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van Dijk, Marijn

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Research review

A complex dynamical systems approach to the development of feeding problems in early childhood

Marijn van Dijk

Heymans Institute for Psychological Research, University of Groningen, Grote Kruisstraat 2/1, 9712, TS Groningen, the Netherlands



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ABSTRACT

Though it is commonly agreed upon that the development of feeding problems in early childhood is a complex process, much of the research on these problems has a component-oriented focus, and very little attention is paid to the mechanisms that lead to these kinds of problems in individual children. The aim of this theoretical paper is to interpret the development of feeding problems in early childhood from a complex dynamical systems viewpoint. In addition to its focus on self-organization and nonlinearity, this approach defines several central properties of development: soft-assembly, embodiment, iterativity, the emergence of higher-order properties, and intra-individual variability. In this paper, I argue that each of these properties is highly relevant for understanding feeding problems and discuss the implications of this for both clinical practice and research purposes.

1. Introduction

Against the background of the current increase of childhood overeating and obesity in most Western countries, many parents struggle with their child's eating difficulties of a different kind: the refusal of food and selective eating. This type of feeding difficulties has a great impact on child development, parenting practices and public health. Children who exhibit feeding problems –such as food refusal and selectiveness– are shown to be at risk for poor growth and delayed cognitive development and their parents have higher levels of parenting stress (Lindberg, Bohlin, Hagekull & Thunström, 1994; Van den Engel-Hoek, 2006). Estimations of the prevalence of these problems range from around 7% to as much as 65% (De Moor, Diddens, & Korzilius, 2007), but definitions vary greatly and in some cases very mild symptoms are also included. Severe feeding problems are reported for roughly 3–10% of all children (Corbett & Drewett, 2004; Ramsay, Martel, Porporino, & Zygmuntowicz, 2011a, 2011b). An estimated 13% of Dutch preschoolers are underweight (Jansen et al., 2012), a percentage which is greater than that of children who are overweight (10% in the Dutch population). Though in many cases, feeding difficulties are mild and transient, the existence of them in early life is predictive of feeding problems later in childhood (McDermott et al., 2008; Marchi & Cohen, 1990; Dahl & Sundelin, 1992) and if unaddressed, these problems can persist into school age and adolescence (Lukens & Silverman, 2014; Babbitt et al., 1994; Rydell, Dahl, & Sundelin, 1995). Currently,

the literature on the development of feeding problems contains many studies on between-person differences in terms of revealing underlying components that explain a part of the variance in a population. Very little attention is paid to the mechanisms that lead to these kinds of problems in individual children. The aim of this paper is to interpret the development of feeding problems in early childhood from a complex dynamical systems viewpoint and to discuss the implications of such an interpretation.

When dealing with early feeding problems, it is important to note that at the moment, there is no agreement about its nomenclature. Frequently used terms are 'neophobia' (for the systematic rejection of novel food), 'picky eating' (for children with low appetite, fussy behavior or sensory problems), 'feeding disorder' (for cases with (severe) nutritional, organic or emotional consequences) and 'feeding difficulties' (an umbrella term indicating that there is a problem with feeding of some sort) (see Kerzner, Milano, MacLean et al. (2015)). The term 'feeding disorder' overlaps largely with the description of the category of 'avoidant/restrictive food intake disorder' (ARFID) (307.59 F50.8) in the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-V) (American Psychiatric Association, 2013), because it explicitly states the negative consequences of the problems with eating. However, ARFID is not specific to children, whereas other terms, such as 'feeding difficulties', are commonly used in the literature to specially refer to problems in (early) childhood. In addition, the spectrum of feeding problems reported by parents is large and includes

E-mail address: m.w.g.van.dijk@rug.nl.

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symptoms such as poor appetite, poor feeding skills and the rejection of unfamiliar food. In these cases, the problems do not necessarily lead to significant nutritional deficiency, weight loss, dependence on enteral feeding or psychosocial problems for the child (yet). This suggests that the ARFID classification does not fully cover what is typical of childhood feeding problems: disruptive mealtime behaviors, food refusal, self-feeding inadequacy, excessive mealtime duration, food selectivity, the use of distraction to increase intake, and parental stress during feeding (Crist & Napier-Phillips, 2001; Kerzner et al., 2015).

Although, there is no agreement on terminology and definitions, there is a consensus on the interpretation that feeding problems in childhood are multidimensional in nature and that the biopsychosocial model can describe their emergence. This model explains that these problems are the result of biological, behavioral, and social factors, which interact with each other (Sanders, Patel, Le Grice, & Shepherd, 1993; Johnson & Harris, 2004; Rommel, De Meyer, Feenstra & Veereman-Wauters, 2003). At the same time, many studies—particularly in the pediatric literature—show attempts at isolating and categorizing types of feeding problems (Crist & Napier-Phillips, 2001; Bithoney & Dubowitz, 1984, pp. 47–68; Homer and Ludwig, 1981). For instance, Field, Garland, and Williams (2003) described a widely-used schema which distinguishes four types: 1) oral motor problems, 2) selectivity by type of food, 3) selectivity by texture and 4) food refusal in general. In addition, many studies make a sharp distinction between organic and nonorganic feeding problems. For instance, Kerzner et al. (2015) propose a categorization in terms of 1) low appetite, 2) selectiveness, 3) fear, or 4) parental feeding style, which all need separate treatment plans. These authors acknowledge that children may exhibit problems in more than one of these categories, in which case the necessary interventions need to be prioritized. However, these categorizations testify a component-oriented perspective on feeding problems, in which distinct ‘causes’—components such as ‘oral motor difficulties’ or ‘parental feeding style’—are identified and treated separately.

When reviewing the literature on feeding problems in childhood, it stands out that most studies are multivariable in nature and thus aim at finding (linear) correlations at a group level. They seem to interpret interactions between variables in terms of explained variance between individuals. Much research is directed at identifying variables (e.g. ‘components’, ‘categories’) contributing to the prevalence of feeding problems, such as factors in the child, the environment, culture. By following this approach, a variety of background factors has been shown to correlate with early feeding problems, such as differences in the quality of the mother-child relation (Feldman, Keren, Gross-Rozval, & Tyano, 2004), the child’s temperament (Pliner & Loewen, 1997), familial eating problems (Stapleton, Fielder & Kirkham, 2009) and medical factors such as ex-prematurity (Burklow, McGrath, Valerius, & Rudolph, 2002; Samara, Johnson, Lamberts, Marlow, & Wolke, 2010). On the basis of the results of these studies, inferences are often made about the underlying causes of feeding problems. For instance, the study of Feldman et al. (2004) reports that infants with feeding disorders displayed less affectionate touch, more negative touch, and more rejection of the mother’s touch than infants without feeding disorder. On the basis of these findings, the authors conclude that touch patterns between mothers and infants may serve as a risk factor for growth failure. They argue that it is important to construct interventions that may reverse some of the negative effects of touch deprivation on children’s further development. In the discussion of the article, the authors acknowledge the study’s limitation of not having longitudinal data, and conclude that therefore “it is impossible to assess whether touch problems emerged after birth or developed with the onset of the [feeding] disorder” (pp.1096). This study of Feldman et al. is representative of many studies on feeding problems in the sense that it focusses on between-individual differences and tries to identify an underlying component that has a causal relation with the development of feeding problems. Though the complex interactions over time are often implicitly or explicitly recognized, the data are based on independent

measures from a population sample and the results are correlational in nature. A problem with this approach is that the statistical model of between-person associations in most cases does not correspond with the statistical model of individual process sequences. The reason for this is that psychological constructs are almost always ‘non-ergodic’, which means that properties of a population distribution do not correspond with distribution properties of each individual within this population (Molenaar & Campbell, 2009). This problem is similar to what has been known for a long time and has been called the “ecological fallacy” (see Robinson, 1950), and is also relevant for the study of the development of feeding problems.

Because there are so few studies with many repeated measurements of the feeding behavior of individual children across time, the descriptions of the process of feeding and eating in early childhood are very general and are highly qualitative in nature. We know for instance that children’s eating habits are usually formed by the end of the preschool period and remain rather stable afterwards (Jansen et al., 2012; Ashcroft, Semmler, Carnell, van Jaarsveld, & Wardle, 2008). Some general stages in the development of feeding can also be found in the literature. For instance, Drewett and Young (1998) describe that in typical development, the first stage is of exclusive liquid feeding, in which the infant feeds on milk solely. Though cultural differences exist in timing and feeding content, most infants go through an important transition around the age of 5–6 months when they are being introduced to the first (semi) solid foods. Here, children get acquainted with new types of flavors and food textures and acquire new oral motor skills. In the beginning of the transition, the feeding is often caregiver-assisted, because infants are not yet capable of self-feeding. Over time, children usually start to eat more autonomously (Pearcey & de Castro, 1997). Most children have a relatively long period of ‘combined feeding’ in which they consume both milk and semi-solid food (Young & Drewett, 2000). In the final stage, children eat a variety of foods through self-feeding. Though these stages provide valid qualitative descriptions of the typical development and contain biological, psychological and social elements, the descriptions are so global that they easily fit the majority of all children. In fact, it is hard to imagine any child who follows a different (or even opposite) pattern. There is strikingly little knowledge of the (real-time) processes at the level of the individual child, and of the degree to which individual patterns of development are generalizable to all children or groups of children. However, detailed descriptions of these real-time processes might help understanding the pathways to independent eating and which type of interaction may contribute to the development of feeding problems.

A second observation that stands out when inspecting the literature on the development of feeding problems is that many studies recognize its complex nature, but describe this in only a general sense. Aside from the fact that the biopsychosocial model is frequently mentioned, there are descriptions of the assumed complex interactions between components. For instance, Crist and Napier-Phillips (2001) state “*even when there are contributing organic factors for the feeding difficulties the feeding difficulties frequently arise because of a complex interplay between biological, social and behavioral factors*” (Crist & Napier-Phillips, 2001, p279). Tauman et al. (2011) describe that “*[F]eeding difficulties in healthy children are linked to a variety of causes, including environmental disruption, parental incompetence, the child’s temperament, and psychological factors. It has been shown that certain characteristics of the infant combined with certain vulnerabilities in the parent lead to negative responses and conflict in their interactions*” (pp e616). Several authors have hypothesized that stress may be an important (mediating) factor, because parents who experience feeding problems in their child tend to pressure the child to eat more, causing overstimulation and even greater food refusal (e.g. Tauman et al., 2011; Rommel, Meyer, Feenstra, & Veereman-Wauters, 2003; Lindberg, Bohlin & Hagekull 1991; Field et al., 2003; Ramsay et al., 2011). The descriptions of the assumed complex interactions are very global and hardly specify the causal mechanisms that may be involved. In most cases, the underlying model seems to be ‘additive’ in

the sense that all kinds of factors are being identified that contribute to the development of feeding problems, and the effect on feeding is equal to the sum of the factors' influences. The time-dependent interactions between variables are often addressed in a very global sense.

In summary, most empirical studies on the development of children's feeding problem are component-oriented because the focus is on identifying components in a population. As a result, studies with many repeated measurements are lacking and detailed descriptions of the process of development of feeding problems in individual children are scarce. In addition, there is limited theory-formation on the specific mechanisms of how various components interact and how they lead to feeding problems. This paper attempts to address these issues by framing the development of feeding problems in terms of a complex dynamical system network of time-depending interactions between components.

2. The application of complex dynamical systems ideas to psychological phenomena

In recent years, a shift has occurred in the psychological sciences, in the sense that there is a clear increase in attention to processes and dynamics. However, for many years, the leading paradigm in psychology was component-dominant in nature (Van Orden, Holden, & Turvey, 2003), and we still see many traces of this throughout the behavioral sciences. Within this paradigm, each component is assumed to have its contribution to the end result, and these contributions basically 'add up'. If the contribution of one component would increase, this would immediately be observable in its effect on the resulting behavior. However, the real processes remain out of sight. In their critical paper, Van Orden et al. (2003) have argued that "...[the] products of psychological processes have been mistaken for the processes themselves (Fitch & Turvey, 1978; James, 1890/1950; Turvey et al., 1980, pp. 89–114)." (pp337). According to these authors, development itself does not reside in specific underlying components, but rather in the ongoing interactions among the components that are observable in the moment-to-moment behaviors of the individuals. They argue that development is not component-driven but *interaction-driven*. In this context, it is relevant to note the difference between a complex interaction and a complicated interaction. A complicated interaction means that many factors or components play a role and that they influence each other. However, in such an interaction, the dynamics protect the integrity of the components (Van Orden et al., 2003). Therefore, it is still possible –in theory– to disentangle the separate contributions of each factor. In a complex interaction, on the other hand, the components themselves change as a result of the ongoing interactions (see Den Hartigh, Cox, and van Geert (2017, pp. 657–669) for further explanation of the difference between the two terms). This fits with the idea that development is fundamentally *transactional* instead of just *interactional*, which means that there is a mutually constitutive interplay between individual and context (Sameroff, 2009).

This criticism toward the component-dominant approach of psychology has been voiced by many researchers who advocate a more interaction-dominant approach, and some of them have adopted a complex dynamical systems framework to development. Complex dynamical systems theory provides a meta-theoretical framework that aims to explain development as the result of a process of *self-organization* (Kelso, 1995; Thelen & Smith, 1994; Van Geert, 1994). From this framework, any type of behavior is seen as a state of a *system* (comparable to a physical system in classical or quantum mechanics) consisting of many components (of a biological, psychological and social nature, and including elements of the individual and context) that are all interacting with each other in a non-linear and transactional way (Lewis, 2000). Some of the interactions between components are supportive whereas others are competitive (Van Geert, 2004). The relations can also be symmetric or asymmetric, direct or indirect, and more or less complex (for instance, they can be pre-conditional, nonlinear, etc). Systems are 'open', which means that they are interacting with other systems and

because of this, they can create novelty through their own activity (Smith & Thelen, 2003). This creation of novel properties is referred to by the term 'emergence' and is considered to be the cornerstone of the theoretical framework of complex dynamical systems (Thelen & Smith, 1994). Although, there is no universally acknowledged definition of the term 'emergence' (see Corning, 2002), Goldstein (1999) is often cited by referring to it as "*the arising of novel and coherent structures, patterns and properties during the process of self-organization in complex systems.* (pp 49)". In physical, chemical and biological systems, self-organization is seen as the mechanism that causes a spontaneous emergence of order (Prigogine & Stengers, 1984). Because the state of any system depends on so many different elements and the interrelations are complex, development is often nonlinear in nature. In psychology, the interactions and transactions between components can take various forms and are person-specific (Van Geert, 1991, 1994, 2014). This viewpoint has also been voiced by Gottlieb (1992, 1997) who sees behavior as "*the result of the fusion of biological and psychosocial factors, by probabilistic epigenetic events rather than by preprogrammed genetic or other biochemical ones*" (see Greenberg et al., 1999, pp 169). A certain variable can strongly support another variable in one individual but have no effect in another individual. Because of the individual differences in body, nervous system, experiences and interactions, the precise course of development is largely unpredictable (Thelen, 2005). Mathematical network models based on complex dynamical systems ideas have demonstrated that it is impossible to predict the course of development based on an initial state, but that this predictability increases with age (Den Hartigh, Van Dijk, Steenbeek, & Van Geert, 2016).

Ideas from the theoretical framework of complex dynamic systems have been around in the study of human development from the early 1990s onwards, first in the domain of infant motor coordination and action-perception (e.g. Thelen & Ulrich, 1991), followed by psychological domains such as cognitive and language development (e.g. Fischer & Bidell, 1998, pp. 467–561; Van Geert, 1991), and emotional/social development (e.g. Fogel, 1993; Lewis, 1996). Initially, they were mainly used as conceptual tools (rich theoretical metaphors and mathematical models) and gave rise to various methodological innovations in analyzing developmental data (Fogel, 1999; Lewis & Granic, 2000; Smith & Thelen, 2003; Thelen & Ulrich, 1991). Currently, these ideas and methods are being applied to a wide variety of topics in psychology and related disciplines, such as parent-child interactions (e.g. Hollenstein, 2007), self-esteem (e.g. De Ruiter, van Geert, & Kunnen, 2017; Vallacher, Nowak, Froehlich, & Rockloff, 2002), education (e.g. Van Geert & Steenbeek, 2005), children's reasoning skills (e.g. Meindertsma, van Dijk, Steenbeek, & van Geert, 2014), second language acquisition (e.g. De Bot, Lowie, & Verspoor, 2007), and psychopathology (e.g. Fried & Robinaugh, 2020).

The core concepts of the framework of complex dynamical systems are also relevant for feeding. For instance, Goldfield (2007) saw the early coordination among sucking, swallowing, and breathing during liquid feeding of newborns as a dynamical process with a certain degree of 'synergy' in its coordination patterns. In a previous publication (Van Dijk, Van Voorthuizen, & Cox, 2018), we have argued that the introduction to solid food –which is one of the major milestones in feeding– should also be seen as a complex system in transition (as defined by Fogel (1993), Thelen (2005) Smith (1994), and Van Geert (1994)). In the present paper, I suggest that the general framework of complex dynamic systems can also be used to understand the emergence of feeding problems during early childhood. This theoretical interpretation has far-reaching consequences for the way in which feeding problems should be approached in future research and clinical practice.

Let's consider the following case as an illustration:

A 1-year old girl and her primary caregiver are sitting at the dinner table. The caregiver observes that the girl is a bit restless. She attempts to stand up in her high chair, whines a little bit, and stretches out her arms towards the caregiver. The caregiver responds by saying "you are so impatient", and by showing her a piece of bread. The girl looks at the bread, stops whining,

reaches for the piece, takes it in her mouth and starts chewing on it. The caregiver takes a deep breath.

This short interaction illustrates the transactional character of the feeding interaction. The caregiver observes the child's actions, interprets them, and responds by talking and offering some food at a specific moment. After this, the child's affective state changes, and after observing the result also the caregivers affective state. This short interaction is history-dependent, in the sense that it is probably based—in some way—on previous experiences. It is likely that this caregiver has previously given this child some food when she was whining and it is also likely that this child previously stopped whining when given some food. On the basis of these earlier experiences, child and caregiver have organized a pattern of 'whining leads to food, which leads to stopping whining, which leads to peace and quiet'. This pattern is a form of spontaneous emergence of order, in the sense that it was not pre-determined and probably initially not fully intentional. There were many other options: the caregiver could have taken the child out of the high chair, or ignore the behavior altogether, and the child could have pushed away the food or started to cry. All these options were part of the behavioral repertoire of this particular dyad, but they did not translate into actions at this very moment. The interaction is dyad and time specific, in the sense that the action of offering a piece of bread may have worked for this child at this very moment, whereas it may not have had the same effect in another child or at another moment in time.

Now consider the following scenario

The same 1-year old girl and her primary caregiver are sitting at the dinner table. The caregiver observes that the girl is a bit restless. She attempts to stand up in her high chair, whines a little bit, and stretches out her arms towards the caregiver. Suddenly, the cat jumps on the piano and makes a lot of noise. The girl looks at the cat and stops whining. The caretaker walks towards the cat and puts it on the floor. The caregiver and the girl make eye contact and smile. The caregiver offers the girl a piece of bread.

In the illustrations described above, many different factors (or components) interacted to lead to the specific outcome of the interaction (such as the child's appetite, temperament, alertness, motor skills, the caregiver's responsiveness and level of stress, and situational factors such as a cat jumping on piano). All these components, interact with each other on a moment-to-moment basis and their interactions can be described in a *network*. In fact, the complex dynamical systems approach—which I introduced in the previous paragraph—can be seen as a network approach (see Barabási, 2002). The focus of such a network approach is not so much on the separate elements (or components) but on the characteristics of the network as a whole. For many other topics in psychology, researchers are currently starting to try to understand the actual processes and how they emerge over time. In the field of clinical psychology, for instance, the dynamic network approach has convincingly shown that psychiatric conditions (such as clinical depression, anxiety disorder) originate from causal interactions at the symptom level (such as lack of concentration, sleep problems, mood) (Schmittmann et al., 2013; Wichers, 2014). It has been argued that the relation between a disorder and its symptoms therefore needs to be reconsidered (Schmittmann et al., 2013). Whereas in the literature, reflective and formative interpretations dominate (i.e. the disorder is the *cause* of the symptoms or the symptoms together *are* the disorder), Schmittmann et al. argue that psychiatric conditions should be reinterpreted in terms of their dynamical network properties. In such a network, the symptoms (components) interact constantly with each other in a person-specific architecture (the network). This means that the disorder (for instance 'clinical depression') does not necessarily refer to a latent construct which has a causal role, but to the components and structure of the network as a whole. In fact, the structure of the interactions is more important than the exact structure and content of the components. A similar approach has also been applied to the development of talent (Den Hartigh, Van Dijk, Steenbeek, & Van Geert, 2016) Here, it has been argued that the key to excellent performance does not reside in specific underlying components, but rather in the ongoing interactions among

the components, and the nature of those components may be highly idiosyncratic.

This conceptualization of a dynamic network can be also applied to the development of feeding problems in childhood; symptoms of feeding difficulties interact at a moment-to-moment basis and these interactions create a higher order interaction pattern. Fig. 1 depicts an illustration of such a network of symptom variables for a specific child-caregiver dyad. The network in this illustration is not intended to be exhaustive and other variables may be relevant as well. It is important to stress that the relations are not necessarily linear or stable over time. The underlying relations that are described in Fig. 1 do not represent a group model but describe the dynamics within an individual dyad. In this specific case, for instance, there is a moderate positive relation between low appetite and food refusal: when the child has a low appetite, this more often leads to food refusal. In addition, there is a strong relation (indicated by the thicker line) between food refusal and caregiver distress, between caregiver distress and pressure to eat and between pressure to eat and food refusal. This means that there is a self-enhancing feedback loop: food refusal leads to caregiver distress, which leads to pressure to eat, which in turn leads to greater food refusing, and so on. The illustration shows several of such feedback loops and describes the complex nature of the interactions.

3. Properties of a complex dynamic system applied to the development of feeding problems

The complex dynamical systems approach defines some further core properties of any developing system. In the psychological literature, authors differ in the order in which these properties are summarized, and some of them partly overlap in definition or follow from each other. However, there is considerable consensus on the following characteristics. The first is *soft-assembly* which means that all actions (for instance a cognitive or motor activity, or a social behavior) are created on the spot in an interaction with the immediate context. The second property is *embodiment*, meaning that properties of cognition, emotion, behavior are shaped by the properties of the body, because they arise from interactions between body and environment (Thelen, Shoner, Scheier & Smith, 2001). The third property is *iterativity* (also called *iterative causality* or *recursiveness*), which means the current state of a system immediately influences the next state, which in turn influences its next state, and so on. This process is self-organizing, and not governed by top-down influences (Van Geert, 1994). Instead, the constant iterations often show feedback loops, and can be self-amplifying, or self-stabilizing (Van Geert, 1998). As a result, global patterns are formed that are referred to by the term *attractor states*. These higher-order patterns emerge from the level of the interactions between lower-level components (e.g. Barabási, 2009; Strogatz, 2001; Watts & Strogatz, 1998), which in turn constrain the lower level interactions. The final property of a complex dynamic system is *intra-individual variability*. Developmental change is almost never gradual, but shows many sudden increases and decreases and a large degree of temporal variability. Children's behaviors and skills can change from day to day, from moment to moment and this variability is functional for development and not the results of measurement error (Van Dijk & Van Geert, 2015). In the next section, I will elaborate on these properties of a complex dynamical system and I will argue their relevance for understanding the development of feeding problems in early childhood.

3.1. Soft assembly

The concept of soft-assembly is predominantly used in the context of motor and cognitive skills of young children and refers to the idea that actions emerge in an immediate interaction between individual and its context. Soft assembly is usually contrasted with 'hard assembly', which proposes that specific functions exist autonomously of the context it appears in, e.g. in the form of internally represented action programs or

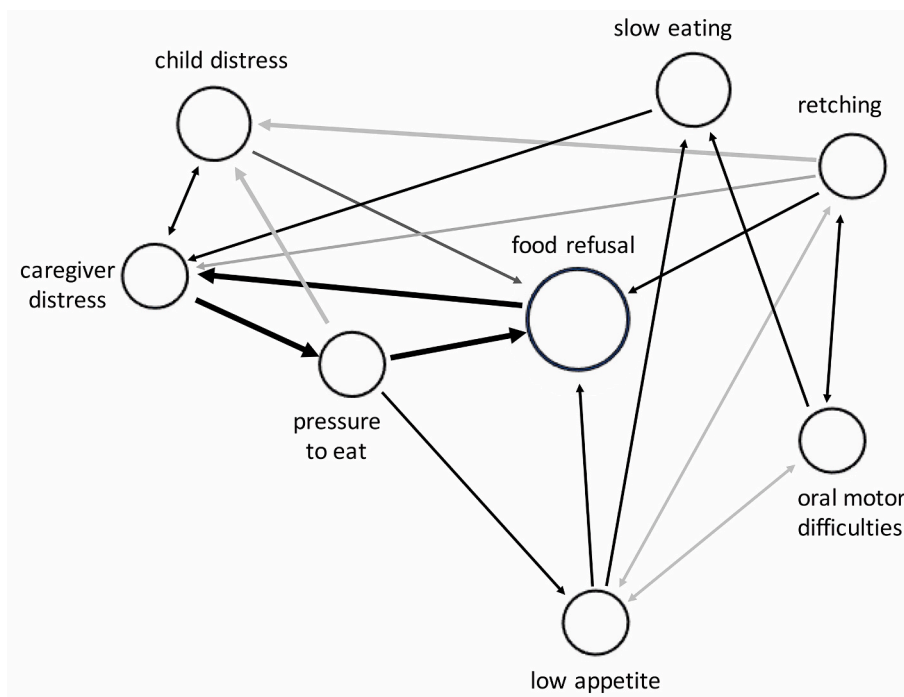


Fig. 1. Illustration of a network of interacting symptoms in a (hypothetical) specific child-caregiver dyad (emergent-causality approach).

instructions (Kloos & Van Orden, 2009). The concept of soft assembly is also relevant outside the action-perception domain, for instance in the context of social cognition, in which the complex social dynamics are conceived to play a constitutive role (De Jaegher & Di Paolo, 2007; De Jaegher et al., 2010). Applied to the context of feeding problems, a hard assembly approach would mean that a child “has feeding problems”, that –in principle– also exist outside of the context of eating. In contrast, soft-assembled abilities come into existence in real-time, at the exact moment of interaction with the environment. The functions or problems also do not exist at any other moment, for instance in the form of a representation in the mind or brain.

The importance of the moment-to-moment caregiver-child interactions that emerge on the spot has long been acknowledged. Children’s behaviors change and are changed by the behavior of their caregivers (Olson & Lunkenheimer, 2009, pp. 55–76). In the developmental psychology literature, the concept of caregiver-infant synchrony is often used to refer to the *coordination* of behavioral, physiological, and emotional responses (e.g. Cohn & Tronick, 1988; Feldman & Greenbaum, 1997). This coordination occurs from moment to moment and the affective exchanges that take place happen in close temporal proximity (Feldman, 2007; Fogel, 1993). Timing is therefore an essential aspect of the synchronization process (Feldman, Greenbaum, & Yirmiya, 1999; Rosenfeld, 1981, pp. 71–97). Synchronization is a continuous process by which individuals mutually adjust their actions to the actions, and the anticipated actions, of the social partner and is also referred to by the term *co-regulation* (Fogel, 1993). These concepts are also highly relevant to the context of feeding. The feeding interaction between child and caregiver unfolds within a certain moment, and its course depends on the micro behaviors and subtle cues of both dyadic partners. Here, the actions of both individuals are not entirely conscious or planned in advance, but they come into existence at the very moment of the interaction and for this reason are very context dependent. We have seen this in the short case illustrations of the child in interaction with her caregiver that were described in the previous paragraph. Here, the caregiver responded to the restless behavior and the whining of the child by giving her a piece of bread. This short interaction is coordinative in nature and can be seen as a ‘consensual frame’ (infant and caregiver share consensus on what to do with what). It is history dependent, but is

‘enacted’ in this specific moment. It is also highly fluid in the sense that any small perturbation in the interaction (such as a cat jumping on a piano) can change the causal chain of events and can lead to a completely different outcome. The concept of soft-assembly also stresses the importance of context in child development and thus in the development of feeding problems.

3.2. Embodiment

The second property of a complex dynamical system in the behavioral sciences is *embodiment*, which means that cognition and action arise from interactions between brain, body and the environment (Thelen, Shoner, Scheier & Smith, 2001). As a result, perception, action, and cognition form an integrated system that cannot be partitioned (Spencer et al., 2006). Embodiment is a specific form of the more general theoretical stance of ‘holism’. Here, holism refers to how any system relates to its parts and assumes non-reducibility (properties of the system cannot be reduced to properties of its parts) and non-separability (parts of the system cannot be separated from the system as a whole) (Lundh, 2015). Combined with the phenomena of soft-assembly and co-regulation, a complex dynamical systems approach fits within the ‘holistic-interactionistic paradigm’ as defined by Magnusson (2001). It also fits with the current shift in social cognition research, which moves away from their traditional focus on the individual’s capacities towards an embodied and participatory view of social understanding (De Jaegher et al., 2010).

This construct of embodiment also applies to feeding, because the feeding system consists of the oral-motor and oral sensory subsystem, the hunger-satiety subsystem, the socio-emotional subsystem (etc.), all of which are interrelated. In it, various internal states (arousal, cognitive ability, hunger, attitude, affective states, etc.) and external states or events (the general context, a recent illness, etc.) have an effect on how a particular feeding interaction will come into existence. For instance, a noisy room in combination with a tired child and stressed-out caregiver can cause a ‘rocky start’ of any meal, but once the infant starts to eat, these factors will have almost no effect for the feeding, because for instance, the infant is hungry and the food tastes great. However, this combination of states may have led to crying, distress and food refusal

on any other day. During feeding, all subsystems are deeply intertwined because the system as a whole is embodied. This may explain why [Burklow et al. \(2002\)](#) have found that behavioral issues (defined broadly to include poor environmental stimulation, dysfunctional caregiver-child interaction, behavioral mechanisms and/or emotional difficulties) were present in 85% of all instances of feeding problems. Even in cases where clear somatic factors are involved (e.g. oral motor problems), behavioral aspects obviously play an important part in its development and maintenance. This finding may demonstrate that problems in one domain or subsystem (e.g. of a somatic nature) easily spill over in another problem domain or subsystem (e.g. fear and avoidance) and become intertwined. We also know that children are sensitive to the nutritional values of the food they eat, but that the social context also determines how they respond to these internal and external cues ([Birch, McPhee, Shoba, Steinberg, & Krehbiel, 1987](#)). For instance, a study of [Jansen et al. \(2012\)](#) reported that preschoolers with a low BMI show distinct eating behaviors (such as fussiness, emotional undereating and satiety responsiveness) and that their parents are more likely to pressure during mealtimes. This suggests that in the development of feeding problems, body, mind and environment form an inseparable whole and hence that feeding problems are embodied.

3.3. Iterative causality

The third property of a complex dynamical system is *iterativity*, a term which is used to refer to the mechanism that the state of a system at time point t is the result of the state of that same system at time point $t-1$, and that $t-1$ is the result of the state at $t-2$, etcetera. The iterations specifically refer to the *causal* element of each consecutive behavior. The cause-and-effect relation is not necessarily deterministic but can be seen as a matter of conditional probabilities. This type of causality is different from a ‘classical billiard-ball-like causality’ ([Juarrero, 2010](#), p. 2). In this context, it should be noted that the term ‘causality’ (or ‘causation’) is a topic of debate, and that social scientists describe various forms of causality, such as necessary, sufficient, conjunctive, structural causes ([Kincaid, 2009](#); for an introduction on causation see [Beebe, Hitchcock, & Menzies, 2009](#)). However, much research that attempts to address causal relations in the biological and social sciences is based on observed *correlations* in a population with background *causal assumptions*, and do not say anything about individual causal relations ([Osaka, 2009](#)). At the level of individual causality, psychological theories can be distinguished

into ‘generative-causality’ theory and ‘emergent-causality’ theory ([De Ruiter, 2015](#)). From the generative-causality perspective, a latent trait is assumed to generate surface phenomena, which are generally not seen as being causally interdependent (see [Borsboom, Mellenbergh, & Van Heerden, 2003](#); [Schmittmann et al., 2013](#)). For instance, a generative-causality approach to feeding problems assumes that the symptoms (such as lack of appetite, slow eating, food refusal, acting up during meals) are caused by the underlying latent trait (e.g. ‘feeding problems’, ‘feeding disorder’, ‘ARFID’) (see [Fig. 2](#)).

In this view, causality is unidirectional: from the latent trait to the observed behavior or symptoms. From the perspective of the emergent-causality approach, causality is a bi-directional process, instead of a unidirectional one. In this approach, temporal causality is self-generated by the intrinsic dynamics of a phenomenon ([Markus & Borsboom, 2013](#)). An emergent-causality approach to feeding problems would argue that the symptoms interact in such a way that they ‘feed’ into each other from moment to moment, in ‘real time’. For instance, lack of appetite leads to slow eating and food refusal, which lead to stress and even less appetite, and so on (see [Fig. 1](#)). The symptoms at any point in time are not caused by a latent construct but are caused by all the interactions between symptoms at the previous moment in time. Both the processes and the outcomes are history-dependent, meaning that the internal structure of any dynamic system reflects its history ([Juarrero, 2010](#), p. 3). Real-time causal chains are embedded in larger patterns, which are created by repeated iterations ([De Ruiter, 2015](#); [Vallacher & Nowak, 1997](#)). In this way, short and long term development form a nested structure, and the layers within it influence each other continuously and mutually: the real-time interactions cause the formation of higher-order structures (regularities/patterns), and these higher-order structures consecutively constrain the real-time interactions ([Haken, 1978](#); [Kelso, 1995](#); [Thelen & Smith, 1994](#); [Hollenstein, 2007](#)). This process of higher-level subsystems organizing and shaping the interactions of lower-level subsystems is also referred to by the term ‘downward causation’ (see [Campbell, 1974](#)). These dynamics are illustrated in [Fig. 3](#).

When applied to the context of feeding, this means that a specific action (or cognition, or emotion) of a caregiver, leads to a specific response of the child, which leads to the next action of the caregiver, etcetera. This idea overlaps partly with the concepts of soft-assembly and co-regulation, as discussed previously, where child and caregiver respond constantly to each other’s actions and anticipated actions. For instance, repeated experiences with food refusal may lead to

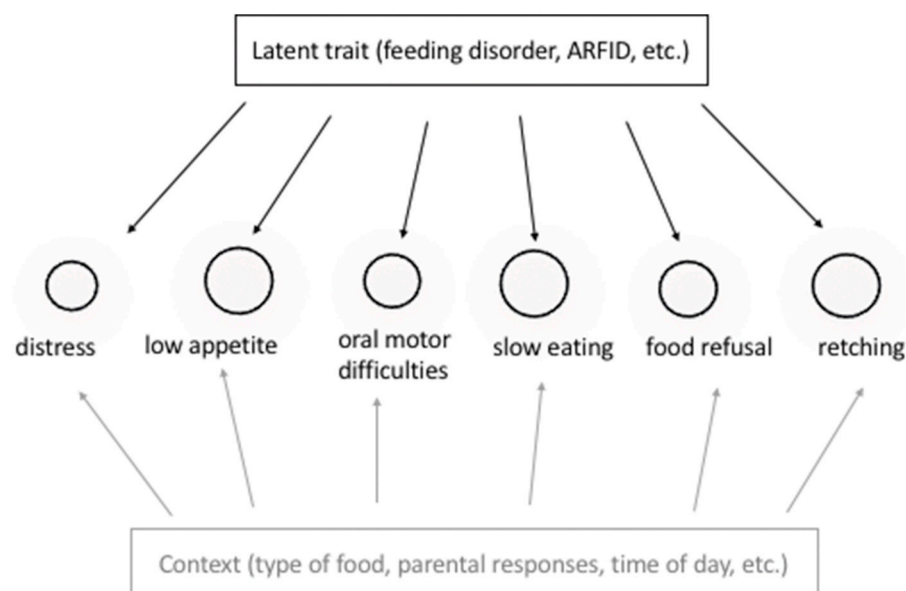


Fig. 2. Illustration of a generative-causality approach to feeding problems.

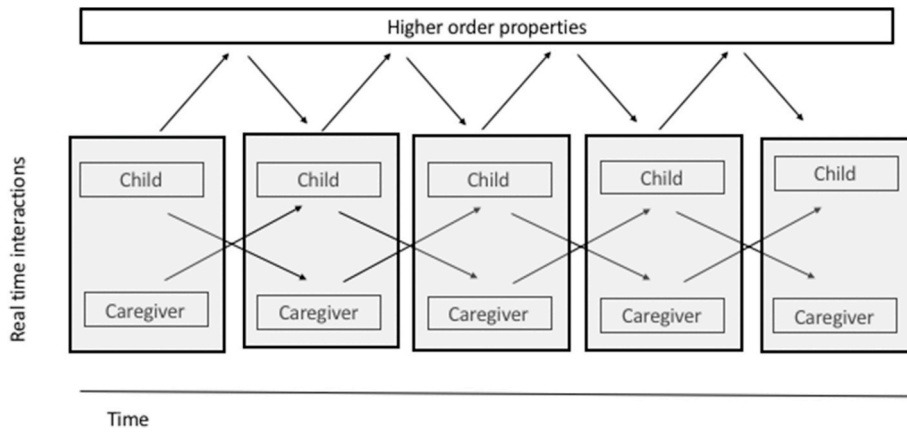


Fig. 3. Illustration of iterativeness and the emergence of higher order properties in a child-caregiver system.

anticipatory distress in a caregiver, who – as a result– may start a specific feeding session in a state of agitation or nervousness. The same repeated experiences of the infant may have caused a slightly more aversive state of the infant, who will become fussy more quickly. In this situation, a very subtle event can spiral into a negative interaction easily; for instance, a certain facial expression of the infant can trigger more controlling behavior of the caregiver (coaxing, putting food in the infant mouth), causing greater aversion and refusal in the infant. After many iterations, the interaction moves into the patterns more quickly and the probability that the interaction will revert to this pattern will increase.

According to a complex dynamical systems perspective, any interaction can be described in a *state space*, an abstract multidimensional space that describes the set of all possible interactive states of a system. For feeding, the state space can consist of all imaginable combinations of actions of the infant (eating, refusing, looking away, grasping, smiling, crying, climbing out of the chair, chewing, etc.), combined with all imaginable actions of the caregiver (giving food, retracting, holding, talking, walking away, etc.). At any moment in time, a system exists in one state only, but a wide variety of states may be possible. Dynamical systems have a tendency to stabilize in only a subset of all possible patterns over time (Van Geert, 2003). In the previous paragraph, I described how short- and long-term development form a nested structure, and how the real-time interactions cause the formation of

higher-order/patterns. In some cases, these patterns become relatively stable states, and are called *attractors* (or attractor states). Attractors are described as states or patterns of change toward which a dynamical system evolves over time, and to which the system returns after it has been perturbed (Nowak, Vallacher, & Zochowski, 2005). Once attractors are formed, other subsets of patterns tend to be ‘avoided’ by the system and occur only rarely, which are called ‘repellers’. The formation of attractors is often illustrated by means of showing a rolling ball in a landscape, as shown in Fig. 4. Here, the dimension of time is represented on the z-axis, where development evolves from ‘back’ to ‘front’. The specific realized behaviors are represented by a ball, finding its path. Over time, deeper or shallower ‘valleys’ emerge, which makes it more probable to go to a certain state among all possible states. The deeper the attractor, the more energy it takes for the system to get out of the state.

Not all attractors are the same. Some are deeper or shallower than others, and some are wider or narrower than others. In some cases, a system organizes towards a single point in state space regardless of its initial conditions; in other cases, there may be different points of attraction depending on the initial conditions (Eckmann & Ruelle, 1985; Nowak & Vallacher, 1998). However, attractors are typical patterns of interdependent behaviors that the system reverts to (Juarrero, 2010).

The mechanism of attractor formation is seen across developmental domains, for instance in the context of parenting. For instance, Granic

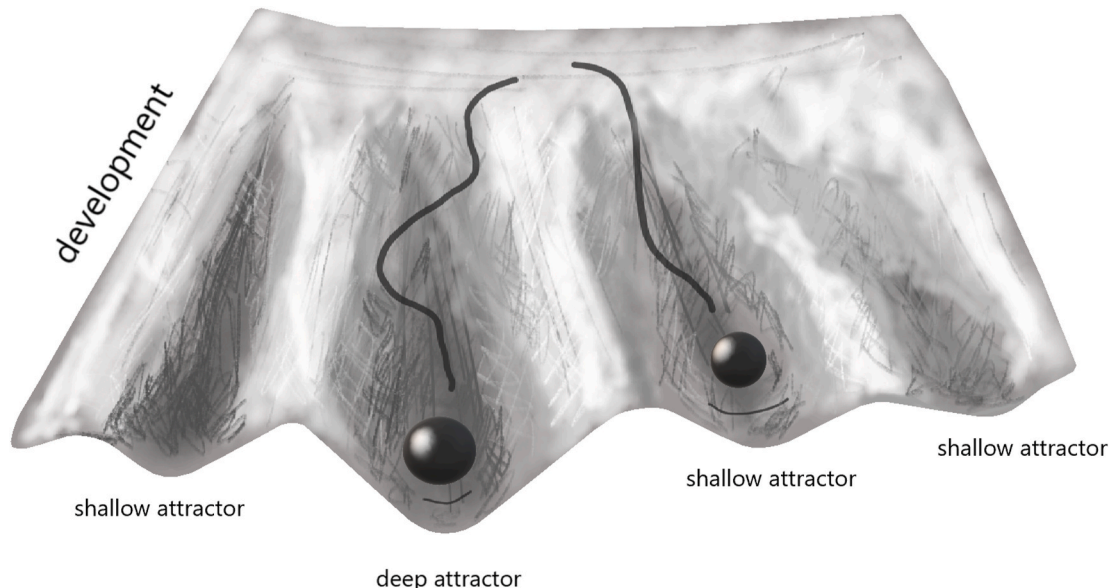


Fig. 4. Illustration of the emergence of attractors in the course of development.

and Patterson (2006) have interpreted the existence of ‘coercive cycles’ as the emergence a specific attractor state. In a coercive cycle, an argument between a child and caregiver escalates because both are trying to coerce each other into backing down, a dynamical interaction pattern which ‘traps’ them in a negative interaction spiral (Patterson, 2002). The (unintentional) reinforcement of the child’s misbehavior creates a positive feedback cycle, whereby parent–child interactions become increasingly negative, leading to the escalation of aggressive behaviors over time (Lunkenheimer, Olson, Hollenstein, Sameroff & Winter 2016). According to the framework of complex dynamical systems, a coercive cycle is the result of the self-organizing nature of the parent-child system. This moves the system towards a particular stable pattern, which then constrains the behavioral repertoire for future interactions (Granic & Patterson, 2006). It is important to note that the properties of an attractor state may be different from the properties of its components. This is also typical of the concept of emergence, because emergent properties are different than the properties of the components out of which that property emerges. It explains for instance why peaceful people can form a violent mob (Vallacher, Coleman & Nowak, 2013). In the context of parenting, it clarifies how after repeated interactions a generally loving and emotionally stable parent and child can end up in a huge power struggle.

Translating the concepts of history dependency and the formation of attractors to the context of feeding, this explains how the moment-to-moment interactions shape a global “feeding interaction style” which acquires a certain degree of stability over time and constrains the moment-to-moment interactions between caregiver and child at later moments (see Fig. 5). Over time feeding interactions become more or less ‘fixed’ ways of how a specific meal evolves.

In a previous study (Van Dijk, Hunnius, & Van Geert, 2012), we investigated the feeding interaction between infants and caregivers during the transition to solid food. Here, we have presented the interaction behaviors as a phase space, employing the ‘state space grid’ (SSG) technique (Hollenstein, 2007; Lewis, Lamey, & Douglas, 1999). A state space grid represents the conditional probabilities of behaviors on two dimensions and between successive combinations of these behaviors. In Fig. 6, the coded actions of the caregivers are presented on the x-axis (five mutually exclusive ways of giving food), and those of the infant on the y-axis (three mutually exclusive responses to the food). Each grid represents the interactions in five meals that took place in two consecutive weeks, and the three grids of each dyad that are depicted below stem from three observation waves within the period of 12 weeks. The examples show that the caregiver-infant dyad generally stabilizes quickly. The emergence of such relatively stable states can be conceived as the formation of a ‘feeding style’.

Once attractors have emerged, they tend to become self-sustaining. This may be the case for the ‘parental feeding style’ a term which is

often used in the literature of feeding in early childhood. Research has indicated that a feeding style includes behaviors and cognitions about feeding such as restrictive feeding, monitoring child food intake and pressuring the child to eat more of some foods (Birch et al., 2001). This feeding style is relatively stable (Farrow & Blissett, 2011), and has a long-term impact on eating behavior of the child (Fisher, Sinton, & Birch, 2009, pp. 17–33; Spruijt-Metz, Lindquist, Birch, Fisher, & Goran, 2002), such as eating in the absence of hunger and body weight (Faith, Scanlon, Birch, Francis, & Sherry, 2004; Steinsbekk, Belsky, & Wichstrøm, 2016). It also has a clear effect on the child’s emerging food preferences (Birch, Marlin, & Rotter, 1984), intake patterns, and developing self-regulation of food intake (Birch, McPhee, Shoba, Steinberg, L. & Krehbiel, 1987). The relation between feeding style and children’s eating behavior is probably bidirectional (Birch & Fisher, 2000) and there are indications that child eating behaviors such as food approach and avoidance predict changes in maternal feeding, at least in early childhood. Pickiness of the child and disturbing behaviors during mealtimes are shown to be related with the use of multiple types of parental strategies simultaneously (De Moor et al., 2007; Hofman-van den Hoogen, 1998). Children with feeding problems most often display behaviors such as whining, crying, and spitting out food as ways of refusing food and parents are more likely to use various strategies such as coaxing, posing threats, force-feeding, or making multiple meals (Crist & Napier-Phillips, 2001). These findings make sense from a complex dynamical systems viewpoint. They show that repeated real-time feeding interactions can ‘drive’ the system to an attractor state and therefore limit the possible interactive states of a system. The emergence of coercive cycles is also observed in the context of feeding. For instance, Sanders et al. (1993) describe observational data that show a typical sequence of parental coaxing and pressuring the child to eat. The authors speculate that such parental behaviors are likely to be reinforced by intermittent consumption of food by the child, which over time may lead to either increasing coercion or acquiescence by the parents, which in turn lead to the persistence of the child’s feeding difficulties. As a result, mealtimes become more and more negative for both parent and child. Sanders et al. illustrate that a dysfunctional feeding pattern may in fact be similar to the emergence of a coercive cycle. This shows that iterativity and the formation of higher order properties (attractor states) –which are the core mechanisms of self-organization—are also observed in the development of feeding problems and are useful in explaining why these negative interaction cycles are so hard to break once they are formed.

It may be speculated that stress works as a catalyst in the system. Stress has a clear impact on attractor formation. During a period of increased stress, caregiver-infant dyads need to reorganize and maintain optimal adaptation (Fogel, Hsu, Shapiro, Nelson-Goens, & Secrist, 2006; Sravish, Tronick, Hollenstein, & Beeghly, 2013). This has also been

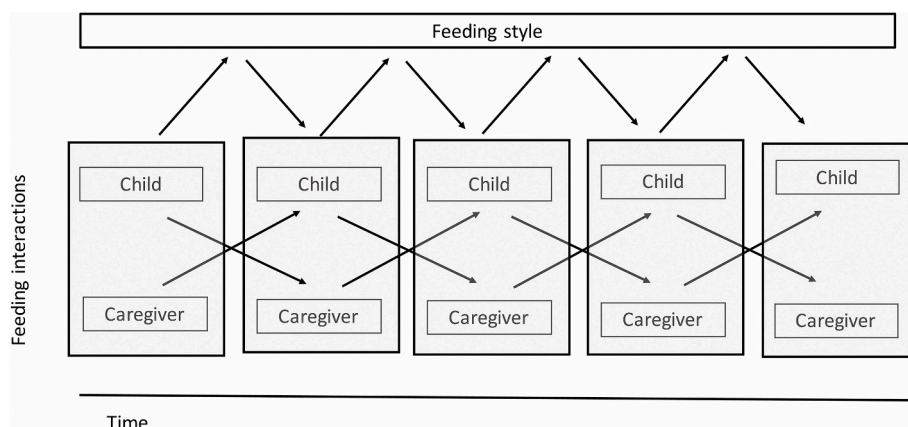


Fig. 5. The emergence of a feeding style as a result of iterative feeding interactions.

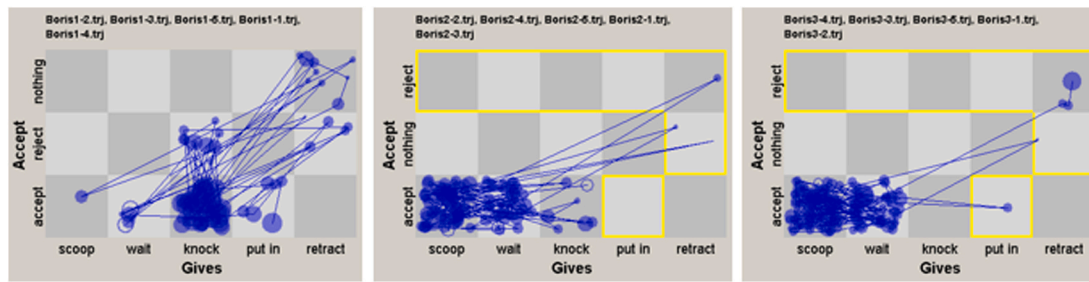


Fig. 6. Examples of state space grids of one mother infant dyad (Boris and his mother).

illustrated in a study of Provenzi, Borgatti, Menozzi, and Montiroso (2015) who investigated the influence of stress on the mother-infant system using the still face paradigm. The results show that after a stressor two new attractor states emerged: one which was characterized by maternal positivity and infant play and one which was characterized by affective mismatch. This shows that the dyads did not automatically move back to the pre-existing pattern, but sometimes reached new attractor states, one of which was clearly negative. This shows that stress can contribute to attractor formation, which may be relevant in understanding the development of feeding problems.

3.4. Intra-individual variability

Because of the complex moment-to-moment interactions between all subcomponents in an open system, development is often non-linear (Van Geert, 1994). Each study that follows development through time and has sufficient measurement points shows that individuals display a large degree of intra-individual variability and that their development is characterized by sudden jumps, temporarily stable states and relapses. The term ‘intra-individual variability’ (IIV) is often used for fluctuations on a relatively short time frame (between moments, days, or weeks). IIV has been demonstrated to exist in various domains of early development, for instance in sleep patterns (e.g., Jenni, Deboer, & Achermann, 2006), infant temperament (e.g., Crockenberg & Smith, 1982; Peters-Martin & Wachs, 1984; Worobey & Blajda, 1989), emotion behavior (e.g., Bornstein & Tamis-LeMonda, 1990), infant crying (e.g., Barr, 1990; Rebelsky & Black, 1972), play behavior (Tamis-LeMonda & Bornstein, 1991), and motor and mental development (e.g., Freedland & Bertenthal, 1994; McCall, Eichorn, & Hogarty, 1977). Previous research suggests that eating and feeding behavior in early childhood also show a lot of this type of variability. For instance, in a sample of toddlers and preschoolers, Birch, Johnson, Andersen, Peters and Schulte (1991) reported large meal-to-meal variability in energy consumption, but a much lower degree of variability across days. Young and Drewett (2000) found that one-year olds display high meal-to-meal variability in specific behaviors in the feeding interaction, such as giving and retracting food, self-feeding, accepting, refusing, and rejecting. The authors speculate that this variability may be a form of regulating the intake as a response to variable food composition. Also, contextual factors (e.g. timing and the number of people present) might play a role, according to the authors.

According to a complex dynamical systems viewpoint, IIV is a product of the system as a whole and its amount and structure contain important information about the systems internal dynamics. Instead of considering it to be caused by random measurement error or ‘context’ factors, it should be seen as an important characteristic of development that should itself be a focus of further investigation (Lewis, 2000; Thelen & Smith, 1994; Van Geert, 1994). The individual is not a passive recipient of changes in the context, but an agent who creates his or her own variability (Fogel & Garvey, 2007). A large degree of stability emerges when interactions are organized, whereas a high degree of variability is the result of a high level of context dependency and exploration (Thelen & Smith, 1994). This way, IIV can be seen as the result of two complementary forces. The first force is the self-sustaining

character of many interaction processes (which is relevant in the formation of attractor states), aimed at energy reduction and causing the system to have a certain robustness against perturbation. The second force is the ability to adapt and respond to changing circumstances in the context, which is essential for human survival. According to Juarrero (2010), a system is called stable if it returns to or fluctuates minimally around a constant state. Paradoxically, when the coupling between the subsystems is relatively flexible, the overall system is relatively stable. The reason for this is that the system is better at responding to perturbation. During human development, individuals acquire a large variety of skills and this does not happen in gradual way. Instead, many qualitative developmental changes occur around so called ‘transition points’. A transition point is the moment when systems often show an increased degree of variability, because of their increased susceptibility to small changes in context (Thelen & Smith, 1994). Within a complex dynamic system, transitions are marked by periods of instability where old patterns are replaced by new ones (Lewis, 2000). Such transition moments also occur in feeding, for instance when infants shift from feeding on milk to eating a variety of solid food. In a previous publication (Van Dijk, Hunnius, & Van Geert, 2009), we have focused on the introduction moment of semi solid food and expected to observe a large degree of variability in the interaction behavior right after the introduction. The results showed evidence for two complementary trends: the first was that the intra-individual variability (in intake, food refusal and feeding efficiency) stabilized in the few weeks after the introduction, and the second was that the inter-individual differences became more distinguishable as dyads ‘settled’ into a certain repertoire of actions. This means that variability in feeding behavior is to a certain degree a developmental phenomenon, as predicted by the framework of complex dynamic systems. However, it has been argued that intra-individual behavior may not only be the result of the systems dynamics, but have an adaptive function in itself, particularly in infancy (De Weerth & van Geert, 2002). A high degree of variability ensures the infant of ongoing care because it attracts a high level of caregiver involvement, increasing the infant’s chances of survival. In addition, a high degree of variability creates a wide space of exploratory opportunities. This may take place during feeding, where the variability in the child responses are part of a healthy feeding dynamics, evoking a greater variety of caregiver responses. Though speculations about the role of variability in the development of healthy feeding are clearly interesting, research in this area is still badly needed. Based on the possible emergence of a ‘coercive’ attractor state in children with feeding problems, as discussed above, it may be the case that a lack of variability during a specific moment in development may indicate that infants and caregivers are getting ‘stuck’ in their respective behavior or that there is a lack of healthy exploration and adaptation to new circumstances. We also see this in other domains of early development, where a lack of variability is indicative of problems, for instance crying in infancy (see seminal publications such as Wessel, Cobb, Jackson, Harris, & Detwiler, 1954; Barr, 1989) and mother-daughter interactions in adolescence (see Lickwarck-Ashoff, Kunnen and Van Geert (2009)). On the other hand, it may be the decrease of variability over the course of development is actually functional, as we have seen in early motor coordination (e.g.

Thelen, 1985). There are indications that not only the amount of variability is important, but also its internal structure. Research has shown that in many cases, IIV has a characteristic pattern. Particularly one type of pattern called ‘pink noise’ turns out to be optimal between flexibility and determinism (Van Orden et al., 2003). To what degree such a pattern can also be observed in typical or problematic feeding has not been studied so far. In a previous study (Van Dijk, Van Voorthuizen, & Cox, 2018), we took a first step towards such an analysis by exploring the structure of the real-time variability of feeding interactions during the weaning period. The results showed that after the first 6 weeks after the introductions of solid food the temporal structure of the feeding interactions between infant/caregiver dyads showed signs of increased temporal synchronization. This suggests that a change in the temporal dynamics may be an important indicator of a healthy feeding dynamics.

In summary, I have argued that the core mechanisms of a complex dynamical system –soft-assembly, embodiment, iterative causality and intraindividual variability—also apply to the development of feeding problems in early childhood. Components of the feeding systems (infant, caregiver and context, with all their subsystems) form a network composed of various components which interact on a moment-to-moment basis. These interactions create higher order interaction patterns (attractor states), which tend to become self-sustaining and have their typical patterns of intra-individual variability. In some cases, these patterns lead to the emergence of symptoms such as food refusal, slow eating, lack of appetite, fussiness, parental stress, which all feed back into the system, creating even deeper attractor states. This conceptualization is radically different from a component-driven approach, because it no longer tries to isolate causal variables with either the child or the caregiver or attempts to categorize types of feeding problems based on such ideas. Instead, this view on feeding problems argues that these kinds of problems should be seen in terms of *interaction patterns* and *interaction dynamics* between components.

4. Implications for research in feeding problems

When understanding the development of feeding problems from a dynamical systems point of view, it becomes clear that research into the phenomenon should be designed in such a way that is able to capture its developmental and dynamic nature. In typical development, feeding behavior, food acceptance and refusal and caregiver-child synchrony are not stationary phenomena, but are highly adaptive and subject to change. For instance, we have observed that temporal structure of the behaviors of mothers and their infants during the weaning period (Van Dijk, Van Voorthuizen, & Cox, 2018) becomes increasingly synchronized during the introduction of solid food. In addition, it has been reported that in the case of feeding difficulties, the symptoms tend to build up over time in early childhood (Van Dijk, Timmerman, Martel, & Ramsay, 2011); De Moor et al., 2007). However, at this point we only have very limited knowledge of the longitudinal effects of the dynamical processes of early childhood feeding, given that research on the topic is predominantly cross-sectional in nature. Studies with many repeated measures are therefore indispensable. This necessity of longitudinal studies with repeated measures is already recognized in many studies. However, most authors do not fully realize that the observation frequency is crucial and that this should be sufficient to capture the typical variability of the process. This implies that a handful of observations is not sufficient in most cases.

In addition, if feeding problems are caused by a process of self-organization within a system –as I have argued in this paper– it is important to investigate the link between processes that unfold on the micro-level time scale and outcomes at the longer-term time scale. The micro-level of development is the everyday reality in which children interact with their caregivers and larger environment, eat (feel, explore, etc.) the food, and where the interactions self-organize into patterns which lead to specific developmental outcomes. According to Granic (2005), these moment-to-moment interactions can be seen as the

‘building blocks’ or ‘raw material’ of development (Granic, 2005). However, when we look at the literature on feeding, one thing that stands out is that there is a lack of detailed descriptions of these building blocks. This should be a focal point for future research.

Researchers currently have access to many methodological tools to analyze the temporal structure (or ‘complexity dynamics’) of a developing system. These tools are now being used in studies on various domains across development and can also be applied to the study of feeding problems. For instance, techniques such as spectral and fractal analysis and (Cross) Recurrence Quantification Analysis (Marwan, Romano, Thiel, & Kurths, 2007; Cox, van der Steen, Guevara Guerrero, Hoekstra, & van Dijk, 2016) and State Space Grids analysis (Lewis et al., 1999; Hollenstein, 2007) have been successfully applied to the study of syntactic coordination during language development (Dale & Spivey, 2006), parent-child conversations (Cox & Van Dijk, 2013; Lichtwarck-Aschoff, Hasselman, Cox, Pepler, & Granic, 2012) mother-infant synchrony (de Graag, Cox, Hasselman, Jansen, & de Weerth, 2012), and developmental dyslexia (Wijnants, Hasselman, Cox, Bosman, & Van Orden, 2012). These studies have demonstrated that the methods yield rich information on the fine-grained interaction patterns that possibly predict later developmental outcomes. For instance, Hollenstein, Granic, Stoolmiller, and Snyder (2004) have used State Space Grid analyses to investigate whether parent-child interaction rigidity was related to young children’s externalizing and internalizing behavior problems. The results showed that rigidity –operationalized as a decrease in variability of the parent-child interactions, and a tendency to remain in the same affective states– predicted an increase in externalizing problems during the kindergarten year. Lichtwarck-Aschoff et al. (2012) used a combination of cross-recurrence quantification analysis and latent class growth curve analysis to investigate change in mother-child interactions over the course of a treatment for childhood aggression. The results showed that the temporal structure of the interaction predicted treatment effectiveness, that is: a ‘destabilization pattern’ in real-time behaviors was related to better treatment outcomes. Both studies illustrate that applying these novel techniques can yield important information about the underlying processes and their relation to later developmental outcomes, which is also relevant for feeding problems. However, these techniques require many (dense) measurements and this emphasizes the importance of the collection of many repeated observations for understanding the development of these problems in early childhood.

5. Implications for clinical practice

One of the main implications of the complex dynamical systems approach to understanding the development of feeding problems for clinical practice is to cease attempting to categorize ‘types’ of feeding problems or to find ‘the main problem’. Because feeding problems emerge from complex interactions between a multitude of factors it is highly unlikely that a singular cause would be responsible for the development and persistence of these problems. Even if there would have been such a single cause (for instance, a choking episode), this has set an entire system in motion which responded, transformed, and self-organized in a specific and sometimes unpredictable way. Assessing the variety and severity of symptoms is still relevant, but this should not be focused on isolating ‘causes’; the system as a whole and its interactions should always be a focal point in order to understand the patterns that have self-organized in such a way that they can resist change to external influences. These ideas have been present for a long time among many clinicians and infant mental health professionals and are generally accepted in the scientific community. However, the complex dynamical systems framework provides a solid theoretical framework for this.

The interaction-dominant conceptualization also influences the way we think about the nature of feeding problems and offers concepts or metaphors –such as ‘valleys’, ‘rolling marbles’ or ‘streams’ – for communicating about these kinds of problems (see: Vallacher, Coleman, & Nowak, 2013). These terms are useful when trying to move away from

the tendency to focus on child characteristics and fit with a more systemic approach to diagnosis and treatment as Davies et al. (2006) argue. Because feeding problems are processes and systems are ideosyncratic, it is important to fully acknowledge its history dependence. Because ‘time’s arrow never goes backward’ –as Thelen (2005, pp. 265) has put it so eloquently– it is impossible to truly return to an earlier state when the feeding problems did not exist yet. The only thing clinicians can try to do is create a new pathway and shift a specific trajectory into a new attractor state. The aim should be to change the attractor landscape and to create a more varied repertoire.

A second implication of this interaction-dominant approach to feeding problems in infancy is that clinicians should always pay attention to the intra-individual variability of the feeding behavior of the child and the repertoire of the interactions with parents and broader context. In the domain of parenting, it has been observed that a reduction of variability is in fact a measure of rigidity which indicates that a system is ‘stuck’ (e.g. Lichtwarck-Aschoff et al., 2012; Lunkenheimer, Olson, Hollenstein, Sameroff, & Winter, 2011). A certain degree of IIV is part of typical development (Van Dijk & Van Geert, 2015) and an increase of it a certain point in time is often observed in the vicinity of a developmental transition (Grannott, Fischer & Parziale, 2002; Thelen & Smith, 1994; Hosenfeld, van der Maas, & van der Boom, 1997; Van Dijk & Van Geert, 2007). This means that information about short-term variability is highly relevant for any clinician trying to understand the dynamics of feeding problems and estimate the severity of problems (‘attractor strength’) of a particular child. If parents experience distress around feeding and the feeding interactions become increasingly rigid, this can be a red flag and call for intervention. In those cases, it would be wise not to wait until the system has lost its variability and has become ‘stuck’, because it may be much harder to elicit change once an attractor has become deeper and/or narrower. This is not a new insight, since early intervention is already widely regarded as a key component of successful intervention outcomes for feeding problems, but the complex dynamical systems framework does provide an explanation of why this is the case.

The question is: when a system is stuck in an undesirable and distressing attractor state, how can we get it to become ‘unstuck’ with any kind of treatment or intervention? First of all, because a complex dynamical systems approach assumes that feeding problems emerge from complex interactions between a variety of components that are individual- or system-specific, we should be suspicious of any treatment that emphasizes just one or very few components or that applies a ‘one-size-fits-all approach’ (Den Hartigh et al., 2016) or highly standardized treatment protocol. In fact, in recent years, various publications have appeared on idiosyncratic prevention science which offer interesting suggestions (e.g. Ng & Weisz, 2016; Ridenour, Wittenborn, Raiff, Benedict, & Kane-Gill, 2015). Secondly, the implication of the complex dynamical systems frame is that any treatment for feeding problems should be targeted at the moment-to-moment child-caregiver interactions themselves. One powerful option would be to do this by means of joint review of video-recorded feeding sessions. Here, parents and practitioner closely observe the parent-child interactions, try to understand the underlying feedback loops and think about ways to change these interactions. Various intervention programs are based on this idea and interaction guidance already exist and are shown to be evidence-based, such as Positive Parenting and Sensitive Discipline/VIPP-SD (Juffer, Bakermans, Kranenburg, & Van Ijzendoorn, 2018) and Video Interaction Guidance/VIG (Kennedy, Ball, & Barlow, 2017). The complex dynamical systems framework provides an explanation of why this approach is so effective: these interventions try to change the interactions among the components and to enable the formation of new interaction patterns. By focusing on the micro-level timescale, they aim to change the attractor landscape as a whole. After close observation and analysis, a clinician may attempt to ‘perturb’ the system by changing many components at the same time, and by introducing a lot of variability into the system. However, the effect of

such a perturbation –or any type of intervention– is largely unpredictable. In some cases, it may lead to a greater flexibility and behavioral repertoire; in other cases, the attractor may turn out to resist to change and actually become more entrenched. In addition, introducing variability and trying to create new interaction patterns does not mean that the original patterns are no longer present. If an attractor is deep enough, the system can easily revert back to it under the right (or wrong) circumstances.

Unfortunately, following a complex dynamical systems approach to diagnosing and treating feeding problems does not make things less complicated; it only does better justice to these problems’ complex nature (see for instance Rusoja et al. (2018) and Lich, Ginexi, Osgood, and Mabry (2012)). Both clinicians and researchers working on feeding problems in early childhood should keep in mind that feeding behavior always shows elements of both variability and stability and that these are related to the dynamic interaction between various components in the child and the environment.

Declaration of competing interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.appet.2020.104982>.

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