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

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Chapter 6:

DISCUSSION

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The goal of this last chapter is to find out whether or not the findings of the previous chapters fit in with the specific developmental framework (bottom-up) that lays at the basis of the research design in order to transform data by ordering to information and eventually scientific knowledge about development and, in case of deviant development, intervention. The information derived from the research data is described in the light of the theoretical framework – frame of knowledge – presented in chapter 1 and suggestions for ongoing research are given.

Data transformed into information

In chapter 2 data is ordered into information about ontogeny of the human nervous system. By this ordering several aspects about this developmental pathway come forward. In chapter 2 we concluded that the development of the human brain is characterized by a protracted, neatly orchestrated chain of specific ontogenetic events. The continuous changes of the nervous system have consequences for the vulnerability to adverse conditions, for diagnostics and for physiotherapeutical intervention. The term “orchestrated”, however, may be a little confusing in that it seems to refer to a director and thus introducing the homunculus problem. I did not mean to refer to a specific cause, or a causing entity, it is the affordance structure of both endogenous, and exogenous events and structures – the environment of development- that shapes development through more or less specific pathways (more or less consistent between organisms of the specie). The environment consists both of endogenous and exogenous processes and developmental “results”. Environment does not solely refer to external context; RNA and proteins, for instance consist, of the relative environment of DNA.

The presence of periods with specific neuro-developmental events results in windows of specific vulnerability for adverse influences. The ontogenetic neural timetable might have consequences for the timing of early intervention. The period between 28 weeks Post Menstrual Age and 15 months postnatally seems to offer the best opportunities. The findings of chapter 2 suggest restricting intervention prior to 40-44 weeks to forms of intervention which aim at mimicking the intrauterine environment, such as proposed in the Neonatal Individualized Developmental Care and Assessment Program (NIDCAP) (Als et al 1994).

Besides the therapeutical consequences, it was derived from the data that the infant's age-specific nervous system invokes the need of an age-specific neurological assessment. That is, the application of neuromotor evaluation techniques which are adapted to the age-specific characteristics of the nervous system. In addition, the age-dependent characteristics of the nervous system affect the way in which neural dysfunction is expressed. Neurological dysfunction in adults is expressed by means of specific and localized signs, e.g., by means of the specific syndrome of a spastic hemiplegia in case of stroke. In contrast, neurological dysfunction in young infants is expressed by means of generalized and aspecific dysfunction.

The marked developmental changes of the brain have important implications for the prediction of developmental disorders at early age. The neurodevelopmental changes can induce a disappearance of dysfunctions present at early age. The reverse is also possible: children can be free from signs of dysfunction at early age, but grow into a functional deficit with increasing age due to the age-related increase in complexity of neural functions (Vohr and Carcia Coll 1985, Hadders-Algra 2002).

In summary, chapter 2 provides information and the information does not show how contextual changes will positively affect motor development. However, it offers a time-window in which intervention theoretical would have the best possible chance to be successful.

Information transformed into scientific knowledge

Typical development

Especially, chapter 4 shows that Edelman's (1987, 1989) notions about motor development can be recognized in the development of postural control. Hadders-Algra (2005) stated this before in a review about development of postural control during the first 18 months of life. Selection occurs on postural activity that is characterized by variation. The study reported in chapter 4 demonstrated that about 50% of reaching movements in lying and sitting infants aged 4 and 6 months are accompanied by direction-specific postural adjustments. At 4 months variation dominates, but at 6 months a preference to recruit muscles in a top-down order (during sitting) and in the configuration of the complete pattern (both supine and sitting position) has emerged. Interestingly, the postural characteristics were related to the success and the kinematics of reaching. The findings differ from those of the Van der Fits (1999 a, b) studies. Mainly the differences can be attributed to the more precise definition of direction-specific trials in the present study. The more precise definition resulted in substantially lower rates of direction-specificity. It is noteworthy that elongation of the transport Movement Unit (MU) correlated in particular to improved postural control, not only at 4 months but also and even more so at 6 months. As the transport MU is the part of the reaching movement which is largely determined by feedforward programming (Von Hofsten et al 1991), the finding suggests that between 4 and 6 months feedforward processes become increasingly important in the control of reaching and its associated postural adjustments (*cf* Massion 1998).

In both chapters 4 and 5 a main part is used for development of the first level of postural control; direction specificity. Hedberg et al. (2004, 2005) suggested that this basic level of control in the organisation of postural adjustments might have an innate origin. The theoretical framework of chapter 1 states that explanation by innate systems seems implausible. A different explanation derived from the data of chapter 4, literature and the theoretical framework of chapter 1 might solve this problem.

Hedberg et al (2004) evaluated postural muscle activity due to sudden perturbations in sitting position in infants from 1 month onwards. The results revealed that at the age of 1 month, direction-specific activity – defined in the same precise manner as in the study in chapter 4 - was present in 85% of the trials requesting activity of the dorsal postural muscles and in 72% of the trials requiring activity of the ventral muscles (Hedberg et al. 2004). Between 2 and 4-5 months the rate of direction-specific adjustments remained 70-85% to increase to a virtually consistent presence in infants aged at least 7-8 months (Harbourne et al. 1993, Hadders-Algra et al. 1996, Hedberg et al. 2005). However, a perturbation is a quite forceful stimulus. The postural threat during reaching while lying supine or while sitting supported is considerably less. Apparently young infants recruit direction-specific activity only in 50% of trials in this less dangerous situation.Van der Heide et al. (2003) showed that older children do use consistently direction-specific adjustments while reaching in a stable sitting position. The youngest children whom they had studied were 2 years old. This means that it is currently unclear at which age the consistent recruitment of direction-specificity emerges. Further research is needed. However, the finding that only 50% of reaching movements of young infants were accompanied by direction-specificity also indicates that direction-specificity is not a prerequisite for the generation of reaching movements.

Direction specificity is defined as the postural activity in the muscles at the dorsal side when the body sways forward and vice versa. It seems likely that this reaction occurs by the contextual forces that interact with the muscles. Indeed, Hedberg et al (2004), could not rule out that cutaneous mechanoreceptors, which are known to be extremely sensitive to direction specific stretch in combination with propioceptive information resulted in information generating the direction specific response (Olausson et al. 2000). In addition, Berger et al. (1987) showed that in infants, just able to walk, monosynaptic stretch potentials were responsible for the postural response. In fact, it was not until the age of 6 years that an adult like pattern was reached with suppression of monosynaptic stretch reflexes and an early cerebral potential during a perturbation. So, whenever a force, forceful enough, displaces an infant at early age, the muscles might react through this kind of feedback mechanism. Which muscles react depends on the vector of the displacement. It is possible that these are the first direction specific reactions Hedberg et al (2004) found.

Within the theoretical framework of chapter 1 it is possible that these reactions in feedback processes to the primary repertoires for motor commands are responsible for a hierarchic integrated pattern (selection at the supraspinal level) that counts for the selection of consistent direction specific postural activity at the age of 8-9 months, which are used later as central commands (control). It is conceivable that such patterns emerge.

Forssberg and Hirschfeld (1994) already stated that the complex pattern of fast postural adjustments at adult age are centrally generated and not simply composed of various reflexes. However, they assume a Central Pattern Generator (CPG) on the basis of postural adjustments. Nevertheless, this CPG is a same kind of computational model as the LAD (chapter 1), in which assumed inborn parameters (patterns) need to be set by the environment or environmental triggers (selections of the best strategy occurs). CPG encounters the same implausibility's as LAD (see chapter 1). The problems that computational approaches meet are nicely paraphrased by Edelman (2006, p.8): "there has been a widespread, largely unsupported, tacit view that the brain operates like a computer". With respect to modeling the brain, Edelman states that although "the computer is an essential tool for such a task; it is not an appropriate model for the brain" (p. 8). Moreover, the vision of a CPG was based on animal experiments of Macpherson (1986, 1988 a,b) and the notion that in human adults the same principals were found (Macpherson 1989). It is noteworthy that all these experiments are done with adults (cats and humans). So, it is presumable that at adult age central commands are responsible for the postural response, but this is not necessarily the case at young age and pattern-variation, like Hedberg (2004, 2005) states, is not enough prove for an innate system. Besides, other studies failed to show such an early direction specific response. Woollacott and coworkers (1987) did not find direction specific adjustments at the age 4-5 months, but in this study infants were fully supported by an infant seat. Harbourne et al (1993) found direction specificity at this age, but failed to show it at 2-3 months of age. Finally, the less dangerous situation of reaching in grasping in chapter 4 showed only direction specificity in 50% of the reaches at 4 and 6 months of age, which also indicates that direction-specificity is not a prerequisite for the generation of reaching movements. For future research I would suggest to replicate the study of Hedberg et al. (2004) and to expand the design with Cerebral Potentials (CPs), like the study of Berger et al (1987), to check the above mentioned hypotheses and to find out at which age central commands (control) are integrated in the postural response.

The postural characteristics were related to the success and the kinematics of reaching. The data indicated that - although direction-specificity turned out not to be a prerequisite for being able to reach – the presence of direction-specific activity in sitting resulted in a higher proportion of reaches which ended successfully in touching or grasping of the object. In addition, the relative duration of the transport unit was also related to other postural characteristics. At 6 months, the relative duration of the transport MU of reaching movements which were accompanied by the complete postural pattern in which all direction specific postural muscles were activated in concert, was significantly longer than that in reaching movements accompanied by other direction-specific postural patterns. Moreover, the relative duration of the transport MU was longer during reaching movements accompanied by direction-specific activity with top-down recruitment than during reaches without top-down recruitment. We stated that this was a sign that between 4 and 6 months feed-forward processes become increasingly important in the control of reaching and its associated postural adjustments.

Feed-forward denotes planned actions. This fits well with the theory about peripheral coordination's and central commands (control). Feedback mechanisms become possible as soon as relatively more *central* neural maps emerge on basis of output provided by the more *peripheral* (lower) neural systems accompanying coordinated actions (see also Edelman, 1987; neural maps which relate to exogenous activity logically precede the emergence of neural maps which have as input the output of such preceding maps, that are still interacting with the physical environment). The top down process of central control is logically impossible *until* neural maps have emerged that do not communicate in a direct way with the outside environment. In other words, as soon as peripheral coordination is displayed in such 'abstract' (feedback) neural maps, the process of central control being feed-forward processes, can be activated. The fact that in the postural 'better' trials reaches showed 'better' kinematics supports Edelman's notions about the partly innate value system, in which the feedback of these reaches are valued higher and make hierarchic integrated patterns possible. Thus, the value-system can be regarded as a feedback mechanism. Edelman's value-system is in fact a logical prerequisite in shaping development. This might be why the second level seems to be based on the basic level of direction specificity and why the study of chapter 4 shows that the more strict definition of direction specificity leads to a developmental pathway of variation leading to selection. Further research to establish these notions is needed.

Effect of intervention

The last part of this discussion focuses on possible effects on motor-development of contextual changes. In chapter 3 specific postural support, like suggested in chapter 1, affects the variability in Specific Movements (SpM); movements displayed in a repeatable and definable way. However, it is not shown whether this change in variability affects developmental outcome. So, more research is needed to establish an effect on developmental outcome of this specific pillow support.

In Edelman's notions variation in motor behaviour promotes motor-development. In General Movements (GMs) variation is known as the indication of normal movements (Hadders-Algra 2004). GMs are complex and variable movements which involve the whole body. GMs start at 8 weeks PMA and continue to be common until 4-5 months postnatal age. However, specific pillow support did not affect the quality of GMs. This finding underscores the notion that GMs are endogenously generated motor patterns, which are relatively insensitive to direct environmental influences (Prechtl 2001, Hadders-Algra 2004).

Specific pillow support, however, did affect the size of the repertoire of specific movements, in particular in infants with minor neurological dysfunction (MND) which indicates the presence of mild neurological abnormalities and/or mildly abnormal GMs. The support provided by the pillows appeared to facilitate spontaneous exploration of specific movements, which in turn seems to be associated with favourable motor development (Hadders-Algra 2000). The question why these SpM, which also must be mostly endogenously generated, are affected by specific pillow support and not the GMs, might be answered with the theoretical framework of Edelman.

GMs do not interact with the context. The SpM are interacting with the context, otherwise these movements could not be repeated in a definable way. The interaction with the context, in general the own body, might trigger a value-system, as was mentioned in Edelman's theory. According to Edelman and coworkers, "Previous studies of synthetic neural models have demonstrated the critical importance of the ability to sense environmental saliency in producing adaptive patterns of behavior. We suggested that saliency, or value, is largely but not wholly mediated by the activity of neuronal value systems. The defining characteristics of such value systems are their responsiveness to salient sensory stimuli, their anatomical projections that reach widespread areas of the brain, and their ability to modulate neural activity and/or synaptic change (Sporns et al, 2000, p.130)." So, although, the primary neuronal repertoires are derived from the GMs, in the generation of these primary neuronal repertoires the value system might not play a significant role. In the development of goal directed movements, however, the value system does play a significant role. This might be why more variability is displayed when specific pillow support is provided to the infant.

Hence, when Hadders-Algra (2006) suggests that only the phase of GMs can be considered as primary variability in NGST, she might point at the role of the value systems in motor-learning, instead of the primary and the secondary neuronal repertoires, because she also 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.

The finding that specific pillow support did not affect GMs quality but did affect the frequency and repertoire of specific movements, suggests that specific pillow support may facilitate motor behaviour first after the major neural transformation occurring at the age of 3 months (Prechtl 1984). The age of 3 months is the age at which specific movements become a prominent part of motor behaviour (Prechtl 1984). It is the age of transition in postural development (Hadders-Algra 2005) after which spontaneous motor behaviour and reaching movements become more tightly coupled to postural behaviour (Van der Fits et al 1999, Hedberg et al 2005). This in combination with the above described theory may explain why infants with MND, who in general have minor dysfunctions in postural control (Hadders-Algra 2005), may benefit from external postural support during the early developmental phases of goal directed motor behaviour. Richness in the internal degrees of freedom – a lot of variation in GMs– makes it possible to reach the goals for SpM proposed by the value system with relative ease. However, whenever the internal possibilities are restricted (infants with MND) it will be much more difficult to reach such movement goals. The aid of external support will be of more importance; restricted internal possibilities plus external aid by restricting the degrees of freedom to *miss* the goal leads to comparable success as reaching that goal given a rich enough internal general movement system (typically developing infants).

In chapter 5 the switch at 3 months of age is also mentioned. The Positron Emission Tomography studies of Chugani (1998) indicated that around the age of 3 months substantial changes occur in the distribution of metabolic activity in the brain. In newborn infants, the highest degree of glucose metabolism, which might serve as an indicator of functional activity, is found in the primary sensory and motor cortex, cingulate cortex, thalamus, brain stem, cerebellar vermis, and hippocampal region. At 2 to 3 months of age glucose utilization increases in the parietal, temporal, and primary visual cortices, basal ganglia and cerebellar hemispheres. It seems that central commands, which we coupled to feedforward processes, are becoming a part of the developmental process. Combining this with the role of the value-system and the fact that the value system might be an essential trigger for effect of intervention, 3 months of age seems to be the most proper time to start with intervention for infants with a high risk for developmental motor disorders. In addition, 3 months of age is exactly in the period of the time-window for early intervention derived from chapter 2. However, whether the effect of pillow support is also present in infants with clear neurological dysfunction and – even more important – whether daily application of pillow support would result in a more favourable neuromotor development, are pressing questions for future research.

Finally, in chapter 5 preliminary results were given of an intervention study which started at 3 months of age in infants with a high risk for developmental motor disorders. The Intervention COPCA 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). It seems the COPCA intervention increases the ability to generate direction-specific postural activity, is able to increase the repertoire of postural muscle activity and to promote situation appropriate selection out of the repertoire. On the other hand, only some preliminary results were given and it is not known whether the effect of the COPCA intervention can be replicated, neither if the effect is still present at later age. There is some other evidence that intervention affects the development of postural control in typically developing infants (Hadders-Algra et al 1996, Sveistrup and Woollacott 1997). There is also some support that balance training can improve postural control in children with CP (Shumway-Cook et al. 2003, Woollacott et al. 2005). Still, much future research is needed.

Concluding remarks

Data derived from typically developing infants fit within the framework of Edelman Brain Body Devices (BBD, NGST 1987, 1989, 2006). From movements variability selection emerges. In addition, from this point of view it is doubtful (discussible) whether or not the first level of postural control has an innate origin, at least in so far that innate is defined as a pre-determined structure or device, like the assumed central pattern generator (CPG).

Examining the data, it was suggested that feedforward processes may be regarded as instances of *central control* and the feedback mechanism stemming from *peripheral coordination*. Edelman's value systems (2003, 2006, Sporns et al 2000) could be envisioned as a feedback mechanism acting on peripheral coordination. The difference in affecting the quality of GMs and SpM seems to be based on the influence of this value system. It appears that context is a prerequisite to 'recognize' and to 'value' the movements. GMs do not interact with context, but it is assumable that the development of the GMs follow the principles of NGST; variation in movements and selection of the primary repertoires which can be used for development of goal-directed motor behaviour.

The principles of the value-system as feedback mechanism become visible in the influence of specific pillow support on SpM. The effect is more prominent after the age of 3 months. Three months of age can be regarded as an age of a major transition (Prechtl 1984, Van der Fits et al 1999, Hedberg et al 2005, Chugani 1998). It is assumable that at this age the value system starts to interact with motor-development and that it is the most promising age to start successfully with intervention. In the time window derived from biological data, three months of age is exactly which suggest that intervention should start between 28 weeks PMA and 15 months of age. However, the data suggested that intervention before 44 weeks PMA should aim at mimicking the intra-uterine environment.

The success of intervention starting at 3 months of age is supported by preliminary data of the VIP-project. It seems the COPCA intervention increases the ability to generate direction-specific postural activity, is able to increase the repertoire of postural muscle activity and to promote situation appropriate selection out of the repertoire.

However, lots of research need to be done to establish above mentioned notions.

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