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The brain and plurilingualism

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Cette contribution présente les bases théoriques d'une recherche effectuée à Bruxelles sur le cerveau des enfants plurilingues. En s'inspirant surtout des travaux d'Edelman & Tononi (2001) et de leur théorie néo-darwinienne de la sélection de groupes neuronaux, les auteurs considèrent le cerveau comme un système dynamique, auto-organisé et «ouvert» qui, en même temps, est sélectif et adaptif. Deux groupes de sujets plurilingues sont distingués dans cette étude: les «précoces» et les «précoces retardés». Ils sont issus de familles plurilingues et de l'enseignement basé sur l'approche EMILE (Enseignement d'une Matière par Intégration d'une Langue Etrangère). La recherche expérimentale consiste à comparer ces deux groupes par le biais d'une méthode d'imagerie neuronale (résonance magnétique fonctionnelle) et des tests verbaux et arithmétiques.

1. Introduction

The following paper outlines the theoretical framework used to develop an experimental procedure investigating brain organisation and plurilingual education. At first a short overview of the bilingual brain is offered. Here we will set forward why a holistic view of the brain is maintained. In order to uphold this holistic view, a system theoretic approach is necessary. For that purpose we will set forward a theory of the brain as an open dynamic system with as its main feature qualitative change. In order to account for qualitative changes in the developing brain we will look at the theory of selectionism or Neural Darwinism. In this part the three stages of brain development will be rendered in accordance with the view on plurilingualism as a dynamic process. Qualitative change in the developing brain consists of the mechanism of reentry that will be elaborated upon in the fifth part. Afterwards, the role of plurilingual education in inducing this qualitative change is handled. Finally a quick overview of neuroimaging techniques is given with an elaboration on the design of the current experimental research project aiming at investigating what this qualitative change brings about on the overall cognitive and neurological level of plurilingual subjects.

2. The Bilingual Brain

Since the beginning of the previous century the cognitive effects of bilingualism have been explored. Until the 1960's it was argued that bilinguals

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suffered from their linguistic abilities in other fields. Improved methodologies changed this view and with the Peal & Lambert study in 1962 a new tradition in bilingual studies started. However the 'Paradox of Bilingualism' remains: language pathology has shown us that the subcomponents of two languages in one aphasic patient can be dissociated (Fabbro, 2001) while language acquisition in early bilinguals seems to occur almost effortlessly (Petitto, 2001).

It is, however, of paramount importance to account for the overall cognitive influences of bilingualism in the light of educational policy. Many such policies today still entail the possibility of negative effects of early bilingualism and therefore offer a curriculum with one dominant language and the formal instruction of a second language at much later stages. The current trend in plurilingual studies is however that bilingualism induces positive cognitive effects. As for now we will avoid the discussion on the effects bilingualism imposes but take up the argument that it must have some consequences. The key question then is how these cognitive effects affect the neurological structure of the brain. In this contribution we will use plurilingualism in stead of bilingualism as it is a more general term.

A prerequisite for ascribing plurilingualism as inducing cognitive change is to view the brain in a holistic way. This view contradicts the idea of anatomically isolated and strongly independent cognitive modules. Instead we must focus on the billions of neurons that come in all shapes and perform all sorts of functions. And although they tend to become organised in functional sets, they stay connected to a huge amount of other neurons all over the brain. These functional sets organise themselves in nuclei and layers so as to be able to perform precise tasks, but this organisation is never rigid and subject to constant fluctuation. Interconnectivity, interaction and plasticity are therefore three of the most basic descriptive features of the brain. It can thus be assumed that every activity has an influence on a thousand other activities and nothing goes by unnoticed.

Linguistic processing is highly lateralized which implies that this neurological locus preferably tackles language-specific or language-similar features. It cannot come as a surprise then that a second or third language influences the set-up considerably. Taking into account the fact the brain is an open system, every subsystem must yield some intrinsic reorganisation. Considering that a second language consists of an additional set of subsystems, a system theoretic approach for the description of its influence is needed. In the next section some basic concepts of open dynamic systems will be explained so as to be able to fit plurilingualism and the brain into the dynamic view.

3. Open Dynamic Systems

The most fundamental feature of dynamic systems is *non-linearity*. Gleick (1988, 24) provides an intelligible example explaining the difference between a linear and a non-linear system: when calculating the amount of energy needed to accelerate a hockey puck without taking into account friction, one is solving a relatively straightforward linear equation. If friction is to be included as a variable it becomes a whole different story. No absolute weight can be attached to friction because it depends on speed. But then again speed depends on friction. This interchangeability makes it almost impossible to pin down the relationships between the variables. But they all have, nevertheless, a substantial influence on the system.

The concept of non-linearity can be used to look at plurilingual proficiency as a *dynamic system*. Traditionally, two views of bilingualism are upheld. The first is the “Monolingual or Fractional View of Bilingualism” (Baker, 1996, 7) in which the bilingual is regarded as two monolinguals in one person. In other words, his or her linguistic proficiency is measured as the sum of L1 and L2. In this respect, the bilingual’s proficiency is measured against that of a native monolingual. Since the bilingual may use his/her languages in completely different domains it is fairly obvious that the monolingual will outperform the bilingual on some occasions and that the comparison is rather shaky. The holistic view of bilingualism as proposed by Grosjean (1994) is therefore a more suitable alternative that fits into the dynamic view of plurilingualism. Here plurilingual proficiency is not regarded as the sum of different language systems but as a set of dynamically interacting linguistic subsystems which do not represent a constant state but rather ongoing variation. It is in this sense that plurilingualism is a dynamic *open system* (Herdina & Jessner 2002).

A dynamic open system seems to be chaotic but comes to some point of stability through a process known as *self-organisation*. Self-organisation is the force that holds together any assembly of interplaying components in a non-linear system (Kauffman, 1995). One mechanism to self-organise is to bring about some intrinsic change to the global make-up of the system. In other words, an emergent property arises from the interacting system that would not be present if we were just to sum up the distinct elements.

The mechanism that leads to the emergent property of the dynamic open system of plurilingualism is what Herdina & Jessner (2002) refer to as *qualitative change*. In this view, plurilingualism consists of a set of language systems gathered in a dynamic open system, which will provide by means of self-organisation some sort of qualitative change. Linguistic ability, pragmatic ability, verbal memory, social ability... all make up a language system and it is exactly the multiplicative interaction of these components that makes the system dynamical.

The most important question is of course what brings about this qualitative change. The answer is feedback. Feedback provides the system with the necessary qualitative change so that it can maintain itself (Kauffman, 1995). In other words feedback is the mechanism that induces an emergent property in a system by which it can self-organise itself. Feedback can be positive or negative thus qualitative change can consist of regulation or amplification of properties of a system. We will now first look into a dynamical holistic view of the brain and determine the feedback mechanism *reentry* as described by Edelman & Tononi (2001). Afterwards we will return to plurilingualism and implement the new model in a framework of plurilingual education and plurilingualism.

4. Selectionism

The instructionist model of the brain can be compared to the way a computer works as an input – output system. Instructionism implies the idea, however, that the environment provides the kind of information needed by the processor (Gould, 1977) in the same way programmers supply the necessary guidelines for a computer to function properly. However, the brain is not provided with well-organized pre-specified information from the environment. Instead, it has to figure out for itself how to categorise and organise its 'input' and 'output'. A rigid brain theory such as instructionism is, therefore, not adequate for the description of neurological processesing. A dynamic alternative is *selectionism* or *Neural Darwinism* as proposed by Edelman and Tononi (2000).

They propose a global brain theory in which some key features applicable in a non-linear open system are also present. Three selectionist stages are proposed as the means by which the brain develops and is able to categorise perception and action without pre-defined information: (i) developmental selection, (ii) experiental selection, and (iii) reentry.

Developmental selection is the first stage in which mostly physiological and anatomical processes induce an organisation of primary networks. Mostly through cell division and cell death some connections get strengthened resulting in a *primary repertoire* (Edelman & Tononi, 2001). This primary repertoire consists of a highly diverse set of circuits that are, however, not fully functionally specified and operational. For this purpose a second selection of pathways, induced experience, strengthens or prunes the previous ones.

Experiental selection occurs mainly by changes in the strength of synaptic populations. In other words, the connection strength of some synapses is reinforced while others are weakened so that certain circuits established in the primary repertoire persist and others disappear. This yields a secondary repertoire. As a result we have now some well established circuits interconnected to millions of other ones. This mechanism that functionally coordinates the activity of this mass of circuits and tunes up these pathways so as to perform the desired integrated role is referred to by Edelman & Tononi (2001) as reentry.

5. Reentry

With the establishment of a secondary repertoire millions of neuronal groups linked by an enormous amount of reciprocally organized connections are available to the brain. A simple feedback mechanism consisting of a single fixed loop will not suffice for the integration of those circuits. What is needed is a feedback mechanism able to operate across multiple parallel pathways where information is not pre-specified.

> Reentry is the process of ongoing parallel and recursive signalling between separate brain maps along massively parallel anatomical connections most of which are reciprocal. (Edelman & Tononi, 2001, 48)

What the process actually does is continuously adapt the activities of the neuronal groups so that it is coordinated in space and time. Reentry not only alters the activity of neuronal groups but is also altered by them. We have here a clear instance of non-linearity, where the components of the open system change and are changed by other components by means of their interaction. By establishing short-term temporal correlations among the activity of distant neuronal groups it performs its most basic function as an integrative mechanism.

In the selectionist view, we can account for the brain as an open dynamic system. Developmental and experiental selection are the processes that build neuronal groups as specific functional groups. Primary and secondary repertoires are nevertheless flexible units, fluctuating over time and space. The main mechanism that ensures self-organisation of the system is reentry, which in itself is a function of primary and secondary repertoire. It assures the integration of the activity of the neuronal groups by establishing short-term correlations among them.

Now that we have established the brain model, we need to apply it to plurilingualism and brain research. First, we will try to establish its usefullness of the model to the issue of plurilingual education. Second, both issues are connected again when discussing the current research project and neuroimaging techniques.

6. Plurilingual Education

We have described reentry as a function of primary and secondary repertoire. Where primary repertoire is mainly established through developmental physiological and anatomical processes, experience plays a predominant role in establishing secondary repertoire. This feature accounts for the uniqueness of each brain, since no two human beings have the same experiences. Obviously, experience in this context is not only a question of quantity but also of quality. The secondary repertoire consists of the neural pathways developed in the primary repertoire, experience in using those pathways, the frequency of use, and also the cognitive workload of the neural pathways determine its value. The heavier the cognitive workload the more important the manipulation of those pathways will be.

At this point pluriilingual education comes into play. In a plurilingual environment, pupils will engage in more diverse and challenging language behaviour and as a result will have more language experience than pupils interacting in a monolingual environment. Given a school context, the cognitive demand on manipulation of the languages will be high. As a result we can say that using the CLIL method (Content and Language Integrated Learning), whereby part of the curriculum is taught in another language than the mother tongue, language experience will not only increase quantitatively but also qualitatively. Reentry is increased in plurilingual education and in accordance to theory, the feedback mechanism reentry will induce a qualitative change. It is this qualitative change we are interested in.

A number of studies have argued that plurilingualism enhances cognitive benefits (Ben-Zeev, 1977; Diaz, 1991). In the current view, the benefits can only expand if the environment is not only plurilingual but also places high cognitive demands on subjects, as is the case in the Brussels educational scene we are working in. The most frequent cognitive improvements are divergent problem solving and metalinguistic knowledge (Bialystok, 1988). However some studies uphold the view of negative cognitive influence or no cognitive influence whatsoever due to plurilingualism (Jarvis, Danks & Merriman 1995). Therefore, it might be appropriate to consider other methodologies for this question as well. For this reason we turned to neuroimaging.

7. Neuroimaging

Neuroimaging is a recent research method appropriate for functional studies. It allows researchers to view what region of the brain is activated during a specific task. It is a non-invasive technique offering a first glimpse into a normally functioning brain. However, there are also some drawbacks. Experimental set-ups have to be devised in accordance to the technical possibilities of the machinery. Using PET scans (Positron emission tomography) and fMRI (functional Magnetic Resonance Imaging), for instance, it is impossible for the subjects to speak, since this renders artefacts in the recorded images. This, of course, rules out any study of spontaneous productive language use. Other technical difficulties exist as well but the major flaw is that, although it is quite clear what is actually measured, there is no one-to-one correlation to the actual cognitive processing. For this purpose the technique remains as yet imprecise and circumstantial (Paradis, 1999).

Nevertheless, several studies on the bilingual brain have been carried out and have enriched the knowledge as to what actually happens in the brain during specific linguistic tasks. Illes et al (1999) did an fMRI study investigating whether semantic decisions involve different regions of the frontal lobe for L1 and L2. They found that bilinguals make use of a common semantic system located mainly in the left prefrontal gyrus. In a study on the dissociation of working memory in bilinguals, Jae-Jin Kim *et al* (2002) found that, with respect to working memory, two discrete language-related functional systems can be identified in the right dorsolateral prefrontal cortex and the left temporal lobe. This suggests that phonological processing is dependent of different mechanisms for first versus second language. In an fMRI study on bilingual sentence comprehension, Hasegawa, Carpenter & Just (2001) found that, although overlapping activation occurs for L1 and L2, increase in computational demand for L2 triggers a larger activation zone within the functional network. They further examined the effect of affirmative versus negative sentences and arrived at the same conclusion with respect to computational aspects.

These three studies indicate that some general linguistic subcomponents are similar for both languages, but that language-specific functions (such as phonological encoding) are either to be found on a different location or demand a larger zone of activation within the same region. It is, however, rather difficult to compare these studies as they engaged subjects with very different language backgrounds. In the study of Iles *et al* (1999), subjects were very fluent in both languages and acquired L2 at the mean age of 12,25. Jae-Jin Kim *et al* (2002) used subjects who acquired L2 after the age of 12. The precise age of acquisition is not specified but their L2 proficiency is poor. Moreover, they are native Korean speakers who have never lived elsewhere but in Korea and have had little contact with English native speakers. The subjects of the study of Hasegawa *et al* (2001) are moderately fluent in L2 and acquired their second language at an unspecified time but after the age of 12. Although this is by no means an exhaustive list, it gives an indication of the widespread variance these studies have regarding the level of proficiency and the age of L2. As a result comparisons are hard to make.

An example of a study with early bilinguals with high proficiency in L2 is Hernandez *et al* (2001). His group did an fMRI study with subjects who learned both languages at an early time in their life and who are very fluent in both languages. They found no differences in activation in the common regions of interest. This finding can be reinforced by the conclusions of the fMRI study of Kim et al (1997) where a clear distinction concerning language representation was found between *early* and *late* bilinguals. Apparently in Broca's area native and second languages are distinctly represented while there is no or very little difference between activation in Wernicke's area for L1 and L2 for both groups of subjects. This shows that there seems to be a crucial difference in language representation between early and late bilinguals in some activation regions. However many of the fundamental questions concerning these differences still remain to be examined (cf. Paradis, 2000). It is in this light that the fMRI method is chosen to conduct a neuroimaging study of the neuro-cognitive effects of plurilingual education.

8. Research Project

Given the examples above it can be put forward that the earlier the age of acquisition and the higher the proficiency in both languages is, the less difference in activation is to be found for L1 and L2. Furthermore, the amount of activation is less if proficiency increases, since this means that the computational demand diminishes. Referring back to reentry and plurilingual education, it could be hypothesized that, due to the highly cognitively demanding environment in which L2 is acquired, namely a bilingual classroom context, subjects acquiring a second language in a plurilingual education system have a language representation in the brain similar to early bilinguals and different from late bilinguals. If this is the case, it can be hypothesized that less cognitive demand is needed for language use and that this has effects on other cognitive activities, for instance arithmetic.

Four schools in Brussels participate in the research project. Two of them have implemented a CLIL education method in the first year of the primary school. An ideal profile of the subjects was made up. In this profile three groups are distinguished: early and early late bilinguals and a monolingual control group. The early bilinguals are those that are bilingual from birth, with no explicit formal language training, while early late bilinguals are those who have become bilingual at the age of 6 through a plurilingual education programme. At the time of the test, subjects are between 7 and 9 years old. In a first phase, potential subjects are selected by means of a detailed questionnaire in order to gain a picture of their language background. After this first selection, candidates will be contacted further.

The fMRI study itself will use a research-designed test. The test will consist of parametric conditions in block design: a linguistic and an arithmetic test. Off-line the subjects will be tested on divergent problem solving strategies. Proficiency in linguistic and arithmetic skills will be controlled. The key object is to account for neuro-cognitive effects of plurilingualism in young subjects. The main hypothesis is that early late bilinguals as defined in this study, have a similar language representation as early bilinguals. Furthermore, the question as to what other cognitive influences early acquisition and high proficiency have – if any at all – will be addressed by analysing the test results of the three groups of subjects.

9. Conclusion

To avoid too rigid theories of plurilingualism and the brain, such as instructionism, we have opted here for a dynamic approach. In a systems theoretical framework, the interplay between cognitive and linguistic factors should induce a qualitative change in the brain. Moreover, the brain itself is not seen as the mere sum of unyielding component parts, but as a constantly changing entity modified by experience and workload. These two factors are provided to the learning brain by plurilingual education. Not only language experience but also cognitive workload is much enhanced in a plurilingual education setting. The exact nature of the qualitative neurological or cognitive change this will bring about is the key objective of the research project "Bilingual Language Education, its Neuro-cognitive Effect and Opportunities for Integration. Neuroscientific Research and Language Learning in a Multilingual Environment". The set-up consists of observations of pupils in CLIL method schools and others in Brussels as well as an fMRI investigation of a sample of these pupils. In general this research should contribute (i) to the understanding of the way how languages are represented in the brain and (ii) to the understanding of the added-value of plurilingual education.

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