WATCHING THE BRAIN AT WORK - AN EXPLORATORY STUDY OF EEG CHANGES DURING SIMULTANEOUS INTERPRETING (SI)

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Introduction

In 1991, an interdisciplinary research project was launched by the Institute for Neurophysiology together with the Institute of Translation and Interpretation of the University of Vienna in an attempt to study the brain mechanisms involved in simultaneous interpreting (SI). The method of choice was the EEG, which was expected to yield valuable insights into the mental processes underlying activities involving complex verbal thinking.

In this context, special thanks are due to Professor Petsche, who most generously let me benefit from his vast experience as a neurophysiologist and agreed to conduct the research at his institute, so that the project could rely on the support from his highly experienced team (including computer experts and technical assistants) and on the use of highly sophisticated hardware and software.

This paper sums up some of the relevant findings obtained so far. They have been presented at international conferences both on conference interpreting and neurophysiology and published in international journals (Petsche 1991, 1993; Petsche et al. 1993b, 1994; Kurz 1993, 1994). These first results tend to confirm the results and hypotheses of other researchers, notably from the Scuola Superiore di Lingue Moderne per Interperti e Traduttori of the University of Trieste (SSLM), regarding right-hemispheric involvement in bilinguals.

Brain and language

There is no doubt that the brain - that mass of gray and white matter inside the skull, weighing some 1,400 grams - is the organic basis of even the most complex human cognitive activities. This is clearly testified by the effects of cerebral lesions resulting from stroke or accidents - or even by temporary impairments of cerebral function under the influence of alcohol or drugs (Rohracher 1967).
The first data on brain and language were obtained from clinical studies - specifically from studies of aphasia (impairments of speech comprehension and production as a result of damage to specific cerebral regions).

The fact that language comprehension and production are linked with specific brain regions has been known for a long time. As early as 1861, the French anatomist Broca found that a lesion of the posterior part of the inferior frontal gyrus of the left hemisphere in right-handed persons causes a disturbance of speech production. In 1874, the German psychiatrist Wernicke showed that destruction of the posterior third of the superior temporal gyrus of the left hemisphere leads to a disturbance of the understanding of speech.

Numerous studies of monolingual aphasics revealed that in the majority of right-handed individuals the left hemisphere is dominant for language (Deegener 1978, Springer & Deutsch 1981, Friederici 1984, Damasio 1992). Clinical and experimental studies of polyglot aphasics, however, have yielded a far more complex picture - e.g. different types of aphasia in different languages, inability to switch to a second language, mixing of languages, or different recovery patterns for each of the languages known to the patient. (While parallel recovery is the most common pattern in polyglot aphasics, some patients recover only one of their languages, while others evidence regression of the first-returned language as the second-returned language improves.) For a comprehensive review of the literature see Fabbro & Gran 1994.

From an extensive review of the findings on polyglot aphasia, Albert & Obler (1978: 253) conclude that the cerebral laterization of bilinguals may differ from that in monolinguals in four major respects:

1. Language organization in the brain of the average bilingual may be more bilateral than that of a monolingual.
2. Patterns of cerebral dominance may be different for each language in the brain of a bilingual.
3. Different cerebral laterization for each language is influenced by many different factors, including age, manner, and modality of second language acquisition.
4. Cerebral dominance for language in the bilingual is a dynamic process, subject to variations throughout life and sensitive to environmental, especially educational, influences.

In addition to the investigations of polyglot aphasia there exists a wealth of studies on the cerebral organization for language in healthy individuals. Various authors, using such methods as finger tapping (Sussman et al. 1982, Gran & Fabbro 1988, Green et al. 1994)) and dichotic listening (Gran & Fabbro 1987, Gran & Fabbro 1988, Lambert 1989a, 1989b) have been able to demonstrate that bilingual subjects present less marked cerebral asymmetry in the representation of linguistic functions than monolingual controls and show more right-hemispheric involvement for their second language.
All mental processes are accompanied by local changes of cerebral metabolism. Metabolic changes in the cortex produce continuous electrical activity.

The German psychiatrist Hans Berger (1929) was the first to observe electrical brain activity as recorded from the cortex or from the scalp. Since pathological cerebral changes (epilepsy, tumors, etc.) are accompanied by specific patterns of electrical activity, the electroencephalogram (EEG) came to be used as a diagnostic tool, mainly for clinical purposes.

Whereas initially the emphasis was on potential-time diagrams recorded from a few electrodes, the advent of computer technology opened the door for a spatio-temporal approach, or EEG mapping.

Assuming that the spontaneous EEG is more than mere background “noise”, researchers from the University of Vienna developed a strategy for detecting mental processes hidden in the background EEG. They studied the EEG patterns accompanying different cognitive activites, such as listening to music or speech, doing mental arithmetic, silent reading, visuospatial tasks, and creative thinking (Petsche et al. 1986, 1987, 1988, 1992, 1993a, 1994; Petsche & Rappelsberger 1992; Petsche 1990a, 1990b, 1991). Despite considerable interindividual differences (e.g., sex differences) characteristic EEG patterns emerged, suggesting certain common processing strategies underlying each of these tasks.

The past decade of research in neuroscience has been dominated by the concept of the neuronal network - the idea that every location of the brain may be connected to every other location and that the functioning of the whole largely depends upon the harmonious interaction of all these locations. Thus, when investigating brain mechanisms involved in a certain task, researchers try to determine not only which brain area produces the most prominent changes (involvement) but also to what extent it collaborates with other regions (connectivity).

Both aims, the determination of involvement and connectivity, can be approached by means of coherence analysis, which will be briefly described in the following.

“Coherence” indicates the degree of electrical coupling or functional relatedness between two brain regions at any instant. It can range anywhere between 0 and 1. A coherence of 0 between two electrodes means that there is no relation between the electrical activity of these two cerebral regions; a coherence value of 1 indicates that the two regions are operating in sync. (Fig. 1)
Thus, the determination of the coherences between different cerebral regions over a certain period of time and for a specific frequency gives us an idea as to which cerebral regions are involved to what extent in specific cognitive processes. Local coherence is computed between adjacent electrodes, and interhemispheric coherence between electrodes in corresponding regions of the two hemispheres.

The coherences found during cognitive tasks are compared to those found at rest, and the differences between them are calculated to determine their significance. This process yields so-called EEG probability maps - schematic brain maps which reflect the degree of probability for the coupling/decoupling of different cerebral regions during specific mental/cognitive operations.

Coherence changes during SI

Method

EEG mapping was used to clarify such issues as:
1. differences between simultaneous interpreting and other cognitive tasks,
2. interindividual processing mutualities and differences during SI,
3. which areas are most involved during SI,
4. which interhemispheric relationships are associated,
5. the lateralization of speech dominance.

The following experimental design was chosen:

Periods of at-rest EEG activity (1 minute each) and simultaneous interpreting (4 minutes) from the native language (German in cases # 1, 2 and 4, English in
case # 3) into the foreign languages (English in cases # 1 - 4, plus French in case # 3 and Russian in case # 4) and vice versa alternated. In subjects # 1 and 2 shadowing in German (ShG) and English (ShE) was also studied for 4 minutes each. In addition to the language tasks, all subjects were given two non-verbal control tasks: 1 minute each of listening to a Mozart quartet (MO) and doing mental arithmetic (M.A.).

The texts to be interpreted were tape recordings of actual presentations at international conferences dealing with political and economic topics. The vocabularies fell within the range of general knowledge and did not require any special preparation.

Simultaneous interpreting was performed “mentally”, i.e. without actually speaking, in order to avoid speech musculature artifacts in the EEG. One might argue that this created a somewhat artificial situation. It should be pointed out, however, that the purpose of the study was to investigate the cognitive processes involved in SI, irrespective of articulation or motor components. (Besides, a control experiment involving actual speaking yielded virtually identical results.)

The EEG was recorded from 19 electrodes glued to the scalp (10/20 placement system) with the averages from linked ear lobe electrodes as reference, to obtain a survey of the entire skull (Fig. 2).

![10/20 system of electrode placement](from: Petsche et al. 1994)

For data reduction, the EEG spectrum was divided into five frequency bands: theta (4-7 Hz), alpha (8-12 Hz), beta 1 (13-18 Hz), beta 2 (19- 24 Hz), and beta 3 (25-32 Hz).

The topographic charts of the coherence changes observed at each electrode reveal the major areas of connectivity.
A detailed discussion of the method is given in Rappelsberger & Petsche 1988 and Petsche et al. 1993b.

Results

In the following, the major results of four case studies involving conference interpreters will be discussed. For a detailed description the reader is referred to Kurz 1992 (case # 1), Petsche et al. 1993b (cases # 1 - 3) and Petsche et al. 1994 (case # 4).

Case # 1

The research project was started in 1991 with myself (a 47-year old female right-handed conference interpreter with a German A and an English B according to the classification of AIIC) as the first subject.

Fig. 3 Case # 1 (right-handed). Topographic distribution of significant (P<0.05) coherence increases (black squares) and decreases (empty squares) during different tasks.

Fig. 3 shows significant (P<0.05) increases (black squares) and decreases (empty squares) of coherence with respect to the averaged EEG activity at rest for the five frequency bands between 4 and 32 Hz during the following conditions: mental interpreting from English into German (E > G), German into English (G > E), mental shadowing in German (ShG) and English (ShE). In addition, the
results for two non-verbal tasks - listening to a Mozart quartet (MO) and doing mental arithmetic (MA) - are shown.

As can be seen from the topographic charts, numerous significant coherence changes - increases as well as decreases - occur during these mental tasks, both within each hemisphere and across the midline.

What is noticeable at a first glance is that all verbal tasks yield fairly similar patterns, whereas the two control tasks (listening to Mozart and mental arithmetic) clearly differ from these.

The alpha pattern (8-12 Hz) is remarkably similar for all language-related tasks (E > G, G > E, ShG, ShE). In comparison with the state of rest, coherence increases predominate across the fronto-temporal regions of both hemispheres. Colloquially speaking one might say that there is a lot of cross-talk taking place in the alpha band.

During the four language tasks, coherence increases in the beta bands, which are considered to be of particular relevance for information processing tasks, occur mainly in the left temporal region (T3). However, there are differences between E > G and G > E: during SI into English (the subject's B language) the number of these increases is larger than during simultaneous interpretation into German (the subject's native language). This may be an indication of a greater mental effort during SI into the foreign language.

Besides, there is greater involvement of the homologous right hemispheric zone (T4) during interpretation into the foreign language. This corresponds to the findings of other authors (Sussman et al. 1982, Gran & Fabbro 1988) who - using the method of finger tapping and dichotic listening - concluded that there is greater right-hemispheric involvement for the second language than for the first.

For mental shadowing the number of coherence increases is lower than during mental interpreting.

During all language-related tasks there are significant coherence decreases in the beta bands in the right hemisphere.

Case # 2

Fig. 4 shows the results for subject # 2, a 45-year old female left-handed conference interpreter who also has German as her native language and English as a B language. The topographic charts differ markedly from those obtained in case # 1.
Fig. 4  Case # 2 (left-handed). Topographic distribution of significant (P<0.05) coherence increases (black squares) and decreases (empty squares) during different tasks (from: Petsche et al. 1993b).

One major difference concerns handedness: in both instances, the foci of coherence increase are in the dominant hemisphere, i.e. the left hemisphere for subject # 1 and the right hemisphere for subject # 2.

Thus, for most of the tasks, this left-handed subject shows a maximum of coherence increases in the beta bands in the right temporal region (T4).

While subject # 1 shows progressively decreasing coherence activity in successively higher frequency bands, subject # 2 presents a mirror image: progressively increasing coherence activity in successively higher frequency bands.

As in case # 1, EEG changes during periods of interpreting are more pronounced than during shadowing.

Case # 3

Subject # 3 was a right-handed, 48-year old female interpreter with an English A, a French B and a German C. Fig. 5 shows her coherence patterns during three interpreting tasks (F > E, E > F and G > E) as well as during the two control tasks MO and M.A.
Incidence of increases and decreases of coherence with respect to EEG at rest.

**Fig. 5** Case #3 (right-handed). Topographic distribution of significant (P<0.05) coherence increases (black squares) and decreases (empty squares) during different tasks (from: Petsche et al. 1993b).

During interpretation from French into English, i.e. from the subject's B into her A language, coherence increases focus around T3 and T4 (left and right temporal regions) in the alpha band, around T3 (left temporal area) in beta 1, and around T4 (right temporal area) in beta 3.

During interpretation from German into English, i.e. from the subject's C into her A language, coherence increases in the theta to beta 1 bands are similar to those during F > E (B into A).

When the subject is interpreting from English into French (A into B), the left temporal region is again a focal point in the beta 1 and beta 3 bands. In addition, there is higher involvement of the right hemisphere during interpretation into the foreign language. (Compare case #1.)

As in the two previous cases, the control tasks (music-listening task and mental arithmetic) produce patterns that are clearly different from those found during the language-related tasks.

**Case #4**

Subject #4 was a 26-year old male interpreter with a German A, an English B and a Russian C. Four interpreting tasks (E > G, G > E, R > G, G > R) were compared with M.A. and MO.
Fig. 6 Case # 4 (right-handed). Topographic distribution of significant (P<0.05) coherence increases (black squares) and decreases (empty squares) during different tasks (from Petsche 1993).

As can be seen from Fig. 6, interpreting is associated with coherence increases in the temporal regions. During interpretation into the native language (E > G, R > G) coherence increases in the left hemisphere (T3) predominate.

Additional right-hemispheric involvement (T4) in beta 2 and beta 3 is noticeable during G > E and particularly G > R, i.e. interpretation into the subject's B language (English) and C language (Russian). Again, a tentative explanation is that these activities involve a greater mental effort.

As with subjects # 1 - 3, the distribution of focal areas during the control tasks M.A. and MO is different from that during verbal tasks.

Discussion

These initial investigations into possible reflections of verbal thinking in the EEG support previous findings obtained during other cognitive tasks.

The results obtained from these exploratory studies give rise to a number of conclusions (Petsche et al. 1993):
1. Interindividual differences in the relationships between coherence increases and decreases are striking.
2. EEG patterns arising during verbal thinking (mental interpreting and shadowing) are clearly different from patterns observed during non-verbal tasks, such as listening to music and doing mental arithmetic.

3. Information on verbal thinking can be obtained from the ongoing EEG - in particular from coherence changes.

4. The incidence of these changes tends to be higher in particular areas ("focal areas" of coherence).

5. These "focal areas" - most consistently in the temporal regions, appear to be of particular significance for the task in question.

6. The areas with the highest incidence of coherence increases tend to be located in the language-dominant hemisphere.

7. Interpreting into a foreign language tends to be associated with greater coherence increases in the temporal region of the non-dominant hemisphere.

According to Petsche and Rappelsberger (1992), localized areas of increased as well as of decreased coherences may be interpreted as "hot spots" in certain mental tasks under certain conditions. Their assumption is that most probably an increase between two recording sites points to an increasing number of synchronously activated neuronal connections between these two sites. "Focal areas" of increased coherence, therefore, seem to indicate that such places give rise to activation of neuronal coupling with several other regions. An interpretation of the functional meaning of coherence decreases is more difficult. One tentative explanation is that they may reflect reductions of cognitive work in the hemisphere less needed for the mental task in question in favour of the more active hemisphere (Petsche et al. 1993b). Indeed, the highest incidence of focal areas of decreasing coherence in the beta range was often found contralaterally to the highest incidence of decreases during verbal tasks. Cognitive psychologists speak of "resource allocation" and "automaticity" in this context (Anderson 1990). Similar processes are suggested by Gile (1985, 1990: "effort model").

Summing up briefly, it can be said that the data described above confirm the value of using computer-assisted neurophysiological measures to investigate the cortical processes during simultaneous interpreting. The findings and hypotheses of other researchers (Sussman, Gran and Fabbro) regarding right-hemispheric involvement in bilinguals, albeit obtained by completely different methods, could in part be confirmed.

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