Towards a Dynamic Systems Approach to the Development of Language and Music: Theoretical Foundations and Methodological Issues

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ABSTRACT

Music and language are considered as distinct auditory systems that serve different communicative uses. From the perspective of infants rather inexperienced with their native musical and linguistic systems, these differences are less apparent. One of the enduring puzzles related to human cognitive development is the question of how children acquire these complex systems with such effortlessness and speed, and how developmental change can be explained. Dynamic systems theory (DST) can make significant contributions to our understanding of cognitive development, and has already been successfully applied to first and second language development. By drawing together findings from various scientific fields, we will argue that our understanding of musical and linguistic development can be crucially enhanced by i) cross-domain research, ii) applying DST and iii) new methodologies in empirical research. Language and music are seen as complex non-linear dynamical systems that may interact at various stages of development, such as in syntactic development. Major developmental shifts occur around the same time up to the age of four in both systems. DST also has potential to shed new light on common methodological issues in developmental research: intra-subject variability in behavioural data receives a positive meaning and is not considered as noise but as sound.

I. INTRODUCTION

How do infants and young children develop a profound knowledge of their native language and musical system with such effortlessness and speed? And how can we understand these cognitive transformations over developmental time? It is still a marvel how the human mind with all its mental capacities develops from an immature human infant, and how this change can be explained. We propose that language and music development may be best understood as *change* within two complex non-linear dynamical systems that follow similar developmental routes in the first four years of life and probably beyond. The similar transitions in the developmental pathways may be explained by the perceptual and conceptual similarities between the domains of language and music, such as rhythm and syntax (Besson & Schön, 2001; Fitch, 2006; Patel, 2008), and by the maturational transitions in general brain development (Kagan & Baird, 2004). Dynamic systems theory in combination with cross-domain research can open new avenues for theories of musical and linguistic development and fertile future research paradigms.

The different scientific approaches to language and music development have changed in many respects over the last hundred years, largely influenced by technological advances and the subsequent rise of neuroscience and computing. However, there is a fundamental philosophical debate reflected in current psychological and linguistic approaches to the study of development in language and music: the so-called *nature-nurture debate* refers to the ongoing debate between empiricists and rationalists about the question of whether language is being *learned* or *acquired* (Tomasello & Slobin, 2005). Aristotle in the ancient world and later St. Thomas Aquinas in the middle ages were in favour of the empiricist view, which inspired empiricism and sensualism of Locke and Hume in the 17th century and later behaviourism. Rationalism has its roots in Plato's dualist metaphysics, which influenced Descartes in the 16th century and Leibniz' theory of innate ideas in the 17th century. Noam Chomsky is a current representative of rationalism, arguing that innate Universal Grammar (UG) explains how a child can acquire a complex system like language within a short time and without effort, and this in an environment of limited imperfect input (Lindner & Hohenberger, 2009). The extreme views taken by followers of empiricism or rationalism have been recently questioned, for example by the radical middle approach (Hennon, Hirsh-Pasek, & Golinkoff, 2000) and the mutual acknowledgement of UG and statistics (Yang, 2004). Tomasello and Slobin (2005) also state that no serious attempt at explaining language learning gets around acknowledging the two main ingredients, namely nature *and* nurture. We argue that the same holds true for any complete theory of musical development.

At the beginning of the 20th century, psychologists such as Watson, Pavlov and Skinner were mainly interested in learning theories, claiming that all learning involves either classical, instrumental or operant conditioning. In the context of language development, behaviourism was renounced after Chomsky's criticism of Skinner's theory of operant conditioning and language learning (1957). Up to the advent of connectionism, learning processes were consequently largely neglected (Glaser, 1990), especially by researchers in the tradition of Chomsky's theory of generative grammar and language acquisition (1995). Connectionism shares two aspects with behaviourism. First, experience is the dominant factor in learning. Second, the underlying learning mechanism can be described as association based on spatio-temporal contiguity, similarity and analogy (Lindner & Hohenberger, 2009). Simulation of various cognitive processes in neural networks is the main methodology of connectionism (Plunkett, 2001). The characteristics of connectionist models can be best understood by comparing them to the *classical metaphor of cognition* in symbolist frameworks (Cleeremans, 1997). As Bates and Elman (1992) explain, the approach of the classical metaphor can be described by

- Discrete representations
- Absolute rules
- Learning as programming or memorizing, new knowledge arises from hypothesis testing

- Distinction between hardware and software (in line with the computer metaphor)

In contrast to this classical computational view, Cleeremans (1997) defines connectionism by the following features:

- More flexible, graded representations
- Sensitivity of the organism to the pattern of the input
- Continuous learning through experience
- No distinction between hard and software

Connectionist models have convincingly argued that the linguistic input is rich enough in structure as to extract patterns from it. Infants have the ability to effectively extract patterns from the statistical regularities of the input, be it language (Saffran, 2003; Saffran, Aslin, & Newport, 1996; Thiessen & Saffran, 2003) or music (Creel, Newport, & Aslin, 2004; Saffran, Johnson, Aslin, & Newport, 1999). Nevertheless, distributional learning cannot account for the learning of morpho-syntactic regularities in language and thus needs to be supplemented by domain-specific, language particular constraints (Culicover & Novak, 2003; Höhle, 2009; Yang, 2004).

In the 1990s, a new framework emerged and dynamic systems theory (DST) also entered the realms of developmental psychology and linguistics. DST is rooted in fields such as mathematics, chemistry, physics, biology, meteorology and philosophy. Importantly, it is associated with notions such as self-organization, emergence, chaos theory, fractal theory, nonlinear dynamic systems, dissipative systems and synergetics (Hohenberger, 2002). While some argue that DST is closely linked to connectionism (neural networks are nonlinear dynamical systems) (Thelen & Bates, 2003; van Geert, 2008), others claim that DST is a novel paradigm (Beer, 2000; van Gelder, 1998). There may be a difference of emphasis between connectionism and DST: “dynamic systems have emphasized the entire coalitional contributions to behaviour, while connectionism has been concerned with changes in mental representations” (Thelen & Bates, 2003, p. 389). In general, DST can be characterized as follows (van Gelder, 1998):

- Emphasis on change, not state
- Focus on the position of a state in relation to other states
- Structure is laid out temporarily
- Timing of events more important than order of events
- Dynamic systems work in parallel, not serially
- Ongoing processes
- Coupling between the environment and the system
- Representations are not static but can be graded
- Dynamical systems are not necessarily representational

Dynamic systems theory may provide an interesting alternative to reconcile the opposing views of empiricism and nativism by regarding development as the experience-dependent shaping of genetic predispositions (Hohenberger & Peltzer-Karpf, 2009). As such it has already been discussed in the context of first (Hirsch-Pasek, Golinkoff, & Hollich, 1999; Karpf, 1990; Mohanan, 1992; van Geert, 2000) and second language development (De Bot, Lowie, & Verspoor, 2007; Ellis, 2007; Larsen-Freeman, 1997; Verspoor, Lowie, & Van Dijk, 2008). To our knowledge, DST has not been applied to musical development yet. We thus argue that linguistic and musical development should be investigated under a common framework of DTS. Specifically, we acknowledge distributional/statistical learning (nurture) and genetic endowment as well as the computational human language faculty (Hauser, Chomsky, & Fitch, 2002; Pinker & Jackendoff, 2005) and several basic musical features that are partly determined by innate constraints and could form a capacity for music (nature) (Jackendoff & Lerdahl, 2006; McDermott & Hauser, 2005). Moreover, it can be stated that linguistic structures and constraints emerge through self-organization on various time-scales: macrogenetic (evolution of a language of a particular group), phylogenetic (origin of language, language change), ontogenetic (language development), and microgenetic (language processing) (Hohenberger 2002; Culicover & Nowak 2003). We propose that music in relation to language can also be discussed within this temporal framework, providing a coherent approach to various issues in language-music comparisons.

In the realm of cognitive science, linguistic and musical development has been conceived as having a clear beginning and end state. The path of development is usually regarded as linear and monotonic, and the focus has been on knowledge representation and information processing (De Bot et al., 2007; Lindner & Hohenberger, 2009). However, studies have shown that language and language development are more complex, intricate and unpredictable than a linear view would allow. Linguistic theories such as cognitive linguistics, functional linguistics as well as the emergence model for language development and the competition model of language processing assume that there are many interdependent variables, not only within the language system, but also within the psychological system of an individual and the social environment. These theories recognize “the crucial role of interaction of a multitude of variables at different levels: in communication, constructing meaning, learning a language and among the languages in a multilingual mind” (De Bot et al., 2007, p.7). DST can be a powerful overarching theory that allows for many interacting variables, nonlinear behaviour and unpredictable outcomes (Lewis, 2000), and can also enrich cognitive science in many ways (Bickhard, 2009). Moreover, DST successfully accounts for “real-life messy facts” (De Bot et al., 2007, p. 7). In the context of DST and development, music can be seen as a system that is also in interaction with the system and subsystems of the native language, and in the case of bilingualism, with the subsystems of the second language.

In summary, DST provides a relatively new framework to discuss the interaction of systems in time and to explain change. So far, DST has been applied neither to the development of music nor to a comprehensive discussion of music *and* language development. Here, we will try to fill this gap by providing theoretical foundations that stand in contrast to standard developmental approaches of the 20th century, as proposed by Chomsky, Gibson, Vygotsky and Piaget (Thelen & Bates, 2003). We will also address methodological issues that refer to DST and developmental psychology.

II. DYNAMIC SYSTEMS THEORY

Mathematics play an important role in the physical and biological sciences. In the field of applied mathematics, DST is used to describe the behaviour of dynamical systems by using differential or difference equations. From a mathematical perspective, the essential ingredients of a dynamical system are a *phase space*, whose points represent possible states of the system, *time*, which may be discrete or continuous, and the *time-evolution law*, which is "a rule that allows us to determine the state of a system at each moment of time from its states at all previous times" (Katok & Hasselblatt, 1997, p. 1). *Constraints* can govern the application of the evolution law (van Geert, 2008). The *CRC Concise Encyclopedia of Mathematics* (Weisstein, 1999) provides a particularly frugal definition of a dynamic system, namely "a means of describing how one state develops into another state over the course of time" (p. 501).

At the beginning, appliers of DST were interested in the investigation of simple dynamical systems, such as two coupled variables in a double pendulum. Although there are only two degrees of freedom (two interacting variables), the trajectory of the system is complex. A human being or a society have innumerable interacting variables and the system gets very complex (De Bot et al., 2007): "*Complex systems* are systems with many components that interact, meaning that they co-determine each other's time evolution" (van Geert, 2008, p. 181). Such complex systems can *self-organize* and thus dynamic systems can also be defined as "systems that change over time and that can autonomously generate complexity and form" (Smith & Thelen, 1993, p. xii). This change over time can be regarded as the major property of a dynamic system and the fundamental equation is $x_{(t+1)} = f(x_{(t)})$, for any functions that describes how a state x at time t is transformed into a new state x at time $t+1$. This basic equation is iterative and a series of *x's* describes a process (van Geert & Steenbeek, 2005).

High-level mathematics are not needed in order to understand the basic assumptions of DST. Dynamic systems consist of interconnected variables; therefore, any change of one variable will affect all other variables. This makes the calculation of the outcome of a complex system very difficult, if not impossible because the variables that are interacting change over time. The outcome of these interactions cannot be solved by analytical methods (De Bot et al., 2007).

Dynamical systems are nested, so every system is part of another system, going from the submolecular particles to the universe. The same dynamic principles operate at each level. Dynamic subsystems settle in *attractor states*, which are temporary and can be simple, complex or chaotic. Depending on the strength of the attraction, more or less energy is needed to change a system that is in an attractor state to another attractor state. An example of an attractor state are the different ways horses can run, they either trot or gallop, but there is no in-between. *Repeller states* are states that are not preferred and the opposite of attractors (De Bot et al., 2007; Smith & Thelen, 1993). Another term for an external disturbance of a system's time evolution is *perturbation* (van Geert, 2008).

The development of dynamic systems depends on the initial state of a system, therefore minor differences at the beginning may lead to big differences at later stages (*the butterfly effect*). The notion of non-linearity is also related to this characteristic. *Non-linearity* refers to the fact that minor perturbations may lead to huge effects and that large perturbations may be absorbed by the system without any obvious effects (De Bot et al., 2007).

Another important feature of complex dynamic systems is the ability to self-organize. *Self-organization* can be defined as "irreversible processes in non-linear dynamical systems, leading to more complex structures of the overall system by the cooperative activity of subsystems" (Ebeling, 1991, p.118). Self-organization is flexible and adaptive (van Geert, 2008), and a specific form of *emergence*: "Emergence is the spontaneous occurence of something new as a result of the dynamics of a system" (van Geert, 2008, p. 182). Complex structures self-organize through the dissipation of energy (Prigogine & Stengers, 1984) and are found between *chaos* and *order*, in other words, at the edge of chaos (Kauffman, 1995). When systems are in threat of becoming chaotic, complexity arises: the imminent chaos is collapsed by differentiation. This explains why Cohen and Stuart (1994) argue that it is easier for an evolving biological system to become more complex than to become less complex.

III. LANGUAGE DEVELOPMENT AND DYNAMIC SYSTEMS THEORY

As Thelen and Smith (2003) state, the idea of emergence, i.e., "the coming into existence of new forms through ongoing processes intrinsic to the system" (p. 343) is not completely new to developmental psychology. The epigenetic nature of ontogenetic processes were already discussed by developmental theorists, such as Kuo, Oyama and Gottlieb. Biologists and psychologists such as von Bertalanffy, Lewin, Gsell and Waddington discussed "behaviour and development as morphogenetic fields that unify multiple, underlying components" (Smith & Thelen, 2003, p. 343). However, dynamic systems theory is still a young approach within the field of developmental psychology (Beer, 2000; Smith & Thelen, 1993; van Geert, 1995, 1998, 2000; van Geert & van Dijk, 2002; van Gelder, 1998) and standard approaches focusing on information processing are still predominant. The lack of publications on dynamical systems and development in the last twenty years may be due to the demands of dynamical systems in terms of mathematics and data collection (van Geert, 2008; van Geert & Steenbeek, 2005).

Van Geert (2008) argues that there are three approaches to development taken within DST. First, DST is defined as a theory of embodied and embedded action, largely developed by Esther Thelen and Linda Smith: "The dynamic system at issue is the continuous coupling between the organism and its environment, showing a time evolution that takes the form of intelligent action" (van Geert, 2008, p. 184). Second, the qualitative properties of dynamic systems are emphasized, for example, by Marc Lewis. The developmental system is characterized by non-linear behavior, self-organization, emergence and attractor states. Third, van Geert is a representative of the position that applies DST to describe and investigate changes in time, focusing on time evolution and rules (van Geert, 2008).

DST has very recently been successfully applied to the study of first, second and multilingual language development, and there has been a recent increase of publications in the field (Ellis, 2008; Hohenberger & Peltzer-Karpf, 2009; Jessner, 2008; Larsen-Freeman, 2006, 2007, 2008; Larsen-Freeman & Cameron, 2008; Pienemann, 2007; Plaza-Pust, 2008; Raczaszek-Leonardi & Kelso, 2008; Samuelson, Schutte, & Horst, 2009; Tuller, Jantzen, & Jirsa, 2008; van Geert, 1991, 2007, 2008; van Geert & Steenbeek, 2005; Verspoor et al., 2008). In addition, DST has been used in the study of motor development (Rakison, 2002; Goldfield & Wolff, 2004; Clark & Phillips, 1993; Whitall & Getchell, 1995; Smith & Thelen, 2003; Thelen, 1989, 2000) and emotional development (Camras & Witherington, 2005; Lewis, 2005).

One of the central concepts in DST in the context of language development is *language growth,* both *neurocognitive* and *cognitive growth* (van Geert, 1991). Growth is not defined as learning in the traditional sense of learning, but as "autocatalytic quantitative increase in a growth variable, following the emergence of a specific structural possibility in the cognitive system" (van Geert, 1993, p. 274). Cognitive variables, such as words or constructions in language, grow by themselves in a cognitive environment (the mind/brain), and synergy at the microscopic level (the lexicon) leads to new qualitative order on a macroscopic level (words figuring in syntactic phrases) (Hohenberger & Peltzer-Karpf, 2009).

Language development can be regarded as a *chaotic itinerary* (Hohenberger & Peltzer-Karpf, 2009; Kaneko, 1990). The inital state is characterized by randomness, the final state by synchronous behaviour by coupling. The system moves from "a previously global and relatively undifferentiated state to an increasingly fine-grained and functionally complex mosaic" (Hohenberger & Peltzer-Karpf, 2009, p. 485). A class of mildly unstable dynamical systems (*globally-coupled dynamical systems*) has been recently identified in the brain (Tsuda, 2001) and may be useful to cognitive scientists (Kampis, 2004). The attractivity of this new class of dynamical systems lies in their mutability between stable and transitory states which gave them their name. The system moves between low-dimensional states of stability and high-dimensional transitory states. The transitory states lead away from the previous stable state (so that the system intermittently dwells in chaos for some time until it is attracted again to a stable state). In the case of an ordered state, the state may be stabilized due to epigenetic factors (environmental and maturational). Chaotic itinerancy is of potential interest to cognitive science since the spontaneous cycling between stable and unstable states might explain why systems, due to their particular dynamics (mild overall instability), have the inherent capacity to fall into ordered states for no obvious reasons.

From a developmental perspective, the following phenomena are crucial (Karpf, 1993): i) the selection of input data, ii) the emergence of varying degrees of order, and iii) the dissociation of (sub)systems (i.e. the rise of modular organization within the developmental course). The chaotic itinerary of language begins with the *inital quasi stable state,* which comprises pre-speech behaviour, and is characterized by a transition from holistic to gradual analytic processing. In the *intermediate states,* there is a focus on rule formation, the organisation of clusters and the onset of system specific phase-shifts. Uniform patterns, coherent clusters and stability are typical of the *final steady state* (Hohenberger & Peltzer-Karpf, 2009).

The time course of these behavioral changes is closely linked to the development of the young brain. Singer (1995, 2000) convincingly argued that the brain's basic plan is predominantly genetically determined, but the establishment, modulation, and fine-tuning of neural networks is affected by the brain's activity and its interaction with the environment during the early years of life (Singer, 1995, 2000). What actually causes the behavioral outcome can be better accounted for by *process determinism* (van Geert, 1997). According to van Geert, dynamic models can account for causal or conditional chains by explaining how a previous state gives rise to a subsequent state. In epigenetic models like the one we propose, experience directly calls upon neural processes. Through consistent processing neural circuitry builds up and, furthermore, the expression of relevant genes may be modulated. Recurrent processing sets into motion the self-organization of mental and neuronal functions through non-linear phase-transitions and emergence. This is how the genes and the environment jointly determine language behavior – in the wider framework of self-organization.

Developmental cognitive neuroscience has provided many findings that can be useful to researchers applying DST. The neural prenatal processes of the developing brain can be summarized as follows

- Production of neurons (embryonic day 40-125)
- Migration of cells via growth cones (radial units)
- Proliferation of neuronal production (= overshoot phase)
- Final positioning and formation of the cortical proto-map
- Columnar organization and modification of the cortical proto-map (Rakic, 2000)

After the creation of first patterns during prenatal development, postnatal development is characterized by the following steps

- Establishing connections (synapse formation)
- Modifying connections (reorganization of inital inputs)
- Proliferation and subsequent elimination of superfluous connections (Rakic, 2000)

The developing brain is characterized by significant maturational transitions. They occur at 2-3 months, 7-12 months, 17-24 months, 4-8 years, and puberty. Between 2 to 8 years, the most fundamental brain change can be described as a massive interconnectedness involving both hemispheres, anterior and posterior cortical sites, and cortical and subcortical structures (Kagan & Baird, 2004).

Neuronal growth can be considered as *stimulus-induced postnatal netting* running through phases of exuberance and reduction" (Hohenberger & Peltzer-Karpf, 2009, p. 488). The operating word guiding all these changes is *plasticity* which can be defined as the brain's capacity to get organized and to reorganize itself as a reaction to internal or external changes (Black, 2004). Plasticity can also be made responsible for the *(in-)determinism of language* in the sense that our genetic blueprint sets the guidelines for the general path of language development allowing for variation in the self-organization of systems: Initial cellular events (such as the proliferation, migration, aggregation, and death of cells that form the brain), the subsequent outgrowth of axons, and the establishment of connections proceed in an orderly fashion in each individual according to a species-specific timetable and are regulated by differential gene expressions (modulated by genes such as FOXP2). In contrast, the later phases of development, including the selective elimination of neurons, axons, and synapses, as well as the shaping of the final circuits within topographical maps, are influenced by activity-dependent mechanisms which – after birth – involve individual experience (Rakic, 2000).

Language development in the first year of life can be summarized by three major perceptual shifts (Locke, 1993; Vihman, 1996).

- Infants' sensitivity moves from psychoacoustic to phonological categories
- The discrimination of phonetic contrasts is narrowed down to those of the native language
- There is a shift from perceiving prosodic to perceiving segmental properties

Another important transition that plays a role in the chaotic itinerary discussed above is the shift from *holistic* to *gradual analytic decoding*. The segmentation of the input seems to move from prosodically to phonotactically and syntactically driven mechanisms (Höhle, 2009). These cascades in the detection and extraction of hierarchical groupings give rise to the gradual establishment of canonical patterns on various levels as a basis for drawing conclusions about the types of phonetic and prosodic patterns prevalent in the given language. A critical mass of sound patterns collected by the end of the first year is an absolute must for early lexical organization. About one year later a critical mass of lexical elements triggers off syntactic processes and morphological marking (Hohenberger & Peltzer-Karpf, 2009).

DST has been successfully applied to early monolingual development (Hohenberger, 2002a, 2006; Mohanan, 1992; Peltzer-Karpf & Zangl, 2001; Sena & Smith, 1990; van Geert, 2008; Zangl, 1998), following qualitative and/or quantitative approaches in longitudinal studies (mostly) on early grammatical development. For example, Zangel and colleagues (Zangel, 1998) investigated the development of lexical catgories, the mean length of utterances and their relation to phase shifts in the linguistic development of a German monolingual child by collecting and analyzing a rich corpus of utterances. The researchers found evidence for temporal asynchrony in system development, i.e. that linguistic "[sub]systems do not develop simultaneously but at different times. This implies a changing sensitivity to input cues with different tasks being foregrounded at different times." (Hohenberger & Peltzer-Karpf, 2009, p. 493). The early phases of language development are characterized by a succession of several significant shifts which occur in more or less regular intervals of five to six months:

- Between 1;5 and 1;8: onset of a rapid lexical increase
- Around the age of two: first evidence of morphological and syntactic variants
- Between 2;5 and 2;6/2;7: stabilization of subject-verb-congruency, followed by higher syntactic mobility and productive use of morphological markers

The vocabulary spurt around the age of 1;6-1;8 has previously been reported (Goldfield & Reznick, 1990). In the context of the *chaotic itinerary* to language, the age of two is a turbulent phase in which the lexical, morphological and syntactical subsystems are reorganized: "This blooming linguistic period is predominantly characterized by (1) the expansion of existing lexical-syntactic patterns (productive use instead of lexeme-bound behaviour) and (2) increasing structural heterogeneity resulting from the inclusion of morphological variants" (Hohenberger & Peltzer-Karpf, 2009, p.492). Another major shift occurs between 2;5 and 2;7, which can be summarized by the following characteristics (Zangl, 1998):

- The basics of the syntactic frame are set up
- Significant increase in past reference (extended to negation and interrogation)
- Increase in overgeneralizations (plural and past tense)
- First word formation processes in lexical categories other than nouns

This data provided also evidence for fact that the major shifts in early linguistic development coincide with more general neural and cognitive changes.

In a similar vein, Bassano and van Geert (2007) collected a corpus of one-word, two-and-three word and four-and-more-word utterances from two French children during the second and third year of life. They were interested in the relationship between utterance length and grammatical development. The researchers fitted a *dynamic-growth-model* and by applying a statistical manipulation method they showed two striking peaks of variability and a temporary rapid growth of utterances. They argue that these phenomena refer to transitions that are essential in grammatical development and could be related to the emergence of simple combinatorial and syntactic stages. Importantly, the researchers emphasize the importance of analysing intra-individual variability because variability offers information on a system's current state. Longitudinal qualitative studies mostly conducted by linguists will hopefully be further enriched by computational and neurodevelopmental methods.

IV. LANGUAGE AND MUSIC: THE DANCE OF DYNAMIC SYSTEMS?

To our knowledge, DST has not been applied to musical development so far, although it has provided fruitful insights in other developmental fields. We thus propose that music and language development in infants and pre-schoolers could be compared and discussed within a common framework of DST. Two questions need to be addressed in this challenging future venture:

- Can music development be better understood by applying DST?
- If yes, how can DST account for both language and music development?

We argue that the successful application of DST in developmental psychology provides a good basis for an application in the domain of music. In the current developmental research on musical development, longterm studies are rare, and the interest in the study of continuous change is rather low. We think that the field of developmental research on music is advanced enough to address questions that go beyond the mere description of what children can perceive or produce at a certain age in the course of development and the neural underpinnings thereof. Questions referring to *how* the brain and behaviour *changes* can be addressed by applying DST. Cross-domain research including computational and neuroscientific methods can help to better understand how children's musical experience changes over time, and how their singing abilities (in analogy to speech production) increase.

Importantly, we also state that one needs to consider language development in order to fully understand music development. First, music and language share many features (Besson & Schön, 2001; Jackendoff, 2009; Patel, 2008; Patel & Daniele, 2003) although they are considered as distinct communicative domains. For example, language and music unfold in time and are hierarchically organized (syntax). Both domains can be described by segmental (phonemes and tones) and suprasegmental (rhythm, stress, intonation etc.) cues. Differences between language and music may be less apparent in infants (McMullen & Saffran, 2004), or even in the prenatal foetus. Music and language may follow similar developmental paths especially in the early years of life. Second, the development of music and language has already previously been compared and discussed (McMullen & Saffran, 2004; Trainor & Desjardins, 1998; Trehub & Hannon, 2006), but without the development of an overarching theory. DST could provide such a framework. Third, the latest neurocognitive and behavioural findings suggest that there is an overlap in the processing of musical and linguistic syntax (Fedorenko, Patel, Casasanto, Winawer, & Gibson, 2009; Koelsch, 2005; Slevc, Rosenberg, & Patel, 2009) and a dissociation in representational neural networks (Patel, 2003). Thus, it can be assumed that there is at least some overlap in the development of these neurophysiological resources. Fourth, DST in the context of music and language can help to reolve the vexing issue of modularity (Peretz, 2009). Modularity would be seen as an emergent property (Karmiloff-Smith, 1992) and not as a starting point of development (Fodor, 1993). We argue that the question of modularity can be best addressed by discussing functional and representational networks separately. Last, current behavioural research (often with large sample sizes) on musical development does not address the issue of variability. In DST, intra-subject variability in behavioural data receives a positive meaning and is not considered as noise but as sound .

Earlier comparisons between music and language development (McMullen & Saffran, 2004; Trehub & Hannon, 2006) have already pointed out the following similarities: genetic predispositions, prenatal learning, categorical perception, scene segmentation and gestalt perception, grouping, saliency of suprasegmental and auditory stream segmentation, enculturation processes, statistical learning, rule-based learning, and implicit knowledge of syntax. A comparison of the latest literature on music (Hannon & Trainor, 2007) and language (Kuhl, 2004) development including behavioural and neuroscientific approaches shows that music and language develop in very similar ways up to the age of four. Moreover, important transitions in development (perception and production) seem to occur around the same age and may be linked to neurophysiological changes. For example, the decline of foreign vowel perception and of foreign meter and melody perception occurs around 11 months, the first words and songs are produced around the age of one year, and the onset of advanced syntactic knowledge can be found around the age of two in language (Gertner, Fisher, & Eisengart, 2006) and music (Jentschke, 2007). Implicit knowledge of grammar can be seen as the highest level of complexity to be reached in development, and by the age of four children have already substantial implicit syntactic knowledge of their native music and language systems (Marin, in press). We propose that the emergence of syntax in music and language around the same time in development is no coincidence because there is evidence that syntactic processing networks are already shared in children (Jentschke, Koelsch, Sallat, & Friederici, 2008).

In a first step, DST could qualitatively be applied by conducting longitudinal studies and testing for specific musical and linguistic abilities and trying to understand how different subsystems interact during development across domains. For example, the *dynamic growth model* on the development of utterances by Bassano and van Geert (2007) is based on three *generators* (holophrastic, simple combinatorial, and syntactic) and two major transitions. The first two generators emerge and then disappear successively in the course of development. The development of singing could be investigated in a similar way and then be compared to linguistic development. A subsequent quantitative step would imply the simulation of musical and linguistic growth. Another issue of interest is the question of how and why subsystems should positively interact or even be shared. One explanation could be van Geert's (1991, 1995) idea of *connected growers*. In a system, resources for the growth of different subsystems is limited and not all subsystems require the same amount of resources. Connected growers (subsystems such as lexical development and listening comprehension) need fewer resources in growth than unconnected ones and thus enhance development (De Bot et al., 2007).

V. METHODOLOGICAL ISSUES

Larsen-Freeman and Cameron (2008) discuss methodological issues in the context of DST and language development: "The dynamic, nonlinear, and open nature of complex systems, together with their tendency toward self-organization and interaction across levels and timescales, requires changes in traditional views of the functions and roles of theory, hypothesis, data, and analysis" (p.200). What type of data can be collected and what type of measurements can be made in a complex system in which everything is connected and changing? Importantly, the authors argue that variability is part of a system's behaviour and that traditional statistical approaches cannot be used. Changes of variability are important indicators of a system's state. Furthermore, they point out that complex sytems consist of a number of nested systems that interact and operate on different timescales, which needs to be considered in the analysis as well. Among other things, the authors suggest to include context as part of a system under investigation, to avoid reductionism, to take a complexity view of reciprocal causality, and to identify collective variables. Computer simulations have shown great promise in research on dynamic systems.

VI. CONCLUSION

DST has been successfully applied in the language domain; thus, it may also enhance our understanding of musical development. Most importantly, DST may act as an overarching theory of language and music development and be particularly useful in explaining the emergence of syntax in both domains. However, such an approach calls for a dramatic shift in the choice of research designs, methodologies and statistical methods. Intense interdisciplinary collaboration between linguists, musicologists, psychologists, neuroscientists and computer scientists will probably be the only way to increase our understanding of language *and* music development.

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