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# Linguistic procedure in ‘awake neurosurgery’

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By means of a metaphoric introduction on the linguistic evaluation during awake neurosurgery, we show that the purpose of the procedure is total tumour removal (particularly gliomas) without causing morbidity or handicap. In-depth linguistic evaluations, mainly based on a selection of PALPA, AAT and specific “home-made” language tasks, are performed in the preoperative phase to obtain anatomoclinical correlations (functional and structural MRI results and linguistic findings). Pre-operatively, it is of utmost importance to evaluate the patient’s abilities (psychological status) to undergo an awake surgical intervention. In addition, the patient should be trained by means of a detailed scenario of instructions to make him familiar with the intra-operative procedures.

The operative linguistic evaluation is based on an individual adaptation (filter) of linguistic test results. During this evaluation, the neurosurgeon stimulates the cortex with a bipolar stimulator. An intensive cooperation between the patient, the aphasiologist and the neurosurgeon is achieved under anesthesiological control. During the procedure a second aphasiologist constructs a colour map of the results. Spontaneous speech is the proof of the pudding in this procedure.

Post-operative linguistic evaluations according to a standard protocol are repeated after one week, 6 months and 1 year and 6 months. This specific language procedure seems to offer unique opportunities to reduce the risk of permanent language impairments during an awake craniotomy in functionally important language areas. Follow-up and long-term evaluation of language functions refines the insight in the linguistic and non-linguistic sequellae.

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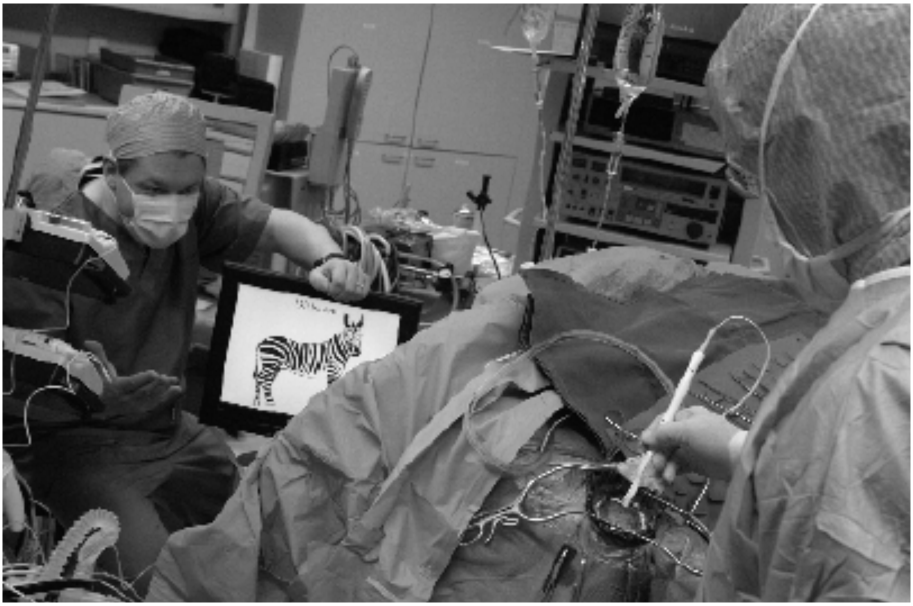

**A story about tracking down terrorists in an inaccessible mountain region “The map is not the territory” (Korzybski, 1933)**

It has never been easy to find a needle in a haystack. One could burn the hayrick, but in that case our animals would starve. The use of some sort of super magnet might give better results. For the best results are always due to a well-adapted methodology.

Until recently, a major problem in the neurosurgical resection procedure of brain tumours was “the lack of insight” in the function of the part of the brain surrounded or invaded by the tumour. So it happened that a treated patient was found partly paralysed, or left with severe communication disorders. In many respects, a neurosurgical operation was analogous to the dropping of an atomic bomb on enemy territory in the hope to kill the leader of a terrorist organisation. However, thanks to the development of visual technology, such as fMRI, it has become possible to localise functional activity (Rutten et al., 2002). However, Roux et al. (2003) demonstrated that language fMRI cannot be used to make critical surgical decisions in the absence of direct brain mapping. Illustrative is the comparison with the satellite system of the American army, used for the localisation of precision bombardments. On the one hand, the images of these satellites look terrifyingly realistic (it is said that they can zoom in to localise objects as small as a football). On the other hand, it has become evident that the destruction of the targets, based on these “realistic images”, is often not reliable. One could say that one is overshooting its mark. A brick building can indeed include the headquarters of a terrorist organisation but it also can be an improvised local school. Many innocent civilians die in this apocalypse of mass destruction. This so-called "collateral damage" could be reduced if one was able to look inside the buildings one is targeting. The dropping of "special task forces", to continue this military example, is an attempt to acquire this extra information.

The equivalent of "scouting the territory" is known as "direct electrical cortical stimulation" in the field of neuroscience. With some kind of monopolar or bipolar tools, certain parts of the cortex are electrically stimulated. This technique to map the motor- and sensory cortex was originally developed by Penfield (1937). In the seventies, the American neurosurgeon Ojemann (1979) refined the technique and started to map linguistic functions. Because cortical cells are not pain sensitive, the patient suffers no pain during the electric stimulation. By means of the patient's behavioural response to the electrical stimulation the neurosurgeon finds out which functions relate to which specific area in the cortex. It is therefore important that the patient is fully conscious and cooperative during the stimulations; he helps the surgeon with the removal of his or her own brain tumour.

It is a matter of utmost importance that the "special task forces" are perfectly well prepared for their mission. They are supposed to speak the language of the local community; they have extensive knowledge of the political, cultural and socio-economic situation of the region, the mores, the customs, the norms, etc. It is important that they have a clear view about what their mission may bring.

Similar requirements hold for the aphasiologist – a specialist in neurological language pathologies who is acquainted with the linguistic and cognitive manifestations of a brain lesion and who is able to settle anatomoclinical correlations. In other words, the aphasiologist is supposed to know where to localise different brain functions such as "naming", "repetition", "comprehension", "articulation", etc. (Ilmberger et al., 2001). Because of individual variability in the functional anatomy of the brain (and consequently in language activity and behaviour) this is not an easy thing to accomplish. The aphasiologist must therefore, in a subtle interplay with the neurosurgeon, differentiate between patients and must determine, via empirical testing, whether the assumed "standard location" of a function coincides with the location of that function in the patient's brain. It is clear that during the development of a tumour, healthy tissue is invaded and forced to functionally reorganise itself. In crisis situations (as in conflict situations) other laws apply… In the elimination of a terrorist network the question always remains whether one has eliminated the "brain" of the network or just the fundamentalist suicide killer who received his instructions from superiors.

An identical question holds during cortex stimulation: am I temporarily disconnecting merely a connection, or the "nerve centre" itself? It is an intricate problem to determine whether a certain part is *responsible for* or *involved in* a linguistic process. This crucial distinction refers to the fundamental problem of this methodology: how well can one distinguish between "responsible" and "involved" parts in a linguistic network, which cannot be mapped hierarchically (Meyer et al., 2001) ? It is clear that identification of brain tissue according to this distinction is of utmost importance during a neurosurgical intervention to spare important functional tissue from resection!

The rule holds that the true responsible must be saved from definitive elimination *at all costs*. For the destruction of "responsible tissue" leads to a definite catastrophe; a patient never being able to communicate with his or her direct environment. The target is to eliminate the maximum number of terrorists without harming the hostages.

The same difficulties hold for the removal of a brain tumour, when the neurosurgeon wishes to ***maximise*** the end result. To decide whether cortical tissue is "responsible for" or "involved in" a critical language process is an extremely difficult balancing act. From a holistic point of view, the whole brain is organized in such a way that brain tissue is always involved but never solely responsible for any function. On the other hand, it is well-known from pathology that an extremely small brain lesion can cause a global aphasia (Robert et al., 2003). Some brain areas indisputably have a full responsibility for a specific (non) linguistic function. Numerous neurosurgical publications illustrate this claim. For example, Russel et al. (2003) describe the occurrence of amusia following resection of a right Heschl gyrus glioma.

The development of intracranial visualisation by fMRI has been an important step but required to be complemented by "awake" neurosurgery with linguistic mapping. This new approach not only significantly improves quality of life, it also makes accurate interventions possible in patients that were previously considered inoperable. By determining the boundaries of functional "responsible" parts of the brain, this technique has broken the mould of "blind" resection.

## Pre-operative linguistic evaluation

As soon as a patient is diagnosed with a lesion situated in the motor or language areas, the aphasiologist will create a detailed linguistic protocol. In a first pre-operative linguistic evaluation, the degree of aphasic symptoms rather than a fall out in speech is assessed. More specifically, aphasic symptoms are looked for by using the AAT (Aachner Aphasia Test, Graetz et al., 1992) and dysarthric symptoms by using the FDA (Frenchay Dysarthria Assessment, Enderby, 1983). Handedness is always assessed by means of the standardized questionnaire EI (Edinburgh Task, Oldfield, 1971). At the same time, fMRI is performed to measure "brain activity" during certain motor or language tasks (Abutalebi et al., 2003). The neuroradiologist will indicate the proximity of a certain "function" to the tumour. In addition, it is essential that language dominance is determined (Quinones-Hinojosa et al., 2003; Bartha et al., 2004).

The aphasiologist has to investigate possible correlations between fMRI results and the patient's linguistic performances (Price, 2000). In addition, a comparison is made between these correlations and the results of the first diagnostic profile. Finally, the aphasiologist will relate all the results to his neurolinguistic knowledge of classical localisations and of cognitive neuropsychological frameworks.

At this stage, the PALPA (Psycholinguistic Assessment of Language Processing in Aphasia, Bastiaanse, et al., 1995) becomes important. Certain tasks of the PALPA are much more sensitive to detect a phonological problem than the AAT. Task 32 tests whether non-words can be repeated. In task 52 "naming" is tested in relation to low/ medium/high frequency words. The fact that one has to do an individual testing for each single patient, makes the pre-operative assessment time consuming.

For example, in the pre-operative phase, naming is assessed by a Naming Task consisting of 200 pictures combining PALPA test 52 (naming task), the Boston Naming Test (Kaplan et al., 1983) and some other not standardised items. Three days later, the task is repeated. The items the patient is unable to name after repeated presentation are left out of the series. A set of items, consisting of correctly named items is built to apply during surgery. As a result, the naming errors occurring during the surgical procedure are due to cortical stimulation and not to a pre-existing anomic deficit. By selecting the pictures (only pictures the patient can name without any problem) we try to avoid "false cues" during the stimulation. Given the fact that we are only looking for tasks that **never take longer than 4 second**s (the time of one electrical stimulation in a language paradigm; Duffau 2004), the number of suitable available tasks is limited. Time pressure is highest in specific semantic tasks. Questions such as "If Charles is older than John, who of the two is the youngest?" do not always lead to an immediate answer. As a result, many "home made tasks" have been invented to accommodate to the limited time factor.

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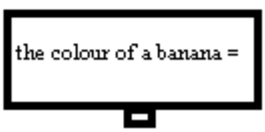

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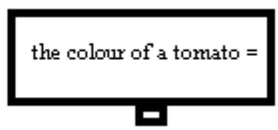

etc..

Figure 1

In addition, visual complexity has to be considered. Especially in cases of posterior localised tumours, the visual pathways may be under pressure during resection. A permanent evaluation can be done by reading aloud 4 words and ask for the odd word out (for example " eye ").

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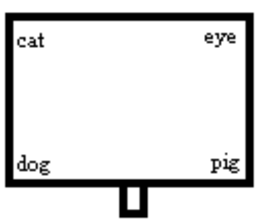
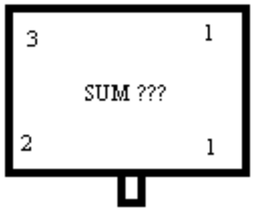


(4 seconds) etc..

Figure 2

We examine acalculia by reading aloud and asking the sum of the 4 numbers (for example "7").

Apart from a thorough linguistic evaluation based on specific tasks, insight has to be gained in the patient's premorbid communicative abilities. This is done through an

(4 seconds) 

(4 seconds) etc...

Figure 3

interview. Since the patient is awake for three hours on average during the surgical intervention, the aphasiologist must know about the patient's family, work, hobbies etc. He needs to know which painful issues not to mention, for example the recent death of a relative, or a phobia. Spontaneous speech is indeed the proof of the pudding in our procedure and the key to success for a good awake intervention. This may be the only way to assess certain aspects of language use, such as sentence production/ grammar.

It is crucial that the aphasiologist get a confidential relation with his patient and that he is able to put him at ease. This is done mainly by providing detailed information about the intervention. In our procedure, a patient is aroused by his favourite music on CD. In addition, the patient must be informed about what exactly is expected from him (i.e. the tasks he will be asked to perform) and what he is supposed to inform the aphasiologist about (e.g. sensation of pain, a tendency to vomit, a movement or tingling of the fingers, the face, the limbs, etc.)

The patient's confidence can be gained by repeating the procedure over and over again, by making him feel at ease with the tasks he will have to do – to such a degree that no surprises occur during the awake intervention. Very important is that the patient is informed about the fact that there will be several instances during the intervention that he or she will *not* be able to speak, even more, that exactly these moments of "speech arrest" are looked for. The aphasiologist makes it clear that the patient will be the guide during the awake intervention. By doing all this pre-operative preparations, the aphasiologist estimates the patient's ability to undergo the awake procedure (is there sufficient cooperation, confusion, anxiety,…) All those aspects will be presented in an interdisciplinary staff discussion.

## Intra-operative mapping

All patients undergo surgery under local anaesthesia (Huncke et al., 1998) so that cortical and subcortical mapping can be carried out using direct brain stimulations. This method, including the electrical parameters and the intra-operative clinical tasks, is described outstandingly by Duffau et al., 2002; and Duffau 2004. In our setting, a

bipolar electrode with 5 mm spaced tips delivering a biphasic current (pulse frequency of 60 Hz, single pulse phase duration of 1 ms, amplitude from 2 to 10 mA) (Ojemann Cortical Stimulator 1, Radionics*, Inc., Burlington, Mass., USA) is used.
The neurosurgeon is the conductor of the operation. In the General Hospital Sint-Lucas Ghent, the neurosurgeon Henry Colle has developed a new procedure to map functional areas (Colle et al., 2003). While he peers trough a microscope, every movement of his stimulator is projected on a screen with a "grid", enabling everyone in the operating room to see in which "square" the cortical stimulation is done. The surgeon will stimulate an area on or around the tumour. As a rule, each area is checked 3 times.

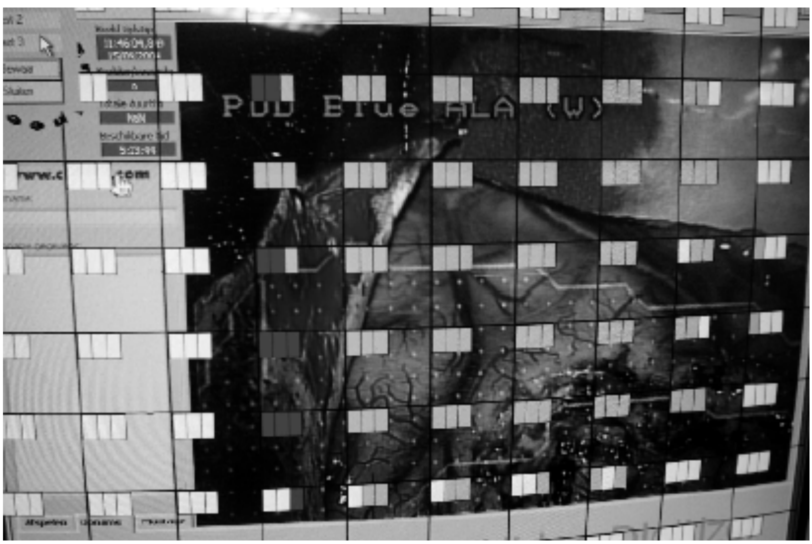
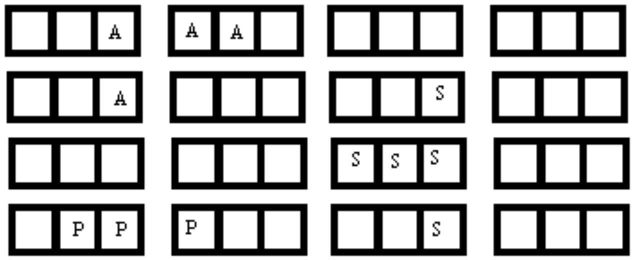


Figure 4

One of the two aphasiologists is working directly with the patient; the other aphasiologist is responsible for the colour-mapping on a computer. This mapping is at any time visible for the neurosurgeon.
This way of mapping results in a functional colour map which indicates at what place a certain function (e.g. "naming") becomes disrupted. It is also possible to write a code in the grid and to make as much grids as the linguist needs in order to have a reliable result of one specific language modality.

The main advantage of this procedure is that "marking with tickets on the brain", as described by Ojemann (1989), is redundant. During stimulation, there is constant video monitoring of the patient to visualize blocks and seizures (the neurosurgeon is able to observe the face of his patient permanently).
Based on the results of the colour mapping obtained during linguistic task perfor-




(simulation view)

**A** = anomia **S** = semantic paraphasia **P** = phonological paraphasia.

Figure 5

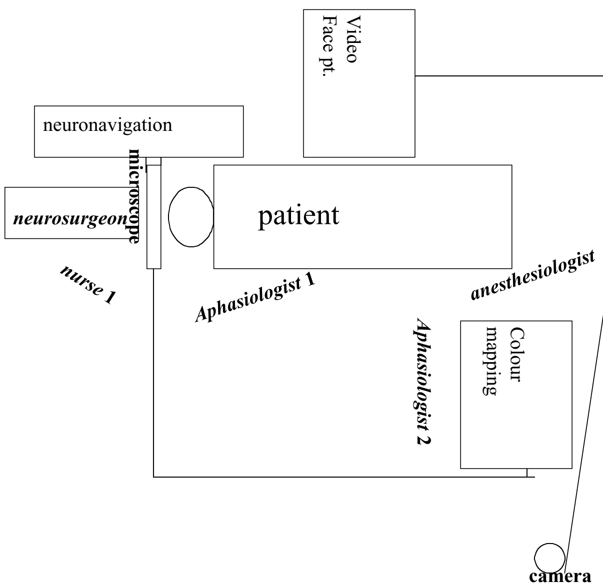



Figure 6

mances, the neurosurgeon will decide how to approach and remove the tumour. He will protect language and motor areas. The most important factor for predicting post-operative language deficits and their duration is the distance of the resection margin from the nearest language site: 1cm-safety rule (< 1 cm: more risk for longer lasting or permanent deficits) (Laaskelainen et al., 2003). Keeping the patient awake during the *subcortical* coagulation of the tumour has also great advantages.

Many linguistic pathways can be followed to the internal capsule, the arcuate fasciculus, etc.. This is the reason for keeping the patient awake for 3 hours on average. By mapping these subcortical routes, we have a better postoperative outcome on motor and language modalities (Duffau et al., 2003a). The aphasiologist his mission is to encourage the patient continuously and to provide a permanent evaluation of his or her comfort during this long awake procedure.

## Post-operative linguistic evaluation

In our setting the post-operative linguistic evaluations are started one week after surgery. This is necessary because almost all the patients are dismissed within 10 days of hospitalisation. Also, the direct postoperative problems that tend to occur transiently (Whittle et al., 2003) remain a challenge. The whole test battery is repeated to objectify the post-operative outcome. After a period of 6 months and 1 year and 6 months, the same assessments are again made. Having started this project in 2002 in Ghent, we hope to establish a formal European standard protocol for the linguistic procedures in the near future.

## Conclusion

This time-demanding (in-depth testing adapted to individual patients) and expensive (two aphasiologists and duration of the intervention) procedure has considerable advantages with regard to the patient's outcome. For the first time it has become possible to *limit* the devastating sequellae of neurosurgical interventions in functionally critical areas. As a result, the *quality of life* of a patient with a brain tumour is hereby maximally secured. However, it is important to realise that the further course of the disease will also be determined by the tumour histopathology and the patient's reaction on postoperative radio- and/or chemotherapy. A long-term analysis on the *quantitative consequences* (real life expectancy) of the procedure explained in this paper is thus necessary. Nevertheless, irrespective of the outcome, it is already becoming clear that the science of aphasiology is revolutionised by the insights of current research in the field of awake neurosurgery. The results of such an approach are very well documented by Duffau (2003b) in a consecutive series of 103 patients in low-grade gliomas located within eloquent brain regions.

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