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Time takes time to pass; considerations about neuro-motor development and early intervention

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Chapter 1:

INTRODUCTION

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Introduction

Development (in general) is a dynamic process of improvement, which implies a change, an evolution, growth and advancement (Skeldon 1997). This is a global definition on development. Human and more specific child development is described as a multifaceted, integral, and continual process of change in which children become able to handle ever more complex levels of moving, thinking, feeling, and relating to others (Inter-American Development Bank: Sustainable Development Department. 2005). However, there are still many discussions about how the process of typical development can be regarded, what happens when deviant developmental processes occur and whether or not we can influence development in an organized way, like in intervention programs.

A theory of development attempts to describe the emergence of process and eventually novelty. For example, the development could be described in which people were finally able to build complex computers and international virtual realities, while they started long ago as simple hunters using very simple tools. Development is not always straight-forward, and it often follows discontinuous switches. To adopt a development perspective, it is required to show how complexity arises from relatively simple initial conditions. However, in writing a thesis such requirement is clearly much too ambitious. For instance, it is still unknown how life arises from matter (organic structures arise from inorganic structures). Inorganic structure develops according to the rules of the entropy: the degree of consistency (complexity) inevitably decreases over time, whereas life displays the inverse (neg-entropy). In living, on every scale systems complexity

increases during development. This can be seen in the development of species (evolution, or phylogenesis, from a amoeba to a complex mammal was a long evolutionary way to go), on the scale of the development of the individual (ontogenesis, from fetus to adulthood), in the development of knowledge (from lance to computer), in social development (from nomads to a multicultural society), etc.

This thesis is in the field of the developmental neurology. In adopting a development perspective it is important that development is not put between brackets. This sounds trivial, but it is not. Everyone will understand that it makes no sense to assume that an amoeba already possesses the complexity of for instance the human cortex as a potential developmental outcome, and that only a mechanism of selection, given the appropriate context, constitutes the difference between amoeba and human cortex. Whereas it can be of immense value to study the relation between a control parameter (like a deviation in the DNA structure) and a more or less stable ontogenetic outcome, for instance a disease like schizophrenia, such relation does not yet make up a developmental theory. That is, assuming that there exists a blueprint (a genetic construction plan) for reaching or complex motor activity, does not yet depict the developmental dimension. Whenever a blueprint theory is presented as a developmental theory, it does in fact put development off-side. This thesis calls attention to the developmental perspective, because exactly such a perspective distinguishes developmental neurology (and also developmental psychology) from neurology and psychology. For that purpose it is argued that in developmental sciences, the central focus should be on the developmental processes itself.

This thesis is about human and child development, more specific motor-development and in particular neuro-motor development in infants

during the first half year of life. In this introduction chapter considerations about human development and in more detail motor-development are described from a theoretical point of view. To understand experimental data about typical and deviant development, a theoretical framework is needed. Without such framework, data would be just *data*, and of course it could be transformed by ordering to *information*, for instance about whether or not a child develops within the range of typical development. However, without a theoretical framework, this information could not be transformed to scientific *knowledge* about development, intervention, in case of deviant development. Without such framework, the information (ordered data) about typical or deviant outcomes would just lead to speculation or wild guesses, because it is not known how and why the processes flow the way they do.

This chapter is the only chapter in the thesis which aims at describing the global theory or description of development that may be useful and in fact is used in the other chapters to interpret the *specific* data attained in the studies reported in the other chapters of the thesis. This chapter starts from a *global* theoretical framework (top-down). In the other chapters we depart from data to find out whether or not it fits in with the specific developmental framework (bottom-up) that laid at the basis of the research design. Thus, chapters 2 to 5 are data based chapters and in chapter 6 the information derived from the research data is described in the light of the theoretical framework – frame of knowledge - of chapter 1.

This chapter starts with a short global sketch of historical views on development, next the focus is on non-linear development (Dynamical System Theory DST) and more specific the use of DST in a theory on motor-development by Gerald Edelman (1989, 2006) in his view on Brain Body Devices (BBD). For readers not interested in the theoretical

framework used in this thesis to describe motor development, it is possible to pass over the next sections and start at the outline of the thesis.

History of theories on development

At least since Aristoteles, there has been disagreement about visions of development. Ideas alternate between *nativism* (knowledge and behavioral (re)actions are assumed to be already present at birth, they just need to be unfolded) and *environmentalism* (from experience the structures are derived that are hold responsible for functional knowledge and behavior). In history, the debate has appeared in several forms with several names: nativism versus epigenism, nature versus nurture, innateness theory versus environmentalism, maturation versus learning theory, instructionism versus constructivism, etc. In the first half of the twentieth century, environmentalism became the dominant view (with the so called Pavlov reaction, 1927 and behaviorism). Departing from a functional stance, stimulus-response connections shaped by the responses consequences were assumed to write history on the functional tabula rasa of our minds.

In the second half of the twentieth century, computationalism became the dominant developmental view, stemming from the computer as a metaphor for the organism in transforming *input* (perception) into *output* (overt or covert action, doing or thinking) on basis of algorithms (software) that control the hardware (architecture). Goal directed behavior is to be computed on basis of the innate (for instance genetic) algorithms.

Chomsky (1957, 1959, 1965, 1975) was one of the pioneers in envisioning organisms as organic input-output devices, from which cognition stems, and biologists followed (see for example Goodwin 1995,

Monod 1971), for instance in envisioning traits as stemming from a specific gene (*gene for a trait*, the gene pre-forms the trait, -preformism- see the discussion between Chomsky, Monod and Piaget in Piattelli-Palmarini, 1980 a, b). Chomsky explicitly presented his theory to be a new form in the old preformistic (innateness) tradition, and he opposed his computationalism to epigenism (Chomsky 1975). Chomsky assumed an innate language organ, a language acquisition device (LAD).

In line with Chomsky's preformism, neural development was dominantly envisioned on the basis of innate faculties (hardware) in which inborn parameters only need to be set by the environment or environmental triggers (neuromaturation, Gessel 1928, for a review see Goodwin, 1995; Gottlieb, 1992). In this vision development (learning) is instructed by the genes (evolution) and triggered by the environment.

However, learning in virtue of innate systems would be based on phylogenetic instruction. According to some researchers, this vision is implausible (Gottlieb, 1992; Thelen & Smith, 1994; Goodwin, 1995). These researchers claim that instead of being transmitted by some instruction or entity, nature is constructed. Oyama (1985, 1989), for instance, defines an organisms nature as the characteristics that define an organism at a given time. She states that nature does not stem from a preexisting plan or program, and thus that an organisms nature is not genotypic but phenotypic, not static but transient. According to this view, nature and nurture are not alternative sources of form and causal power. Instead nature is the temporary outcome of the process of nurture, where nurture is defined as developmental interactions at many conceivable levels. Ontogeny defines evolution instead of the other way round; nature does depend just as deeply and profoundly on the genome as on developmental context at any other level (see also Gottlieb, 1992).

Other critics against preformation state that the question becomes what are the determinants of the assumed genetic instruction and where do they come from? The threat is the pitfall of infinite regression of causes: what determines the genetic/innate instruction that determines ontogeny, and then again, what determines these determinations? This is also called the instruction-problem (Gottlieb, 1992). For further explanation of this problem, called by many different names, I refer to Meijer (1988) *the hierarchy debate*, Keijzer (1994), *theoretical hitchhiking*, Bongaardt (1996), *the robot dilemma*, De Graaf (1999) *the learning paradox*.

Epigenesis

On the contrary of preformation (development is the simple unfolding or growth of pre-existing structures), one can find epigenesis (novel structures emerge during the course of development) (Gottlieb 2006, 2007). In the twentieth century epigenesis the mathematical theory of dynamical system (DST) became important, at first as a metaphor for epigenesis, second as a descriptive tool (see for instance Van Geert, 1994), and at last, especially in the work of Edelman, as a combination of the two, the metaphorical use and the exact use combined. In the next section, the focus is on DST in contemporary epigenesis.

Dynamical System Theory

In the twentieth century, developmentalists increasingly used concepts from DST to describe epigenetic maturity. For instance in Waddington's epigenetic landscapes, he metaphorically used the DST concept "*attractor*" and *canalization (trajectories)* to describe in which way

an organism produces the same phenotype in various different environments. In doing this, he imagined a marble rolling down a hill through a trajectory, through the grooves on the slope, coming to rest at the lowest point, the attractor (Waddington 1942, 1960; fig 1).

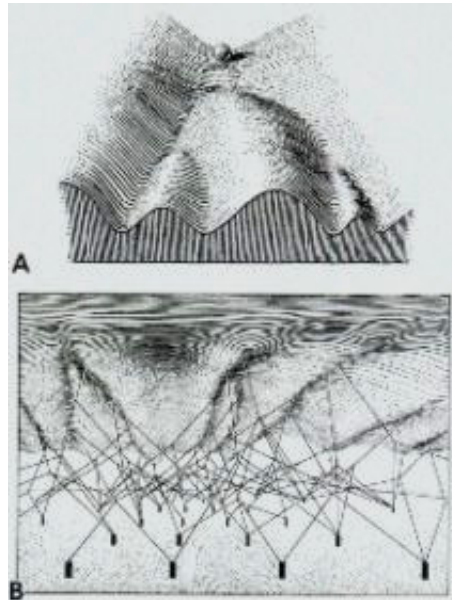


Figure 1.

Waddington's "Epigenetic Landscape" (Waddington, 1942, 1960)

Waddington used DST concepts to show that nature is the temporary outcome of developmental interactions at many conceivable levels. Interactions at many conceivable levels could change the shape and thus dynamics of the landscape. Consequently, the phenotypically altered structure could form a mal for the offspring, on which in a non-linear way, again a DST concept, the phenotypes could be directed. Waddington (1960) made use of fruitfly experiments, showing that after for instance subsequently breeding with 10 generations of environmentally altered

phenotypes (for instance subjecting embryo's to heat shocks), the new morphology (for instance an extra set of wings) came "automatically" into being, even without the environmental alterations. From this he concluded that phenotype can become genotype, and thus he pleaded for non-linear direction in evolution. In contemporary biology, as we already stated, the idea of ontogeny preceding evolution has become more commonly accepted.

In DST mathematics, an attractor is a set to which the system will evolve. For the set to be an attractor, trajectories that get close enough to the attractor must converge to the attractor (for instance a point, or a curve or a manifold). Only if a distortion is beyond a critical value, the trajectory might bifurcate to another attractor. Another feature of DST is the spontaneous creation of coherent forms (self organization), which sets in as energy is linking different levels to each other in which novel macroscopic and microscopic structures support each other. From this novelty emerges, in which the novel state is progressive, discrete, idiosyncratic and unpredictable. In the process of self organization, the complexity of the (usually open) system increases, while it is not guided or managed by an outside source. Instead, the system is subject to internal and external constraints, shaping the attractor landscape. In this way, it challenges the classical paradigm of ever decreasing order (entropy): the flow of matter and energy allows the system to self-organize, thus exchanging entropy with the environment (see Prigogine, 1980, stating that self-organization can only occur far away from equilibrium. He calls these dissipative systems).

Besides Waddington's use of DST concepts, Gestalt psychology used the DST concept of nonlinearity metaphorically in psychology. In biology and psychology, DST is a model of self organization in which the

whole ensemble can be more (or better, something else) than the sum of the parts. For instance, a global – macroscopic - pattern can emerge from lots of microscopic interactions of the consisting parts without a specific predetermined relation (sum or any other linear relation) between the parts and the whole (fig 2).

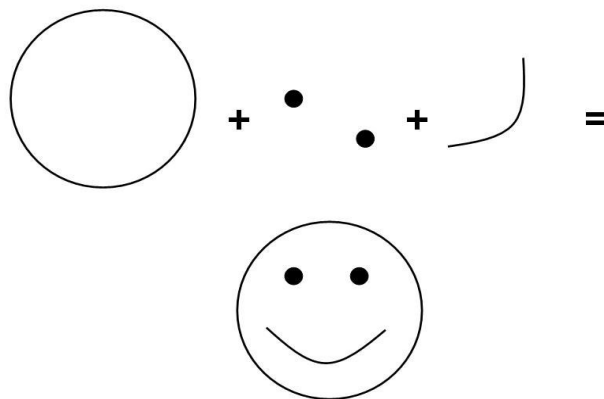


Figure 2:
Sum of parts

A dynamical system approach (DSA) has the advantage to avoid the instruction-problem; the macroscopic whole (coordination) stems from self organization of the microscopic participants in a not predetermined manner. More precisely, dynamic systems research examines skill learning over time with mathematical tools, borrowed from physics and biology, for investigating how change occurs as many elements intermingle. Essential is that in a given system a parameter, called control parameter, by change forces the system to a new equilibrium. For example, above a critical speed a horse is forced to switch from trotting to gallop. There is no phase in-between, the switch is discontinuous.

Epigenesis and orthogenesis: DST in life-sciences

In life-sciences influential names like Baldwin (1902, 1960), Waddington, Piaget (1970) and Werner (1948, 1957) adopted epigenesis. They described development rather than they used a mathematical approach. In their view learning (development) always follows certain stages.

Heinz Werner (1890-1964) born in Vienna was one of the gestalt-psychologists. Werner (1948, 1957) called the stages of development orthogenesis. Werner adopted the biological principle of orthogenesis as a process that governs development over the long term. The idea is that the direction of development is progressively flowing into increasing complexity without determination. Increasing differentiation and specification of primitive action systems that were initially fused in a global organization, that causes the emergence of action systems that are more differentiated and that begin segregated and develop to be more integrated over time, such that the more advanced systems (more differentiated, specified and internally integrated) hierarchically integrate (subordinate and regulate) the less developed systems. The differentiated microscopic elements form a new whole (macroscopy called a hierarchical integration), which is not linear determined by the sum of the parts (the differentiations that constitute the new integration).

A new hierarchical integrated ensemble can be differentiated from other such hierarchical integrated ensembles, and thus forming a new relative microscopy, from which will inevitably emerge a new macroscopy again by hierarchical integration, and so on (recursion or iteration, essential DST features). Development bootstraps in this way, forever integrating less developed systems into new more complex systems, resulting in discontinuous switches in behaviour.

Werner's theory explains why in learning a skill, learners hit plateaus in their progress, before suddenly making vast progress till a next plateau. At first differentiation occurs, collecting the elements acting together in order to reach a goal, and after quite a while, the hierarchical integration emerges. It can also explain why learners often still make progress, without practicing. For instance, after a vacation or a break in skill achievement (playing guitar, or learning morse code, or typing) from weeks to even years, often more progress emerges than in non-stop practicing. A break may be useful in getting out of a groove (an attractor), and thus in abandoning dead-end coordination's. During such break, previously-learned coordination's may get weaker, differentiate again, leaving room to be replaced by new, more serviceable hierarchical integrations.

However, the orthogenetic principle was not extrapolated to the brain. It did not describe how order developed in the brain, nor how central order or instruction in the brain emerged. Nevertheless this approach is adapted to coordinated movement, for example, by Kelso (1984). In this view coordinated movement is produced by many interacting elements with potentially many degrees of freedom, constituting a nonlinear system which can attain a certain number of dynamic states. This way rhythmic swimming motions can be described by relatively few parameters (such as frequency and amplitude), that are characterized by only a few degrees of freedom, even though many neurons, muscles, and bones may be involved in their generation. As a matter of fact, we can decide to a goal-directed movement; for example, our brain can send a command to our peripherally coordinated walking pattern, which stems from self organization as Thelen showed (Thelen 1984, 2001). It stays unclear in which way we can command our periphery patterns although our nervous system is assumed

to play a vital role in both central instruction, and peripheral coordination (automation).

Motor development: the Bernstein problem

So both peripheral coordination and central commands (instruction) are required in goal directed movement. The control of (purposeful) coordinated action encounters the degree of freedom problem. Although the human musculo-skeletal apparatus is a highly complex and nonlinear system, coordinated and controlled movements emerge. The degrees of freedom problem, addresses a redundancy phenomenon. There are many more muscles than joints, and the redundancy explodes at the neural level, signifying an excess of the degrees of freedom in order to acquire motor behaviour. At the neural – control - level, there is an enormous number of components involved in the generation and coordination of a movement. It is impossible to demand a one to one relation between distal or peripheral coordination, and central instructions. Bernstein (1935, 1967), who was one of the first to apply the orthogenetic principles in a more formal model for motor-learning, suggested the advance of synergies in the control issues raised by the excess number of degrees of freedom in motor control (called the Bernstein problem by Sporns and Edelman, 1993). The synergies in motor control enable the system to reduce the number of afferent signals and to reduce the number of efferent activities. This means that in movement control the brain has not need to specify each single muscle contraction, but can have access to neuronal representations with structured motor commands. Bernstein proposed three stages in motor learning and development. First, freezing, in learning a new skill or movement, the peripheral degrees of freedom are reduced to a minimum.

Subsequently, relaxation, as a consequence of experiment and exercise, restrictions at the periphery are increasingly lifted, until *all* degrees of freedom are incorporated. Finally, reactive forces, both *external*, working on the body (like gravity, head- or side wind, etc), and *internal*, generated by the body parts (on other body parts, on objects in the environment) are exploited, and the most efficient movements are selected. Also, control of the last and the processing of feedback become more automatic.

Edelman's solutions

Already in 1922, Garstang wrote that phylogeny is not 'a direct succession of adult forms, but a succession of ontogeny' (p. 82) and 'Ontogeny does not recapitulate Phylogeny; it creates it' (1922, p. 82). However, only recently it has become more common to acknowledge that nature is the temporary outcome of the process of nurture, where nurture is defined as developmental interactions at many conceivable levels. As we already stated, in contemporary biology/psychology it is recognized that ontogeny defines evolution instead of the other way round. Nature depends both on the genome as on developmental context at any other level (Gottlieb, 1992). Recognizing the conception of the reversed relation between evolution and ontogeny, it was Gerald Edelman with his book "Neural Darwinism" who placed the DST concept self-organization at the heart of ontogeny. As Darwin proposed a mechanism for phylogeny – selection of random mutation in function of adaptation – Edelman took a slightly adapted selection mechanism to describe ontogeny: selection of self-organization in function of adaptation. He called his ontogenetic mechanism "Neural Darwinism" (Edelman, 1987).

Edelman recognizes the importance of DST concepts: "Like selectionism, dynamical systems theory rejects instructionism and an

algorithmic treatment of learning and motor development” (Sporns and Edelman, 1993, p. 966). Moreover, he incorporates DST to a large extent in his selectionism: “(M)any basic concepts (such as the importance of nonlinear self-organizing interactions within a complex system) of these dynamical theories are consistent with selectionism” (Sporns and Edelman, 1993, p. 966). Edelman uses DST in his modeling (see for instance his equations: Wray and Edelman, 1996, the DST equations on p. 702). Edelman’s theory goes beyond DST in two ways. At first, it is explicitly based on neuroanatomy and neurophysiology and explicitly recognizes the importance of analyzing the interactions of multiple levels of organization (such as neural circuits or limb biomechanics). In particular, dynamical systems theory by itself does not identify specific neural mechanisms of developing and mature motor systems. Second, Edelman’s proposal is “to abandon the instructive or computational paradigm” (Sporns and Edelman, 1993, p. 967). Sporns and Edelman continue: “Development has nothing to do with any kind of instruction, or pre-programming”, and so they reject the computational approach. They welcome the fact that “dynamical systems theory rejects instructionism and an algorithmic treatment of learning and motor development” (p. 966). However, in DST computation still plays a major role while, according to Sporns and Edelman, “(C)ordinated movement is possible without explicit computations of desired movement paths ... there is little direct evidence that the nervous system pre-computes desired trajectories, computes comparisons between actual movements and desired ones, or uses explicit error signals to adjust individual components of the motor control system and minimize future error.” (p. 978). In this way even DST is often still implicitly deterministic. Both the outcome (behavior) is always derived by computation, and the dynamical system is a closed system (deterministic in its mathematical

nature). According to Edelman, the brain does not work like a computer. Edelman (2005, p. 8): “there has been a widespread, largely unsupported, tacit view that the brain operates like a computer”. In Edelman’s system only a *value system* is partly innate, partly acquired: “Because it has no instructional program, but works by selection upon variation, the brain of a conscious animal must relate perception to feeling and value, whether inherited or acquired. These are the constraints –feeling and value- that give direction to selection within the body and brain” (Edelman 1995, 40).

Edelman focuses on the notion of population; however, it is not the population of a species, in which some features are favoured over others and survive, but the immense, overabundant population of neurons, each with thousands of synaptic connections in the brain, resulting in what Edelman calls *neuronal maps*. These neuronal maps physically connect with maps of sensory receptor cells (of eyes, ears, etc.) and also between themselves (maps to maps) within the anatomy of the brain, a process he calls *global mapping*. The signals between maps go back and forth, constantly, in large numbers, a process that Edelman calls recursive *reentrant signaling* (Edelman, 1989, p.64). In this dynamic process some of the many connective patterns thus formed become strengthened, because they possess salience or meaning (“feeling and value”) for the individual – they work – whereas those not of value are weakened or die. It is this process, Edelman states, that in particular accounts for perceptual categorization and memory. Over many repeated movement trials those connective patterns that work are strengthened, while those that are unsuccessful are weakened. The firing patterns remain the same, what changes is their selection. The patterns that are strengthened are more likely than others to fire again. For Edelman, selection is guided by *value* imposed in the brain by the brain. What the brain possesses is not a set of

genetically acquired 'rules', but rather a *value system*, physically located in the 'old' evolutionary brain stem, which works by sending chemical signals throughout the brain, reinforcing those connections that have meaning and salience for the individual. For Edelman, memory is value-dominated and results 'from a process of continual re-categorization', on the basis of previous categorization, each time modifying previously selected neuronal groups (Edelman, 1989, p.99). Thus we have a notion of memory, and indeed of the mind, as always reinventing itself. However, the value system itself isn't static. Edelman (2000) states: "If acquired value is disabled, transfer of the value signal to stimuli preceding innately salient events does not occur, and behavioral responses due to aversive conditioning are subject to rapid extinction" and "We suggest that plasticity in sensory afferents to value systems may provide a neurobiological basis for mediating the changing effects of saliency on adaptive behavioral responses (Sporns et al. 2000, p.129). Even with respect to the value systems, Edelman's only presumed innate system; Edelman takes an epigenetic stance, exchanging innatism into creatism; instead of being determined by phylogeny, ontogeny creates it.

In the Neuronal Group Selection Theory (NGST) –Edelman recently speaks of Brain Based devices (BBD, 2006) - Edelman solves the Bernstein problem in his model by using the orthogenetic principles of differentiation and hierarchical integration at the level of the brain. NGST stresses the importance of the selection of neuronal groups into maps for the transformation of a primary movement repertoire into a set of motor synergies and adaptive action patterns.

NGST distinguishes two stages. First, primary repertoires are generated and separated, forming the basis of every new motor-task (the stage of differentiation). Second, the stage of forming the secondary

repertoires, selected from the fine-tuned maps, neuronal groups, hierarchical integrated in order to make possible rapid, redundant and effective behavior given a certain task (the automatic pilot). For that purpose (automatic pilot), the secondary maps originate, in which superfluous connections are removed. For instance, if one learns something new, one can try to extend the secondary map. However, one must often start again from the primary circuits. For example, in learning 10-finger typing, after having mastered 2-finger typing, it is better to start all over again with ten fingers, because the fast and automated secondary maps are no longer available for essential (thorough) modifications. Hence, NGST is a relative principle. Werner's orthogenetic principle can be identified in the two NGST stages: first differentiation occurs, collecting the elements acting together in order to reach a goal, and second, after quite a while, a hierarchical integration emerges.

Edelman's solution of the Bernstein problem can be explained with an example of motor learning. The primary repertoires (independent of age, dependent on the stage of skill acquisition) are the basis for Bernstein's phase of freezing all degrees of freedom. In a difficult new task to learn, for example playing the guitar, at first motor behaviour looks rigid and not adapted to the task. In holding the guitar the person seems to need a lot of strength to keep the fingers at the right place and when something goes wrong it is not predictable what is going to happen. In the errors variability (differentiation) is found. All kind of strategies are used to resolve the state of an equilibrium which fits the task. In this phase the behaviour shows the possible solutions of the brain and it reveals the 'talent' to be an excellent player or not. When all degrees of freedom have been incorporated the playing still seems rather rigid, but the player succeeds in accomplishing the task. A selection of incorporating all degrees of freedom (hierarchical

integration) has been made, but the player is solving the problem over and over again the same way, implying that according to NGST a typical pattern of neurons has been selected. Then again a phase of variation in the selection of the secondary neuronal repertoires occurs, but this time adapted to the specific situation. It stands for the phase of relaxation and reactive phenomena of Bernstein's model. During guitar playing, it is visible after the phase of selection. The guitar player masters the task, the playing looks more relaxed and when a movement is made the system lines up a selection of secondary neuronal repertoires of the learned possible next moves, or solutions when something changes in the situation, all adapted to the situation.

In Edelman's view the orthogenetic principle of differentiation and hierarchical integration in theory can go on forever, but is limited by the degrees of freedom of the biological/ psychological system in the primary and secondary neuronal repertoires and other biomechanical constraints.

Child development

As stated before, Edelman's objection to DST originates in that an exact mathematical model is used to describe development (what we called using DST as an exact descriptive tool). Mathematical equations, of course, are always deterministic. Describing development solely in terms of a mathematical dynamical system, of course, is predetermined, because of the necessity of prior knowing the algorithms, see for instance Kelso (1984) and Turvey (1977, 1990). In this way, every formal system is a closed system (entropic) and can not account for any emergence of new forms, behaviour, in child development (De Graaf 1999). In child development Thelen uses DST in a metaphorical way, showing how collective behaviour

(the macroscopic level) emerges from microscopic interactions in a non-linear way by means of self organization between microscopic components from different levels and systems, such as the nervous system, arms, vision (Thelen 2001, 2003).

In 1987, Edelman started with a brain-model, NGST, but later incorporated the whole body, rather using the more multi-component systems of Thelen (different systems on the microscopic levels). That is why Edelman converted his brain model - NGST - to a Brain Body model calling it Brain Based Devices (BBD, 2006). In fact, Edelman refers many times to Thelen's propositions with respect to child development.

Hadders-Algra (2000, 2006) applied NGST to infant motor development. She introduces the terms primary variability and secondary variability. In 2006 Hadders-Algra suggest that primary variability can only be found in General movements and establishing the primary neuronal repertoires in secondary neuronal repertoires. From already 8 weeks gestational age the fetus starts to move. These early movements are called General Movements (GM) and are spontaneous generated complex movements which involve head, trunk, arms and legs. GM wax and wane in intensity force and speed. Onset and end are gradual. The majority of extension or flexion movements of the arms and legs are complex and variable. GM continues to be common until three to four months post-term. Three phases can be distinguished. In the first phase there is abundant variation till 36-38 PMA. In the second phase the movements become more forceful and are called writhing GM. In the last phase, from 6-8 weeks post term (after birth) the GM become like an elegant dance in which much tiny movements of the trunk can be found and is called fidgety GM. GM from three to four months post term are gradually replaced by goal-directed motor behavior (Hadders-Algra 1996, 2001). Hadders-Algra (2000)

suggests that the variability found at the early stages of life, is not random. Instead, it should be caused by spontaneous activity of the epigenetic determined and mainly specified supraspinal primary neuronal repertoires. In this view, spinal activity is considered to be the starting point. This is supported by the fact that only 8 weeks after conception, the above-described GM can be found. At the moment of onset of this GM, in the spinal cord the monosynaptic circuits (the classical bow of reflex) have emerged (Prechtl 1997). Although, Edelman rejects any notion of instruction or pre-programming, Hadders-Algra (2000) states that the NGST could offer the perfect balance between the Neuro-Maturationist and Dynamic Systems theories.

Secondary variability and selection of neuronal groups in Hadders-Algra's view are found in development of goal-directed movements. Hadders-Algra (2006) states that on a macroscopic level the structure of the primary repertoires and the secondary repertoires do not differ, but that in the microscopic level of synapses, receptors and transmitters they do.

In my opinion, in NGST the spontaneously generated activity results in the exploration of many possible movement patterns not adapted to the specific situation. The observed motor behaviour is an expression of peripheral coordination not adapted to a specific task, not hindered by central order or instructions. In feedback to the CNS and randomly spontaneous activity of the supraspinal primary neuronal repertoires, new primary neuronal repertoires which can be used for central control for possible movements emerge (hierarchical integration of the primary repertoires into primary repertoires which can be used as central commands). These formed repertoires should again be called primary neuronal repertoires, because these are just repertoires in which the system 'learned' about the possible movements which can be made, but in

these repertoires no goal-directed movements are determined. Still these are the primary repertoires which are the starting point for goal directed motor-learning. Edelman (1987) states that in general for every new motor task we start with these primary repertoires. However, we can't go back to the state of the primary repertoires of GM, because redundant phenomena in the hierarchical integration and the fact that we use the same structures for both new differentiations and hierarchical integration make it impossible. The same principles can be found in language development (de Graaf-Peters 2002).

The more variability in the GM can be observed the more degrees of freedom a system possesses for motor development. Van Heijst, Touwen and Vos (1999) also label the GM as ingredients of primary variability and they also stress that rather a decrease than an increase in these patterns is to be conceived of as a predisposition of abnormal motor development. In fact, Prechtl (1990) was the first to notice that qualitative changes of spontaneous movements in fetus and preterm infant are a marker of neurological dysfunction. Definitely abnormal GM, i.e.; less variable, stereotyped, monotonous and non fluent GM are associated with a high risk (>90%) for the development of cerebral palsy and mildly abnormal GMs with minor neurological dysfunction (Hadders-Algra and Groothuis 1999, Groen et al. 2005).

Hence, in my opinion, primary variability as part of primary neuronal repertoires goes beyond GM, in fact primary variability can be found in every new learning motor task, for instance in infants in the first reaching and grasping, development of posture control, but also in adults who learn to play an instrument as described above.

In infant development the principles of NGST are nicely shown in the development of postural control. Postural control basically deals with

keeping balance, keeping the centre of mass within the support surface (Massion 1998). To acquire any goal-directed movement one also has to learn to control the postural consequences. In addition postural control is known as a complex task and children with developmental motor disorders almost always show dysfunctions in postural control (Brogren et al. 2001, van der Heide et al. 2004). In the development of postural control two functional levels are distinguished. The first level deals with direction specificity. Direction specific postural adjustments on the dorsal side of the body are found when the disturbance of balance induces a forward sway and on the ventral side of the body during a backward sway. The second level of postural control is the fine-tuning of these direction specific postural adjustments. This fine-tuning can be achieved various ways, for instance, by changing the number muscles which are part of the postural pattern, order of recruitment (cranial-caudal or vice versa), and modulation of the amplitude (Forssberg & Hirschfeld 1994). Development of postural control is characterized by variation and selection according to the NGST (Hadders-Algra 2005).

In development of postural control also first a phase of primary variability where postural activity is marked as highly variable and minimally adapted to the specific situation (Hadders-Algra 2005). The phase of selection and secondary variability starts when the second level of postural control becomes functionally around 6 months of age. Primarily, secondary variability is only found in simple ways, like selection of the complete pattern and a preference for a specific recruitment order in a specific situation, i.e.; top down recruitment order during reaching in supported sitting and bottom up recruitment order in reaching during unsupported sitting (Van der Fits 1999). From 9-10 months onwards more subtle ways of secondary variability can be found in adaptation the degree of muscle

contraction (Hadders-Algra et al. 1996). However, development of fine-tuning postural control in the phase of secondary variability first reaches an adult level of control after adolescence (Van der Heide 2003).

The advantage of NGST for research and possible implications for intervention

In the NGST it is possible to describe motor-development beyond the instruction and the Bernstein problem in a real developmental perspective. In fact Edelman (2006, p.9) states: “We have shown that studies of BBDs that operate without any programming or instruction on our part can address many different problems.” In addition, maybe more important, this theory makes it plausible that motor-development can be affected by contextual changes. In infants with a high risk on developmental motor disorders the restriction in degrees of freedom occurs somewhere within the system, for example, a lesion in the brain. As a result of a limitation in the number of degrees of freedom at the neuronal level, much more rapidly this pattern will exceed a critical mass (number) of times that the neuronal structure is exposed to it. This critical mass points at the number of times of exposure that is necessary to change the variant neuronal response to the pattern into an invariant contingent neuronal pattern. This *too soon* becoming invariant at the neuronal level will inevitably result in a *too soon* consolidation of the patterns (a loss of the ability to ‘remark’ fine-tuned variance among ‘input’ patterns because the different patterns are too soon converged into only one ‘frozen’ neuronal pattern).

At an early stage try to expand the primary repertoires by providing variation seems an option. Indeed, Hadders-Algra states (2000, p 712) ‘The

NGST advocates that intervention therapies for children with motor dysfunction at an early age should focus on the provision of variable sensorimotor experiences. The latter might be achieved by means of the application of variable postures which counteract the infants' propensity for stereotyped activity. With increasing age, the emphasis of intervention shifts to provision of ample opportunities for active practice, as this might compensate for the impaired selection. As children with brain dysfunction need more practice than their non-affected peers, it is important to reinforce the child's motivation by creating a familiar, playful setting with positive feedback.'

However, a description of the structural development of the human nervous system is important in order to interpret the *information* stemmed from research *data*, in order to come to *knowledge*. The timing of ontogenetic events in the structural development of the human nervous system is of great value in to make hypotheses about the best moment in time to start successfully with an intervention.

Outline of the thesis

In chapter 2, current data on the structural development of the human nervous system are reviewed. Focus is on the timing of ontogenetic events in the telencephalon. The development of the human brain seems to be characterized by a protracted, neatly orchestrated chain of specific ontogenetic events. The continuous changes of the nervous system have consequences for vulnerability to adverse conditions, for diagnostics and for physiotherapeutical intervention. In addition, it is crucial to describe typical development of the Central Nervous System (CNS) to know whether or not it is possible to influence development. The deviant system will tend

to develop neural networks on basis of the restricted possibilities. In therapy, it is important to capture the possibility to alter the trajectory in which neural motor development ensues. The ultimate concern is to create appropriate possibilities at the functional/behavioral level to allow the system to function on its own. Ultimately, any possibility is credited for the functional behavior, and the underlying processes from which the functional behavior stems, is of no importance. There's a problem with intervention, in that it comes from outside the system, while aiming to force changes within the system. In aiming to force motor development in another, yet contextual useful developmental trajectory, early intervention seems obvious. At the neuronal level this means that one tries to stimulate the system (tries to bring it at the edge of chaos) so that other networks are engaged and activated than those that are at usual most easy contingent on motor behavior (engaged in motor development). In this way maybe, the number of emerging motor associated patterns in the brain will be extended, resulting in development more similar to typical development. Several times, Kolb and coworkers (2001) demonstrated the possibility of an expansion of the motor cortex in reaction to for example tactile stimulation. However, Kolb et al. (2001) also reports a slightly loss of accuracy of the spatial functions after the expansion of the motor cortex. In addition, pleading for the plasticity of the brain outside the field of motor development is the fact that relatively normal language develops in the right hemisphere in children without the left hemisphere (Lenneberg 1967).

The third chapter of this thesis is about experimental studies on motor development the first half year of life. It mostly focuses on typical development and possibility to be on influence by environmental changes. Of course the main concern of pediatrics, researchers and therapists in the field of developmental neurology, is the question what the possibilities are

in case of high risk on developing motor disorders to intervene in order to elicit a more normal development, or a more successful development at the functional level, resulting in more successful motor behavior? Two major forms of developmental motor disorders can be distinguished. First cerebral palsy, which is an umbrella term for 'a group of disorders of the development of movement and posture, causing limitation in activity that are attributed to non-progressive disturbances that occurred in the developing foetal or infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, cognition, communication, perception, and/or behaviour, and/or by a seizure disorder' (Bax et al. 2005). 1 out of the 500 live-born infants develops CP. The attribution of CP to anomalies in the brain can not always be visualized by imaging techniques and although there can be found a relation between lesions of the periventricular white matter and spastic diplegia, this does not correlate precisely with the motor dysfunction (Nieman et al 1994, Krägeloh-Mann et al 1995, Okumura et al 1997). Second, developmental coordination disorder (DCD), a term denoting children who have such poor motor coordination that it affects daily activities at home and at school, but with normal intelligence and without obvious neurological pathology (American Psychiatric Association 1994). Nowadays, the prevalence of DCD is 6-13 %. In children with DCD the connection between structural abnormalities of the brain and motor dysfunction is still more ambiguous (Rutter et al 1970, Gillberg et al 1985, Kadesjö and Gillberg 1999). There is large heterogeneity in both groups. To investigate whether it is possible to be on influence on typical motor-development during the first half year of life, in chapter 3 possible influence of contextual changes, in this study by specific postural support, are studied in normal and mildly abnormal motor development in infants at early age.

Chapter 4 and 5 of this thesis focus on reaching and postural control. First normal development of postural control during the first half year of life during reaching in supine and sitting with support position is described (chapter 4). The main question in this chapter is: How progresses typical development of reaching and postural control during reaching in supine and sitting with support position during the first half year of life?

In the following chapter, as an introduction to the question whether it is possible to influence the development of postural control in infants with a high risk on developmental motor-disorders (chapter 5), Current knowledge on development of postural control in typical development and children with CP is described. In the last part of this chapter knowledge about the effect of training and intervention on EMG-parameters in development of postural control is reviewed. Also preliminary results of the Early Intervention project Groningen (VIP-project) are discussed. The aim of this project is to compare the effect of two forms of early intervention on developmental outcome in infants at high risk for developmental motor disorders such as CP (chapter 5). The interventions which were compared consisted of traditional paediatric physiotherapy and COPCA (Coping with and caring for infants with neurological dysfunction – a family centred program). The latter has been recently developed by Tineke Dirks and Mijna Hadders-Algra. The programme is based on the motor developmental principles of the Neuronal Group Selection Theory (NGST; Edelman 1989) and on new insights in the field of education and family care (Dale 1996, Rosenbaum et al. 1998).

In chapter 6 the information derived from the research data is described in the light of the theoretical framework – frame of knowledge - of chapter 1 and suggestions for ongoing research are given. It is reviewed

whether or not the (bottom-up) information derived from the chapters 2 to 5 fits in with the specific developmental framework that laid at the basis of the research design in order to transform data by ordering to *information* and eventually scientific *knowledge* about development, intervention, in case of deviant development.

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