Part II

Intraindividual Variability and Development During the Early Life Span
This page intentionally left blank
3 The Nature and Meaning of Intraindividual Variability in Development in the Early Life Span

Marijn van Dijk and Paul van Geert

Introduction

In the last two decades, more and more studies have taken a process perspective and looked at how young children are developing over time. This process approach is dependent on the collection of (many) repeated measurements with the same individuals. However, when we start observing the changes in behavior across time, we are struck by the large differences from measurement to measurement. As Thelen and Smith (1994) have pointed out in their seminal publication, it is important to distinguish stability and variability on two time scales. The first time scale is the “view from above,” where we observe global structure across “developmental time.” For instance, when learning to communicate verbally, infants display roughly the same behaviors. They most often start with expressive vocalizations, and go through a “babbling” stage. The second time scale views development “from below,” and measures the changes that occur from moment to moment. From here, a much more irregular—almost chaotic—picture emerges. In real time, development turns out to be variable and changes from moment to moment. We see, for instance, that not all infants use the same types of vocalizations and that there is large variability in vocalization and communication from day to day. Thus, though development might seem to be ordered at a macroscopic time scale, the microscopic time scales reveals large differences between and within individuals.

In a previous publication, we have defined intraindividual variability as “differences in behavior within the same individuals, at different points in time” (van Geert & van Dijk, 2002, p. 341). Though variability may exist at all possible time scales, the term is most often used for fluctuations on a relatively short time frame (between weeks, days, or even smaller units of time), corresponding to the view from below (Thelen & Smith, 1994) as described before. The aim of this chapter is to provide a general orientation on intraindividual variability as an important phenomenon in early child development. In the first part, we will review the traditional theoretical interpretations of intraindividual variability in early development. The second part of the chapter describes more current theoretical developments and discusses the reasons why studying variability in early development is important. After this, a review of empirical work on variability will be given. Here the most common patterns of variability in early development will be described. We limit ourselves mainly to the domain of early interaction behavior, ranging from emotional expressions in very young infants to language acquisition in toddlerhood (for examples on motor or cognitive development, see Chapters 4 and 5 in this volume). After this, various methodological advances for studying intraindividual variability will be reviewed. After discussing future challenges and limitations, we will end this chapter with a general summary and conclusion.

Traditional Views on Variability

It has long been acknowledged that individual development is almost never smooth, but that it shows many irregularities. Though intraindividual variability seems to be a rather universal
finding, its importance has not always been recognized. Traditionally, the most common theoretical explanations are (a) that variability is a result of context changes or (b) that variability is caused by measurement error.

The first explanation is that intraindividual variability is nothing else than the expression of the fact that behavior is adaptive and reactive to variable circumstances. For instance, a child might be crying in response to hunger, and thus variation in crying is a consequence of variation in hunger; or the child might be crying in response to threat, and variations in threat cause variations in crying. Many different influences may take place at the same time and are additive; the sum of these lead to variations in crying. Intraindividual variability is thus a stable characteristic of any (developing) behavior, in the sense that it is an expression of sensitivity to internal and external influences. However, the underlying model is that there is a direct relation between changes in the environment and the changes in behavior. This way, the variability in the dependent variable (the behavior) is a result of changes in the independent variable (the context). These relations may be linear or nonlinear, but in essence it is assumed that all variability in behavior can be explained by changes in context.

The second explanation is that variability is caused by measurement error. This interpretation originates from true score theory (Cronbach, 1960; Lord & Novick, 1968; Nunnally, 1970), which states that each observed score is the result of a true psychological score plus an error term. This error term consists of all circumstances that lead to a difference between the performance (or behavior) of a child and his or her underlying competence. For instance, a young child may have acquired a certain linguistic competence (e.g., making combinatory utterances), but this is not always expressed on a specific measurement occasion (the time frame is too short, the child is tired, etc.). Variability is considered to be externally “added” to the underlying psychological process. The measurement error hypothesis considers fluctuating developmental levels to be the results of random error, and deals with them as a methodological problem. Because these errors are, by definition, independent of the true developmental level, observed data points are often averaged out by using central tendency measures or data smoothing. The observed variability is thus a surface phenomenon, accidental variation superimposed on an underlying property that is virtually constant at the time scale of the observed variation. Behavior may be variable, but the underlying latent factors (the psychological variables) are considered more or less constant. This viewpoint largely overlaps with the previous viewpoint of sensitivity to context, but the difference is that the measurement error concept is more focused on the problem of psychological measurement of latent variables, and thus it is translated into a measurement problem needing a methodological solution.

These classical views have been, and to a certain extent still are, the dominant perspectives on variability in developmental psychology. As a result, most studies have focused—or are still focusing—on general trends of development or on revealing differences between individuals or conditions, and most studies take a limited number of observations per individual.

New Theoretical Developments

In the early 1990s, a new theoretical framework called dynamic systems theory (DST) initiated a departure from the more classical approaches to variability described in the previous section. According to this theory, variability should be seen as an intrinsic property of development and thus as an important characteristic that should itself be a focus of further investigation (Lewis, 2000; Thelen & Smith, 1994; van Geert, 1994). DST provides a metatheoretical framework, using principles of self-organization to explain how novelty can emerge without predetermination (Lewis, 2000). Development is seen as the result of many nonlinearly interacting components in a system. In physical, chemical, and biological systems, self-organization refers to the
mechanism that causes the spontaneous emergence of order. When these systems are far from equilibrium, the flow of energy links their energy into orderly arrangements and gives rise to an increased organization and complexity (Prigogine & Stengers, 1984). The framework of DST was first and most extensively applied to human development in the domain of motor coordination (by authors such as Thelen, Ulrich, and Smith), followed by cognitive and language development (by authors such as van Geert, Fischer, Case, and Granott) and more recently social-emotional development (by authors such as Fogel, Granic, and Lewis).

The assumption that variability is a genuine property of behavior is not limited to child development. Variability is a characteristic of all behavior, including mature behavior and immature behavior. Similar conditions can cause different reactions, or a reaction or behavior can vary in spite of the fact that the context does not change. The individual is not a passive recipient of changes in the context, but an agent who creates his or her own variability (this explanation fits with the concept of “ordinary variability”; see Fogel & Garvey, 2007). However, the essence of the DST explanation is that of a circular causation: Variability and context create each other, and this interaction is a driving force of development.

In the previous sections, we have described different viewpoints on the phenomenon of intraindividual variability. In all of these, the context in which the developing behavior takes place has an important position. The biggest difference between these explanations is whether the variability is seen as a dependent variable of context or whether it has a causal role in creating the context and, thus, a causal role in development. In other words, the main question is whether variability is a reactive or causal phenomenon. The latter view is defended by the theoretical framework of DST, which advocates that variability has a central role in the process of self-organization in development.

There are two important strands of reasoning on why variability is important for developmental psychology. First, variability is a source of information to gain insight into developmental transitions or the interactions between different developmental variables. Second, variability is functional for development. These explanations are not independent from each other, but they stem from the same theoretical background of DST.

Let us first address the idea that intraindividual variability is a source of information. From this viewpoint, the existence of a relatively unstable period—or periods of increased variability—is seen as a sign that a system is changing. Whereas stability in behavioral patterns indicates that an interaction is organized and consolidated, variability indicates a high degree of context dependency and exploration (Thelen & Smith, 1994). One of the central concepts of DST is that human development occurs within embedded time scales (Lewis, 2011): (a) It emerges in the real-time microscopic changes of the system in a specific context, and (b) these micro-level changes constrain developmental change in the long term (Fogel, 2011). Within a dynamic system, global reorganizations occur at transition points, periods of instability where old patterns break down and new ones emerge (Lewis, 2000). Around these transition points, systems are extremely susceptible to small changes in context. Some transitions are discontinuous in the sense that abrupt changes occur, and some transitions are more gradual. Variability is important because its presence can be used to detect transition points and, thus, can be used to explain and predict change (Granott, Fischer, & Parziale, 2002). Whereas an increase in variability is associated with a developmental transition, a decrease in variability indicates a higher degree of organization in a system. According to DST, variability is especially large during or right before a period of reorganization, because at that time there exists a particularly high level of exploration of adaptive strategies (Thelen & Smith, 1994). From a more formal perspective, systems have to become “unstable” before they can change (Hosenfeld, van der Maas, & van der Boom, 1997). This association between increased variability and a developmental transition has been empirically validated in several domains. Examples of studies will be described in the next section.
Stability and variability in development can be explained by means of the concept of a state space continuum, which can be described as the abstract representation of all (combinations of) possible states in a certain system. In such a state space, attractors emerge, which are relatively stable states to which the system gravitates (Granott et al., 2002).

A state space is often described by means of a landscape of peaks and valleys (Granic & Hollenstein, 2006). Here, a time series of development is traceable as a trajectory, for instance, as the path of a ball that moves around in this landscape, going in and out of several attractor valleys. An example of this representation can be seen in Figure 3.1.

The width and depth of these valleys correspond to the strength of the attractor on the behavior in development. The stable use of certain strategies, the occurrence of certain interaction patterns, and so forth can be represented as attractor states. A strong attractor is deep or wide; a weaker attractor is shallower or less deep. The depth of an attractor describes the strength of the "gravitation" on behavior that leads to relative stability. The width of the attractor refers to the range of initial conditions that lead the system to the same attractor point. In Figure 3.1, the initial attractor on top of the figure is wide and shallow, meaning that all initial conditions—for instance, different contexts—will lead to the same attractor. However, since this attractor is very shallow, the system will show a high degree of spontaneous variability and a high degree of sensitivity to accidental events in this context. In the middle, the system is characterized by three attractors, which means that it will randomly alternate between these three attractor states. Wider and less deep attractors lead to more intraindividual variability in behavior. The behavior is most variable when it is at a transition point between attractors, or when it is in a wide and shallow attractor valley.

In order to understand these transition points better, a group of DST-inspired researchers took a special interest in catastrophe theory. This theory is predominantly used to conceptualize

![Figure 3.1 Graphical representation of an attractor landscape with five attractors. Copyright 2009 from Language Development Over the Lifespan by Kees de Bot and Robert W. Schrauf. Reproduced by permission of Taylor and Francis Group, LLC, a division of Informa plc.](image-url)
discontinuities in behavioral variables as functions of continuous variation in control variables (Fischer & Paré-Blagoev, 2000). Thom (1975) described seven typical catastrophes, and one of these—the cusp—became the focus of attention for a group of developmental psychologists (see Figure 3.2 for a graphical representation of the cusp catastrophe).

A central feature of a cusp is that a bifurcation emerges at the point of phase transition (which is the point of the “fold” in the graph). To detect cusp catastrophes in developmental data, a set of empirical “flags” can be applied (Ruhland & van Geert, 1998; van der Maas & Molenaar, 1992). One of these flags is called anomalous variance, referring to an enlarged amount and/or different pattern of variability in the vicinity of a transition. According to this criterion, variable behavior may be used to predict a discontinuity. Another indicator of a cusp catastrophe is bimodality, implying that an individual can switch between two “modes” of behavior, dependent on the control parameters (i.e., the context). The fact that people function at different levels of development during a particular point on the developmental time scale leads to behavioral variability. Thus, in conclusion, the presence of intraindividual variability is informative; it can be an indicator of a period of rapid development, in the form of either a more gradual transition or a more discontinuous type of change, such as the cusp.

The second reason why variability is important for developmental psychology is that it is functional for development. Variability can be a driving force for change. It is clear that Thelen (1985) placed great importance on behavioral variability as a precursor of a new behavioral repertoire. She argued that variability offers flexibility and room for exploration, which promotes development following the Darwinian principles of variation and selection. Formulated in this way, it is highly reminiscent of Campbell’s (1960) classic theory that creativity and discovery depend on “blind variation and selective retention” (BVSR). Here, the central assumption is that an individual varies on a given idea in many different ways, eventually selecting the best variants. The process is repeated until an adequately creative solution

![Figure 3.2 Graphical representation of a cusp catastrophe (phase transition with two control parameters).](image-url)
is reached. In this theory, a specific type of variability is a precondition for the emergence of true discovery. For an overview of BVSR, we refer to Simonton (2007).

One of the underlying driving mechanisms of these Darwinian principles is the theorem of operant conditioning by Skinner (1937), stating that learning is dependent on the consequences of the individual’s actions. According to this theory, the basis for learning is the variation and selection of a behavioral repertoire. This operant behavior must show a particular bandwidth of variability in order for selection, based on reinforcement of successful behaviors, to occur. In this sense, variability is a precondition for development because it enables the individual to adapt to new situations. Variability, therefore, not only co-occurs with change, but is also one of its causes.

Applying these principles to the domain of cognitive development in childhood, Siegler (1996, 2006) argued that variability is one of the core mechanisms that cause the evolution of new strategies in children’s problem-solving behavior. In this particular case, variability is the expression of an increased degree of exploration, which offers the possibility for differential reinforcement of successful strategies (many examples are reviewed in Siegler, 2006). Siegler formulated the overlapping-waves theory, which states that the analysis of cognitive change occurs along five dimensions: path, rate, breadth, source, and variability. The last concerns how individual children apply fluctuating sets of strategies, or more specifically, how a child’s behavior varies across tasks within a specific domain. Across development, periods with low variability (i.e., stable states) alternate with periods of high variability (i.e., developmental transitions) in a cyclical fashion (Siegler, 2006). Although the overlapping-waves model was originally proposed as a theory of cognitive development, it actually offers a framework for thinking about developmental changes in general.

An overlapping-waves model is easily understood when related to the concept of connected growers (van Geert, 1994). Here, a less advanced grower (this could be a strategy, interaction pattern, etc.) is a precursor to a more complex grower and has a supportive relation to its growth. Thus, the less advanced grower stimulates the increase of the more advanced grower. However, when the more advanced grower has a competitive relation to the less advanced grower, then the less advanced grower gets used less and less often, and eventually dies out. The result of this simple asymmetric relation between variables is the presentation of development as a series of overlapping waves with less advanced types of behavior overlapping with more advanced ones (see Figure 3.3 for an example). In conclusion, the reason

![Figure 3.3 Overlapping-waves model of skill development.](image)
why variability is important is that it is a prerequisite for the selective reinforcement of more complex behaviors.

Behavioral variability can also be functional in the sense that it serves an adaptive function in itself, especially in infancy. De Weerth and van Geert (2002a), for instance, have suggested that an increased level of variability may lead to a higher degree of maternal attention and responsiveness. According to these authors, this finding points at a possible adaptive strategy of infants. Intraindividual variability, they claim, ensures the infant of maternal care because fluctuations in the behavior of the infant will address different parental demands. The authors argue that it might be a natural goal for mothers to obtain homeostasis in their relationship with the infant (in this case, a certain stability in interaction). At the same time, the infant’s rapid development during the first year of life will diminish the chances of attaining long-lasting and unchanging periods of homeostasis. Periods with greater short-term variability attract a high level of parental involvement and a variety of parenting behaviors, increasing the infant’s chances of survival.

**Review of Current Research**

In the previous section, we discussed two theoretical reasons why it is important to study variability in early development. In this section, we will review examples of current research that have focused explicitly on common patterns of variability and will describe their findings.

**Common Patterns of Variability**

When reviewing the literature on early development, it becomes clear that variability is prominent in various domains, such as 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), 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). However, in many other studies, variability is not a focus of attention. Instead, the analysis of behavior is mostly performed in terms of global trends (smoothed data) or averages within age groups.

As we described before, intraindividual variability is a natural phenomenon of human behavior that may be a constant across development. However, in many cases, the amount of variability is not stable across time. Those studies that do pay explicit attention to changes in variability across development generally report one of three typical patterns: (a) a general decrease in variability, (b) a general increase in variability, or (c) a peak in variability, that is, an increase followed by a decrease (this can also be a cyclical pattern where peaks and stable periods alternate).

In the case of a decrease in variability, we initially observe unpredictable behavior with a general stabilization when development proceeds. We described this pattern in our own study on feeding during the introduction to solid food around the age of 6 months (van Dijk, Hunnius, & van Geert, 2009). In this context, mealtime success (measured as food intake, meal duration, feeding efficiency, and food acceptance) exhibits considerable short-term variability, which is largest right after the introduction of solids. When zooming in on the interaction behaviors of infants and caretakers (van Dijk, Hunnius, & van Geert, 2012), the same pattern is found: Initially the interaction is rather unstable, with both effective and noneffective strategies alternating with each other, but after a few weeks, the smooth interactions predominate and the give-and-take actions show a much higher degree of “automaticity.” Figure 3.4 provides an illustration of this pattern among the 20 participating dyads.
In Figure 3.4, the percentage of smooth interactions (y-axis) is plotted across time (x-axis; for details on the measurement design and coding, see van Dijk et al., 2012). The figure shows a clear decrease in variability, although individual differences also exist. This pattern can be linked to the emergence of a greater degree of coregulation of the caretaker–infant system. Coregulation (Fogel, 1993) is described as a continuous process by which individuals mutually adjust their actions to the actual and anticipated actions of the social partner. It plays an important role in constraining the behavior of children and caretakers and in limiting variability in a certain context.

This pattern of decreased variability has also been reported in the domain of crying in infancy. A study by de Weerth, van Geert, and Hoijtink (1999) showed that the first months after birth are characterized by a high degree of day-to-day fluctuations in crying: Some days, the infant cries a lot, whereas other days, the amount of crying is rather low. However, from the age of 10 months onward, these behaviors were shown to stabilize. Thus, in this case, the average crying decreases, but this is only caused by a decrease in short-term variability (the crying peak days disappear). A similar pattern of a general decrease in variability was also reported for amount of body contact, although the decrease appeared to be slightly less pronounced.

This pattern also corresponds to data on the development of cortisol across the first year of life (Tollenaar, Jansen, Beijers, Riksen-Walraven, & de Weerth, 2010). A stable decrease of basal cortisol was found from 6 weeks to 5 months and to 1 year. However, the degree of intraindividual variability decreased much more steeply (quadratically instead of linearly) toward the end of the first year. Initially, the degree of variability turned out to be so large that basal cortisol could not be used as a reliable measure (de Weerth & van Geert, 2002b).

The same pattern of a general decrease in variability is also prevalent in other developmental domains. For instance, it has previously been observed in early motor development; young infants lack coordination of different body parts, but this variability reduces over time (Piek, 2002; Thelen, Skala, & Keslo, 1987).

The second common pattern is that of a general increase in variability across time, where children start out with a rather limited behavioral repertoire that grows as they develop. For
instance, in van Dijk and van Geert (2011a), we reported that between the ages of 1.5 and 2.5 years, children show an increasing range of intraindividual variability in their mean length of utterance (MLU). Initially, their production ranges are relatively small, and they only increase after a certain minimal value has been achieved (i.e., MLU is greater than 2). With regard to this relation between child speech and the child-directed speech of the parent, it seems as if the range of variability of the child’s language “grows into” the range of variability of the parents’ language (see Figure 3.5 for an example of a single child). The same pattern is found in the distribution of utterances across sessions (one-word utterances, two- to three-word utterances, and four-or-more-word utterances; see van Dijk & van Geert, 2011a).

In another study, the development of the use of spatial prepositions showed an even steeper, and in some cases more discontinuous, increase in variability across time. This was probably because the use of a lexical category is a less global linguistic measure than utterance length (see van Dijk & van Geert, 2007).

Taken together, these examples are illustrative for many other acquisition processes in development, but serve to specifically illustrate processes in language acquisition. In these cases, children acquire a greater repertoire of behavior, offering them a larger degree of flexibility, greater ability to express nuances, and greater adaptability to a variety of circumstances.

In the case of peak variability, we see an initial increase in variability followed by a decrease in variability. This type has also been called “cyclical” (Siegler, 2006), indicating that a single developmental grower can show multiple phases of increased and decreased variability. There are indications that these patterns exist, for instance, in problem solving in early toddlerhood (Chen & Siegler, 2000) and in infants’ displays of attention and emotion during early face-to-face communication (Lavelli & Fogel, 2005).

Several studies have corroborated the idea that variability is relatively high in the vicinity of a developmental “jump.” For instance, Courage, Edison, and Howe (2004), who reported

Figure 3.5 Range (min/max representation) of the MLU of Jessica (solid squares) and her parents (open squares). Source: van Dijk & van Geert, 2011a. Reprinted with permission.
longitudinal data on the development of self-recognition in infancy, showed that 9 out of 10 children in their sample underwent a phase in which they displayed a high degree of variability. This phase was positioned between constant sequences of either successful or unsuccessful behaviors. In other cases, a local increase in variability is associated with peak performances or discontinuities at the same moment in time. In a microgenetic study by Amsterlaw and Wellman (2006) on the development of “false belief” in preschoolers, all improving children also showed variability in performance in the sense that they failed tasks they had previously passed. Fluctuations were especially prevalent right before children’s mastery of the tasks, providing evidence of a transitional period in children’s theory of mind development.

There are also examples from the area of language development. In van Dijk and van Geert (2011b), for example, we aimed at studying qualitative combinations of the length of prepositional phrases with the grammatical constructions that were used. The sample consisted of the longitudinal data of two children. Here, we found that initially, the relation between prepositional phrase use and sentence length was rather “fixed” to one-word utterances and the use of only single prepositional elements. However, large variability in strategies emerged when sentences became longer. When utterance length finally increased to above four words (i.e., indicating more advanced grammatical development), the strategy use stabilized again (into the target construction).

The study by Bassano and van Geert (2007), which was also based on two cases, reported periods of increased intraindividual variability in the development of utterance length. All results converged on the conclusion that an increase in variability was no statistical artifact but that it was related to meaningful local transitions, in this case accelerations of more advanced strategies and decelerations of less advanced strategies. In fact, this study represents a clear example of the application of the overlapping-waves model described before, where a less advanced grower stimulates the increase of the more advanced grower. In Figure 3.6, the peaks of within-session variability (of a single child) are expressed as those instances at which the variability exceeded the 95% bandwidth of variability around the observed values.

In one of her seminal publications, Thelen (1985) argued that variability is a precursor for structural change in early motor development. In a study on the supine kicks of infants between the ages of 2 weeks and 10 months (see also Thelen & Smith, 1994), one of the motor behaviors studied was the coordination between kicks. During the first few months, kicks were predominantly alternating. However, this period was followed by a period with high levels of variability. This instability led to new forms of coordination between legs—for instance, simultaneous kicking of both legs. Thelen argued that it appears that the infants must
“free themselves” from the stable patterns of the newborn period before they can assemble new behavioral modes. Structural change is thus preceded by increased variability.

The association between increased variability and developmental transition has been empirically validated in several domains. We already listed some examples in the previous section of the chapter (Amsterlaw & Wellman, 2006; Bassano & van Geert, 2007; Courage et al., 2004; van Dijk & van Geert, 2011a), but there are other examples from the fields of socio-emotional behaviors of toddlers (Lewis & Cook, 2007), language (Alibali & Goldin-Meadow, 1993; Ruhland & van Geert, 1998), and cognitive development (Siegle, 1995; Graham & Perry, 1993).

Some studies report that increased fluctuations in one developmental domain sometimes correspond to fluctuations in another domain. For example, Robertson, Bacher, and Huntington (2001) have demonstrated that movement variability in 3-month-old infants is inversely related to variability in visual inspection. According to the authors, this indicates that the motor and visual attention systems are coupled at that age. This suggests that patterns of variability can be used to reveal interactions within a developing system. Hsu and Porter (2004), for instance, have related intraindividual variability to spurts in neurological development. In their study on infant behavior around the 2-month transition, they argue that changes in infants’ reactivity to mild perturbation may be a function of underlying neurobiological shifts. Variability in one factor is related to changes in another factor and thus indicates how different variables are coupled during development.

Another example is provided by Bacher and Robertson (2001), who suggest that variability in motor activity in early infancy may regulate visual attention. They present evidence that the ability to visually disengage from objects appears to be coupled with rates of change in motor behavior. The authors refer to studies by Hoffmann (1983) and Farnsworth and Beecham (1999) to argue that randomness in search behavior has advantages for young infants. Irregular fluctuations may result in unpredictable perturbation of perceptual and cognitive processes that depend on attention.

In summary, we have seen that variability is not necessarily stable across early development. We have distinguished three meaningful patterns of variability: a general increase, a general decrease, and a peak (or cyclical) pattern. However, it should be noted that not all individuals show identical patterns and that these differences might have many causes. Some researchers speculate that these differences can relate to differences in temperament or reactivity (seen as vulnerability to mild perturbations). For instance, Wachs, Creed-Kanashiro, and Gurkas (2008) have investigated whether or not the degree to which infants show behavioral fluctuations is a stable trait (i.e., related to the construct of temperament). The results confirm that there are positive associations between variability at the age of 3 months and variability at the age of 12 months, but the effects are only of moderate size. This indicates that the degree of intraindividual behavioral variability is not a stable trait, but that it changes across development. Individual differences may also be a reflection of different learning styles or different styles of adaptation (van Dijk et al., 2012; van Dijk et al., 2013). For instance, in van Dijk and van Geert (2011a), we found large differences in the use of noun determiners in the three participating children across development. Though two children showed a relatively long phase (10 months or longer) of large variability in determiner/filler use, there was one child who had a much more abrupt switch between determiner omission and determiner use (and for whom the variable period was limited to just a few months). Whereas the global change in the first two children suggests a rather gradual acquisition, the same process in the latter child seems to fit more with the idea of discontinuous development.

Methodological Developments

Intraintividual variability always exposes itself within a specific measurement design. For instance, a design consisting of three consecutive measurements will provide an entirely
different pattern of variability than a design consisting of 30 such measurements made over the same time span (only in the hypothetical case that there is no real variability, e.g., when the pattern is entirely smooth or linear, will both designs reveal the same pattern). If it occurs, the observed variability is thus critically dependent on that specific design and measurement level. Every developing behavior has a real-time dimension, which is a sequence of actions in a specific context. The different time scales at which variability reveals itself are not natural scales, but instead are a matter of measurement unit within a certain research design (see Chapter 17 in this volume). For instance, when behavior is scored in a dichotomous way, the variability can express itself only in consecutive 0/1 shifts. When behavior is averaged over sessions or time intervals, this limits the description of variability at smaller time scales and compresses the total amount of variability. Thus, in order to study intraindividual variability, the time scale of measurement (coding, data processing) must be sufficiently short and the measurement frequency must be sufficiently high to capture the real-time behaviors.

A highly suitable way to study developmental processes is by means of the microgenetic method (Flynn & Siegler, 2007; Lavelli, Pantoja, Hsu, Messinger, & Fogel, 2006). Within this method, short-term development is studied by means of dense observations of learning behavior. The center of attention is the process of change at a rather microscopic level; fine-grained information of real-time behavior is considered to be essential for grasping macro-level change processes (Lavelli et al., 2006). The dense observations before, during, and after a developmental transition reveal how variability changes across time and what its structure is (Siegler, 1995; Lavelli et al., 2006). Around the early 1990s (and partly inspired by DST viewpoints), the microgenetic research design was put forward for the analysis of cognitive development (Siegler, 1995, 1996, 2006). According to Siegler (2006), one of the leading researchers promoting this research design, examinations of variability are significant in identifying mechanisms of development. He argues that microgenetic designs enable researchers to investigate how children’s novel behaviors evolve, a fundamental issue in learning (for a review of the microgenetic framework and a review of research findings, we refer to Siegler, 2006). Though the method was originally designed to study learning, it is currently also used to study other developmental processes, such as self-awareness (Fogel & DeKoeyer-Laros, 2007; Trevarthen, 1993), emotional development (Fogel & Garvey, 2007), and infant attention and emotion (Lavelli & Fogel, 2005). Specifically interesting is the fact that several microgenetic studies have demonstrated that averaging over individual participants’ developmental jumps gives a smoothed presentation of their actual development and evens out much of the variability (Benigno, Byrd, McNamara, Berg, & Farrar, 2011). The microgenetic method enables us to track individual pathways of change and to analyze patterns of intraindividual variability.

Variability is always both qualitative and quantitative, but the way it becomes visible is dependent on the way the developmental variables are operationalized. Children may show qualitative variability in the sense that they exhibit categorically different behaviors within a certain time frame. The variability may thus be scored nominally. But variability may also be expressed in a certain fluctuating “frequency” or “level” of behavior across time. In most cases, qualitative variability can be translated into quantitative variability. In some cases, data can be recoded into a more microscopic level of analysis. For instance, if the category eating is redefined as a particular succession of categories like opening mouth, actual food intake, munching, swallowing, spitting out, and so forth, the action of eating can vary from scoop to scoop. In other cases, the occurrence of particular nominal categories may be counted and a statistical association between frequencies of such categories can be analyzed. And vice versa, by collapsing quantitative data into sets of meaningful patterns, different patterns can be constructed qualitatively. However, in all these cases, the way the behavior is measured remains a determinant of how the patterns are exposed and can be analyzed.
It should be stressed that intraindividual variability occurs and should be approached at the individual level, and in order to get a valid description of its development across time, many repeated measurements and reports are required. A crucial first step is to express variability in a measure to describe how it changes over time for each individual. In the next section, we will discuss several measures that can be used for this purpose. The initial focus should not be on the correlates of variability, but on its structure across time. In van Geert and van Dijk (2002) and van Dijk and van Geert (2007), we suggested simple descriptive techniques that can be applied to time series of a single behavior, such as the moving min/max graph (for an example of this technique, see Figure 3.5), the skewness analysis, and peak analysis. Other measures describe the interaction of variable behaviors. For instance, Lewis and colleagues (Hollenstein, 2013; Lewis, Lamey, & Douglas, 1999) developed the state space grids (SSG) method to depict the sequential structure of nominal or ordinal behaviors in the way they interact in two dimensions. An SSG is a graphical representation of the interaction between ordinal variables on two axes. The cells represent all possible combinations of behaviors, each cell representing a specific combination. An example of such a graph can be seen in Figure 3.7.

In Figure 3.7, each dot represents a single moment in time (in this example, a 10-second time frame) at which the behavior of the parent and the behavior of a child are coded along an affective/emotional dimension. The lines connecting the dots show the progression through time (the open dot is the starting point). In this example, the interactions show moments of stability (see the concentration of dots in the NEU-NEU/INT cells, suggesting “neutral” or “interested” dialogical interactions to be most frequent) and moments of increased variability (movements across many states).

![Figure 3.7 State space grid of affective parent–child interactions (n = 5) during a single play session (NON = no interaction, AGR = aggression, FOR = force, RES = resistance, WHI = whining, NEU = neutral, INT = interest, JOY = joy, and AFF = affection).](image-url)
SSGs are very easy to plot and describe the stability and variability of the interactions between variables, which makes it easy to compare variability within and between individuals. Some measures concern the movements across the entire grid (across all combinations), whereas others represent a selected region of the grid or individual cells (i.e., a specific cluster of combinations). Examples of whole-grid measures are dispersion, the sum of the squared proportional durations across cells, which is a measure of total grid variability, and visits, the number of cells in each trajectory. A measure that can be used to analyze only a preselected part of the grid is return time, which is the mean time it takes for an individual to return to a preselected region or individual cell. In recent years, the SSG technique has become increasingly popular in the field of parent–child interactions (see, e.g., Dishion, Nelson, Winter, & Bullock, 2004; Granic & Lamey, 2002; Hollenstein, Granic, Stoolmiller, & Snyder, 2004; Hollenstein & Lewis, 2006; Lewis, Granic, & Lamm, 2006; Lunkenheimer, Olson, Hollenstein, Sameroff, & Winter, 2011; van Dijk et al., 2012) but also in a broader domain, such as teacher–child interaction (Mainhard, Pennings, Wubbels, & Brekelmans, 2012), young children’s peer relationships (Martin, Fabes, Hanish, & Hollenstein, 2005), peer interaction during sport (Murphy-Mills, Bruner, Erickson, & Côté, 2011), and narrative in psychotherapy (Ribeiro, Bento, Salgado, Stiles, & Gonçalves, 2011).

One of the most promising advances in the analysis of individual variability patterns is offered by recurrence quantification analysis (RQA), which also has a DST background. RQA is a nonlinear toolbox for analyzing recurrence plots, plots that visualize the recurrence of states in a phase space (Marwan, 2008; Webber & Zbilut, 2005). Figure 3.8 shows an example of such a recurrence plot in the field of infant emotional expressions.

![Figure 3.8 Example of a recurrence plot of infant behavior. Multivariate time series of a boy for whom weekly observations of five variables are represented: body contact, crying duration, fretting, smiling, and crying frequency.](image-url)
RQA is a technique for exploiting the temporal structure of a time series (i.e., the temporal variability pattern) to quantify the dynamic organization of a system. This is helpful, for instance, for detecting transitions in the system dynamics of time series (Marwan, Romano, Thiel, & Kurths, 2007). RQA measures include recurrence (the percentage of points in phase space occupied by recurrent points), determinism (the percentage of recurrent points that form diagonal line segments), and maxline (attractor strength). All these measures express the degree of determinism, or order, in a single time series. Nowadays, RQA is mostly applied to life sciences, including psychology and neuroscience, earth sciences, and engineering (Marwan, 2008). Though the application to the field of human development is rather new, the technique has been successfully applied to the study of variability in human development, such as syntactic coordination during language development (Dale & Spivey, 2006), parent–child conversations (Cox & van Dijk, 2013; Lichtwarck-Aschoff, Hasselman, Cox, Pepler, & Granic, 2012) and mother–infant synchrony (de Graag, Cox, Hasselman, Jansen, & de Weerth, 2012), developmental dyslexia (Wijnants, Hasselman, Cox, Bosman, & Van Orden, 2012), and motor control (Wijnants, Bosman, Hasselman, Cox, & Van Orden, 2009).

The measures of variability we described above can be used in traditional univariate and multivariate statistics, such as repeated-measures ANOVAs and t-tests. However, due to advances in computing and software, some nonlinear multivariate techniques that are better suited for the hierarchical structure and variable nature of time serial data sets have recently become available. These methods are not suited for measuring or describing (patterns of) individual variability, but incorporate patterns of short-term individual/dyadic variability in a multivariate analysis.

An example of such a statistical tool is multilevel survival analysis (Stoolmiller & Snyder, 2006), which is a technique for studying real-time interaction processes between dyads and relating them to developmental outcomes. An example of a research question that can be answered with this method is “How do children respond affectively to their parents, and how do these response tendencies differ according to the level of antisocial child behavior?” The central variable in this analysis is the real-time affective interaction, which by definition shows variability from moment to moment. Instead of averaging or summing over these moment-to-moment changes, the analysis is performed on the original time series and thus leaves the variability pattern intact. Multilevel survival analysis is a variant of sequential analysis and includes estimation of multilevel random effects. The method focuses on the hazard rate, which is the rate at which an event occurs at a particular moment in time (for more information, see Stoolmiller & Snyder, 2006).

Other statistical tools suited to analyzing transactional processes are hidden Markov modeling (Rovine, Sinclair, & Stifter, 2010) and latent differential equation modeling (Nicholson, Deboeck, Farris, Boker, & Borkowski, 2011). Hidden Markov models are based on a simple Bayesian network and give information about the sequence of latent states in terms of probabilities. This method works with multivariate categorical and continuous variables based on time-series data. Latent differential equation models aim at expressing the relationships between current states of individuals and how individuals are changing over time. In both methods, models with different specifications that describe the dynamic interactions are compared to one another using measures of fit (Akaike information criterion [AIC], Bayesian information criterion [BIC], etc.). What these methods have in common is that they are able to answer multivariate questions for processes that are dynamic and variable in nature. In doing so, they move beyond discrete time analysis and models of linear change. These methods are suited to analyzing transactional, dynamic relations (couplings) between variables at different time points, but they aim at providing a model to explain variance in group data instead of describing (changing) patterns of variability and the role they play in development.
Though these methods have an important added value to many studies in developmental psychology, we argue that researchers should not too easily shy away from analyzing their data at the individual level by moving to multivariate techniques aimed at explaining population variance. Instead, they should explore the richness of their observations by performing a critical and thorough exploration of the individual time series by means of visualization and descriptive techniques such as those discussed above (see also van Geert, 2011, for more elaborate discussion of individual versus multivariate data analysis).

**Future Work and Challenges**

In this chapter, we have described how DST and microgenetic methods have radically changed the perspective on intraindividual variability. There are many examples of studies that have adopted this new perspective and have focused on variability and real-time interactions as important developmental indicators in early childhood. In 1994, Thelen and Smith were already urging researchers to treat intraindividual variability as data and to use it in their analyses instead of averaging it out by means of smoothing techniques. Two decades later, we can see that many researchers, from various domains, have implemented this recommendation. Rapid developments in computation and software have clearly been a catalyst in this process. Many innovative methods have been developed with regard to data analyses and description, which are a prerequisite for the labor-intensive study of variability. The application of these new descriptive and statistical methods to a wide variety of topics in early child development is a clear direction for future work on intraindividual variability.

A practical challenge for many variability-centered studies may be the composition of a study’s sample. Analyzing patterns of variability requires the collection of many repeated measurements, which can be time-consuming. Because in the average research project the time dedicated to data collection is limited, it can be difficult to find an optimal balance between the number of measurements and the number of participants (van Geert, 2011). It is expected that developments with regard to data collection and processing, such as automated video-recording, coding, and transcription, may play an important role in determining this optimum.

The study of intraindividual variability also leads to challenges of a more fundamental nature. Probably the most prominent finding in studies with many repeated measurements is that developmental patterns turn out to be highly idiosyncratic. In all the studies described in Section 4 of this chapter (with regard to feeding, crying, talking), interindividual differences in intraindividual variability patterns clearly existed: Some individuals stabilized more quickly than others, some individuals developed more gradually, and others developed more discontinuously. Crucial questions are “How can any description of the process provide a valid representation of all these unique trajectories?” and more fundamentally “How do we generalize from these idiosyncratic patterns to more general knowledge about the developmental process under investigation?” Multivariate techniques—such as the techniques described in Section 4—are typically suited to answering these questions, but they encounter a similar problem. For example, with regard to the application of hidden Markov models (though the problem applies to the other measures and statistical techniques as well), Rovine et al. (2010) have already mentioned that the model with the best fit offers a solution (a common model that is used to define the states) that should fit all individuals, because individuals can differ only in the sequence of and duration of time spent in these states. These authors offer two alternative approaches: The first is to estimate a separate model for each individual (which, according to them, has the drawback of hindering direct comparison between individuals), and the second is to attempt to find subgroups for which a common set of state definitions would be adequate. Thus, instead of aiming to construct a model that describes or explains...
the development in all cases, these authors suggest that one can start with the identification of groups of individuals that share certain similarities. This leads to a more nuanced type of generalization and does better justice to both interindividual and intraindividual variability.

A few critical remarks are also in order. First, we argue that the individual is the level where the developmental processes take place and should therefore be the primary focus of attention when studying these processes (see van Geert, 2011). Variability, which is an important property of development, also takes place at the individual level, implying that patterns of variability should also be analyzed at this level. Because of the ergodicity principle (e.g., Molenaar & Campbell, 2009), there is no reason to assume that developmental models based on aggregated group data have any logical relation with individual processes. Therefore, individual development can (almost) never be adequately modeled by a generic trajectory model based on sample information. Second, we should reconsider the meaning of the concept of “generalization.” Currently, most empirical work in developmental psychology is based on sample-based explanations of variance, and generalization is predominantly viewed in terms of “sample generalization” (see van Geert, 2011). In many cases, it boils down to whether a distribution of properties in a sample carries information about the distribution of those properties in the population or how much of the variance between individuals is explained by a single model. However, generalizability should also be viewed in terms of how individual development relates to an underlying theory of development (van Geert, 2011). The identification of subsets of similar individuals can be an important step in achieving a more legitimate generalization to a certain population (Molenaar & Campbell, 2009; Rovine et al., 2010).

Conclusions and Implications

In summary, we have shown that intraindividual variability is a prominent feature in (early) child development. Several theoretical conceptions of the causes of this phenomenon have been reviewed. In the early 1990s, dynamic systems theorists put forward the view that variability is an important characteristic of self-organization in development. Finally, influenced by the DST viewpoint, we have argued that variability is important for developmental research because it can be used to detect and predict developmental transitions and also to detect interactions between domains of a developing system. There are also indications that variability is an adaptive and functional feature of human development.

Empirical studies have shown that different forms of variability exist (i.e., increasing, decreasing, and peak variability) and that these forms can be related to the underlying state space dynamics of the changing variable at hand. However, the way variability is revealed is critically dependent on the way development is measured. The measurement should be detailed enough to capture the real-time behavior in its context. Microgenetic designs offer optimal possibilities for the study of variability in development. In recent years, a variety of new methods have been developed to measure variability, to describe its patterns, and to incorporate variability in multivariate analyses. The application of these methods to the various topics in early child development is one of the greatest challenges for future research on intraindividual variability.

It should be noted that the first few years of life are characterized by a high degree of interconnectedness of developmental domains. Moreover, all major developmental transitions in early childhood occur in a dynamic interaction between the child, the social environment, and the context. Young children acquire skills and knowledge about the world through social and material interactions, while at the same time actively shaping their environments. Variability and stability play a central role in this process. Developing behavior is adaptive and reactive in nature. For instance, when an infant cries, this is always in response to the internal or external context (e.g., hunger, cold). However, we have seen that it is also a way to select and
create situations, and thus aims at creating a certain degree of stability. This way, development always shows elements of both variability and stability, which are related to the dynamic interaction between the child and the environment.

Notes
1 This is supported by empirical research. For instance, Jenni, Deboer, and Achermann (2006) report that in the first few months of life, sleep patterns exhibit a rather monotonic increase to a greater degree of regulation, but with fairly stable fluctuations across the trend.
2 However, it should be remarked that in this case, the behavior was coded dichotomously, meaning that the variability may also be an expression of an underlying gradual development.
3 Note that we use individual as a generic term, referring to an individual unit of analysis, which can indeed be a specific individual person, such as infant x, but also a specific dyad, such as infant x and mother y.
4 For example, the studies of Martin et al. (2005) and Lunkenheimer et al. (2011) combine SSG measures of variability with traditional statistics, such as t-tests, correlations, and structural equation modeling.
5 The example is taken from the study of Stoolmiller and Snyder (2006).
6 An example of such an approach can be found in van Dijk et al., 2012.

References


M. van Dijk and P. van Geert


