:923–36.
25. Hilbig A, Kersting M. Effects of age and time on energy and macronutrient intake in German infants and young children: results of the DONALD Study. *J Pediatr Gastroenterol Nutr* 2006;43:518–24.
26. Alexy U, Kersting M. Time trends in the consumption of dairy foods in German children and adolescents. *Eur J Clin Nutr* 2003;57:1331–7.
27. McAndrew F, Thompson J, Fellows L, et al. Infant Feeding Survey 2010. *http://www.hscic.gov.uk/searchcatalogue?productid=9569*. Published November 30, 2012. Accessed April 19, 2013.
28. Bolling K, Grant C, Hamlyn B, et al. Infant Feeding Survey 2005. *http://www.hscic.gov.uk/catalogue/PUB00619/infa-feed-serv-2005-rep.pdf*. Published May 14, 2007. Accessed April 23, 2013.
29. Robinson S, Marriott L, Poole J, et al. Dietary patterns in infancy: the importance of maternal and family influences on feeding practice. *Br J Nutr* 2007;98:1029–37.
30. Northstone K, Emmett P. Multivariate analysis of diet in children at four and seven years of age and associations with socio-demographic characteristics. *Eur J Clin Nutr* 2005;59:751–60.
31. Hanel B, Riphahn RT. The Employment of Mothers: Recent Developments and Their Determinants in East and West Germany. Discussion Paper No. 5752. Bonn: Institute for the Study of Labor; 2011.
32. Briefel RR, Reidy K, Karwe V, et al. Feeding Infants and Toddlers Study: improvements needed in meeting infant feeding recommendations. *J Am Diet Assoc* 2004;104 (1 suppl):S31–7.
33. Synnott K, Bogue J, Edwards CA, et al. Parental perceptions of feeding practices in five European countries: an exploratory study. *Eur J Clin Nutr* 2007;61:946–56.
34. NHS Survey. Surrey Infant and Child Feeding Guidelines. *http://www.surreyhealth.nhs.uk/index.php/downloads/finish/7/68*. Published August 2010. Accessed July 7, 2013.
35. Koletzko B, Bauer CP, Brönstrup A, et al. Säuglingsernährung und Ernährung der stillenden Mutter. Aktualisierte Handlungsempfehlungen des Netzwerk Gesund ins Leben - Netzwerk Junge Familie, ein Projekt von IN FORM [Infant Nutrition and nutrition for breastfeeding mothers. Updated practice recommendations of the network "Healthy Start - Young Family Network" a project of IN FORM]. *Monatsschr Kinderheilkd* 2013;137:1309–14.
36. Maier AS, Chabanet C, Schaal B, et al. Breastfeeding and experience with variety early in weaning increase infants' acceptance of new foods for up to two months. *Clin Nutr* 2008;27:849–57.
37. Coulthard H, Harris G, Emmett P. Delayed introduction of lumpy foods to children during the complementary feeding period affects child's food acceptance and feeding at 7 years of age. *Matern Child Nutr* 2009;5:75–85.
38. European Commission. Commission Directive 2006/125/EC of 5 December 2006 on processed cereal-based foods and baby foods for infants and young children. *Off J Eur Union* 2006;339:16–35.
39. Stordy BJ, Redfern AM, Morgan JB. Healthy eating for infants–mothers' actions. *Acta Paediatr* 1995;84:733–41.
40. van den Boom S, Kimber AC, Morgan JB. Nutritional composition of home-prepared baby meals in Madrid. Comparison with commercial products in Spain and home-made meals in England. *Acta Paediatr* 1997;86:57–62.
41. Zand N, Chowdhry BZ, Pollard LV, et al. Commercial 'ready-to-feed' infant foods in the UK: macro-nutrient content and composition. *Matern Child Nutr* 2012 October 1 [Epub ahead of print].
42. Zand N, Chowdhry BZ, Wray DS, et al. Elemental content of commercial 'ready to-feed' poultry and fish based infant foods in the UK. *Food Chem* 2012;135:2796–801.
43. Garcia AL, Raza S, Parrett A, et al. Nutritional content of infant commercial weaning foods in the UK. *Arch Dis Child* 2013;98:793–7.
44. Smithers LG, Golley RK, Brazionis L, et al. Dietary patterns of infants and toddlers are associated with nutrient intakes. *Nutrients* 2012;4:935–48.

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Research report

Associations between commercial complementary food consumption and fruit and vegetable intake in children. Results of the DONALD study ☆

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ABSTRACT

Objectives: Fruit and vegetable (FV) consumption is influenced by individual taste and food preferences that are developed early in life. Thus, the sensory properties of foods given during complementary feeding may shape later food acceptance and dietary intake. However, those experiences differ with respect to the preparation method of complementary food (CF), that is, homemade and commercial CF. The aim of this study therefore was to examine the association between the infant's consumption of commercial CF and FV intake and variety during infancy, preschool and school age. *Methods:* In total, 281 children of the DONALD Study with 3-day weighed dietary records at 0.5 and 0.75 (infancy), 3 and 4 (preschool age), 6 and 7 years of age (school age) were included in this analysis. Percentage of commercial CF (%cCF) was averaged at 0.5 and 0.75 years. Individual FV intake (g/day) and FV variety scores were calculated and averaged separately for all three age groups. Multivariate linear regression was used to analyse associations between %cCF and FV intake and variety. Models were adjusted for early life and socioeconomic factors. *Results:* For boys, higher %cCF was associated with lower vegetable intake in infancy ($p < 0.0001$) and preschool age ($p = 0.036$) as well as lower total FV intake in preschool and school age ($p < 0.009$). For girls, higher %cCF was associated with lower vegetable intake ($p < 0.0001$) in infancy. FV variety scores showed no clear associations with %cCF in girls and boys. *Conclusion:* The results of the DONALD Study suggest that the preparation method of CF is associated with FV consumption in infancy and at least for boys also in preschool and school age.

Introduction

Although it is well known that a high intake of fruits and vegetables (FV) especially in addition to a high variety reduces the risk of different chronic diseases and cancer (Boeing et al., 2012; World Cancer Research Fund (WCRF) & American Institute for Cancer Research (AICR), 2007), intake is far below recommendations in adults (Mensink et al., 2013) as well as in children (Hilbig et al., 2011; Mensink et al., 2007). Some of the major determinants of a high FV consumption are individual preferences and liking (Krolner et al., 2011; Rasmussen et al., 2006). Given that taste preferences that were built in infancy and childhood track into adulthood (Nicklaus, 2009; Nicklaus et al., 2005), it is important to set the foundations for favourable dietary preferences as early as possible.

Emerging research indicates that the sensory properties of different foods given early in life can shape later taste preferences and food choices (Mennella, 2014). The exposure to different flavour experiences begins as early as in the womb. Flavours of the maternal diet, e.g. garlic or carrot, are transmitted to the foetus via amniotic fluid and later to the infant via breast milk (Mennella & Trabulsi, 2012; Ventura & Worobey, 2013). Breastfed children tend to have a higher vegetable consumption as well as a higher FV (and overall food) variety in childhood (Burnier, Dubois, & Girard, 2011; Scott, Chih, & Oddy, 2012) compared to formula fed infants.

Abbreviations: FV, fruit and vegetable; CF, complementary food; %cCF, percentage of commercial complementary food; DONALD Study, Dortmund Nutritional and Anthropometric Longitudinally Designed Study; FrS, fruit variety score; VegS, vegetable variety score; FrVegS, fruit and vegetable variety score; ALSPAC, Avon Longitudinal Study of Parents and Children.

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With the introduction of complementary food (CF) the spectrum of different flavours and textures increases further. Infants learn to accept unfamiliar foods more easily through repeated exposure and early dietary variety (Maier et al., 2007, 2008; Mennella, 2014; Mennella et al., 2008; Nicklaus, 2011; Remy et al., 2013). However, sensory properties of commercial CF are likely to differ from those of homemade CF by (1) differences in flavour or texture experiences (Birch et al., 1998; Blossfeld et al., 2006; Coulthard, Harris, & Emmett, 2010), (2) multiple combinations of flavours diluting the taste of individual FV (Caton, Ahern, & Hetherington, 2011), (3) a lower exposure to FV (Maier et al., 2007; Mesch et al., 2014) or (4) a combination of all these factors mentioned above.

For this reason, German recommendations on infant feeding state that given their respective advantages and disadvantages, both homemade and commercial CF are equally acceptable alternatives for infant feeding. However, parents are encouraged to not only rely on commercial products as homemade CF provides a broader range of different flavours and textures (Koletzko et al., 2013).

Nevertheless, recent data show that commercial CF dominates complementary feeding in Germany (Foterek, Hilbig, & Alexy, 2014). The overall vegetable variety in German commercial CF is rather low with a total of 16 different vegetables available in retail (compared to 26 different vegetables used in homemade CF) and 60% of commercial CF meals containing carrot as main vegetable (Mesch et al., 2014). Thus, exposure to a broad taste range of different FV across meals during complementary feeding and with this the chance to develop favourable food preferences seems to be rather limited. Moreover, commercial CF contains on average more different vegetables per meal than homemade CF (2.2 vs. 1.6, Mesch et al., 2014) which may impede learning about the particular flavour of single vegetables (Caton et al., 2011).

Therefore, we hypothesized that the extent of total commercial CF consumption and not only the preparation type of FV could affect preference for FV in infancy and beyond. The objective of this study was to examine the short-term and long-term association between the consumption of commercial CF in infancy and FV intake as well as FV variety during infancy, preschool and school age.

Materials and methods

Study population

The current analysis is based on data from the DONALD (DOrtmund Nutritional and Anthropometric Longitudinally Designed) Study, an ongoing open cohort study. Details of the study design have been published elsewhere (Kroke et al., 2004). Briefly, since 1985, detailed information concerning diet, growth, development, and metabolism has been collected in healthy subjects between infancy and early adulthood. Every year, infants are newly recruited and first examined at the age of three months. Each child returns for three more visits in the first year, two in the second, and then annually until young adulthood. The non-invasive assessments include 3-day weighed dietary records, interviews on lifestyle, anthropometric measurements, and a medical examination. The study was approved by the Ethics Committee of the University of Bonn and all examinations are performed with parental written consent.

The inclusion criterion for this analysis was the availability of three pairs of plausible 3-day weighed dietary records at 0.5 and 0.75 (infancy), 3 and 4 (preschool age), 6 and 7 (school age) years of age. Participants who were still fully breast- or formula-fed by the age of 0.5 years were excluded from this analysis (n = 42). Thus, 281 children born between 1985 and 2005 were included in the study sample.

Nutritional assessment

Dietary intake was assessed by 3-day weighed dietary records. The parents of each child were instructed to weigh and record all foods and beverages consumed by their child using electronic food scales (±1g) on three consecutive days. The participants chose the day of the beginning of dietary recording within a given period of time. Also foods and beverages consumed during any type of child care were recorded. Recipes (ingredients and preparation) of homemade CF as well as a detailed description including type and brand of commercial CF were also requested. If exact weighing was not possible, semi-quantitative recording with household measures (e.g. number of glasses, cups, and spoons) was allowed. A trained dietitian visited the family at home and checked the record for accuracy and completeness.

Subsequently, any recorded food or drink was entered into the continuously updated in-house food composition database LEBTAB, which incorporates information from standard nutrient tables. For commercial food products, e.g. commercial CF, energy and nutrient content was estimated using recipe simulation based on the labelled ingredients and nutrients (Sichert-Hellert et al., 2007). Dietary supplements and pharmaceuticals were recorded, too, but excluded from this analysis. Data on total daily energy intake (kcal/d) and food intakes (g/d) were derived for each participant from the mean of the three days of recording.

Infant feeding

CF was defined as all semi-solid, pureed or mashed foods fed with a spoon during complementary feeding. Snack foods intended for infants and toddlers (e.g. biscuits or cereal bars) were not included in the definition of CF due to their solid texture. Commercial CF was defined as all industrially processed, pre-packaged foods (from jars or packets). Homemade CF was defined as all home-prepared semi-solid, pureed or mashed foods made from scratch. If homemade CF was mixed with commercial CF products within a meal (e.g. homemade vegetable puree in combination with a commercial baby-meat jar), the complete meal was categorized according to the preparation method of its fruit or vegetable component. Commercial CF consumption (g/day) was summed up for every record at 0.5 and 0.75 years of age and calculated as percentage of total CF (%cCF) based on weight; subsequently both percentages were averaged for every participant to represent the habitual extent of commercial CF consumption during infancy.

Fruit and vegetable intake and variety

Individual FV intake was calculated as the sum of all recorded FV (including fresh, dried, frozen, and canned products). Nuts, seeds, and herbs were excluded. The FV proportion of composite foods with at least 50% FV content based on weight (e.g. coleslaw, soups) and 100% FV juices were also included in the calculation of FV intake.

To describe FV variety, three variety scores were calculated (Jeurnink et al., 2012). The individual number of different fruits and vegetables respectively, eaten at least once in a 3-day diet record were counted (FrS, VegS) and also summed up for a total score (FrVegS). According to Daniels et al. (2009) only FV with an amount of above 10g were considered for the variety score calculation. In contrast to the calculation of FV amounts, FV juices were excluded from the variety score calculation. To represent FV intake and variety in infancy, preschool, and school age, FV amounts as well as FV variety scores were averaged at 0.5 and 0.75, 3 and 4, 6 and 7 years respectively, for every participant.

Potentially confounding factors

On their child's admission to the study, parents were interviewed about family characteristics (e.g. household size) and were weighed and measured by the study staff. Information on the child's birth characteristics were abstracted from the 'Mutterpass', a standardised document given to all pregnant women in Germany.

For this analysis, the following characteristics were considered as potential confounders: averaged total energy intake (kcal/d) of the child at the respective age, ongoing breastfeeding at 3 and 6 months (yes/no, respectively), date of birth, birth weight (g), being firstborn (yes/no), household size (number of persons), high maternal educational status (≥12 yrs of schooling, yes/no), maternal age at birth (yrs), and maternal overweight (BMI ≥25 kg/m^2, yes/no). For missing values the respective median of the total sample (n = 50 for household size, median 3 (0.5–3 yrs) and 4 persons (4–7 yrs) respectively; n = 3 for maternal overweight, median: 23.4 kg/m^2) was used.

Statistical analyses

SAS® procedures (Version 9.1.3; Statistical Analysis System, Cary, NC, USA) were used for all data analyses. Descriptive data are presented as frequencies, means with standard deviation or medians with inter-quartile range in the case of skewed data. P values less than 0.05 were considered as significant.

As the outcome variables were not normally distributed, intake and score values were transformed prior to analysis to obtain normal distribution using appropriate mathematical procedures. Multivariate linear regression analyses (PROC GLM in SAS) were used to analyse associations between %cCF during infancy and FV intake as well as FV variety scores during infancy and prospectively at preschool and school age. Since there were no significant interactions between gender and %cCF in FV variety but several in FV intake, we decided to stratify all models of FV intake by gender to maintain comparability. Results are presented as adjusted means in tertiles of %cCF. The basic models for both intake and variety scores were adjusted for total energy intake (kcal/d) and date of birth. As data from girls and boys were pooled in the FV variety models, sex was added in these basic models. For the fully adjusted models each potential confounder was initially considered separately and only those variables that (1) had a significant, independent effect on the outcome variable, (2) modified regression coefficients (β) in the basic models by ≥5%, or (3) led to an improvement of the coefficient of determination (R^2) by ≥10% (Maldonado & Greenland, 1993) were considered in the final models.

Results

Study sample characteristics

Descriptive data on the study sample are presented in Table 1. The current analysis included 132 girls (47%) and 149 (53%) boys. Mean birth weight-SDS of the children of our sample was slightly higher than that of the German reference population. Three quarters of the participants received any breast milk at 3 months of age; more than half of them were still partially breastfed at 6 months. Median birth year was 1997, with 65% being the firstborn child in their family. Mean maternal age at birth was 32.5 years with nearly 30% of the mothers being overweight and almost 70% having a high educational level. Low and high commercial CF consumers did not differ in any of these characteristics except energy intake in infancy (Supplementary Table S1).

The median %cCF during infancy (0.5 and 0.75 yrs) was 58.7%. Fourteen participants received no commercial CF in both records at all, whereas 12 consumed commercial CF exclusively (data not shown). As both extremes reflect common dietary practices those participants were included into the analysis.

Table 2 shows that total FV intake increased with age from 162g/d (infancy) to 355g/d (school age, p < 0.0001). In all age groups, fruit intake was higher than vegetable intake (p < 0.0001). Boys had a higher FV juice intake (p < 0.015) as well as higher total FV intake (including juices, p < 0.012) in all three age groups than girls.

Regarding FV variety, total FrVegS increased with age from 4.5 in infancy to 6.5 at school age (p < 0.0001, Table 3). Vegetable variety was higher than fruit variety across all age groups (p < 0.0001). There were no significant gender differences in any variety score (data not shown).

Commercial CF and FV intake and variety during infancy

In girls as well as in boys, a higher %cCF was strongly associated with a lower vegetable intake (p < 0.0001, Table 4). Additionally, a higher %cCF in boys was associated with a lower total FV intake (p = 0.024), but only in the basic model. For girls, a positive

Table 1
Characteristics of 281 participants of the Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) Study.

Variables	Values
Female, n	132 (47.0%)
Early life characteristics	
Birth weight, g	3456 ± 486
Birth weight-SDS[a]	0.22 ± 1.00
Birth year	1997 (1993; 2002)
Breastfed at 3 months, n	211 (75.1%)
Breastfed at 6 months, n	158 (56.2%)
Family characteristics	
Firstborn, n	182 (64.8%)
Household size, n persons	3.2 ± 0.5
Maternal age at birth, years	32.5 ± 3.6
Maternal overweight[b], n	82 (29.2%)
High maternal educational status[c], n	194 (69.0%)

Values are medians (Q1; Q3), means ± SD or frequencies.
[a] Calculated using the German sex- and age-specific percentiles by Kromeyer-Hauschild et al. (2001).
[b] BMI ≥25 kg/m^2.
[c] ≥12 years of schooling.

Table 2
Fruit and vegetable (FV) intake of 281 participants of the Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) study in infancy, preschool, and school age [Median (Q1; Q3)].

	Infancy (0.5–0.75 years)			Preschool age (3–4 years)			School age (6–7 years)		
	All	Girls (n = 132)	Boys (n = 149)	All	Girls (n = 132)	Boys (n = 149)	All	Girls (n = 132)	Boys (n = 149)
Total FV intake[a] [g/d]	162 (108; 216)	145 (104; 196)	168 (126; 234)	315 (239; 450)	283 (233; 403)	328 (253; 501)	355 (250; 486)	330 (241; 429)	399 (259; 516)
Fruit [g/d]	69 (47; 104)	61 (42; 88)	82 (53; 117)	100 (65; 150)	103 (65; 142)	98 (66; 155)	113 (70; 162)	113 (78; 154)	113 (61;168)
Vegetable [g/d]	45 (21; 72)	47 (23; 68)	43 (18; 78)	60 (39; 82)	62 (39; 85)	58 (40; 79)	79 (53; 114)	88 (56; 116)	73 (51; 107)
FV juice [g/d]	30 (13; 55)	25 (11; 47)	36 (19; 65)	140 (79; 234)	126 (59; 191)	178 (89; 291)	134 (52; 262)	108 (46; 215)	152 (66; 300)

[a] Including FV juices.

Table 3
Fruit and vegetable (FV) variety scores of 281 participants of the Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) study in infancy, preschool, and school age [Median (Q1; Q3)].

	Infancy (0.5–0.75 years)	Preschool age (3–4 years)	School age (6–7 years)
Fruit and vegetable variety score[a] (FrVegS)	4.5 (3.0; 6.0)	6.0 (4.5; 8.0)	6.5 (5.0; 8.0)
Fruit variety score[a] (FrS)	2.0 (1.5; 3.0)	2.5 (2.0; 3.5)	2.5 (1.5; 3.5)
Vegetable variety score[a] (VegS)	2.5 (1.5; 3.0)	3.5 (2.5; 4.5)	3.5 (3.0; 5.0)

[a] Score includes total number of different fruits and vegetables, respectively (>10g) eaten at least once in a 3-day diet record (Daniels et al., 2009; Jeurnink et al., 2012).

association between %cCF and FV juice intake ($p = 0.001$) was found.

Regarding the variety scores, data from girls and boys were taken together in one model. While total FV and fruit variety scores showed a significant positive association with %cCF in the basic models ($p < 0.05$) meaning that a higher commercial CF proportion is related to a higher FV variety in infancy; both associations did not stay significant in the fully adjusted models (Table 5).

Commercial CF and FV intake and variety in childhood

In our sample, no associations between %cCF in infancy and later FV intake in preschool or school age could be found in the fully adjusted models for girls (Table 4). For boys, there was an inverse relationship between %cCF and total FV intake as well as FV juice intake ($p < 0.017$) in preschool and school age. Thus, the boys' tertile with the highest commercial CF consumption had a significantly lower total FV intake as well as a lower FV juice intake in preschool and school age than those with a low commercial CF consumption. For boys at preschool age, a higher %cCF was also associated with a lower vegetable intake ($p = 0.036$).

There were no significant prospective associations between %cCF and FV variety at preschool or school age (Table 5). Solely, the vegetable variety score at school age decreased with higher %cCF ($p = 0.029$).

Discussion

Our data from the DONALD study suggest that the consumption of commercial CF is associated with FV consumption in infancy and beyond. For boys, a higher commercial CF proportion was associated with lower vegetable intake in infancy and preschool age as well as lower total FV intake in preschool and school age. The latter might be at least to some extent due to the notable differences in FV juice intake in these age groups. For girls, higher commercial CF proportion was associated with lower vegetable intake as well as higher juice intake in infancy, whereas no prospective association could be observed. With respect to variety, no clear associations could be found, except for the fact that a higher commercial CF proportion was related to a higher vegetable variety in school age.

Table 4
Associations between percentage of commercial complementary food (%cCF) in infancy and fruit and vegetable (FV) intake (g/d) in infancy, preschool, and school age (basic and fully adjusted regression models).

	Infancy (0.5–0.75 years)				Preschool age (3–4 years)				School age (6–7 years)			
	T1	T2	T3	$p_{for\ trend}$	T1	T2	T3	$p_{for\ trend}$	T1	T2	T3	$p_{for\ trend}$
GIRLS												
FV intake[a] (g/d)												
Basic model	147.6	156.1	139.0	0.414	280.9	297.9	302.6	0.732	302.5	369.5	313.4	0.096
Fully adjusted model	151.6	158.9	137.9	0.272	265.7	277.7	290.9	0.673	282.1	346.6	301.7	0.129
Fruit intake (g/d)												
Basic model	67.0	64.0	65.0	0.935	95.5	111.6	100.0	0.425	102.1	125.1	113.5	0.191
Fully adjusted model	65.9	62.5	61.6	0.860	88.8	101.8	97.1	0.571	101.1	121.9	112.5	0.279
Vegetable intake (g/d)												
Basic model	60.9	42.9	32.1	<0.0001	64.8	63.6	57.3	0.473	86.7	84.7	82.5	0.916
Fully adjusted model	60.6	43.1	32.1	<0.0001	65.3	62.7	56.7	0.437	84.1	80.5	80.2	0.913
FV juice intake (g/d)												
Basic model	13.2	35.9	29.2	0.0003	106.2	115.6	128.1	0.656	85.9	145.9	92.3	0.041
Fully adjusted model	14.2	35.7	27.9	0.001	91.7	100.6	117.9	0.528	69.0	124.0	82.2	0.054
BOYS												
FV intake[a] (g/d)												
Basic model	193.0	172.9	147.8	0.024	400.1	349.2	302.7	0.016	446.2	337.5	375.5	0.020
Fully adjusted model	191.0	166.7	155.4	0.103	409.5	349.2	295.4	0.004	453.6	334.6	362.8	*0.009*
Fruit intake (g/d)												
Basic model	76.2	85.3	74.7	0.502	114.0	102.1	96.0	0.361	102.5	119.1	115.5	0.505
Fully adjusted model	75.9	83.1	78.9	*0.788*	115.2	100.2	94.8	0.288	109.8	125.1	114.4	0.600
Vegetable intake (g/d)												
Basic model	73.0	39.7	24.4	<0.0001	68.2	53.5	55.2	0.041	88.2	73.2	76.2	0.243
Fully adjusted model	71.1	36.5	26.0	<0.0001	70.1	54.9	56.5	0.036	82.9	68.9	74.2	0.331
FV juice intake (g/d)												
Basic model	30.8	34.3	39.5	0.540	212.3	179.8	133.8	0.033	220.8	124.1	144.5	0.016
Fully adjusted model	35.1	34.3	46.5	0.261	220.5	177.6	129.4	0.017	222.1	112.3	124.2	0.003

Data are presented as adjusted means by tertiles of percentage of commercial complementary food (%cCF). Basic models: adjusted for total energy intake [kcal/d] and date of birth. Final models: basic model + adjustment for all other potentially confounding factors (ongoing breastfeeding at 3 and 6 months [y/n, respectively], birth weight [g], being firstborn [y/n], household size [n persons], high maternal educational status [≥12 years of schooling, y/n], maternal age at birth [years], and maternal overweight [BMI ≥25 kg/m^2, y/n]) that had a significant, independent effect on the outcome variable, modified regression coefficients (β) in the basic models by ≥5%, or led to an improvement of the coefficient of determination (R^2) by ≥10% (Maldonado & Greenland, 1993).

[a] Including FV juices.

Table 5
Associations between percentage of commercial complementary food (%cCF) in infancy and fruit and vegetable (FV) variety scores in infancy, preschool, and school age (basic and fully adjusted regression models).

	Infancy (0.5–0.75 years)				Preschool age (3–4 years)				School age (6–7 years)			
	T1	T2	T3	$p_{for\ trend}$	T1	T2	T3	$p_{for\ trend}$	T1	T2	T3	$p_{for\ trend}$
Fruit and vegetable variety score[a] (FrVegS)												
Basic model	4.25	4.76	4.89	0.019	6.37	6.05	5.80	0.183	6.81	6.55	6.37	0.419
Fully adjusted model	4.48	4.96	4.96	0.055	6.30	5.94	5.72	0.181	6.68	6.32	6.25	0.378
Fruit variety score[a] (FrS)												
Basic model	1.94	2.24	2.30	0.0498	2.85	2.75	2.53	0.248	2.43	2.74	2.49	0.287
Fully adjusted model	2.06	2.36	2.32	0.098	2.71	2.60	2.39	0.247	2.45	2.72	2.47	0.359
Vegetable variety score[a] (VegS)												
Basic model	2.09	2.26	2.38	0.113	3.55	3.36	3.28	0.376	4.17	3.64	3.66	0.029
Fully adjusted model	2.21	2.36	2.42	0.284	3.54	3.35	3.25	0.366	3.99	3.43	3.55	0.029

Data are presented as adjusted means by tertiles of percentage of commercial complementary food (%cCF). Basic models: adjusted for total energy intake [kcal/d], sex, and date of birth. Final models: basic model + adjustment for all other potentially confounding factors (ongoing breastfeeding at 3 and 6 months [y/n, respectively], birth weight [g], being firstborn [y/n], household size [n persons], high maternal educational status [≥12 years of schooling, y/n], maternal age at birth [years], and maternal overweight [BMI ≥25 kg/m^2, y/n]) that had a significant, independent effect on the outcome variable, modified regression coefficients (β) in the basic models by ≥5%, or led to an improvement of the coefficient of determination (R^2) by ≥10% (Maldonado & Greenland, 1993).

[a] Score includes total number of different fruits and vegetables respectively (>10g) eaten at least once in a 3-day diet record (Daniels et al., 2009; Jeurnink et al., 2012).

One of the most consistent results of this study is that the proportion of cCF% in infancy is associated with lower vegetable intake at the same age. This raises the obvious question, whether it is the high commercial CF consumption that determines later FV intake or rather the early low vegetable consumption that tracks into childhood. However, our observational study design is not able to conclusively answer this question.

In general, absolute FV intake was low in this sample, which is in line with other national and international findings of FV consumption in infants and children (Fox et al., 2010; Hilbig et al., 2011; Mensink et al., 2007; Siega-Riz et al., 2010). Given that taste is a main reason for not liking FV (Krolner et al., 2011), especially the general low intake of vegetables could at least to some extent be explained by the inborn taste preferences with children preferring sweet and salty rather than bitter and sour tastes (Mennella, 2014). Given that children's food preferences are not only influenced by genetic but also environmental factors (Fildes et al., 2014; Mennella, 2014), they can still be modified by caregivers during infancy and early childhood. One of the main influencing factors is the repeated exposure of unknown (or initially disliked) foods that begins already via amniotic fluid and continues via breast milk and CF. Also the variety of foods introduced during complementary feeding as well as sensory properties of those foods (texture, taste and flavours) facilitate the development of food acceptance at the beginning of complementary feeding (Mennella, 2014; Nicklaus, 2011). In Germany, complementary feeding usually starts with a single vegetable mash (mostly carrot). Especially vegetables offer a high potential of flavour variety and therefore the opportunity to get used to the taste of FV early in life depending on whether they are cooked from fresh products providing a broader range of flavours similar to that of fresh table foods or commercially prepared with a rather uniform taste and texture (Coulthard et al., 2010).

However, very few studies have analysed the relationship between early infant feeding and later FV intake or FV variety to date. Burnier et al. (2011) showed that children's vegetable intake at 4 years of age was influenced by exclusive breastfeeding duration. Besides flavour experiences transmitted via breast milk, there is also a suggested association between early FV feeding and later FV consumption. In the Avon Longitudinal Study of Parents and Children (ALSPAC), the frequency of home-cooked, but not ready-prepared FV consumption at 6 months was positively associated with FV intake and variety at 7 years of age (Coulthard et al., 2010). Given that FV are not only consumed separately but also as part of a whole meal or the entire diet our analysis followed the rather holistic approach of using percentage of commercial CF as an indicator for the general quality of CF. Thus, data from the DONALD study provide further evidence for possible long-term differences in FV intake with respect not only to early FV but also overall CF preparation methods at least in boys.

Apart from that gender is known to be a strong influencing factor on FV consumption and this effect already occurs during childhood with girls eating more FV than boys (Brug et al., 2008; Rasmussen et al., 2006). However, reasons for this are not yet fully understood (Bere, Brug, & Klepp, 2007). Since our sample showed significant interactions between percentage of commercial CF and FV intake those analyses were stratified by gender. Although several studies report gender differences in breastfeeding and complementary feeding practices with boys being breastfed for shorter periods than girls and more often introduced to solid foods early (Alder et al., 2004; Pande, Unwin, & Haheim, 1997; Wright, Parkinson, & Drewett, 2004), possible explanations remain hypothetical in this context, especially since breastfeeding and complementary feeding practices did not differ between boys and girls in the present sample. For boys, different flavour experiences in CF may have more potential to shape favourable food preferences and consumption patterns in the long-term. One can only assume that for girls, other factors apart from infant feeding practices like home accessibility, different maternal feeding styles or role models might play an important role in later FV acceptance and intake (Bere et al., 2007; Faith et al., 2004) and therefore rule out the rather small effect that the preparation method of CF might have.

As stated in the introduction data about FV variety in commercial CF is limited and rather inconsistent. In a cross-sectional US survey of a low income population, those infants receiving commercial CF consumed a larger variety of FV (Hurley & Black, 2010). This is supported by recent data from the DONALD Study showing that vegetable variety with 12 (but not with 6 or 9) months of age was higher in infants fed commercial CF (Mesch et al., 2014). However, in the present analysis, the positive associations between the commercial CF proportion and total FV variety as well as fruit variety were no longer significant after adjustment. Thus, we cannot conclude that the effect of commercial CF on later FV intake is an effect of exposure to a low FV variety in infancy.

To the best of our knowledge there is only one study focusing on prospective relationships between early feeding practices and FV variety. In Australian children, total breastfeeding duration was associated with total food variety as well as FV variety at 2 years of age (Scott et al., 2012). While the different flavours transmitted via breast milk tend to affect later food acceptance and variety, the later occurring flavour experiences of CF seem to have no or only minor influences on children's FV variety according to our findings.

A major strength of this analysis is the well-established design of the DONALD Study allowing both cross-sectional as well as prospective analyses on children's food intake. However, our study is neither designed to compare the effect of different influences on FV consumption nor to identify which properties of commercial CF explain the found associations that might as well not even be causal. Still, this rather explorative analysis provides important indications for further studies that may have the ability to look closer into causality.

The strengths of our analysis also include the detailed dietary assessment and the comprehensive food composition database. The intake data from 3-day weighed dietary records is more reliable than those from FFQs or 24 h recalls that were used in other studies on that topic (e.g. Coulthard et al., 2010; Hurley & Black, 2010; Scott et al., 2012) regarding the consumed amounts of CF and FV. Furthermore, our in-house food composition database LEBTAB allows the differentiation between homemade and commercial CF. In addition, all composite commercial products can be broken down into single ingredients on the basis of the integrated recipe simulation procedure (Sichert-Hellert et al., 2007).

Given that breastfeeding is a strong influencing factor on later FV intake and variety (Burnier et al., 2011; de Lauzon-Guillain et al., 2013; Scott et al., 2012), another advantage of this analysis is the inclusion of breastfeeding data in the models. Especially, in the variety models, breastfeeding proved to be an important confounding factor that we were able to adjust for. Other potential confounders as the age of introduction of either CF in general or FV in particular were not assessed continuously in this study sample. However, literature states that the introduction of FV does not have a clear consistent effect on the later FV intake in childhood (de Lauzon-Guillain et al., 2013; Nicklaus, 2011).

Also parents' consumption of FV was not assessed in the DONALD Study and could therefore not have been taken into account, although it is known to be a strong determinant of children's FV consumption. However, this influence might to some extent also be mediated through home availability and accessibility (Rasmussen et al., 2006). Food choices of preschool and school aged children are still somewhat limited depending on the FV amount and variety purchased and provided by their parents.

Although 3-day weighed diet records have their advantages in assessing food amounts, it is not the preferred assessment method to determine food variety. To ease the burden of recording total food intake, the same foods and meals could have been fed during the whole record period for practical reasons (Mesch et al., 2014). Also seasonal variations in FV variety could not be captured by the diet records. Thus, FV variety especially in homemade CF may be underestimated in this sample.

Further, the generalizability of our results may be limited due to the fact that participants in the DONALD study are characterised by their relatively high educational and socioeconomic status (Kroke et al., 2004). Usually, a lower socio-economic background is associated with a lower or less frequent FV intake (Rasmussen et al., 2006). Also, the preparation method of CF differs with regard to the educational status of the mother (Foterek et al., 2014). Thus, the associations found here may look different in the general population.

Conclusion

Overall, our data suggest that the preparation method of CF is associated with FV consumption in infancy and at least for boys also in preschool and school age. Although these associations are only explorative and not necessarily causal, they underpin the importance of different sensory experiences with varying flavours and textures as well as a high FV variety during infancy to facilitate FV acceptance during infancy and beyond. Thus, infant feeding guidelines should put more emphasis on a high variety of FV within and between meals during complementary feeding. Offering homemade CF can therefore help to provide a higher FV variety with a broader natural flavour and texture variation due to seasonal changes or different cooking methods. As dietary patterns and food preferences at infancy and toddler age track into childhood and early adult life (Nicklaus, 2009; Nicklaus et al., 2005), it is important to set the foundations for a high FV intake already during infancy.

References

Alder, E. M., Williams, F. L., Anderson, A. S., et al. (2004). What influences the timing of the introduction of solid food to infants? *The British Journal of Nutrition*, *92*(3), 527–531.

Bere, E., Brug, J., & Klepp, K. I. (2007). Why do boys eat less fruit and vegetables than girls? *Public Health Nutrition*, *11*(3), 321–325.

Birch, L. L., Gunder, L., Grimm-Thomas, K., et al. (1998). Infants' consumption of a new food enhances acceptance of similar foods. *Appetite*, *30*(3), 283–295.

Blossfeld, I., Collins, A., Kiely, M., et al. (2006). Texture preferences of 12-month-old infants and the role of early experiences. *Food Quality and Preference*, *18*, 396–404.

Boeing, H., Bechthold, A., Bub, A., et al. (2012). Critical review. Vegetables and fruit in the prevention of chronic diseases. *European Journal of Nutrition*, *51*(6), 637–663.

Brug, J., Tak, N. I., te Velde, S. J., et al. (2008). Taste preferences, liking and other factors related to fruit and vegetable intakes among schoolchildren. Results from observational studies. *The British Journal of Nutrition*, *99*(Suppl. 1), S7–S14.

Burnier, D., Dubois, L., & Girard, M. (2011). Exclusive breastfeeding duration and later intake of vegetables in preschool children. *European Journal of Clinical Nutrition*, *65*(2), 196–202.

Caton, S. J., Ahern, S. M., & Hetherington, M. M. (2011). Vegetables by stealth. An exploratory study investigating the introduction of vegetables in the weaning period. *Appetite*, *57*(3), 816–825.

Coulthard, H., Harris, G., & Emmett, P. (2010). Long-term consequences of early fruit and vegetable feeding practices in the United Kingdom. *Public Health Nutrition*, *13*(12), 2044–2051.

de Lauzon-Guillain, B., Jones, L., Oliveira, A., et al. (2013). The influence of early feeding practices on fruit and vegetable intake among preschool children in 4 European birth cohorts. *The American Journal of Clinical Nutrition*, *98*(3), 804–812.

Daniels, M. C., Adair, L. S., Popkin, B. M., et al. (2009). Dietary diversity scores can be improved through the use of portion requirements. An analysis in young Filipino children. *European Journal of Clinical Nutrition*, *63*(2), 199–208.

Faith, M. S., Scanlon, K. S., Birch, L. L., et al. (2004). Parent-child feeding strategies and their relationships to child eating and weight status. *Obesity Research*, *12*(11), 1711–1722.

Fildes, A., van Jaarsveld, C. H., Llewellyn, C. H., et al. (2014). Nature and nurture in children's food preferences. *The American Journal of Clinical Nutrition*, *99*(4), 911–917.

Foterek, K., Hilbig, A., & Alexy, U. (2014). Breastfeeding and weaning practices in the DONALD study. Age and time trends. *Journal of Pediatric Gastroenterology and Nutrition*, *58*, 361–367.

Fox, M. K., Condon, E., Briefel, R. R., et al. (2010). Food consumption patterns of young preschoolers. Are they starting off on the right path? *Journal of the American Dietetic Association*, *110*(12 Suppl.), S52–S59.

Hilbig, A., Alexy, U., Drossard, C., et al. (2011). GRETA. Ernährung von Kleinkindern in Deutschland. [German representative study of toddler alimentation]. *Aktuel Ernaehrungsmed*, *36*, 224–231.

Hurley, K. M., & Black, M. M. (2010). Commercial baby food consumption and dietary variety in a statewide sample of infants receiving benefits from the special supplemental nutrition program for women, infants, and children. *Journal of the American Dietetic Association*, *110*(10), 1537–1541.

Jeurnink, S. M., Buchner, F. L., Bueno-de-Mesquita, H. B., et al. (2012). Variety in vegetable and fruit consumption and the risk of gastric and esophageal cancer in the European Prospective Investigation into Cancer and Nutrition. *International Journal of Cancer*, *131*(6), E963–E973.

Koletzko, B., Bauer, C. P., Brönstrup, A., et al. (2013). Säuglingsernährung und Ernährung der stillenden Mutter. Aktualisierte Handlungsempfehlungen des Netzwerk Gesund ins Leben. Netzwerk Junge Familie, ein Projekt von IN FORM. [Infant nutrition and nutrition for breastfeeding mothers. Updated practice recommendations of the network "Healthy Start. Young Family Network" a project of IN FORM]. *Monatsschrift fur Kinderheilkunde*, *137*(24), 1309–1314.

Kroke, A., Manz, F., Kersting, M., et al. (2004). The DONALD Study. History, current status and future perspectives. *European Journal of Nutrition*, *43*(1), 45–54.

Krolner, R., Rasmussen, M., Brug, J., et al. (2011). Determinants of fruit and vegetable consumption among children and adolescents. A review of the literature. Part II. Qualitative studies. *The International Journal of Behavioral Nutrition and Physical Activity*, *8*, 112.

Kromeyer-Hauschild, K., Wabitsch, M., Kunze, D., et al. (2001). Perzentile für den Body-mass-Index für das Kindes- und Jugendalter unter Heranziehung verschiedener deutscher Stichproben. [Percentiles of body mass index in children

and adolescents evaluated from different regional German studies]. *Monatsschrift fur Kinderheilkunde*, *149*(8), 807–818.
Maier, A., Chabanet, C., Schaal, B., et al. (2007). Effects of repeated exposure on acceptance of initially disliked vegetables in 7-month old infants. *Food Quality and Preference*, *18*(8), 1023–1032.
Maier, A. S., Chabanet, C., Schaal, B., et al. (2008). Breastfeeding and experience with variety early in weaning increase infants' acceptance of new foods for up to two months. *Clinical Nutrition (Edinburgh, Scotland)*, *27*(6), 849–857.
Maldonado, G., & Greenland, S. (1993). Simulation study of confounder-selection strategies. *American Journal of Epidemiology*, *138*(11), 923–936.
Mennella, J. A. (2014). Ontogeny of taste preferences. Basic biology and implications for health. *The American Journal of Clinical Nutrition*, *99*(3), S704–S711.
Mennella, J. A., Nicklaus, S., Jagolino, A. L., et al. (2008). Variety is the spice of life. Strategies for promoting fruit and vegetable acceptance during infancy. *Physiology and Behavior*, *94*(1), 29–38.
Mennella, J. A., & Trabulsi, J. C. (2012). Complementary foods and flavor experiences. Setting the foundation. *Annals of Nutrition and Metabolism*, *60*(Suppl. 2), 40–50.
Mensink, G. B. M., Heseker, H., Richter, A., et al. (2007). Forschungsbericht Ernährungsstudie als KiGGS-Modul (EsKiMo). <https://www.bmel.de/SharedDocs/Downloads/Ernaehrung/EsKiMoStudie.pdf?__blob=publicationFile> Last accessed 20.11.14.
Mensink, G. B., Truthmann, J., Rabenberg, M., et al. (2013). Obst- und Gemüsekonsum in Deutschland. Ergebnisse der Studie zur Gesundheit Erwachsener in Deutschland (DEGS1). [Fruit and vegetable intake in Germany. Results of the German Health Interview and Examination Survey for Adults (DEGS1)]. *Bundesgesundhbl Gesundheitsforsch Gesundheitsschutz*, *56*(5–6), 779–785.
Mesch, C. M., Stimming, M., Hilbig, A., et al. (2014). Food variety in commercial and homemade complementary meals for infants in Germany. Market survey and dietary practice. *Appetite*, *76*, 113–119.
Nicklaus, S. (2009). Development of food variety in children. *Appetite*, *52*(1), 253–255.
Nicklaus, S. (2011). Children's acceptance of new foods at weaning. An easy guide to introducing solid foods. *Appetite*, *57*(3), 812–815.
Nicklaus, S., Boggio, V., Chabanet, C., et al. (2005). A prospective study of food variety seeking in childhood, adolescence and early adult life. *Appetite*, *44*(3), 289–297.
Pande, H., Unwin, C., & Haheim, L. L. (1997). Factors associated with the duration of breastfeeding. Analysis of the primary and secondary responders to a self-completed questionnaire. *Acta Paediatrica*, *86*(2), 173–177.
Rasmussen, M., Krolner, R., Klepp, K. I., et al. (2006). Determinants of fruit and vegetable consumption among children and adolescents. A review of the literature. Part I. Quantitative studies. *The International Journal of Behavioral Nutrition and Physical Activity*, *3*, 22.
Remy, E., Issanchou, S., Chabanet, C., et al. (2013). Repeated exposure of infants at complementary feeding to a vegetable puree increases acceptance as effectively as flavor-flavor learning and more effectively than flavor-nutrient learning. *The Journal of Nutrition*, *143*(7), 1194–1200.
Scott, J. A., Chih, T. Y., & Oddy, W. H. (2012). Food variety at 2 years of age is related to duration of breastfeeding. *Nutrients*, *4*(10), 1464–1474.
Sichert-Hellert, W., Kersting, M., Chahda, C., et al. (2007). German food composition database for dietary evaluations in children and adolescents. *J Food Compos Analy*, *20*(1), 63–70.
Siega-Riz, A. M., Deming, D. M., Reidy, K. C., et al. (2010). Food consumption patterns of infants and toddlers. Where are we now? *Journal of the American Dietetic Association*, *110*(12 Suppl.), S38–S51.
Ventura, A. K., & Worobey, J. (2013). Early influences on the development of food preferences. *Current Biology*, *23*(9), R401–R408.
World Cancer Research Fund (WCRF) & American Institute for Cancer Research (AICR). (2007). Food, nutrition, physical activity, and the prevention of cancer. A global perspective. <http://www.dietandcancerreport.org/cancer_resource_center/downloads/Second_Expert_Report_full.pdf> Last accessed 20.11.14.
Wright, C. M., Parkinson, K. N., & Drewett, R. F. (2004). Why are babies weaned early? Data from a prospective population based cohort study. *Archives of Disease in Childhood*, *89*(9), 813–816.

Appendix: Supplementary material

Supplementary data to this article can be found online at doi:10.1016/j.appet.2014.11.015.

3.3

British Journal of Nutrition, page 1 of 8
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Commercial complementary food consumption is prospectively associated with added sugar intake in childhood

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Abstract

Given that commercial complementary food (CF) can contain high levels of added sugar, a high consumption may predispose to a preference for sweet taste later in life. This study examined cross-sectional associations between commercial CF consumption and added sugar intake in infancy as well as its prospective relation to added sugar intake in pre-school and primary-school age children. In all, 288 children of the Dortmund Nutritional and Anthropometric Longitudinally Designed Study with 3-d weighed dietary records at 0·5 and 0·75 (infancy), 3 and 4 (pre-school age) and 6 and 7 years of age (primary-school age) were included in this analysis. Individual commercial CF consumption as percentage of total commercial CF (%cCF) was averaged at 0·5 and 0·75 years. Individual total added sugar intake (g/d, energy percentage/d) was averaged for all three age groups. Multivariable logistic and linear regression models were used to analyse associations between %cCF and added sugar intake. In infancy, a higher %cCF was associated with odds for high added sugar intake from CF and for high total added sugar intake (>75th percentile, $P<0·033$). Prospectively, a higher %cCF was related to higher added sugar intake in both pre-school ($P<0·041$) and primary-school age children ($P<0·039$), although these associations were attenuated in models adjusting for added sugar intake in infancy. A higher %cCF in infancy may predispose to higher added sugar intake in later childhood by virtue of its added sugar content. Therefore, offering home-made CF or carefully chosen commercial CF without added sugar might be one strategy to reduce sugar intake in infancy and later on.

Key words: Infant feeding: Commercial complementary foods: Home-made complementary foods: Added sugar: Sweet preference

British Journal of Nutrition

High intakes of dietary sugar are extensively discussed to have adverse health consequences. Concerns relating to high sugar intakes comprise its contribution to the development of dental caries, excess weight gain, type 2 diabetes and CVD, as well as a lower nutritional adequacy of the diet, as added sugar itself does not provide essential nutrients[1–4]. Therefore, current dietary guidelines do emphasise the limitation of dietary sugar intake, focusing on the avoidance of sugar added during processing (added sugar) rather than sugars naturally occurring in foods[5]. More recently, the World Health Organization[4] published new guidelines now setting a population goal <10 energy percentage (En%) for free sugars (added sugars + sugars naturally present in fruit juices and fruit juice concentrates) and a conditional recommendation to further limit free sugar intake <5 En% to achieve additional health benefits.

It is therefore of relevance to investigate factors shaping added sugar intake levels already in childhood. Although humans are born with a natural preference for sweet taste, which continues into childhood but then attenuates in adolescence and adulthood[6–8], children's liking of sweet-tasting foods is not solely a consequence of their inborn taste preferences. Sensory properties of foods given early in life and repeated exposure to specific flavours can shape later taste preferences and food choice[6–8]. Apart from early exposure to a variety of flavours transmitted via amniotic fluid or breast milk[6,9], flavour experiences from complementary food (CF) might also shape long-term dietary behaviour[10,11]. Added sugar content of CF may thus represent a relevant modifiable factor shaping long-term sweet preference.

Although there is a broad consensus in infant feeding recommendations that CF should contain preferably no or only a minimum level of added sugar or other sweeteners[12,13], commercial CF, that is, the main source of CF[14], and commercial toddler foods can contain high levels of (added)

Abbreviations: %cCF, percentage of commercial complementary food; CF, complementary food; DONALD Study, Dortmund Nutritional and Anthropometric Longitudinally Designed Study; En%, energy percentage.

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sugar[15–20], although a detailed representative survey is lacking. This may entail the development of less-favourable taste and food preferences in contrast to a weaning diet concentrating on home-made CF.

We thus hypothesised that a higher consumption of commercial CF and the concomitant early exposure to added sugar in infancy may predispose to higher intakes of added sugar in later childhood. To address this hypothesis, the cross-sectional associations between commercial CF consumption and total added sugar intake in infancy as well as the prospective relation to added sugar intake in pre-school and primary-school age were investigated.

Methods

Study design and population

The current analysis is based on data from the DOrtmund Nutritional and Anthropometric Longitudinally Designed (DONALD) Study, an ongoing open-cohort study. Details of the study design have been described previously[21]. In brief, as recruitment began in 1985, detailed information concerning diet, growth, development and metabolism has been collected in healthy subjects between infancy and early adulthood. Every year, approximately forty infants are newly recruited and first examined at the age of 3 months. Each child returns for three more visits in the 1st year, two in the 2nd year and then annually until young adulthood. The non-invasive assessments include 3-d weighed dietary records, interviews on lifestyle, anthropometric measurements and a medical examination. The study was approved by the Ethics Committee of the University of Bonn, and all examinations were performed with parental written consent and later on with the children's consent[21].

The inclusion criterion for this analysis was the availability of three pairs of plausible 3-d weighed dietary records at 0·5 and 0·75 (infancy), 3 and 4 (pre-school age), and 6 and 7 (primary-school age) years of age. As the starting study sample included children and adolescents between the age of 2 and 18 years, data for the first few years of life were not always available[21]. In addition, many recruited children have not yet reached 7 years of age. Participants who were still fully breast- or formula-fed at the age of 0·5 years were excluded from this analysis (*n* 46). Thus, 288 children born between 1985 and 2007 were included in the study sample.

Nutritional assessment

Dietary intake was assessed by using 3-d weighed dietary records. The parents of each child were instructed to weigh and record all foods and beverages consumed by their child using electronic food scales (±1 g) on 3 consecutive days. The participants chose the day of the beginning of dietary recording within a given period of time. Moreover, foods and beverages consumed during any type of child care were recorded. Recipes (ingredients and preparation) of home-made CF as well as a detailed description including the type and brand of commercial CF were also requested. If exact weighing was not possible, semi-quantitative recording with household measures (e.g. number of glasses, cups and spoons) was allowed. A trained dietitian visited the family at home and checked the dietary records for accuracy and completeness.

Subsequently, any recorded food or drink was entered into the continuously updated in-house food composition database LEBTAB, which incorporates information from standard nutrient tables. For commercial food products, for example, commercial CF, energy and nutrient contents were estimated using recipe simulation based on the labelled ingredients and nutrients. As the labelled ingredients are listed in decreasing order of their weight in the final product, they allow quantitative estimations of their amounts. A deviation lower than ±5 % of the food's calculated nutrient content from the labelled content was accepted. Any new food product that already exists in the database, but has changed in composition (e.g. new ingredients, fortification), received a new food code with a new simulation[22].

Infant feeding

CF was defined as all semi-solid, puréed or mashed foods fed using a spoon during infancy. Commercial CF was defined as all industrially processed, pre-packaged, CF foods (from jars or packets). Home-made CF was defined as all self-prepared, semi-solid, puréed or mashed foods made from scratch[10,14]. If home-made CF was consumed together with commercial CF products within a meal (e.g. home-made vegetable purée in combination with a commercial baby-meat jar), the individual ingredients were assigned to their respective preparation methods. Snack foods intended for infants and toddlers (e.g. biscuits or cereal bars) were not included in the definition of CF (exposure variable) because of the only minor differences in taste and texture between commercial and home-made products. For the purpose of this analysis, snack foods were considered as table foods, and thus still accounted for total energy intake as well as for total added sugar intake (outcome variable). Total CF consumption (g/d) was summed up for every record at 0·5 and 0·75 years of age. As we were interested in the habitual commercial CF consumption in infancy we then calculated average percentage of commercial CF (%cCF) by dividing commercial CF (g/d) by total CF (g/d).

Total added sugar intake and food sources of added sugar

Added sugar is defined as sugars and syrups that are added to foods or beverages during processing or preparation at home and/or by the food industry[23]. The following foods were defined as added sugar: white sugar, brown sugar, raw sugar, maize syrup, maize syrup solids, high-fructose maize syrup, malt syrup, maple syrup, pancake syrup, fruit syrup, fructose sweetener, liquid fructose, honey, molasses, anhydrous dextrose and crystal dextrose[24]. Conversely, naturally occurring sugars such as lactose in milk/formula or fructose in fruits were not included. The sugar content of maltodextrin was defined as 50 % of its carbohydrate content, because maltodextrin consists of a mixture of monomers, dimers, oligomers and polymers of glucose. Sugar substitutes and added sugar in medicines were neglected[24].

In this analysis, different food sources of added sugar were also examined: added sugar from commercial, home-made and total CF (definitions see above), added sugar from beverages (defined as added sugar from regular soft drinks, diet soft drinks and fruit drinks), added sugar from sweets (defined as added sugar from candy, chocolate, sweet spreads, ice cream, pastries and other sweeteners), added sugar from milk products (defined as added sugar from infant formula other than lactose, milk and milk products), and added sugar from other food sources (i.e. the remainder of food sources, e.g. breakfast cereals, convenience products).

Individual data on daily absolute (g/d) and relative added sugar intakes (En%/d) as well as energy intakes (kJ/d) were derived from the mean of the 3 d of recording. For each participant, dietary intake values from 0·5 and 0·75, 3 and 4, 6 and 7 years of age were averaged to obtain estimates of the habitual intake in infancy, pre-school and primary-school age, respectively.

Potentially confounding factors

Parents were interviewed about family characteristics (e.g. parental education) as well as weighed and measured by the study staff on their child's admission to the study, and thereafter at 4-year intervals. Information on the child's birth characteristics was abstracted from the 'Mutterpass', a standardised document given to all pregnant women in Germany.

In addition to the dietary records, breast-feeding status was enquired by the study dietitians at each of the first visits until the infant was fully weaned. Ongoing breast-feeding was defined as any breast-feeding (full or partial) at 3 months and partial breast-feeding at 6 months of age (full breast-feeding at 6 months of age was an exclusion criterion).

For this analysis, the following characteristics were considered as potential confounders: total and remaining energy intake (i.e. total energy intake minus energy intake from added sugar, kJ/d) of the child in the respective age group, ongoing breast-feeding at 3 and 6 months of age (yes/no, respectively), date of birth, birth weight (g), being firstborn (yes/no), high maternal educational status (≥12 years of schooling, yes/no), maternal age at birth (years) and maternal overweight (BMI ≥ 25 kg/m^2, yes/no). For missing values, the respective median of the total sample (*n* 3 for maternal overweight, median: 23·4 kg/m^2) was used.

Statistical analyses

SAS® procedures (version 9.1.3; Statistical Analysis System) were used for all data analyses. *P* values < 0·05 were considered as statistically significant.

For all the analyses, the predictor variable %cCF was categorised into tertiles (low ≤ 43·0 %, medium 43·1– ≤ 71·0 %, high >71·0 %). Owing to the number of zero values and the resulting skewness of the outcome variables (total added sugar intake and added sugar intake from CF in infancy), multivariable logistic regression models (PROC LOGISTIC in SAS) were used to calculate OR for associations between %cCF and high added sugar intake in infancy. The outcome variables total added sugar intake and added sugar intake from CF were defined as high, if intake values exceeded the 75th percentile (high total added sugar intake >4·6 En%/d or 8·1 g/d, high added sugar intake from CF >2·6 En%/d or 4·4 g/d, respectively). The outcome variables total added sugar intakes in pre-school and primary-school age were log-transformed to obtain normal distribution. Multivariable linear regression models (PROC GLM in SAS) were used to analyse the prospective associations between %cCF in infancy and added sugar intake (g/d, En%/d) in pre-school and primary-school age.

As analyses indicated no interactions of sex with the associations between %cCF in infancy and added sugar intake (total or from CF), data from girls and boys were pooled for all further analyses. Results are presented as adjusted means in tertiles of %cCF in infancy.

All basic models were adjusted for sex and date of birth. For the adjusted models, each potential confounder was initially considered separately and only those variables that (a) had a significant, independent effect on the outcome variable, (b) modified regression coefficients (β) in the basic models by ≥5 % or (c) led to an improvement of the coefficient of determination (R^2) by ≥10 %[25] were considered in the final adjusted models.

In a further step, we additionally adjusted for absolute added sugar intake levels in infancy, so as to investigate whether added sugar intake in infancy may mediate any potential association between %cCF and later added sugar intake.

Results

Study sample characteristics

Descriptive data of the study sample are presented in Table 1. The analysis included 134 girls (46·5 %) and 154 boys (53·5 %). Two-thirds of the participants were fully breast-fed at 3 months of age; more than half of them were still partially breast-fed at 6 months of age. Nearly 65 % were the firstborn in their family. Mean maternal age at birth was 32·6 years, with <30 % of the mothers being overweight and almost 70 % having a high educational level.

The median %cCF in infancy (0·5 and 0·75 years) was 57·7 %. In all, fourteen participants received no commercial CF in both records at all, whereas eight of them consumed commercial CF only (data not shown). As both extremes reflect common dietary practices, these participants were retained in the analysis.

Commercial complementary food, added sugar intake and food sources of added sugar

In total, thirty-three infants (11·5 %) did not consume any added sugar in infancy (data not shown). Table 2 illustrates that <2 g of total added sugar intake in infancy came from CF, with higher added sugar intake levels from commercial than home-made CF ($P = 0·012$). Median total added sugar intake increased from 2·3 En%/d in infancy to 11·9 and 13·4 En% in pre-school and primary-school age, respectively ($P < 0·0001$). In both pre-school and primary-school age, median added sugar intakes (En%) exceeded the current World Health Organization recommendation[4]. In infancy, the majority of added sugar came from total CF, whereas more than half of the infants did not receive any added sugar from the other food sources. Conversely, sweets were the main source of added sugar in both pre-school and primary-school age, followed by milk products.

Relation of infant commercial complementary food consumption to added sugar intake

In infancy, %cCF was significantly associated with total added sugar intake as well as added sugar intake from CF for both relative (En%) and absolute added sugar intakes (g/d). Infants with a high commercial CF consumption had higher odds for high consumption of added sugar from CF as well as for a high total added sugar intake (Table 3). Given the generally low total added sugar intakes in infancy, the absolute differences in sugar intake between tertiles of commercial CF consumption are less distinct.

Table 1. Characteristics of the analysed Dortmund Nutritional and Anthropometric Longitudinally Designed Study sample, born in 1985–2007 (Numbers and percentages; mean values and standard deviations)

Variables	Values *n*	%
Early-life characteristics		
Birth weight (g)		
Mean	3456	
SD	482	
Full breast-feeding at 3 months	193	67·0
Partial breast-feeding at 3 months	24	8·3
Partial breast-feeding at 6 months	163	56·6
Family characteristics		
Firstborn	186	64·6
Maternal age at birth (years)		
Mean	32·6	
SD	3·6	
Maternal overweight*	82	28·5
High maternal educational status†	201	69·8

* BMI ≥25 kg/m^2.
† ≥12 years of schooling.

In prospective analyses, higher %cCF in infancy was associated with higher relative and absolute added sugar intakes in both pre-school and primary-school age (Table 4). In adjusted models, pre-schoolers in the highest tertile of infant %cCF had a 10 % higher relative added sugar intake than those in the lowest tertile. In primary-school age, relative added sugar intake was 12 % higher in the highest as compared with the lowest tertile of infant %cCF. When the final models were further adjusted for absolute added sugar intake in infancy, these prospective associations were attenuated and most of them were no longer significant. The attenuation was even more pronounced when models for primary-school age were adjusted for absolute added sugar intake in pre-school age (data not shown).

Discussion

The present study provides novel evidence of a sustained relationship between a high contribution of commercial CF in infancy and higher total added sugar intakes throughout childhood. A higher consumption of commercial CF in infancy entailed a higher added sugar intake already during infancy and was also prospectively related to higher added sugar intakes in pre-school and primary-school age. Importantly, the prospective associations were partly explained by total added sugar intake levels in infancy, indicating that higher amounts of added sugar in commercial CF[15,18,26] may be responsible for this adverse relationship.

For the current German baby-food market, the online CF database 'Babynahrungsproduktsuche' illustrates that 17 % of all spoonable CF products contain added sugar[18]. However, information on exact amounts of added sugar is not given in the database. A recent evaluation of ours on the nutrient composition of home-made and commercial CF revealed that added sugar was present in nearly a quarter of all CF meals consumed in the DONALD Study, with the highest contents in commercial dairy–fruit meals (third quartile: 7 g/100 g). In cereal–milk meals as well as in cereal–fruit meals, added sugar content was significantly higher in commercial than in home-made meals[26].

Table 2. Total added sugar intake and relative contribution of food sources to added sugar intake of the analysed Dortmund Nutritional and Anthropometric Longitudinally Designed Study sample in infancy, pre-school age and primary-school age*
(Medians and interquartile ranges (IQR, Q1–Q3))

	Infancy (0·5–0·75 years)		Pre-school age (3–4 years)		Primary-school age (6–7 years)	
	Median	IQR	Median	IQR	Median	IQR
Total added sugar intake						
g/d	4·0	0·7–8·1	34·2	26·9–42·6	49·7	38·9–63·2
En%/d	2·3	0·5–4·6	11·9	9·4–14·7	13·4	10·9–16·7
Added sugar intake from different food sources (g/d)						
CF	1·8	0·3–4·4				
Commercial CF	0·6	0·0–2·8				
Home-made CF	0·1	0·0–1·4				
Beverages	0·0	0·0–0·0	1·8	0·0–6·0	4·0	0·5–9·4
Milk products	0·0	0·0–2·3	6·6	3·6–11·1	8·0	5·0–13·1
Sweets	0·0	0·0–0·4	18·9	13·7–25·4	26·6	21·3–34·6
Other foods	0·0	0·0–0·0	2·3	1·0–5·0	4·8	2·6–8·1

En%, energy percentage; CF, complementary food.
* Added sugar intake levels (g/d, En%/d) were derived from the mean of both 3-d weighed dietary records for the respective age group.

British Journal of Nutrition

Table 3. Cross-sectional relation between percentage of commercial complementary food (%cCF) in infancy and high total added sugar intake or high added sugar intake from complementary food (CF) in infancy (basic and adjusted multivariable logistic regression models) of the analysed Dortmund Nutritional and Anthropometric Longitudinally Designed Study sample*
(Medians and interquartile ranges (IQR); odds ratios, adjusted odds ratios and 95 % confidence intervals)

	OR for high total added sugar intake (>75th percentile)†				OR for high added sugar intake from CF (>75th percentile)‡			
	Low %cCF consumption (reference)	Medium %cCF consumption	High %cCF consumption	$P_{\text{for trend}}$	Low %cCF consumption (reference)	Medium %cCF consumption	High %cCF consumption	$P_{\text{for trend}}$
Relative added sugar intake (En%/d)								
Median	1·5	2·0	3·3		0·4	1·1	1·6	
IQR	0·2–3·7	0·5–4·7	1·4–5·8		0·0–2·1	0·3–2·6	0·5–2·9	
OR	1·00	3·03	3·76	0·003	1·00	2·07	2·98	0·014
95 % CI		1·35, 6·80	1·70, 8·32			0·97, 4·39	1·43, 6·20	
P		0·007	0·001			0·059	0·003	
Adjusted OR	1·00	3·76	4·60	0·003	1·00	2·07	3·41	0·009
95 % CI		1·53, 9·28	1·87, 11·31			0·93, 4·64	1·55, 7·50	
P		0·004	0·001			0·077	0·002	
Absolute added sugar intake (g/d)								
Median	2·6	3·5	5·5		0·8	1·9	2·6	
IQR	0·3–6·4	0·8–8·6	2·3–10·4		0·0–3·4	0·4–4·6	0·9–5·0	
OR	1·00	3·15	3·85	0·003	1·00	2·35	2·77	0·017
95 % CI		1·40, 7·10	1·73, 8·54			1·12, 4·90	1·34, 5·70	
P		0·006	0·001			0·024	0·006	
Adjusted OR	1·00	2·90	3·31	0·012	1·00	2·21	2·56	0·033
95 % CI		1·24, 6·76	1·44, 7·60			1·05, 4·66	1·23, 5·33	
P		0·014	0·005			0·037	0·012	

En%, energy percentage.
* Significant differences between tertiles of %cCF consumption (low, medium, high %cCF) were tested using multivariable logistic regression for ordinal dependent variables. Basic models: adjusted for sex and date of birth. Adjusted models: basic model + adjustment for ongoing breast-feeding at 3 and 6 months (yes/no, respectively) in the model for absolute total added sugar intake and additionally for total energy intake (kJ/d) in the model for relative total added sugar intake; basic model + adjustment for ongoing breast-feeding at 6 months (yes/no) in the model for absolute added sugar intake from CF and additionally for total energy intake (kJ/d) and maternal overweight (BMI ≥ 25 kg/m^2, yes/no) in the model for relative added sugar intake from CF.
† High total added sugar intake >4·6 En%/d and 8·1 g/d, respectively.
‡ High added sugar intake from CF >2·6 En%/d and 4·4 g/d, respectively.

Table 4. Prospective associations between percentage of commercial complementary food (%cCF) in infancy and added sugar intake (g/d and energy percentage (En%)/d) in pre-school and primary-school age (basic and adjusted regression models) of the analysed Dortmund Nutritional and Anthropometric Longitudinally Designed Study sample*
(Adjusted mean values and 95 % confidence intervals)

	Pre-school age (3–4 years)							Primary-school age (6–7 years)						
	Low %cCF consumption		Medium %cCF consumption		High %cCF consumption			Low %cCF consumption		Medium %cCF consumption		High %cCF consumption		
	Mean	95 % CI	Mean	95 % CI	Mean	95 % CI	$P_{\text{for trend}}$†	Mean	95 % CI	Mean	95 % CI	Mean	95 % CI	$P_{\text{for trend}}$†
Relative added sugar intake (En%/d)														
Basic model	10·9	10·2, 11·8	11·6	10·8, 12·5	12·4	11·5, 13·3	0·023	12·5	11·7, 13·3	13·2	12·4, 14·2	14·2	13·2, 15·1	0·013
Adjusted model	11·3	10·5, 12·2	12·4	11·4, 13·4	12·7	11·9, 13·7	0·041	12·6	11·7, 13·5	13·5	12·6, 14·5	14·3	13·4, 15·3	0·017
Adjusted model + added sugar intake (g/d) in infancy	11·4	10·6, 12·3	12·3	11·4, 13·3	12·6	11·7, 13·6	0·116	12·7	11·8, 13·6	13·4	12·5, 14·4	14·2	13·3, 15·2	0·045
Absolute added sugar intake (g/d)														
Basic model	30·9	28·5, 33·4	34·0	31·4, 36·8	35·3	32·6, 38·2	0·021	45·9	42·5, 49·7	48·0	44·5, 52·1	50·9	47·1, 55·0	0·054
Adjusted model	32·0	29·5, 34·7	36·4	33·4, 39·6	36·4	33·7, 39·4	0·035	45·7	41·9, 49·8	48·9	44·9, 53·3	51·4	47·4, 55·7	0·039
Adjusted model + added sugar intake(g/d) in infancy	32·4	29·8, 35·1	36·2	33·2, 39·4	36·0	33·3, 39·0	0·116	46·8	43·1, 50·7	49·4	45·5, 53·6	51·5	47·6, 55·7	0·106

* Basic models: adjusted for sex and date of birth. Adjusted models: basic model + adjustment for being firstborn (yes/no) and high maternal educational status (≥12 years of schooling, yes/no) in the pre-school age models; basic model + adjustment for high maternal educational status (≥12 years of schooling, yes/no) and total energy intake at 6–7 years (kJ/d) in primary-school age models (relative added sugar intake); basic model + adjustment for high maternal educational status (≥12 years of schooling, yes/no), ongoing breast-feeding at 3 months (yes/no), and remaining energy intake at 6–7 years (kJ/d) in primary-school age models (absolute added sugar intake).
† $P_{\text{for trend}}$ refers to *P* values obtained in linear regression models.

A high commercial CF intake in infants might also act as a proxy for a less-favourable infant diet with other sweetened products apart from CF, such as sugar-based instant teas, baby rusks/cookies or sweetened follow-on formula, as supported by the findings of a pattern analysis from the UK[27]. Therefore, it may not only be the added sugar contained in commercial CF itself but also the added sugar from all remaining foods and drinks consumed by infants, with a high commercial CF consumption resulting in a high added sugar intake in later childhood.

In our study, the association between a high %cCF and a higher total added sugar intake also persisted in the long term. It is well known from experimental studies that the inborn preference for sweet taste is further enhanced by the early intake of and repeated exposure to sugar and sweet foods[7]. Infants fed sweetened water after birth showed a greater preference for sweetened water at 6 months, 2 years and 6 years of age compared with those fed plain water[28–30]. In addition, the time of introduction of sweetened foods may affect children's added sugar intake: in a Swedish study, frequent eaters of sweets at 1 year of age had been introduced to sweets nearly 1 month earlier than the other infants[31].

The effect of repeated exposure shaping sweet taste preferences is not only restricted to early infancy but has also been shown during childhood. Children (4–7 years old) whose mothers reported to routinely add sugar to their child's diet were shown to prefer apple juices and cereals with a higher added sugar content compared with children without added sugar experience[32]. Further, even an 8-d short-term exposure to sweetened orangeade in 6–11-year-old children increased the preference for this orangeade after the intervention. This effect was also shown for an overall preference of high sugar concentration independent of the food that sucrose was added to[33]. Although children do not have full autonomy in making their food choices, their actual food intake results from the interaction between the parental provision of foods and the child's individual taste preferences. Accordingly, our findings suggest that the habitual intake of (sweetened) commercial CF leads to a general higher preference for sweetened foods later in childhood.

To the best of our knowledge, our study is the first to describe a prospective association between commercial CF consumption and added sugar intake, although we cannot prove causality given the observational design. It could be argued that differences in sugar intake levels of 1–5 g/d as reported in this study are lacking clinical relevance, yet our study suggests a potential and sustained relevance even of these relatively low total added sugar intake levels for later sugar intake. The association attenuated in the statistical analysis adjusting for total added sugar intake in infancy (and even more for total added sugar in pre-school age), indicating that a high early added sugar intake mediates this association – that is, early added sugar intake is an important determinant of added sugar intake in later childhood. As other studies demonstrated that sweetened snacks and beverages track between infancy and toddlerhood as well as pre-school age[34–37], the consistency of the observed associations may reflect the tracking of early dietary patterns. Thus, our results underpin the proposed hypothesis that the consumption of sweetened foods and beverages later in life is facilitated by a high and frequent added sugar intake via commercial CF in early infancy.

A frequent intake of foods high in added sugar tends to be linked to an overall less-favourable diet in children[31,38–40]. From a public health perspective, our data suggest that providing CF without added sugar may therefore help protect children from excess added sugar intake later in childhood by not further enhancing their inborn sweet preference. Although it seems to be possible to achieve a reasonable diet quality and adequate nutrient intake even within high ranges of added sugar intake[41–43], sugar addition in foods for children is not necessary to enhance their palatability and should be avoided. In an experimental study by Bouhlal *et al.*[44], the level of added sugar did not affect the intake of fruit purée in 2–3-year-old toddlers[44]. Instead, repeated exposure increased the preference for an unknown food regardless of whether sugar was added or not[45]. Therefore, infant feeding guidelines should encourage parents to (at least occasionally) offer home-made CF or to choose commercial CF products without added sugar. The recent decrease in infants' added sugar intake during the last decade already indicates a desirable trend[46].

Major strengths of our analysis include the detailed dietary assessment and the comprehensive food composition database allowing the differentiation between home-made and commercial CF. As added sugar content cannot be analytically determined[5], we were able to identify and calculate the amount of added sugar in composite commercial products as well as home-made recipes, as these could be broken down into their single ingredients on the basis of the in-house recipe simulation procedure[22]. Furthermore, information on several possible confounders such as early-life and parental characteristics was available.

However, the generalisability of our results may be limited, as the DONALD population is characterised by a rather high socio-economic status[21]. Several studies reported a high parental educational level being associated with a less-frequent intake of sweets and added sugar[31,47] or an overall higher diet quality in their children[48,49]. Furthermore, added sugar intake may be underestimated in the current observational analysis as the under-reporting of sugar-rich foods is a common problem in nutritional surveys[50]. Therefore, the average total added sugar intake may be higher in the general population and with that the true associations even more distinct.

An additional limitation of our study is the lack of parental dietary data. Neither parents' added sugar intake nor their overall diet quality was assessed, and could therefore not been taken into account, although it is known to be a strong influencing factor in early infant nutrition.

Conclusion

The data from the DONALD Study suggest that the choice of home-made or commercial CF influences the added sugar intake from CF as well as the total intake of added sugar in infancy. A high commercial CF consumption in infancy may predispose to a higher added sugar intake in later childhood by virtue of its added sugar content. Therefore, offering home-made CF or carefully chosen commercial CF without added sugar might be one strategy to reduce added sugar intake in infancy and later in childhood. To strengthen these study findings, our first explorative results need to be confirmed in large-scale cohort studies. If associations are repeatedly found, well-planned intervention studies are required to allow assertions on causal inference.

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References

1. Alles MS, Eussen SR & van der Beek EM (2014) Nutritional challenges and opportunities during the weaning period and in young childhood. *Ann Nutr Metab* **64**, 284–293.
2. Moynihan PJ & Kelly SAM (2014) Effect on caries of restricting sugars intake: systematic review to inform WHO guidelines. *J Dent Res* **93**, 8–18.
3. Te Morenga L, Mallard S & Mann J (2013) Dietary sugars and body weight: systematic review and meta-analyses of randomised controlled trials and cohort studies. *BMJ* **346**, e7492.
4. World Health Organization (2015) *Guideline: Sugars Intake for Adults and Children*. Geneva: WHO. http://apps.who.int/iris/bitstream/10665/149782/1/9789241549028_eng.pdf (accessed March 2015).
5. Hess J, Latulippe ME, Ayoob K, *et al.* (2012) The confusing world of dietary sugars: definitions, intakes, food sources and international dietary recommendations. *Food Funct* **3**, 477–486.
6. Ventura AK & Worobey J (2013) Early influences on the development of food preferences. *Curr Biol* **23**, R401–R408.
7. Ventura AK & Mennella JA (2011) Innate and learned preferences for sweet taste during childhood. *Curr Opin Clin Nutr Metab Care* **14**, 379–384.
8. Mennella JA (2014) Ontogeny of taste preferences: basic biology and implications for health. *Am J Clin Nutr* **99**, S704–S711.
9. Mennella JA & Trabulsi JC (2012) Complementary foods and flavor experiences: setting the foundation. *Ann Nutr Metab* **60**, Suppl. 2, 40–50.
10. Foterek K, Hilbig A & Alexy U (2015) Associations between commercial complementary food consumption and fruit and vegetable intake in children – results of the DONALD study. *Appetite* **85**, 84–90.
11. Coulthard H, Harris G & Emmett P (2010) Long-term consequences of early fruit and vegetable feeding practices in the United Kingdom. *Public Health Nutr* **13**, 2044–2051.
12. Koletzko BV, Bauer CP, Brönstrup A, *et al.* (2013) Säuglingsernährung und Ernährung der stillenden Mutter. Aktualisierte Handlungsempfehlungen des Netzwerk Gesund ins Leben – Netzwerk Junge Familie, ein Projekt von IN FORM (Infant nutrition and nutrition for breastfeeding mothers. Updated practice recommendations of the network 'Healthy Start – Young Family Network' a project of IN FORM). *Monatsschr Kinderh* **137**, 1309–1314 (in German).
13. Agostoni C, Decsi T, Fewtrell M, *et al.* (2008) Complementary feeding: a commentary by the ESPGHAN committee on nutrition. *J Pediatr Gastroenterol Nutr* **46**, 99–110.
14. Foterek K, Hilbig A & Alexy U (2014) Breast-feeding and weaning practices in the DONALD study: age and time trends. *J Pediatr Gastroenterol Nutr* **58**, 361–367.
15. Düren M & Kersting M (2003) Das Angebot an Kinderlebensmitteln in Deutschland. Produktübersicht und ernährungsphysiologische Wirkung (The range of children's food products in Germany – product overview and nutritional valuation). *Ernaehrungs Umschau* **50**, 16–21 (in German).
16. Elliott CD (2011) Sweet and salty: nutritional content and analysis of baby and toddler foods. *J Public Health (Oxf)* **33**, 63–70.
17. Elliott CD & Conlon MJ (2015) Packaged baby and toddler foods: questions of sugar and sodium. *Pediatr Obes* **10**, 149–155.
18. Forschungsinstitut für Kinderernährung (2015) Beikost-Datenbank 'Babynahrungsproduktsuche'. Informationssystem für die Bereiche Säuglings- und Kleinkinderernährung (Complementary Food Database 'Babynahrungsproduktsuche' – information system for infant and toddler nutrition) (in German). https://verbraucherfenster.hessen.de/service/babynahrung-produktsuche (accessed January 2015).
19. Cogswell ME, Gunn JP, Yuan K, *et al.* (2015) Sodium and sugar in complementary infant and toddler foods sold in the United States. *Pediatrics* **135**, 416–423.
20. Samuel L, Ethan D, Basch CH, *et al.* (2014) A comparative study of the sodium content and calories from sugar in toddler foods sold in low- and high-income New York City supermarkets. *Glob J Health Sci* **6**, 22–29.
21. Kroke A, Manz F, Kersting M, *et al.* (2004) The DONALD study: history, current status and future perspectives. *Eur J Nutr* **43**, 45–54.
22. Sichert-Hellert W, Kersting M, Chahda C, *et al.* (2007) German food composition database for dietary evaluations in children and adolescents. *J Food Compos Anal* **20**, 63–70.
23. Institute of Medicine of the National Academies (2005) *Dietary Reference Intakes: Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids*. Washington, DC: Institute of Medicine of the National Academies. www.nal.usda.gov/fnic/DRI/DRI_Energy/energy_full_report.pdf (accessed June 2014).
24. Herbst A, Diethelm K, Cheng G, *et al.* (2011) Direction of associations between added sugar intake in early childhood and body mass index at age 7 years may depend on intake levels. *J Nutr* **141**, 1348–1354.
25. Maldonado G & Greenland S (1993) Simulation study of confounder-selection strategies. *Am J Epidemiol* **138**, 923–936.
26. Hilbig A, Foterek K, Kersting M, *et al.* (2015) Home-made and commercial complementary meals in German infants: results of the DONALD study. *J Hum Nutr Diet* **28**, 613–622.
27. Brazionis L, Golley RK, Mittinty MN, *et al.* (2012) Characterization of transition diets spanning infancy and toddlerhood: a novel, multiple-time-point application of principal components analysis. *Am J Clin Nutr* **95**, 1200–1208.
28. Beauchamp GK & Moran M (1982) Dietary experience and sweet taste preference in human infants. *Appetite* **3**, 139–152.
29. Beauchamp GK & Moran M (1984) Acceptance of sweet and salty tastes in 2-year-old children. *Appetite* **5**, 291–305.
30. Pepino MY & Mennella JA (2005) Factors contributing to individual differences in sucrose preference. *Chem Senses* **30**, Suppl. 1, 319–320.
31. Brekke HK, van Odijk J & Ludvigsson J (2007) Predictors and dietary consequences of frequent intake of high-sugar, low-nutrient foods in 1-year-old children participating in the ABIS study. *Br J Nutr* **97**, 176–181.
32. Liem DG & Mennella JA (2002) Sweet and sour preferences during childhood: role of early experiences. *Dev Psychobiol* **41**, 388–395.
33. Liem DG & de Graaf C (2004) Sweet and sour preferences in young children and adults: role of repeated exposure. *Physiol Behav* **83**, 421–429.

34. Lioret S, McNaughton SA, Spence AC, *et al.* (2013) Tracking of dietary intakes in early childhood: the Melbourne InFANT program. *Eur J Clin Nutr* **67**, 275–281.
35. Bjelland M, Brantsæter AL, Haugen M, *et al.* (2013) Changes and tracking of fruit, vegetables and sugar-sweetened beverages intake from 18 months to 7 years in the Norwegian Mother and Child Cohort Study. *BMC Public Health* **13**, 793.
36. Park S, Pan L, Sherry B, *et al.* (2014) The association of sugar-sweetened beverage intake during infancy with sugar-sweetened beverage intake at 6 years of age. *Pediatrics* **134**, Suppl. 1, S56–S62.
37. Lioret S, Betoko A, Forhan A, *et al.* (2015) Dietary patterns track from infancy to preschool age: cross-sectional and longitudinal perspectives. *J Nutr* **145**, 775–782.
38. Forshee RA & Storey ML (2001) The role of added sugars in the diet quality of children and adolescents. *J Am Coll Nutr* **20**, 32–43.
39. Livingstone MBE & Rennie KL (2009) Added sugars and micronutrient dilution. *Obes Rev* **10**, Suppl. 1, 34–40.
40. Frary CD, Johnson RK & Wang MQ (2004) Children and adolescents' choices of foods and beverages high in added sugars are associated with intakes of key nutrients and food groups. *J Adolesc Health* **34**, 56–63.
41. Alexy U, Kersting M & Schultze-Pawlitschko V (2003) Two approaches to derive a proposal for added sugars intake for German children and adolescents. *Public Health Nutr* **6**, 697–702.
42. Alexy U, Sichert-Hellert W & Kersting M (2003) Associations between intake of added sugars and intakes of nutrients and food groups in the diets of German children and adolescents. *Br J Nutr* **90**, 441–447.
43. Gibson SA (2007) Dietary sugars intake and micronutrient adequacy: a systematic review of the evidence. *Nutr Res Rev* **20**, 121–131.
44. Bouhlal S, Issanchou S & Nicklaus S (2011) The impact of salt, fat and sugar levels on toddler food intake. *Br J Nutr* **105**, 645–653.
45. Sullivan SA & Birch LL (1990) Pass the sugar, pass the salt: experience dictates preference. *Dev Psychol* **26**, 546–551.
46. Foterek K, Hilbig A, Kersting M, *et al.* (2016) Age and time trends in the diet of young children: results of the DONALD study. *Eur J Nutr* **55**, 611–620.
47. Hilbig A, Alexy U, Drossard C, *et al.* (2011) GRETA: Ernährung von Kleinkindern in Deutschland (German representative study of toddler alimentation). *Aktuel Ernaehrungsmed* **36**, 224–231 (in German).
48. Smithers LG, Golley RK, Brazionis L, *et al.* (2011) Characterizing whole diets of young children from developed countries and the association between diet and health: a systematic review. *Nutr Rev* **69**, 449–467.
49. Kranz S & Siega-Riz AM (2002) Sociodemographic determinants of added sugar intake in preschoolers 2 to 5 years old. *J Pediatr* **140**, 667–672.
50. Rasmussen LB, Matthiessen J, Biltoft-Jensen A, *et al.* (2007) Characteristics of misreporters of dietary intake and physical activity. *Public Health Nutr* **10**, 230–237.

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4 GENERAL DISCUSSION

4.1 Synopsis of research results

The characterisation of breastfeeding and weaning trends in the DONALD Study revealed a decreasing time trend in full breastfeeding duration in the last decade, whereas total breastfeeding duration has not changed (RQ 1.1). Further, commercial CF proved to be of high relevance in today's infant nutrition with almost 60% of consumed CF being commercially prepared, while homemade and combined (i.e. homemade mixed with commercial) CF accounted for circa 20% each. Subjects with high commercial CF consumption were significantly older, had shorter full and total breastfeeding duration, were introduced to CF earlier, and were more likely to have mothers with a lower educational status (RQ 1.2). Both commercial and homemade CF showed opposing, nonlinear age trends; with increasing age the proportion of commercial CF showed a decrease, followed by an increase. However, no time trends could be found during the observed study period (RQ 1.3).

The proportion of commercial CF consumption was associated with fruit and vegetable intake as well as added sugar intake in infancy and beyond; although results differed between boys and girls depending on the respective outcome. Associations between proportion of commercial CF consumption and fruit and vegetable intake were stratified by sex due to significant sex interactions. In contrast, associations between proportion of commercial CF consumption and fruit and vegetable variety as well as added sugar intake showed no significant sex interactions.

In infancy, a higher commercial CF proportion was associated with lower vegetable intake in both sexes and with a higher juice intake in girls only (RQ 2.1). With respect to fruit and vegetable variety, no clear associations could be found (RQ 2.1). Infants with a high contribution of commercial CF had higher odds for a high consumption of added sugar from CF as well as a high total added sugar intake (RQ 3.1).

Prospectively, only boys showed an association between a higher commercial CF proportion and a lower vegetable intake in preschool age as well as lower total fruit and vegetable intake in preschool and primary school age. The latter might be at least to some extent due to the notable differences in fruit and vegetable juice intake in these age groups. For girls, no significant prospective association could be observed (RQ 2.2). The association between proportion of commercial CF and total added sugar intake could also be shown prospectively: commercial CF proportion in infancy was positively related to added sugar intake in preschool and primary school age (RQ 3.2). However, this association attenuated in the statistical analysis when adjusted for total added sugar intake in infancy indicating that a high early added sugar intake mediates this association, i.e. early added sugar intake is an important determinant of added sugar intake in later childhood.

4.2 Interpretation of research results in broader context

Up to now, various, partially interrelated aspects of CF are discussed to potentially impact on later health outcomes: age of introduction of CF, nutrient composition and amount of CF, sensory properties, texture, and preparation type of CF as well as feeding style and frequency [93]. The set of the present three conducted analyses within the DONALD Study is not designed to conclusively prove, which of the properties of commercial CF explains the observed associations or to examine the underlying pathways. Overall, there are two potential mechanisms discussed as the main explanatory approaches, which are, however, not mutually exclusive.

On the one hand, the hypothesis of this thesis builds on the assumption that there are noticeable sensory differences in the taste and flavour profiles of commercial and homemade CF, imprinting later food preferences. Since sensory perception and taste acceptance are difficult to evaluate in infants given the ambiguous outcome measurements (i.e. intake amount, feeding duration/rate of consumption, maternal rating of infants' food acceptance, videotaping facial expression during feeding) the presumed sensory differences between homemade and commercial CF have not been confirmed scientifically yet. However, the different preparation processes are likely to result in different sensory properties with homemade CF providing more varied sensory experiences closer to the natural taste and texture of foods than commercial CF. A certain part of individual taste acceptance and food preferences seem to be programmed in utero and during early infancy (see chapter 1.2). Analogous to the effect of breastfeeding, the higher taste and flavour variation in homemade CF can contribute to the sensory imprinting of favourable food preferences by promoting the familiarisation to and enhancing the liking of unknown tastes and flavours as reflected in the cross-sectional and to some extent prospective higher fruit and vegetable intake. In addition, the absence of added sugar in homemade CF can prevent infants from the intensification of their inborn sweet preference and thereby lower their added sugar intake.

With respect to a potential sensory imprinting induced by early feeding experiences, the recent systematic review by *Nehring et al.* showed that the development of taste acceptance might underlie different mechanisms across tastes. While studies on sweet and salty tastes provided inconclusive results, early bitter and specific (e.g. single vegetables) taste experiences showed a clear programming effect on later acceptance of the same tastes [57]. However, apart from missing studies with long-term follow-ups (> 1 year) there is a lack of evidence of more complex taste experiences like entire CF meals combining various ingredients influencing later taste acceptance or food preferences.

On the other hand, the consistency of the associations between CF feeding practice and dietary behaviour in infancy and childhood may also reflect the tracking of certain dietary patterns established early in life throughout childhood [93] rather than causal effects of differences in CF exposure. Several other cohort studies described the tendency of dietary patterns to be stable throughout infancy and childhood [94–97] – which could also be referred to as 'behavioural imprinting' as proposed by *Nicklaus et al.* [51]. A high commercial CF consumption in infancy may predispose to a highly processed diet with a frequent use of convenience foods later on, which tends to be associated with lower nutrient intakes than healthy diets [98,99]. The increasing offer of toddler foods and in particular toddler meals that are presented in the same style and packaging as CF meals for infants [100] may further contribute to this development. A recent trend analysis of the DONALD Study indicated a slight, but significant shift towards a delayed introduction of family foods that may be triggered by the broad range of available ready-to-eat toddler meals [101]. But even if the observed associations reflect the tracking of a certain dietary behaviour rather than taste programming it remains unclear, whether this results from the persistence of learned food preferences or the continuous impact of other social influences, e.g. parental dietary behaviour. However, the DONALD Study design is not able to distinguish between a possible programming versus tracking effect.

Dietary patterns emerge and differentiate already early in life [99] and are thereby highly influenced by the parental nutritional knowledge and attitudes. Generally, mothers who breastfed for longer durations are more likely to comply with infant feeding guidelines and make better dietary choices in terms of their infant's diet [102,103]. With regards to CF, dietary pattern analyses of infants from different birth cohort studies revealed a typical pattern characterised by a long breastfeeding duration, high frequency of homemade CF consumption, and a seldom use of commercial CF [96,104–107]. As indicated by these findings breastfeeding mothers are likely to pay more attention to the quality of foods offered during weaning. These so-called "healthy" patterns were consistently associated with a higher adherence to complementary feeding guidelines [108], higher maternal age [96,104,106] as well as mothers or families with a higher education level [96,104–106], lower Body Mass Index (BMI) [96,104,105], and a higher diet quality [96]. On the contrary, the preferred use of commercial CF was often accompanied by the consumption of infant formula [105,106,109], biscuits, chocolate, and snack foods [96,105,106].

Further, those commercial CF dominated patterns were more likely associated with a higher maternal BMI, lower maternal education levels [96,105,106] as well as lower maternal diet quality [96] – most of these associations being also reflected in the DONALD Study sample (RQ 1.2). Thus, the observed associations between commercial CF consumption and later dietary behaviour are unlikely to result only from sensory imprinting. Given that commercial CF tends to be preferred from mothers with lower educational levels and lower diet quality, a high commercial CF intake might rather act as a proxy for an overall less favourable diet in infancy and beyond [97,108].

During the transition from infancy to childhood, children's social and food environment is continuously changing. Particularly infants and young children do not have full autonomy in making their food choices; parents or other primary caregivers determine mostly which foods their infants are exposed to [110–113]. While infants are usually fed at home by their parents or other caregivers during their first year of life, new eating environments are introduced gradually when children attend day-care, preschool, and primary school. But also during preschool and primary school age, children are still not choosing their diet independently as most foods are still eaten at or provided from home (e.g. as packed lunch), which may add to the dietary tracking in childhood [114]. It remains unclear to what extent children are actually able to establish their own dietary choices before they enter primary school given the strong parental influence and the obvious accordance between the diets of parents and their children. Thus, the true imprinting of taste preferences via CF may not come into effect as it is overlapped by the parental supply and choice of foods.

The results of this thesis revealed some inconsistencies between boys and girls. While there were no sex differences in breastfeeding and weaning practices (Study I) and the association between commercial CF consumption and added sugar intake (Study III), the prospective association between commercial CF consumption and fruit and vegetable intake (Study II) was only present in boys. In general, boys tend to have less favourable food preferences than girls resulting in different dietary behaviours that already diverge in early childhood [115,116]. The more distinct influence of commercial CF in boys can be ascribed to differences in early feeding practices between both sexes as shown in a Finnish study with the ready-to eat baby food pattern being more present in boys [117]. By the end of toddlerhood, girls are also known to have a higher (fruit and) vegetable intake than boys, while there are no differences in added sugar intake [88]. Hence, there might be more preventive potential to modulate long-term food preferences and favourable dietary intakes in boys by a shift from commercial to homemade CF. Apart from this behavioural perspective there might also be a methodological reason for this discrepancy since all three study samples included fewer girls than boys. The prospective associations between commercial CF consumption and girls' fruit and vegetable intake might have failed to reach statistical significance due to the reduced power in the smaller sample sizes (as discussed in chapter 4.3).

The analyses conducted in this thesis were designed with the intent to examine the influence of early CF feeding practice on later dietary behavior, i.e. fruit and vegetable as well as added sugar intake. However, the possible environmental impact on children's food preference varies by food type according to findings from a UK twin study: While genetic influences dominate children's fruit and vegetable preferences; the individual preference for snacks and sweets is dominated by environmental effects instead [118]. This provides a possible explanation for the more distinct impact of the CF preparation type on added sugar intake compared to fruit and vegetable consumption as shown in this thesis. But even if the preference for fruits and vegetables is highly determined by heritability, this thesis indicates that it is still modifiable by early dietary exposure.

Taken together, the results of this thesis confirm that early feeding practices have the potential to modify long-term dietary behaviour, although our understanding of how they influence it is limited as the observed associations do not prove any underlying causation.

4.3 Methodological considerations

There are several methodological challenges that hamper the identification of specific CF effects, e.g. the long delay between the exposure in infancy and the different outcomes in childhood [93]. Those challenges need to be faced in order to provide clear evidence if and how CF can influence later dietary behaviour. Given the lack of randomised controlled trials in infants, research has to rely on observational studies with their respective assets and drawbacks, although they do not allow causal inference [119].

Study population

The studies presented here were conducted using observational data from the DONALD Study. This unique longitudinal study accompanies its participants from infancy until young adulthood allowing cross-sectional as well as prospective analyses with a longer follow-up duration compared to most other studies. In addition, due to the open cohort design, participants have been continuously recruited from 1985 onwards, providing a suitable data basis for age and time trend analyses [91].

However, the demanding study protocol of the DONALD Study combined with the local recruitment in the city of Dortmund and surrounding communities result in a non-representative convenient sample [91]. The DONALD participants are characterised by a higher socio-economic status and higher level of education compared to the general population as discussed in the resulting publications (see chapter 3). While the external validity (i.e. Study I) may be limited due to the regional sample and since lower-educated mothers are more likely to engage in unfavourable patterns of complementary feeding [120], the internal validity (i.e. Studies II and III) is unlikely to be affected [91]. Although the characteristics of the DONALD population seem to be relative homogenous due to the non-representativeness of the study, the exposure variable (percentage of commercial CF) showed considerable variation as all three study sample included several infants with either no or exclusive commercial CF consumption (data not shown).

In view of the elaborate assessment procedures the sample sizes derived from the DONALD Study are relatively small compared to other birth cohort studies [91] resulting in a reduced statistical power to identify underlying associations. This might be one explanation for the lack of significance of the association between commercial CF and later fruit and vegetable intake in girls (RQ 2.1). Overall, the findings from this thesis should be treated as a pioneering explorative analysis to generate new hypotheses and thus providing important implications for future larger studies whose designs allow looking closer into causality.

Dietary assessment

This thesis makes use of a novel research approach by using the percentage of commercial CF consumption as a nutritional marker characterising the whole diet during infancy instead of only focusing on singular nutrients or food groups as exposure variables [e.g. 84]. In order to represent the typical infant diet and to assess the extent of habitual commercial CF consumption it is imperative to measure the total food intake during multiple days [120]. Most studies on long-term effects of early feeding practices rely on retrospective study designs providing only limited validity due to the high susceptibility to recall biases. In the DONALD Study, the dietary intake is assessed prospectively with consecutive 3-day weighed dietary records, the quasi-gold standard of dietary assessment methods, and does therefore not rely on the participant's memory.

Given the usually structured eating environment of infants and younger children with most food provided from and/or eaten at home, their parents work well as surrogate reporters for children under 10 years of age [121,122]. With increasing age children spent more time away from home and hence parents have less control over what their children eat. Still, the extent of misreporting in 1-13 year old children is known to be very low (1-3%) [123], which adds to the validity of the analysed dietary data. The thesis benefits from its precise and comprising assessment of the dietary predictor and outcome variables providing the exact meal composition as well as the weighed intake amounts, which is superior to most other studies relying only on questionnaires or food frequency questionnaire (FFQ) data with estimated portion sizes [e.g. 42,80,83,84]. Further, all composite commercial products can be broken down into their single ingredients based on the simulated recipes providing comprehensive intake amounts of specific food groups, e.g. fruits and vegetables [92]. As a unique feature the DONALD Study also allows the differentiation between commercial and homemade CF resulting in a well-defined exposure variable [92], which is essential to answer the proposed research questions.

However, due to the high day-to-day variability of children's diets, dietary records are still not ideal to represent the usual diet [124]. Reported foods and recipes may be related during the three consecutive days of recording due to leftovers or offering the same meals to minimize the burden of recording [36]. Further, in our study sample the proportions of homemade and commercial CF shifted with increasing age (Study I). To account for this variability, the subsequent analyses (Studies II and III) assessed CF consumption at two different time points during infancy (beginning and main phase of complementary feeding) in order to properly describe the habitual CF intake. For future analyses, it might be even more feasible to either collect non-consecutive single-day dietary records or to use a blending of methods (e.g. combining 3-day weighed dietary records with FFQs) to assess the use of homemade and commercial CF over a longer time period and to have a more reliable measure of dietary variety, e.g. with respect to seasonality.

Early life and family characteristics

This thesis gains scientific impact due to the several different early life and family characteristics that were taken into account as potentially confounding factors. Since breastfeeding is known to be a strong determinant of later dietary behaviour [80,81,83,102] it is inevitable to include breastfeeding data into the models to investigate the remaining influence of CF. The overall rather small CF effect sizes, which did not always reach statistical significance, can be partly explained by the adjustment for breastfeeding, whose effect is presumably stronger than the additional effect of CF exposure.

The DONALD Study is not designed to assess the parental diet, although particularly the maternal diet is known to impact on children's food intake [111,112,125]. Parents or other primary caregivers act as food providers and role models and thereby influence the child's dietary behaviour directly through home availability and accessibility as well as indirectly through modelling [64,82]. Thus, favourable dietary practices, like a high intake of fruits and vegetables or a low intake of added sugar in infants and young children may reflect the family's overall high diet quality rather than an independent effect of taste programming by the choice of CF. To account for the missing data on the maternal diet in the analyses, maternal education level was used as a proxy assuming that a higher education is functionally related to a better diet quality mediated through a higher nutritional knowledge and income. This is underlined by results of the US Infant Feeding Practices Study II with lower-educated mothers being more likely to exhibit less favourable patterns of complementary feeding [126] and the Identification and Prevention of Dietary- and Lifestyle-induced Health Effects in Children and Infants (IDEFICS) Study where children from higher educated parents were more likely to show a healthy dietary pattern [127].

Moreover, other maternal characteristics like age at birth as well as overweight status were considered as confounding factors to account for potential differences in CF choice or later dietary behaviour based on familial background as discussed in the previous chapter. Further, the birth order or number of older siblings is an established influence on dietary patterns of infants [99]. Since children with older siblings are more likely to be introduced to non-core foods like biscuits, cakes, and ice cream in their first year of life [128] or to display less favourable dietary patterns compared to infants without siblings [96,97,105], it was important to control for this in the present analyses where necessary.

4.4 Public health relevance and practical implications

Given the results from current nutrition surveys increasing children's fruit and in particular vegetable intake in combination with lowering their added sugar intake are essential public health goals [129]. Thus, it is important to closely monitor infant feeding practices and study the relationship between those early dietary experiences during infancy and their relevance for later dietary behaviour. Since most chronic diseases evolve from unfavourable food choices the identification of factors shaping individual dietary behaviour carries implications for effective public health strategies. Besides the well-established preventive capability of breastfeeding also complementary feeding practices may have the potential to influence the risk of noncommunicable diseases later in life [93]. Neither the type of foods fed during weaning nor the quality or preparation type of CF is likely to have a direct effect on growth or later obesity risk [130–132]. The weaning diet and particularly the choice of homemade or commercial CF may, however, still be predictive for the diet during childhood and thus be of relevance for long-term health outcomes through the possible sensory imprinting of favourable food preferences or the continuation of a certain dietary behaviour.

The lack of studies dealing with the different preparation types of CF impedes the provision of consistent infant feeding recommendations with respect to the use of homemade and commercial CF across industrialised countries. While German guidelines do not favour homemade CF over commercial CF at present, the current recommendations in the UK and Ireland encourage the use of homemade rather than commercial CF due to sensory differences (see chapter 1.1), which is supported by the findings of this thesis. The respective German institutions need to consider the observed cross-sectional and prospective associations between a high commercial CF consumption and less favourable dietary behaviour, i.e. lower intake of fruits and vegetable (RQ 2.1 & 2.2) combined with a higher added sugar intake (RQ 3.1 & 3.2) and modify their infant feeding guidelines accordingly. Parents should therefore be encouraged to give their infants the possibility to experience a wide range of varying foods, flavours, tastes, and textures during weaning – which is usually easier to achieve by providing homemade CF. According to the results of this thesis giving homemade CF at least the occasional preference to commercial CF might be one strategy to increase fruit and vegetable intake and reduce sugar intake in infancy and beyond. Although some institutions already recommend to not solely feed commercial CF, most infant feeding guidelines do not provide sufficient guidance on how to prepare CF at home [64]. The provision of simple standard recipes for homemade CF can help parents to overcome potential uncertainties or inhibitions regarding the self-preparation and also ensures an adequate energy content and nutrient composition of homemade CF.

However, infant feeding recommendations should not only constitute the ideal case but also aim to consider current everyday reality reflected by the prevalent dominance of commercial CF (RQ 1.2). Despite the advantages of homemade CF (see chapter 1.1), commercial CF still is a convenient and time-saving feeding option that caters the nutritional needs of infants during weaning well. Although concluding from the results of this thesis the current choice of commercial CF products in retail has some room for improvement. Infants would benefit from commercial CF avoiding added sugar without exception as well as a greater and more diverse offer of single vegetable products. In addition, technological progress is needed to improve sensory properties of industrially produced CF by providing taste and texture experiences that are closer to those of common table foods. In this regard the latest development of deep-frozen CF provides a promising alternative combining the sensory variety of homemade CF with the convenience aspect of commercial CF. In a German pilot study, infants fed with deep-frozen CF showed a greater acceptance of unknown foods than those fed with commercial CF [133]. This study is the first to indicate the potential of other industrially produced CF in promoting food acceptance by providing infants with the essential sensory variety.

In principle, infant feeding guidelines need to provide parents with all necessary information on the advantages and disadvantages of both common CF preparation types to give them the opportunity of making an autonomous, informed choice on what type of CF to feed their infants. Those guidelines should further convey the message that the early sensory experiences provide the foundation for infants' taste development. Hence, parents would benefit from more detailed guidelines with practical advice on how to promote food acceptance during weaning [21]. It is crucial to repeatedly expose infants to a wide variety of different flavours and textures within and between meals from the start of complementary feeding. Moreover, it is important to avoid redundant ingredients like added sugars as they magnify the inborn preference for sweet taste and can thus promote the development of unfavourable food preferences. Consequently, emphasizing the role of repeated exposure and a wide dietary variety as well as the redundancy of added sugar during weaning will help parents to enhance their children's food acceptance and facilitate the development of a healthy dietary behaviour irrespective of the choice of homemade or commercial CF.

5 CONCLUSION AND PERSPECTIVES

Currently, there is a lot of interest in taste programming during infancy and whether exposure to different tastes or certain foods early in life may have implications for lifelong dietary choices. Still, current (German) infant feeding guidelines provide only limited guidance and practical advice on how to promote taste and food acceptance and the development of favourable dietary behaviour during the complementary feeding period. Although the available scientific literature provides profound evidence for the imprinting of individual food preferences through early sensory experiences via amniotic fluid and breast milk during infancy, it is difficult to draw a definite conclusion on the influence of CF's sensory properties based on the existing body of research. The set of three analyses conducted in this thesis contributes to the growing knowledge on what early feeding experience – focusing on the preparation type of CF – looks like and how it can shape children's dietary behaviour by means of increasing fruit and vegetable consumption as well as limiting added sugar intake in this instance.

The observed associations between the consumption of commercial CF and dietary behaviour in infancy and childhood provide important implications for future studies, which may have the ability to look closer into detail to detect underlying mechanisms. Randomised intervention studies with infants fed either commercial or homemade CF exclusively including long-term follow-ups would be urgently needed to verify these results and to better understand the influence of different CF types on later dietary behaviour as they allow causal inferences. However, given their known practical and ethical limitations it is almost impossible to conduct those studies under real-life conditions. Since most available studies on the effects of early feeding experience were conducted in laboratory settings of limited duration with only very small sample sizes this thesis' findings gain relevance as the influence of habitual CF feeding practices has been investigated during a long exposure period throughout infancy. Given the observed differences between high and low commercial CF users with regards to breastfeeding duration and total energy intake, additional analyses in other well-conducted cohort studies should aim to investigate typical dietary patterns that derive from the predominant use of either homemade or commercial CF as well as their possible consequences for health outcomes in infancy and beyond.

Overall, this thesis highlights the important role of commercial CF in today's infant nutrition and further provides first evidence of the CF preparation type being a relevant modifiable factor shaping long-term dietary behaviour. Given the study design, this thesis cannot conclusively answer the questions whether it is the early diet tracking through childhood or the sensory properties of CF imprinting later taste and food preferences. Still, it underlines that the at least occasional provision of homemade CF can help infants to develop beneficial food preferences and contribute to a favourable dietary behaviour, in particular to a higher intake of fruits and vegetables as well as a lower added sugar intake in childhood.

6 REFERENCES

1. Agostoni C, Decsi T, Fewtrell M, et al.: Complementary feeding: A commentary by the ESPGHAN Committee on Nutrition. *J Pediatr Gastroenterol Nutr* **2008**;46(1):99–110.
2. Hilbig A, Kersting M: Einführung von Beikost: Wissenschaftlicher Hintergrund und praktische Empfehlungen [German]. *Die Hebamme* **2014**;27(4):276–281.
3. Koletzko BV, Bauer CP, Brönstrup A, et al.: Säuglingsernährung und Ernährung der stillenden Mutter. Aktualisierte Handlungsempfehlungen des Netzwerk Gesund ins Leben - Netzwerk Junge Familie, ein Projekt von IN FORM [German]. *Monatsschr Kinderheilkd* **2013**;137(24):1309–1314.
4. World Health Organization (WHO): Complementary feeding of young children in developing countries. A review of current scientific knowledge; **1998**. Available online: *http://whqlibdoc.who.int/hq/1998/WHO_NUT_98.1.pdf* (accessed on 9 July, 2015).
5. Ernährungskommission der Deutschen Gesellschaft für Kinder- und Jugendmedizin (DGKJ): Ernährung gesunder Säuglinge: Empfehlungen der Ernährungskommission der Deutschen Gesellschaft für Kinder- und Jugendmedizin [German]. *Monatsschr Kinderheilkd* **2014**;162(6):527–538.
6. Österreichische Gesellschaft für Kinder- und Jugendheilkunde (ÖGKJ), Österreichische Agentur für Gesundheit und Ernährungssicherheit GmbH (AGES), Bundesministerium für Gesundheit (BMG), et al.: Richtig essen von Anfang an! Österreichische Beikostempfehlungen [German]; **2010**. Available online: *http://www.ages.at/fileadmin/AGES2015/Themen/Ern%C3%A4hrung_Dateien/Beikostempfehlungen.pdf* (accessed on 22 April, 2015).
7. Ernährungskommission der Schweizerischen Gesellschaft für Pädiatrie: Empfehlungen für die Säuglingsernährung 2009 [German]. *Paediatrica* **2009**;20(5):13–15.
8. Schweizerische Gesellschaft für Ernährung (SGE): Ernährung des Säuglings im ersten Lebensjahr [German]; **2012**. Available online: *http://www.sge-ssn.ch/media/medialibrary/2013/04/merkblatt_ernaehrung_des_saeuglings_2012_4.pdf* (accessed on 22 April, 2015).
9. British Dietetic Association (BDA): Food Fact Sheet Weaning; **2014**. Available online: *https://www.bda.uk.com/foodfacts/WeaningYourChild.pdf* (accessed on 22 April, 2015).
10. Department of Health: Introducing Solid Foods. Giving your baby a better start in life; **2014**. Available online: *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/216328/dh_125828.pdf* (accessed on 22 April, 2015).
11. British Nutrition Foundation: Factsheet on Weaning your baby; **2015**. Available online: *http://www.nhs.uk/ipgmedia/national/british%20nutrition%20foundation/assets/weaningyourbaby.pdf* (accessed on 22 April, 2015).
12. Food Safety Authority of Ireland: Best Practice for Infant Feeding in Ireland. From pre-conception through the first year of an infant's life; **2012**. Available online: *https://www.fsai.ie/publications_infant_feeding/* (accessed on 22 April, 2015).
13. Kleinman RE: Complementary Feeding. In: Pediatric Nutrition Handbook, 6th ed; Kleinman RE (Ed.): American Academy of Pediatrics, **2009**:113–142.

14. United States Department of Agriculture (USDA): Infant Nutrition and Feeding. A Guide for Use in the WIC and CSF Programs; **2009**. Available online: *www.nal.usda.gov/ wicworks/Topics/FG/CompleteIFG.pdf* (accessed on 23 April, 2015).

15. Österreichische Gesellschaft für Kinder- und Jugendheilkunde (ÖGKJ), Österreichische Agentur für Gesundheit und Ernährungssicherheit GmbH (AGES), Bundesministerium für Gesundheit (BMG), et al.: Richtig essen von Anfang an! Informationen zu Beikost-produkten [German]; **2014**. Available online: *http://www.richtigessenvonanfangan.at/ content/download/4983/28808/file/Informationen%20zu%20Beikostprodukten_A5_2014. pdf* (accessed on 22 April, 2015).

16. Hilbig A, Lentze MJ, Kersting M: Einführung und Zusammensetzung der Beikost: Wissenschaftliche Evidenz und praktische Empfehlungen in Deutschland [German]. *Monatsschr Kinderheilkd* **2012**;160(11):1089–1095.

17. Ternes W, Täufel A, Tunger L, et al.: Lebensmittel-Lexikon [German], 4th ed; Behr‘s Verlag, **2005**.

18. Sato K, Hegarty GR: Warmed-over flavour in cooked meats. *J Food Sci* **1971**;36(7):1098–1102.

19. Boom S van den, Kimber AC, Morgan JB: Nutritional composition of home-prepared baby meals in Madrid: Comparison with commercial products in Spain and home-made meals in England. *Acta Paediatr* **1997**;86(1):57–62.

20. Hoddinott P, Craig L, Britten J, et al.: A prospective study exploring the early infant feeding experiences of parents and their significant others during the first 6 months of life. What would make a difference? **2010**. Available online: *http://www.healthscotland.com/ uploads/documents/13993-RE031FinalReport0809.pdf* (accessed on 17 July, 2015).

21. Caton SJ, Ahern SM, Hetherington MM: Vegetables by stealth: An exploratory study investigating the introduction of vegetables in the weaning period. *Appetite* **2011**;57(3):816–825.

22. Schwartz C, Madrelle J, Vereijken CMJL, et al.: Complementary feeding and “donner les bases du goût” (providing the foundation of taste): A qualitative approach to understand weaning practices, attitudes and experiences by French mothers. *Appetite* **2013**;71:321–331.

23. Synnott K, Bogue J, Edwards CA, et al.: Parental perceptions of feeding practices in five European countries: An exploratory study. *Eur J Clin Nutr* **2007**;61(8):946–956.

24. Cantrup A: Aller guten Dinge sind Brei oder Motive für eine Selbstherstellung von Säuglingskost [German]. *Ernährung im Fokus* **2004**;4(1):7–9.

25. Ljung K, Palm B, Grandér M, et al.: High concentrations of essential and toxic elements in infant formula and infant foods: A matter of concern. *Food Chemistry* **2011**;127(3):943–951.

26. Melø R, Gellein K, Evje L, et al.: Minerals and trace elements in commercial infant food. *Food Chem Toxicol* **2008**;46(10):3339–3342.

27. Mir-Marqués A, González-Masó A, Cervera ML, et al.: Mineral profile of Spanish commercial baby food. *Food Chemistry* **2015**;172:238–244.

28. Zand N, Chowdhry BZ, Wray DS, et al.: Elemental content of commercial ‘ready to-feed’ poultry and fish based infant foods in the UK. *Food Chemistry* **2012**;135(4):2796–2801.
29. Zand N, Chowdhry BZ, Zotor FB, et al.: Essential and trace elements content of commercial infant foods in the UK. *Food Chemistry* **2011**;128(1):123–128.
30. Zand N, Chowdhry BZ, Pollard LV, et al.: Commercial ‘ready-to-feed’ infant foods in the UK: Macro-nutrient content and composition. *Matern Child Nutr* **2015**;11(2):202–214.
31. European Commission (EC): Commission Directive 2006/125/EC of 5 December 2006 on processed cereal-based foods and baby foods for infants and young children. *Off J Eur Union* **2006**;339:16–35.
32. Stordy BJ, Redfern AM, Morgan JB: Healthy eating for infants: Mothers’ actions. *Acta Paediatr* **1995**;84(7):733–741.
33. Garcia AL, Raza S, Parrett A, et al.: Nutritional content of infant commercial weaning foods in the UK. *Arch Dis Child* **2013**;98(10):793–797.
34. Hilbig A, Foterek K, Kersting M, et al.: Home-made and commercial complementary meals in German infants: Results of the DONALD study. *J Hum Nutr Diet* **2015**;28(6):613–622.
35. Kersting M, Alexy U, Schultze B: Kommerzielle Säuglingsnahrung unter der Lupe. Produktangebot und Ernährungspraxis in der DONALD-Studie [German]. *Kinderärztl Prax* **2000**;71(2):80–93.
36. Mesch CM, Stimming M, Foterek K, et al.: Food variety in commercial and homemade complementary meals for infants in Germany: Market survey and dietary practice. *Appetite* **2014**;76:113–119.
37. Garcia AL, McLean K, Wright CM: Types of fruits and vegetables used in commercial baby foods and their contribution to sugar content. *Matern Child Nutr* **2015** [epub ahead of print].
38. Kersting M, Alexy U, Sichert-Hellert W, et al.: Measured consumption of commercial infant food products in German infants: Results from the DONALD study. *J Pediatr Gastroenterol Nutr* **1998**;27(5):547–552.
39. McAndrew F, Thompson J, Fellows L, et al.: Infant Feeding Survey 2010; **2012**. Available online: *http://www.hscic.gov.uk/catalogue/PUB08694/Infant-Feeding-Survey-2010-Consolidated-Report.pdf* (accessed on 26 January, 2014).
40. O’Donovan SM, Murray DM, Hourihane JO, et al.: Adherence with early infant feeding and complementary feeding guidelines in the Cork BASELINE Birth Cohort Study. *Public Health Nutr* **2015**;18(15):2864–2873.
41. Briefel RR, Reidy K, Karwe V, et al.: Feeding Infants and Toddlers Study: Improvements Needed in Meeting Infant Feeding Recommendations. *J Am Diet Assoc* **2004**;104(Suppl 1): S31-37.
42. Hurley KM, Black MM: Commercial baby food consumption and dietary variety in a statewide sample of infants receiving benefits from the special supplemental nutrition program for women, infants, and children. *J Am Diet Assoc* **2010**;110(10):1537–1541.
43. Wardle J, Cooke L: Genetic and environmental determinants of children’s food preferences. *Br J Nutr* **2008**;99(Suppl 1):S15-21.

44. Ventura AK, Worobey J: Early influences on the development of food preferences. *Curr Biol* **2013**;23(9):R401-408.

45. Blissett J, Fogel A: Intrinsic and extrinsic influences on children's acceptance of new foods. *Physiol Behav* **2013**;121:89–95.

46. Beauchamp GK, Mennella JA: Early flavor learning and its impact on later feeding behavior. *J Pediatr Gastroenterol Nutr* **2009**;48(Suppl 1):S25-30.

47. Mennella JA, Trabulsi JC: Complementary foods and flavor experiences: Setting the foundation. *Ann Nutr Metab* **2012**;60(Suppl 2):40–50.

48. Beauchamp GK, Mennella JA: Flavor perception in human infants: Development and functional significance. *Digestion* **2011**;83(Suppl 1):1–6.

49. Lipchock SV, Reed DR, Mennella JA: The gustatory and olfactory systems during infancy: Implications for development of feeding behaviors in the high-risk neonate. *Clin Perinatol* **2011**;38(4):627–641.

50. Hausner H, Philipsen M, Skov TH, et al.: Characterization of the Volatile Composition and Variations Between Infant Formulas and Mother's Milk. *Chem Percept* **2009**;2(2):79–93.

51. Nicklaus S: Development of food variety in children. *Appetite* **2009**;52(1):253–255.

52. Hausner H, Bredie WLP, Mølgaard C, et al.: Differential transfer of dietary flavour compounds into human breast milk. *Physiol Behav* **2008**;95(1-2):118–124.

53. Sandgruber S, Much D, Amann-Gassner U, et al.: Sensory and molecular characterisation of human milk odour profiles after maternal fish oil supplementation during pregnancy and breastfeeding. *Food Chemistry* **2011**;128(2):485–494.

54. Denzer MY, Kirsch F, Buettner A: Are odorant constituents of herbal tea transferred into human milk? *J Agric Food Chem* **2015**;63(1):104–111.

55. Mennella JA, Beauchamp GK: Understanding the origin of flavor preferences. *Chem Senses* **2005**;30(Suppl 1):i242-243.

56. Mennella JA, Forestell CA, Morgan LK, et al.: Early milk feeding influences taste acceptance and liking during infancy. *Am J Clin Nutr* **2009**;90(3):S780-788.

57. Nehring I, Kostka T, Kries R von, et al.: Impacts of In Utero and Early Infant Taste Experiences on Later Taste Acceptance: A Systematic Review. *J Nutr* **2015**;145:1271–1279.

58. Hausner H, Nicklaus S, Issanchou S, et al.: Breastfeeding facilitates acceptance of a novel dietary flavour compound. *Clin Nutr* **2010**;29(1):141–148.

59. Mennella JA: Ontogeny of taste preferences: Basic biology and implications for health. *Am J Clin Nutr* **2014**;99(3):S704-711.

60. Alexy U: Die Ernährung des gesunden Säuglings nach dem „Ernährungsplan für das 1. Lebensjahr" [German]. *Ern Umschau* **2007**;54(10):588–594.

61. Nicklaus S: Children's acceptance of new foods at weaning: Role of practices of weaning and of food sensory properties. *Appetite* **2011**;57(3):812–815.

62. Mennella JA, Nicklaus S, Jagolino AL, et al.: Variety is the spice of life: Strategies for promoting fruit and vegetable acceptance during infancy. *Physiol Behav* **2008**;94(1):29–38.

63. Werthmann J, Roefs A, Havermans R, et al.: Bits and pieces. Food texture influences food acceptance in young children. *Appetite* **2015**;84:181–187.
64. Schwartz C, Scholtens PA, Lalanne A, et al.: Development of healthy eating habits early in life: Review of recent evidence and selected guidelines. *Appetite* **2011**;57(3):796–807.
65. Blossfeld I, Collins A, Kiely M, et al.: Texture preferences of 12-month-old infants and the role of early experiences. *Food Qual Prefer* **2006**;18:396–404.
66. Lundy B, Field T, Carraway K, et al.: Food Texture Preferences in Infants Versus Toddlers. *Early Child Dev Care* **1998**;146:69–85.
67. Northstone K, Emmett P, Nethersole F, et al.: The effect of age of introduction to lumpy solid on foods eaten and reported feeding difficulties at 6 and 15 months. *J Hum Nutr Diet* **2001**;14(1):43–54.
68. Birch LL, Gunder L, Grimm-Thomas K, et al.: Infants' consumption of a new food enhances acceptance of similar foods. *Appetite* **1998**;30(3):283–295.
69. Maier A, Chabanet C, Schaal B, et al.: Effects of repeated exposure on acceptance of initially disliked vegetables in 7-month old infants. *Food Qual Prefer* **2007**;18(8):1023–1032.
70. Sullivan SA, Birch LL: Infant dietary experience and acceptance of solid foods. *Pediatrics* **1994**;93(2):271–277.
71. Leathwood P, Maier A: Early influences on taste preferences. *Nestle Nutr Workshop Ser Pediatr Program* **2005**;56:127–138.
72. Mennella JA, Ventura AK: Early feeding: Setting the stage for healthy eating habits. *Nestle Nutr Workshop Ser Pediatr Program* **2011**;68:153–163.
73. Bonsnes RW: Composition of amniotic fluid. *Clin Obstet Gynecol* **1966**;9(2):440–448.
74. Andreas NJ, Kampmann B, Mehring-Le-Doare K: Human breast milk: A review on its composition and bioactivity. *Early Hum Dev* **2015**;91(11):629–635.
75. Ventura AK, Mennella JA: Innate and learned preferences for sweet taste during childhood. *Curr Opin Clin Nutr Metab Care* **2011**;14(4):379–384.
76. Liem DG, Graaf C de: Sweet and sour preferences in young children and adults: Role of repeated exposure. *Physiol Behav* **2004**;83(3):421–429.
77. Liem DG, Mennella JA: Sweet and sour preferences during childhood: Role of early experiences. *Dev Psychobiol* **2002**;41(4):388–395.
78. Birch LL: Development of food preferences. *Annu Rev Nutr* **1999**;19:41–62.
79. Birch LL, Doub AE: Learning to eat: Birth to age 2 y. *Am J Clin Nutr* **2014**;99(3):S723-728.
80. Burnier D, Dubois L, Girard M: Exclusive breastfeeding duration and later intake of vegetables in preschool children. *Eur J Clin Nutr* **2011**;65(2):196–202.
81. Lauzon-Guillain B de, Jones L, Oliveira A, et al.: The influence of early feeding practices on fruit and vegetable intake among preschool children in 4 European birth cohorts. *Am J Clin Nutr* **2013**;98(3):804–812.

82. Jones L, Moschonis G, Oliveira A, et al.: The influence of early feeding practices on healthy diet variety score among pre-school children in four European birth cohorts. *Public Health Nutr* **2015**;18(10):1774–1784.

83. Scott JA, Chih TY, Oddy WH: Food variety at 2 years of age is related to duration of breastfeeding. *Nutrients* **2012**;4(10):1464–1474.

84. Coulthard H, Harris G, Emmett P: Long-term consequences of early fruit and vegetable feeding practices in the United Kingdom. *Public Health Nutr* **2010**;13(12):2044–2051.

85. Maier AS, Chabanet C, Schaal B, et al.: Breastfeeding and experience with variety early in weaning increase infants' acceptance of new foods for up to two months. *Clin Nutr* **2008**;27(6):849–857.

86. Maier-Nöth A, Schaal B, Leathwood P, et al.: The Lasting Influences of Early Food-Related Variety Experience: A Longitudinal Study of Vegetable Acceptance from 5 Months to 6 Years in Two Population. *PLoS ONE* **2016**;11(3):e0151356.

87. Mennella JA, Bobowski NK: The sweetness and bitterness of childhood: Insights from basic research on taste preferences. *Physiol Behav* **2015**;152(Part B):502–507.

88. Hilbig A, Alexy U, Drossard C, et al.: GRETA: Ernährung von Kleinkindern in Deutschland [German]. *Aktuel Ernaehrungsmed* **2011**;36(4):224–231.

89. Heseker H, Mensink GBM, Richter A, et al.: Lebensmittelverzehr und Nährstoffzufuhr im Kindes- und Jugendalter: Ergebnisse aus den beiden bundesweit durchgeführten Ernährungsstudien VELS und EsKiMo [German]. In: Ernährungsbericht 2008; Deutsche Gesellschaft für Ernährung (DGE) (Ed.), **2008**.

90. Buyken AE, Alexy U, Kersting M, et al.: Die DONALD Kohorte. Ein aktueller Überblick zu 25 Jahren Forschung im Rahmen der Dortmund Nutritional and Anthropometric Longitudinally Designed Study [German]. *Bundesgesundhbl Gesundheitsforsch Gesundheitsschutz* **2012**;55(6-7):875–884.

91. Kroke A, Manz F, Kersting M, et al.: The DONALD Study: History, current status and future perspectives. *Eur J Nutr* **2004**;43(1):45–54.

92. Sichert-Hellert W, Kersting M, Chahda C, et al.: German food composition database for dietary evaluations in children and adolescents. *J Food Compos Anal* **2007**;20(1):63–70.

93. Adair LS: How could complementary feeding patterns affect the susceptibility to NCD later in life? *Nutr Metab Cardiovasc Dis* **2012**;22(10):765–769.

94. Northstone K, Emmett P: Multivariate analysis of diet in children at four and seven years of age and associations with socio-demographic characteristics. *Eur J Clin Nutr* **2005**;59(6):751–760.

95. Northstone K, Emmett PM: Are dietary patterns stable throughout early and mid-childhood? A birth cohort study. *Br J Nutr* **2008**;100(5):1069–1076.

96. Robinson S, Marriott L, Poole J, et al.: Dietary patterns in infancy: The importance of maternal and family influences on feeding practice. *Br J Nutr* **2007**;98(5):1029–1037.

97. Lioret S, Betoko A, Forhan A, et al.: Dietary Patterns Track from Infancy to Preschool Age: Cross-Sectional and Longitudinal Perspectives. *J Nutr* **2015**;145(4):775–782.

98. Lobstein T: Post-2015 agenda: sustainable and healthy food systems for preventing the crisis in child obesity. *SCN News* **2015**;41:19–26.

99. Smithers LG, Golley RK, Brazionis L, et al.: Characterizing whole diets of young children from developed countries and the association between diet and health: A systematic review. *Nutr Rev* **2011**;69(8):449–467.

100. Düren M, Kersting M: Das Angebot an Kinderlebensmitteln in Deutschland: Produktübersicht und ernährungsphysiologische Wirkung [German]. *Ern Umschau* **2003**;50(1):16–21.

101. Foterek K, Hilbig A, Kersting M, et al.: Age and time trends in the diet of young children: Results of the DONALD study. *Eur J Nutr* **2016**;55(2):611-620.

102. Khalessi A, Reich SM: A Month of Breastfeeding Associated with Greater Adherence to Pediatric Nutrition Guidelines. *J Reprod Infant Psychol* **2013**;31(3):299–308.

103. Perrine CG, Galuska DA, Thompson FE, et al.: Breastfeeding duration is associated with child diet at 6 years. *Pediatrics* **2014**;134(Suppl 1):S50-55.

104. Betoko A, Charles MA, Hankard R, et al.: Infant feeding patterns over the first year of life: Influence of family characteristics. *Eur J Clin Nutr* **2013**;67(6):631–637.

105. Smithers LG, Brazionis L, Golley RK, et al.: Associations between dietary patterns at 6 and 15 months of age and sociodemographic factors. *Eur J Clin Nutr* **2012**;66(6):658–666.

106. Brazionis L, Golley RK, Mittinty MN, et al.: Characterization of transition diets spanning infancy and toddlerhood: A novel, multiple-time-point application of principal components analysis. *Am J Clin Nutr* **2012**;95(5):1200–1208.

107. Armstrong J, Abraham EC, Squair M, et al.: Exclusive Breastfeeding, Complementary Feeding, and Food Choices in UK Infants. *J Hum Lact* **2014**;30(2):201–208.

108. Golley RK, Smithers LG, Mittinty MN, et al.: Diet Quality of UK Infants Is Associated with Dietary, Adiposity, Cardiovascular, and Cognitive Outcomes Measured at 7-8 Years of Age. *J Nutr* **2013**;143(10):1611–1617.

109. Schiess S, Grote V, Scaglioni S, et al.: Introduction of complementary feeding in 5 European countries. *J Pediatr Gastroenterol Nutr* **2010**;50(1):92–98.

110. Jones LR, Steer CD, Rogers IS, et al.: Influences on child fruit and vegetable intake: Sociodemographic, parental and child factors in a longitudinal cohort study. *Public Health Nutr* **2010**;13(7):1122–1130.

111. Ashman AM, Collins CE, Hure AJ, et al.: Maternal diet during early childhood, but not pregnancy, predicts diet quality and fruit and vegetable acceptance in offspring. *Matern Child Nutr* **2014** [epub ahead of print].

112. Pearson N, Biddle SJ, Gorely T: Family correlates of fruit and vegetable consumption in children and adolescents: A systematic review. *Public Health Nutr* **2009**;12(2):267–283.

113. Benton D: Role of parents in the determination of the food preferences of children and the development of obesity. *Int J Obes* **2004**;28(7):858–869.

114. Madruga SW, Araújo CLP, Bertoldi AD, et al.: Tracking of dietary patterns from childhood to adolescence. *Rev Saúde Pública* **2012**;46(2):376–386.

115. Cooke LJ, Wardle J: Age and gender differences in children's food preferences. *Br J Nutr* **2005**;93(5):741–746.

116. Bjelland M, Brantsæter AL, Haugen M, et al.: Changes and tracking of fruit, vegetables and sugar-sweetened beverages intake from 18 months to 7 years in the Norwegian Mother and Child Cohort Study. *BMC Public Health* **2013**;13:793.

117. Ovaskainen ML, Nevalainen J, Uusitalo L, et al.: Some similarities in dietary clusters of pre-school children and their mothers. *Br J Nutr* **2009**;102(3):443–452.

118. Fildes A, Jaarsveld CH van, Llewellyn CH, et al.: Nature and nurture in children's food preferences. *Am J Clin Nutr* **2014**;99(4):911–917.

119. Patro-Gołąb B, Szajewska H: Strengths and weaknesses of observational nutritional studies. *World Rev Nutr Diet* **2013**;108:11–17.

120. Jacobs DR: Challenges in Research in Nutritional Epidemiology. In: Nutritional Health: Strategies for Disease Prevention; Temple NJ, Wilson T, Jacobs DR (Eds.): Springer, **2012**:29–42.

121. Magarey A, Watson J, Golley RK, et al.: Assessing dietary intake in children and adolescents: Considerations and recommendations for obesity research. *Int J Pediatr Obes* **2011**;6(1):2–11.

122. Pérez-Rodrigo C, Artiach Escauriaza B, Artiach Escauriaza J, et al.: Dietary assessment in children and adolescents: issues and recommendations. *Nutr Hosp* **2015**;31(Suppl 3):76–83.

123. Sichert-Hellert W, Kersting M, Schoch G: Underreporting of energy intake in 1 to 18 year old German children and adolescents. *Z Ernahrungswiss* **1998**;37(3):242–251.

124. Thompson FE, Subar AF: Dietary Assessment Methodology. In: Nutrition in the prevention and treatment of disease, 3rd ed; Coulston AM, Boushey CJ, Ferruzzi MG (Eds.): Elsevier, **2013**:5–46.

125. Rasmussen M, Krolner R, Klepp KI, et al.: Determinants of fruit and vegetable consumption among children and adolescents: A review of the literature. Part I: Quantitative studies. *Int J Behav Nutr Phys Act* **2006**;3:22.

126. Fein SB, Labiner-Wolfe J, Scanlon KS, et al.: Selected complementary feeding practices and their association with maternal education. *Pediatrics* **2008**;122(Suppl 2):S91-97.

127. Fernández-Alvira JM, Börnhorst C, Bammann K, et al.: Prospective associations between socio-economic status and dietary patterns in European children: The Identification and Prevention of Dietary- and Lifestyle-induced Health Effects in Children and Infants (IDEFICS) Study. *Br J Nutr* **2015**;113(3):517–525.

128. Koh GA, Scott JA, Oddy WH, et al.: Exposure to non-core foods and beverages in the first year of life: Results from a cohort study. *Nutr Diet* **2010**;67(3):137–142.

129. Alles MS, Eussen SRBM, Beek EM van der: Nutritional Challenges and Opportunities during the Weaning Period and in Young Childhood. *Ann Nutr Metab* **2014**;64(3-4):284–293.

130. Grote V, Theurich M, Koletzko BV: Do complementary feeding practices predict the later risk of obesity? *Curr Opin Clin Nutr Metab Care* **2012**;15(3):293–297.

131. Pearce J, Langley-Evans SC: The types of food introduced during complementary feeding and risk of childhood obesity: A systematic review. *Int J Obes* **2013**;37(4):477–485.

132. Robinson S, Fall C: Infant nutrition and later health: A review of current evidence. *Nutrients* **2012**;4(8):859–874.

133. Hilbig A, Schmidt I, Hohoff E, et al.: Fertigprodukte in der Beikost: Tiefgekühlter Brei als Alternative zu Gläschenkost? [German]. *Die Hebamme* **2015**;28(2):130–133.

APPENDIX

A List of presentations

Foterek K, Hilbig A, Buyken AE, Alexy U.
Commercial complementary food and added sugar intake in infants and children in the DONALD Study.
12th FENS European Nutrition Conference, Berlin
Supplement Issue: Annals of Nutrition and Metabolism (2015) 67:196–197 *(poster presented by AE Buyken)*

Foterek K, Hilbig A, Alexy U.
Bedeutung von zugesetztem Zucker vom Säuglingsalter bis zur Grundschule – Ergebnisse der DONALD Studie.
52nd Scientific Conference of the German Nutrition Society, Halle
Proceedings of the German Nutrition Society (2015) 20:10 *(oral presentation)*

Foterek K, Hilbig A, Kersting M, Alexy U.
Der langfristige Einfluss der Art der Beikost auf den Obst- und Gemüseverzehr – Ergebnisse der DONALD Studie.
51st Scientific Conference of the German Nutrition Society, Paderborn
Proceedings of the German Nutrition Society (2014) 19:47 *(oral presentation held by U Alexy)*

Foterek K, Hilbig A, Kersting M, Alexy U.
Percentage of commercial complementary food and fruit and vegetable intake in infancy and childhood – Results of the DONALD Study.
The Power of Programming 2014 – International Conference on Developmental Origins of Adiposity and Long-Term Health"
Proceedings of conference (2014): 79 *(poster)*

Foterek K, Hilbig A, Kersting M, Alexy U.
Verzehrsanteile von industriell und selbst hergestellter Beikost in der DONALD Studie.
50th Scientific Conference of the German Nutrition Society, Bonn
Proceedings of the German Nutrition Society (2013) 18:38 *(oral presentation)*

B Publications during candidature not included in this thesis

Mesch CM, Stimming M, **Foterek K**, Hilbig A, Alexy U, Kersting M, Libuda L.
Food variety in commercial and homemade complementary meals for infants in Germany. Market survey and dietary practice.
Appetite 2014; 76:113–119
DOI: 10.1016/j.appet.2014.01.074

Foterek K, Alexy U.
Säuglingsernährung – praktische Empfehlungen und aktuelle Studienergebnisse [German].
Erfahrungsheilkunde 2015; 64:84–88
Invited article
DOI: 10.1055/s-0041-100509

Beyerlein A, Liu X, Uusitalo UM, Harsunen M, Norris JM, **Foterek K**, Virtanen SM, Rewers MJ, She JX, Simell O, Lernmark Å, Hagopian W, Akolkar B, Ziegler AG, Krischer JP, Hummel S and the TEDDY Study Group.
Dietary intake of soluble fiber and risk of islet autoimmunity by 5 y of age: results from the TEDDY study.
American Journal of Clinical Nutrition 2015; 102(2):345-352
DOI: 10.3945/ajcn.115.108159

Foterek K, Hilbig A, Kersting M, Alexy U.
Age and time trends in the diet of young children. Results of the DONALD study.
European Journal of Clinical Nutrition 2016; 55(2):611-620
DOI: 10.1007/s00394-015-0881-6

Yang J, Lynch KF, Uusitalo UM, **Foterek K,** Hummel S, Silvis K, Andrén Aronsson C, Riikonen A, Rewers M, She JX, Ziegler AG, Simell OG, Toppari J, Hagopian WA, Lernmark Å, Akolkar B, Krischer JP, Norris JM, Virtanen SM, Johnson SB and the TEDDY Study Group.
Factors associated with longitudinal food record compliance in a paediatric cohort study.
Public Health Nutrition 2016; 19(5):804-813
DOI: 10.1017/S1368980015001883

Hilbig A, **Foterek K**, Kersting M, Alexy U.
Home-made and commercial complementary meals in German infants: results of the DONALD study.
Journal of Human Nutrition and Dietetics 2015; 28(6):613-622
DOI: 10.1111/jhn.12325

Roßbach S, **Foterek K**, Schmidt IV, Hilbig A, Alexy U.
Food neophobia in German adolescents: Determinants and association with dietary habits.
Appetite 2016; 101:184-191
DOI: 10.1016/j.appet.2016.02.159

Emerging research indicates that besides innate taste preferences early sensory experiences in infancy via amniotic fluid, breast milk, and infant formula play a crucial role in the development of individual food preferences and dietary behaviour. With the introduction of complementary food (CF) during weaning, the spectrum of different flavours and textures increases further. However, the potential of CF's sensory properties – particularly with regards to its preparation type, i.e. homemade or commercial – in shaping later food preferences has not been extensively examined so far. Thus, the **overall aim** of this thesis was to determine existing trends in complementary feeding practice, and their relevance for later dietary behaviour. Three analyses (Studies I-III) were conducted using data from the German DOrtmund Nutritional and Anthropometric Longitudinally Designed (DONALD) Study, an ongoing, open cohort study.

Study I (n=366) revealed that commercial CF dominated infant feeding, especially in infants who were breast-fed for a shorter duration and whose mothers had a lower educational status. Both commercial and homemade CF showed opposing, nonlinear age trends; however, no time trends could be found during the observed study period (2004-2012). In **Study II** (n=281), a higher commercial CF proportion was associated with lower vegetable intake in infancy in both sexes. Prospectively, only boys showed an inverse association between a higher commercial CF proportion and a lower vegetable intake in preschool age as well as lower total fruit and vegetable intake in preschool and primary school age. For girls, no significant prospective association could be observed. With respect to fruit and vegetable variety, no distinct associations were found. **Study III** (n=288) indicated that infants with a high contribution of commercial CF had higher odds for a high consumption of added sugar from CF as well as a high total added sugar intake. Commercial CF consumption in infancy was also positively related to added sugar intake in preschool and primary school age.

In conclusion, this thesis highlights the constantly high and widespread consumption of commercial CF in today's infant nutrition and further provides first evidence of the preparation type of CF being a relevant modifiable factor shaping long-term dietary behaviour. Although the question, whether it is the early diet tracking through childhood or the sensory properties of CF imprinting later taste and food preferences cannot be conclusively answered, these results underline that the occasional provision of homemade CF can help infants to develop beneficial food preferences and contribute to a favourable dietary behaviour by means of increasing fruit and vegetable consumption as well as limiting added sugar intake in childhood.