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ORIGINAL ARTICLE

The Dynamic Landscape of Exceptional Language Development

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ABSTRACT

Developmental neurocognitive studies have shown that the brain systems supporting the emergence of sensory and cognitive abilities display different profiles of neuroplasticity. The research question posed here is to what extent sensory deprivation influences the dynamics of language development. The findings reported are grounded in studies with vision-impaired children with sighted peers featured as controls (age range 18 months to 3 years). Their data are matched against findings on advanced language development in blind children (age range: from 6 to 10 years; N = 12) and hearing-impaired and deaf children (age range: from 5 to 11 years; N = 20). The data give evidence that language acquisition in sensory-impaired children follows the same overall developmental path with respect to macrostructural changes and the succession of phase-shifts. System-specific temporal discrepancies expressed in protracted phase-shifts and delayed increases of variability are most evident in the early phases. Self-organizing maps (SOMs) help to visualize individual and group-specific variation. The dynamic framework used (1) shows a higher sensibility to system-specific changes, (2) enhances the informative value of the data assessed, and (3) facilitates reliable prognoses concerning the child's cognitive and linguistic future.

KEYWORDS: Neuroplasticity, sensory impairments, lexical development, growth spurts

INTRODUCTION

The contribution of visual and auditory experience has become a key issue in the emergence of language and cognitive functions and is of ultimate relevance in the now hot discussion of neural plasticity. Owing to interdisciplinary research the eminent role of specific biological support for language is beyond doubt. What is required now is teasing apart the genetic and environmental factors that interact to develop cognitive systems. This paper views the multimodal interplay from the perspective of cognitive neuroscience and dynamic systems theory (Hohenberger & Peltzer-Karpf, 2010; van Geert, 2009), taking account of the broad envelope of variability produced by sensory deficits, with special emphasis placed on vision.

The operating word in this enterprise is self-organization, which can be explained as follows: language learning draws on the interplay of genetic predispositions as well as on environmental stimuli in the form of linguistic data and extra-linguistic information. What we are faced with are recurrent growth cycles in the sense that dynamic systems change over time and can autonomously generate complexity and form. To guarantee continuity the current state is a function of previous states and the basis for future states. The driving force for individual variation is the nonlinearity of the processes involved.

PROFILES OF NEUROPLASTICITY

Extensive developmental studies have shown that the different brain systems supporting the emergence of sensory and cognitive abilities display different profiles of neuroplasticity (Bavelier & Neville, 2002; Stevens & Neville, 2009; Stiles, 2000). Concerning neural growth we find considerable differences in the degree and time periods of plasticity displayed by different subsystems within vision, hearing, and language. The cascades of rewiring and retuning the neuronal networks are guided by the development of the prefrontal cortex (PFC), which does not mature until late adolescence. Figure 1 illustrates the scaled maturation of cortical areas and neural processes known to be involved in language development.

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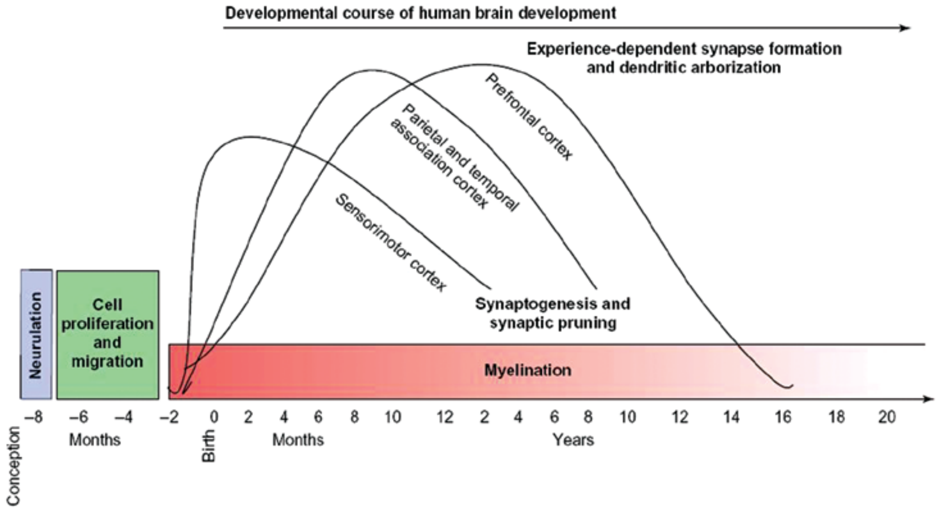

FIGURE 1 Maturational transitions in brain development (with permission of APA (American Psychological Association).

Changes in synapse formation and synaptic pruning are represented in the y-axis:

In the normal course of development the specification and stabilization of neural systems relies on dynamic processes that are based on the interaction of the given genetic toolkit, neural systems, and the input. Recent findings suggest that those aspects of neural processing and related cognitive functioning that show the greatest capability for enhancement also display the greatest susceptibility to deficits under different conditions (for details see Peltzer-Karpf, 2012; Stevens & Neville, 2009).

In the given context we shall not look at how our genes interact with the real world, but rather at how problems caused by nature can be modified by nurture. Of special interest are the alterations caused by missing or incomplete auditory and visual experience. Generally we may assume that systems with a longer developmental time course are more modifiable during development. Questions to be asked here are: How do children decipher language based upon reduced information? How do they parse and bind sensations to establish semantic categories, form grammatical rules, and organize the systems of their native language?

Multiple factors come into play in language acquisition and in the case of deficiency in one domain others seem to be able to compensate. On the functional side nature's remedy for sensory deprivation can be rapid auditory and/or visual processing. Neuropsychological studies give proof of highly differentiated auditory language processing in the primary visual cortex of blind humans (Röder et al., 2002). Compensation does, however, not work both ways. Various investigations have shown that the refractory period for rapidly presented acoustic information, which is enhanced in the blind, shows deficits in other developmental disorders (Bishop, 2003). Congenitally deaf individuals have superior motion detection in contrast to hearing individuals for peripheral stimuli (Stevens & Neville, 2009), but there is no visual compensation with regard to central, visual stimuli (Sireteanu, 1994).

DYNAMICS OF LANGUAGE DEVELOPMENT

The observation that systems do not develop simultaneously but at different times suggests system-specific differences in experience dependency. The crucial question is to what extent sensory deprivation influences the developmental cycle leading to general or system-specific delays.

The emergence of language follows two transitional stages, which can be briefed as follows: stage 1 (covering the first year) is characterized by a shift from holistic to analytic decoding and the gradual move from universal to language specific sounds (Kuhl, 2004). Stage 2 starts out with a rapid lexical increase in the prefunctional stage. The most dramatic change concerns the break into syntax around age 2 (functional stage). It is important to note that fluctuations or variability are not "errors" but rather a fundamental way for a system to test its own stability under the current circumstances.

For cross-reference we cite the succession of shifts in normal development in Table 1: (1) between 18 and 20 months a rapid lexical increase; (2) around age 2: first evidence of morphological and syntactic variants; (3) between 28 and 31 months higher syntactic mobility and productive use of morphological markers; (4) explosion

TABLE 1 Linguistic growth in sighted and vision impaired children

Linguistic spurts in comparison	Sighted	Vision impaired
Lexical spurt	1;8–1;9	2;3–2;4
Semantic & syntactic spurt	2;0	2;6
Accelerated use of morphology	2;4–2;6	2;9–2;10

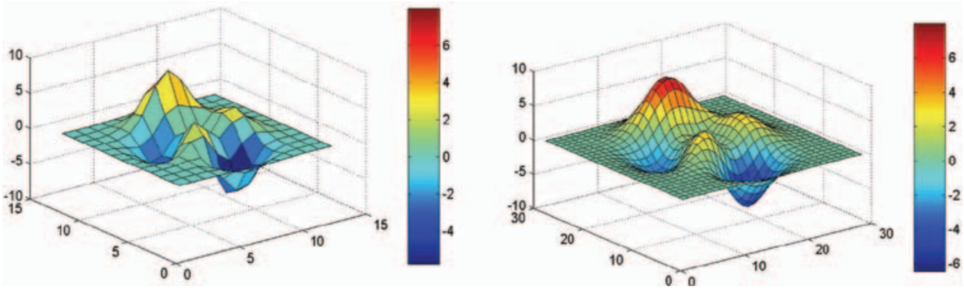

FIGURE 2 Potential landscapes of incipient and advanced linguistic growth.

of communicative intents at around 25 months (Peltzer-Karpf & Zangl, 2001).

EMPIRICAL EVIDENCE

The findings reported here are grounded on studies with vision-impaired children with sighted peers featuring as controls (age range 18 months to 3 years). Their data are matched against findings on advanced language development in blind children (age range: from 6 to 10 years; N = 12) and hearing-impaired and deaf children (age range: from 5 to 11 years; N = 20). Mismatches as to age and design are leveled by the concentration on the general principles of system dynamics. The base line is set by developmental data elicited in seeing and hearing controls. (age range: from 1;5 to 8; N = 40) (Peltzer-Karpf et al., 1994).

Data collection included spontaneous speech and picture-book sessions, communicative assessment, and cognitive tests. In addition we used offline measures of neural development. Complete transliterations of the data were coded in CHILDES/CLAN (MacWhinney,2000).

THE EFFECTS OF CONGENITAL VISUAL DEFICITS ON THE DYNAMICS OF LANGUAGE DEVELOPMENT

The early developmental cycle seems to be most vulnerable to visual deficits. The absence of lip-reading results in an extended sound sorting process and delays in phonological learning. The lack of referential looking as a precursor to lexical acquisition slows down concept formation and herewith morphological and syntactic development. To make amends for the initial delay the single-word stage is followed by a more intense lexical acceleration rate (see Hohenberger & Peltzer-Karpf, 2009; van Geert, 2009).

Morphosyntactic development in total or partial auditory loss follows the same macrostructure as in hearing children. Due to input limitations the accumulation of data requires more time, which in turn leads to longer intervals between major reorganizational processes and phase shifts. The cracking of the structural code, however, is not impeded in deficient auditory conditions—it is rather temporally delayed.

To illustrate individual variation within groups we shall now turn to the comparison of language development in 2 children whom we observed from age 1;5 to 3. Valerie is severely vision impaired; Oliver has normal sight.

Both children exhibit similar tendencies in the course of their lexical development. A dominance of nouns is followed by an increase in verbs and function words; adjectives emerge only later. A comparison of the lexical distribution of Oliver and Valerie at age 2;4/2;5 shows that the girl is around 7 months behind in her development. There are high and low producers in ordinary development, too. In general the number of words a child can say at 20 months is the best predictor of later language abilities, including the onset of grammar (see Bates & Goodman, 1999).

Differences can be seen in both quantity and quality. Oliver commands over a large variety of semantic fields and shows more differentiation in individual semantic domains. However, Valerie performs a formidable task in expanding her vocabulary at an incredible pace. What took Oliver around a year is achieved by Valerie in 6 months only.

The two trajectories are first shown in a diagram and then in potential landscapes and self-organizing maps (details in Peltzer-Karpf et al., 1999).

Designed as potential landscapes these two developmental trajectories look as follows:

Both landscapes are identical in shape but show diffrences in their meshing and coloring. Large fields represent the holistic processing of non-analyzed chunks in the initial stages. Darker colors signify progress expressed in detailed pattern processing and high flexibility.

A self-organizing map (SOM) may be the most compact way to represent changes in the clustering of data and hence in the organization of systems (Kohonen, 2001). Of particular interest is the individual time-coded development within and across groups. SOMs take a top-down view at language development, i.e., the model is focused on phenomena that can be observed such as words, sentences, and semantic and functional categories.

We used SOMs for the visualization of semantic clusters and the ensuing definition of prototypes. Generally speaking, prototypes are essential cornerstones in the organization of the lexicon that economize the lexical input and make the processing of new lexical information easier.

The results for age 2;4 years: The map for Valerie shows no ordering structure; there are neither syntactic nor semantic clusters. Nouns, verbs, and function words are scattered over the map (forming honeycombs). Oliver's map already presents some clusters (forming stripes), e.g., the noun cluster of persons (CHILDREN, MAMA), the noun cluster of objects (TRAIN, BALL); and some verb clusters that lie close to each other.

The changes observed at age 2;9 years: Oliver's map boasts a nearly closed cluster for nouns, including diverse sub-clusters, e.g., (FOOTBALL, AEROPLANE), (ANTELOPE, BEAR, MONKEY…). Good clustering can also be observed for verbs and prepositions. In sum, Oliver's SOMs show lexical clustering, which later branch into larger semantic fields, i.e., honeycombs open up into stripes. Terms belonging to the same lexical class are already grouped together. Adjacent pairs frequently consist of morphological variations of one word. Valerie's maps show the emergence of animal and object clusters. The delayed accumulation of the lexicon results in SOMs organized in honeycombs. Newly acquired items are frequently found dislocated from their semantic domain. The specimen in Figure 3 does not represent actual data but is surely more explicit than a pocket-size copy of our SOMs in all shades of gray sporting lexical clusters (for the originals see Peltzer-Karpf et al., 1999).

Summarizing, one can note that the syntactic and semantic ordering structures of our spontaneous speech samples can be made visible and coincide in principle with the assumed linguistic competence of the children. We get honeycomb patterns in the initial stage, stripes in more advanced development. Not until prototypes are established does a branching into larger semantic fields occur.

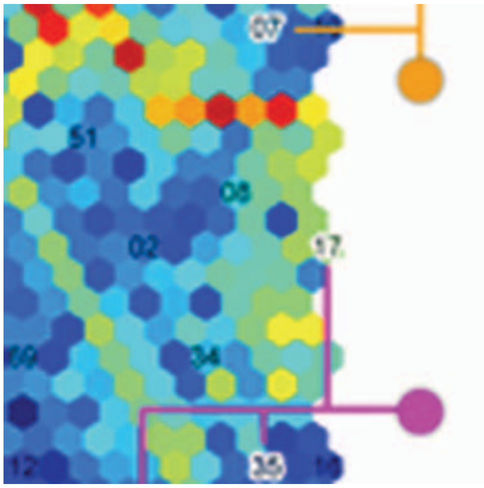

FIGURE 3 SOM illustrating initial and advanced clustering in honeycombs and stripes.

OVERALL RESULTS AND PERSPECTIVES

Language acquisition in sensory-impaired children evinces the same overall dynamics with respect to macro-structural changes allowing for system-specific temporal discrepancies (see Hockema & Smith, 2009; Smith & Thelen, 2003). The various subsystems are selectively affected resulting in more or less striking time-lags, which are most evident in the early phases. The initial lag in overall performance of the seeing-impaired children compared to their age-related seeing peers, however, seems to diminish with increasing age and maturity, resulting in increasingly homogeneous profiles both in cross-domain and cross-specific comparisons. Thus, developmental profiles shall not be age-matched but process-oriented (for developmental charts and data see Hohenberger & Peltzer-Karpf, 2009; Peltzer-Karpf, 2012; Peltzer & Zangl, 2001).

Interdisciplinary, process-oriented research opens the window for optimizing children's developmental cycle, which is most important in deficient starting conditions. It helps to apply multifaceted training programs as early and efficiently as possible and as our investigations have shown therapy can speed up development.

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