Bilingual and multilingual language processing

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Abstract

This chapter addresses the interesting question on the neurolinguistics of bilingualism and the representation of language in the brain in bilingual and multilingual subjects. A fundamental issue is whether the cerebral representation of language in bi- and multilinguals differs from that of monolinguals, and if so, in which specific way. This is an interdisciplinary question which needs to identify and differentiate different levels involved in the neural representation of languages, such as neuroanatomical, neurofunctional, biochemical, psychological and linguistic levels. Furthermore, specific factors such as age, manner of acquisition and environmental factors seem to affect the neural representation.

We examined the question whether verbal memory processing in two unrelated languages is mediated by a common neural system or by distinct cortical areas. Subjects were Finnish–English adult multilinguals who had acquired the second language after the age of ten. They were PET-scanned whilst either encoding or retrieving word pairs in their mother tongue (Finnish) or in a foreign language (English). Within each language, subjects had to encode and retrieve four sets of 12 visually presented paired word associates which were not semantically related. Two sets consisted of highly imaginable words and the other two sets of abstract words. Presentation of pseudowords served as a reference condition. An emission scan was recorded after each intravenous administration of O-15 water. Encoding was associated with prefrontal and hippocampal activation. During memory retrieval, precuneus showed a consistent activation in both languages and for both highly imaginable and abstract words. Differential activations were found in Broca’s area and in the cerebellum as well as in the angular/supramarginal gyri according to the language used. The findings advance our understanding of the neural representation that underlies multiple language functions. Further studies are needed to elucidate the neuronal mechanisms of bi/multilingual language processing. A promising perspective for future bi/multilingual research is an integrative approach using brain imaging studies with a high spatial resolution such as fMRI, combined with techniques with a high temporal resolution, such as magnetoencephalography (MEG).

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1. Introduction: Languages and different forms of bilingualism

There is no evidence of any human groups who do not speak at least one language. At present, more than 6000 spoken languages are used in the world. Moreover, mankind has a unique ability to learn more than one language. This is thought to be mediated by functional changes in the brain.

Fabbro (1999) pointed out that all languages show two main characteristics (i) they make use of the vocal-auditory channel to produce and perceive sounds and (ii) they are organised according to the principle of double articulation or duality of patterning. The latter refers to a level of words which bear meaning and a level of phonemes limited in number.

Language use consists of the socially and cognitively determined selection of behaviours according to the goals of the speaker and the context of the situation. Since it exists in the form of several different languages, it is not surprising that some nations are officially bi- or multilingual. Well-known examples are Canada and India. Most
citizens of these countries are bilingual. Out of the European nations that are officially bi- or multilingual, Belgium, Switzerland and Finland are well-known examples. Other European countries have at least one linguistic minority whose members are, usually, bilingual. One might ask how much semantic overlap there might be between the two languages. Obviously, closely related languages (e.g. Spanish and Italian) share much semantic overlap; in contrast, unrelated languages (e.g. Finnish and English) do not have much in common. There are different forms of bilingualism. Simultaneous bilingualism refers to the learning of two languages as “first languages”. Infants who are exposed to two languages from birth will become simultaneous bilinguals. In other words, a person who is a simultaneous bilingual advanced from speaking no languages at all directly to speaking two languages. In contrast, consecutive or successive bilingualism refers to the learning of one language after already knowing another. This is the situation for all those who become bilingual as adults, as well as for many who became bilingual earlier in life. In addition, receptive bilingualism implies that a person is able to understand two languages but expresses oneself in only one language. However, this is generally not considered to fall under the category of “true” bilingualism but is a fairly common situation worth to mention.

2. Where are the roots of the Indo-European and Non-Indo-European languages?

There is no consensus on where the Indo-European languages originally came from. The origin of the Indo-European language family is “the most intensively studied, yet still most recalcitrant problem of historical linguistics” (Diamond and Bellwood, 2003).

It has been suggested that a family tree of Indo-European languages spread and split about 9000 years ago. It was argued that Kurgan (Siberian) horsemen carried them out of central Asia around 6000 years ago. However, this view was recently challenged by the work of Gray and Atkinson (2003). They analysed lists of 200 commonly used words in 87 different languages, such as “I” and “sky”. Their resulting tree matches many existing ideas about language development. For instance, Spanish and Portuguese came out as sisters and German as their cousin. Hindi was judged as a common source to all three of them but to have a more distant relationship. All other Indo-European languages split off from Hittite, the oldest recorded member of the language groups. According to Gray and Atkinson (2003) this happened between 8000 and 9500 years BP (before present).

But Gray and Atkinson (2003) make a further point. Taken archaeological evidence into account they argue that farming techniques began to spread out of Anatolia (currently Turkey). Along these lines the farmers themselves might have moved and/or natives adopted words along with agricultural technology. Radiocarbon analysis of the earliest Neolithic sites across Europe suggests that agriculture arrived in Greece at some time during the ninth millennium BP and had reached as far as Scotland by 5500 years BP. The Hittite lineage is thought to have been diverging from Proto-Indo-European around 8700 years BP, perhaps reflecting the initial migration out of Anatolia. Tocharian and the Greco-Armenian lineages are shown as distinct by 7000 years BP, with all other major groups formed by 5000 years BP. This hypothesis is consistent with recent genetic studies supporting a Neolithic, Near Eastern contribution to the European gene pool (Chikhi et al., 2002; Richards et al., 2000).

Non-Indo-European languages are classified together as those languages that do not figure as members of this stock. Written evidence of, e.g., the Turkic languages begins with the Orkhon inscriptions of the 8th century AD, found near the river Selenga in Mongoliia.

Genetic relations among Non-Indo-European languages were reported, e.g. for Finno-Ugric languages such as Finnish, Hungarian, and Estonian, Kartvelian languages such as Georgian, Abkhaz and Armenian, and Altaic languages such as Turkic and Manchu-Tungus. However, typological similarities were also observed among the linguistic structures of genetically unrelated languages such as Japanese and Turkish. Studies of geographical culture areas such as the Ancient Near East further show that culturally-linked regions share non-genetic similarities.

Casad and Palmer (2003) tried to outline the dimension of Cognitive Linguistics with respect to Non-Indo-European languages. The authors argued that “the world of non-Western languages offers a breathtaking opportunity to delve into a wide spectrum of empirical and theoretical issues, some of which are new (…) and others that have hitherto resisted satisfactory explanations constructed in other linguistics theories”.

3. Language education and bilingualism

One of the central questions concerns when and how children ought to start learning a second language. It is well known that the earlier the exposure to both languages, the easier and more complete their acquisition. In the best possible way already toddlers are confronted with two different languages during their daily life activities. Foreign language education should already start at pre-school and/or early primary school; young children display a remarkable capacity to adjust to the features of different accents. Thus, young children show a great ability to acquire new languages with ease in that they can quickly become proficient in the accent of the new language.

A controversially discussed question is whether bilingual children turn out to be cleverer than monolinguals. Peal and Lambert (1962) examined monolinguals and French/English bilinguals in Montreal. They tested the children on both verbal and non-verbal measures of intelligence and found that bilinguals had more ‘diversified structure of intelligence’ and more ‘flexibility in thought’. Bilingual children showed ‘greater cognitive flexibility’ and they
recognised the arbitrariness of words and their referents. In contrast, the recent study by Albert et al. (2002) failed to provide sufficient evidence to support the existence of a relationship between either bilingualism and critical thinking ability or between critical thinking disposition and critical thinking ability. However, the authors reported that there was sufficient evidence to support the existence of a curvilinear relationship between bilingualism and critical thinking disposition.

Bialystok (2001) showed that bilingual children develop control processes more readily than monolingual children but that the two groups progress at the same rate in the development of representational processes.

4. Speech disorders in bilinguals and the effect of aging

There is no evidence that bilinguals are more vulnerable to speech disorders, like stuttering, as compared to monolinguals. Jankelowitz and Bortz (1996) examined the relation between bilingualism and stuttering in a bilingual adult (English and Afrikaans) who stuttered. Results indicated that language ability influenced frequency, distribution and nature of disfluencies. The subject was more proficient and stuttered less in his predominant language. The difficulty stutterers might have with individual sounds was investigated by Jayaram (1983) (19 with respect to two modes of speaking (oral reading versus spontaneous speech) and two languages (English versus Kannada). Ten monolingual and ten bilingual stutterers read 16 lists of words (eight in each language). Analysis of stuttering was made with respect to a three-way classification of sounds (vowels, voiceless consonants, and voiced consonants) as well as an eight-way classification (short vowels, long vowels, voiceless stops, voiceless fricatives, voiced stops, voiced fricatives, nasals, and semivowels). Word-initial and total stuttering was analysed. Results indicated that both monolingual and bilingual stutterers were more dysfluent on voiceless consonants and especially on voiceless fricatives, when total stuttering was considered. Findings of the analysis of word-initial stuttering showed that bilingual subjects stuttered more on the nasal sounds. The results of the bilingual comparison indicated the possibility that the phonetic influences on stuttering might be dependent on the number of languages spoken by the subjects as well as the specific language in which the effects were observed.

As yet little is known about the effects of normal aging on the bilingual condition. A decline in bilingual proficiency with age has been reported. There are examples of elderly multilinguals who have maintained only certain languages. MacWhinney and Bates (1989) concluded “A life-time of multilingualism is not sufficient to guarantee maintenance of more than one language across the course of normal aging”. Balota and Duchek (1988) reported that elderly adults can compensate for a loss in processing efficiency under normal conditions with context-based strategies (‘top-down’). However, this may require attentional resources that are hard to maintain over time. Therefore there is a tendency to retreat towards a monolingual condition as a strategy for coping with the hypothetical loss in processing efficiency.

Recently Bialystok et al. (2004) investigated whether a bilingual advantage persists for adults. The authors compared the performance of monolingual and bilingual middle-aged and older adults on the Simon task. This task is based on stimulus–response compatibility and evaluates the extent to which the prepotent association to irrelevant spatial information affects the participants’ response to task-relevant non-spatial information. Results indicate that bilingual subjects showed smaller Simon effect costs for both age groups; bilingual subjects also responded faster to conditions that placed greater demands on working memory. Interestingly, the bilingual advantage was more pronounced for older participants. It was concluded that executive functioning is carried out more effectively by bilinguals and that bilingualism helps to offset age-related losses.

5. What are the neural bases of language processing in one’s mother tongue as compared to a foreign language?

5.1. Lateralisation in spoken and signed languages

For more than a century it is known that the dominant left hemisphere of the human brain is critical for producing and comprehending spoken language. Damage to perisylvian areas within the left hemisphere produces various types of aphasia, whereas damage to homologous areas within the right hemisphere does not generally produce aphasic symptoms. Furthermore, brain imaging studies confirmed that speech activation mainly occurred in the language dominant hemisphere. For instance, Borbely et al. (2003) tested the prediction that single photon emission computed tomography (SPECT) of the blood flow distribution in speech-activated brain identifies the language-dominant hemisphere. The authors compared the results of speech activation to the results of functional transcranial Doppler (fTCD) monitoring in the same subjects. Highest changes of rCBF from baseline to activation were found in the left posterior inferior frontal cortex and in the contralateral cerebellum. The evaluation of hemispheric language dominance based on SPECT showed an agreement with the evaluation based on fTCD.

Similarly, research has indicated that the left cerebral hemisphere is also critical to processing signed languages. It was found that damage to the left perisylvian areas but not to the right hemisphere lead to sign language aphasias (Bellugi et al., 1989; Corina, 1999; Hickok et al., 2001). Bellugi et al. (1989) reported that the left cerebral hemisphere in man is specialised for signed as well as spoken languages, and thus may have an innate predisposition for language, independent of language modality.

Sign languages have many structural features in common with spoken languages, though they do not use the
vocal-auditory channel (Bellugi et al., 1989). Studies of the
signed languages of deaf people have shown that fully
expressive languages can arise, outside of the mainstream
of spoken languages that exhibit the complexities of lin-
guistic organisation found in all spoken languages (Bellugi
et al., 1989). Multi-layering of linguistic elements and the
use of space in the service of syntax appear to be modal-
ity-determined aspects of signed languages. In other words,
the human capacity for language is not linked to some priv-
ileged cognitive-auditory connection. The formal proper-
ties of languages (spoken or signed) appear to be highly
conditioned by the modalities involved in their perception
and production. Analyses of patterns of breakdown of
signed languages provide new perspectives on the nature
of cerebral organisation for language.

Most interestingly, recent evidence suggests a critical
role of the right hemisphere in signed language production.
Using PET, Emmorey et al. (2002) tested deaf native sign-
ers who viewed line drawings depicting a spatial relation
between two objects (e.g., a cup on a table). Subjects were
asked either to produce a classifier construction or an
American Sign Language (ASL) preposition that described
the spatial relation or to name the figure object. Results
indicate that describing spatial relationships with classifier
constructions engaged the supramarginal gyrus (SMG)
within both hemispheres. Compared to naming objects,
naming spatial relations with ASL prepositions engaged
only the right SMG. In contrast, naming concrete objects
in either ASL or English resulted in activation in the left
inferior temporal (IT) cortex. In summary, the study makes
two major points:

1. The results suggest more right hemisphere involve-
ment when expressing spatial relations in ASL. Thus,
when expressing spatial relationships, the visuo-spa-
tial modality of signed languages has an impact on
the neural systems that underlie language production.

2. Findings indicate that the neural systems involved in
the retrieval of ASL signs denoting concrete entities
within distinct conceptual categories are remarkably
similar to those underlying the retrieval of spoken
words denoting the same types of entities. Thus, when
naming concrete entities, the neural structures that
mediate language output are the same regardless of
the mode of output, either speech or sign.

The nature of spatial language differs quite dramatically
from spatial language in spoken languages where single
closed class elements (i.e., prepositions or locative affixes)
denote spatial relations. Therefore it is not surprising to
find within this domain variation between the neural sys-
tems underlying speech and sign production.

Most recently, Sakai et al. (2005) systematically ana-
lysed comprehension of sentences and sentential non-word
detection in different groups of Japanese subjects and stim-
ulus conditions. Under the sign condition with sentence
stimuli in the Japanese Sign Language (JSL) the authors
tested two groups of volunteers: deaf signers of JSL, and
hearing bilinguals, competent of JSL and Japanese. In
the speech condition, hearing monolinguals of Japanese
were tested using auditory Japanese stimuli alone or an
audio-visual presentation of Japanese and JSL stimuli.
Results indicated across all experimental conditions a con-
sistent left-dominant activation involving frontal and
temporo-parietal regions. Activations selective to the com-
prehension of sentences were also found primarily in the
left hemisphere. The authors reported that the opercular
and triangular parts of the left inferior frontal gyrus, the
left lateral premotor cortex (Brodmann area 6), the frontal
eye fields (Brodmann area 8), and the prefrontal cortex
(Brodmann area 9) are specifically involved in grammatical
processing. The function of such a grammar centre for sign
as well as spoken language was further discussed in a recent
article by Sakai (2005).

5.2. Brain imaging of bilingual processing using functional
brain imaging and neurophysiological techniques

5.2.1. State of the art

The cerebral localisation of multiple languages is a topic
of active research. Recent studies have shown variation in
the cerebral activation in the context of processing native
and foreign languages (Dehaene et al., 1997; Kim et al.,
1997; Klein et al., 1994; Perani et al., 1996, 1998). It has
been suggested that there are differences in the cerebral
organisation of language depending on the age of acquisi-
tion and learning strategies (Neville et al., 1992, 1997;
Weber-Fox and Neville, 1996). However, it remained to a
large extent unsettled how multilingual processing takes
place in the brain.

Clinical studies on aphasic disturbances in bilingual
patients have provided information about the recovery of
the respective languages spoken by these subjects, e.g. prefer-
ential recovery of the old as contrasted with the new lan-
guage or preferential recovery of the most familiar
language (Fabbro, 1999; Paradis, 1994; Roberts and Le
Dorze, 1998). These findings suggest that there are multi-
lingual patients, who after brain lesions may become apha-
sic in only one of the languages they originally mastered.
This dissociation is supported by the results obtained with
electrical cortical stimulation: Ojemann and his associates
(Ojemann, 1991; Ojemann and Whitaker, 1978) stimulated
electrically the cortical areas of neurosurgical patients in
order to identify the speech-relevant centres. In the study
by Ojemann and Whitaker (1978) the localisation of two
languages in the lateral cortex of the dominant cerebral
hemisphere was determined by the technique of mapping
sites where electrical stimulation altered naming in two
bilingual patients' languages (patient one Dutch–English,
patient two Spanish–English). The patients had to name
45 common objects which were presented visually through
slides. It was found that sites in the centre of the language
area of each patient were involved in both languages. How-
ever, peripheral to this, in both frontal and parietal cortex,
were sites involved in only one of the languages. It was concluded that in each patient, each language in part used different areas of the brain.

Language mapping in bilingual patients undergoing cortical resection of an epileptic focus has major restrictions: The cortical organisation of language may have been affected by the effects of having a seizure focus established early in life. In contrast, adults presenting with a primary brain tumour offer a different opportunity to study bilingual cortical representation of language sites, because presumably the brain has been unaffected by epilepsy during the first decade of life. Recently, Walker et al. (2004) presented the results for 17 bilingual patients who underwent speech mapping as part of the surgical procedure to undergo tumour resection. Stimulation mapping was performed in each language by use of an object-naming task. A site was classified to be essential for naming in either language if interruption of naming occurred in at least two-thirds of the stimulations at that site. A site essential for naming was identified in the exposed cortex only for 5 of 17 patients. Two out of five patients displayed anomia in both languages, two others had anomia in only one language, and one showed anomia in one language but only hesitation of naming in the other language. The authors concluded that although no site was identified in the majority of the patients, those individuals in whom a site was identified demonstrate that bilingual patients undergoing tumour resection should be mapped for ALL languages before it is decided which cortical and subcortical areas are safe to remove. A recent study with optical imaging preceding a neurosurgical procedure (Pouratian et al., 2000) confirms that cortical language representations in bilingual persons may consist of both overlapping and distinct components.

Using functional magnetic resonance imaging (fMRI), Kim et al. (1997) reported that the mother tongue is localised in Broca’s area and each newly acquired language in anterior portions of Broca’s area. The second language tended to have a more diffuse representation in the left hemisphere than did the mother tongue (Dehaene et al., 1997). Furthermore, it has been proposed that the left supramarginal gyrus in the parietal lobe controls switching from one language to another (Price et al., 1999).

Pillai et al. (2003) studied differences in regional fMRI activation topography and lateralisation between semantic and phonological tasks performed in English and Spanish in bilingual individuals. Eight bilingual Spanish-English individuals had to perform noun-verb association and rhyming tasks in their mother tongue (Spanish) and in a foreign language (English). The authors reported significantly higher laterality indices in the semantic tasks as compared with the phonological tasks in the anterior regions of interest comprising the frontal and superior temporal lobes. A task subtraction analysis demonstrated right hemispheric (inferior frontal gyrus and supramarginal gyrus) foci of significantly increased activation in the combined language phonological tasks compared to the combined language semantic tasks. Pronounced right hemispheric activation was also seen in the English phonological-English semantic subtraction, but the analogous Spanish task subtraction revealed no task-related differences. This divergence in activation topography observed in the foreign language condition suggests that neural networks utilised for phonological and semantic language processing in the non-native language may not be as similar as those in the mother tongue.

Using fMRI Mahendra et al. (2003) examined whether partial overlap of active voxels reflects differential language localisation, or simply the variability known to occur with multiple runs of the same task. They studied two groups of bilingual subjects (early and later learners of L2) when the subjects had to perform word fluency and sentence generation tasks in both languages. They found that early bilinguals showed greater total numbers of active voxels than late bilinguals for both tasks. This effect occurred despite a lack of a behavioural performance differences by the two groups.

Sinai and Pratt (2003) recorded event related brain potentials to assess stages of linguistic processing of first (L1), second (L2) language and of pseudo words when subjects were engaged in a different task and did not attend to the words. Young adults (n = 15) were presented with pairs of auditory stimuli consisting of words and pseudowords in L1 and L2 with different voice onset times (VOT), which served as distractors in a short-term memory task. ERPs were recorded from 11 scalp electrodes. Behavioural results showed that attention was drawn to the primary task and away from the words; yet significant, including semantic, processing was evident in the ERPs to the words, with significant effects of language, meaning and priming. It was concluded that even with barely any awareness of the stimuli, the brain processes words distinguishing between L1 and L2 and relating to the stimuli’s context.

Nakamura and Kouider (2003) reviewed lesion and functional imaging studies of Japanese writing to discuss the possible differences in neural correlates that have been assumed for its two orthographic systems, kanji (logogram) and kana (syllabogram). The author concluded that frontoparietal cortical circuit linking the premotor with posterior parietal areas in the left hemisphere constitutes a basic neural substrate for the motor act of writing. It was argued that writing of kanji utilises these structures in conjunction with the left perisylvian area for spoken language. In contrast, writing of kanji shares this network for motor execution, but recruits the left basal temporal area as an additional device for the generation of motor output. Findings suggest that writing of kanji needs the retrieval of visuospatial information of characters as an additional cognitive demand.

A most interesting question is to analyse how one’s mother tongue affects the acquisition of second languages. Tan et al. (2003) studied with fMRI the neural mechanisms of reading in a second language (L2) in Chinese-English bilinguals. Chinese and English are two written languages.
with a sharp contrast in phonology and orthography. Chinese language (L1) consists of logograms, i.e., single written characters which represent a complete grammatical word as compared to alphabetic English (L2). The authors found that phonological processing of Chinese characters recruits a neural system involving left middle frontal and posterior parietal gyri, cortical regions that are known to contribute to spatial information representation, spatial working memory, and coordination of cognitive resources as a central executive system. Interestingly, when the bilingual subjects read English words, this neural system was most active, whereas brain areas mediating English monolinguals’ fine-grained phonemic analysis were only weakly activated. The authors concluded that bilingual subjects were applying their L1 strategies to L2 reading. In other words, the lack of letter-to-sound conversion rules in Chinese led Chinese readers to being less capable of processing English by recourse to an analytic reading system on which English monolinguals rely. These findings support the idea that language experience tunes the cortex.

The crucial question how the first language affects the acquisition of second languages is a rather difficult topic to investigate. A promising approach is the study by Franceschini et al. (2001) who correlated images of local brain activation during speech production and perception with the language profiles of single persons. Language profiles were obtained by means of so called language biographies. The term language biographies refers to an autobiographical oral narration, thematically focussed on experiences of the informants with his/her own languages during the course of life, directed to an interview partner (Schütze, 1987). It was reported that correlates exist between the type of acquisition (early bilingualism vs. late bilingualism including third languages) and brain activation using fMRI. Wattendorf et al. (2003a) showed that there is a critical period early in life in which exposure to one or two languages determines permanently the participation of the frontal network in language processing. It was found that an activation of the frontal network occurs in early multilinguals, but not in late multilinguals. Furthermore, the frontal activation was differently organised: Broca’s area was preferentially involved during processing of both L1 (early acquired language) and L3 (late acquired language); in contrast, the lateral prefrontal cortex and the orbitofrontal cortex showed relevant activation for the L1 condition only (Wattendorf et al., 2003b). Certainly, this kind of qualitative and inductive approach has its limitations. Nevertheless, to my knowledge, this is one of the first successful systematic approaches which aimed to bridge the gap between language biographies and brain images. Using a non-speech auditory paradigm, Wattendorf et al. (2002) found a pronounced activity in the left inferior parietal cortex and planum temporale in subjects who had been exposed to two different languages before the age of three. It was concluded that an enriched linguistic environment may lead to a modulation of processing strategies in defined cortical areas.

Mechelli et al. (2000) reported that learning a second language increases the density of grey matter in the left inferior parietal cortex of bilinguals relative to monolinguals, and that the degree of structural reorganisation in this region is modulated by the proficiency attained and the age at acquisition. The authors found that there is a more pronounced increase in early rather than late bilinguals, and that the density in this region increases with second language proficiency but decreases as the age of acquisition increases. It was suggested that early bilinguals may acquire a second language through social experience, rather than as a result of a genetic predisposition. Most recently Klein et al. (2006b) investigated the neural substrates involved in the production of a second language (French) after the age of five as compared with those brain regions involved in the repetition of the native language (English). The authors compared word and non-word repetition. Results indicate that subjects activated the left ventral premotor area under both word and non-word repetition in the second language to a greater extent than in the native language. Activation of the premotor cortex (lateral Brodmann area 6) was observed in similar locations during both word and non-word repetition. Future studies are needed to examine real-word and non-word repetition in bilingual subjects in order to disentangle the confounding effects of language-specific and language-acquisitional variables. Taken together the findings are in agreement with the hypothesis that the structure of the human brain is altered by the experience of acquiring a second language.

5.2.2. Encoding and retrieval of word pairs in multilinguals – a PET-study

In our PET-study (Halsband et al., 2002) we addressed the question whether memory processing in two languages belonging to different linguistic groups use common neural systems. We looked for shared and non-shared neural substrates in a paired-word association paradigm for such contrasting languages as Finnish and English.

We used O-15 water PET to study differences in cerebral activation patterns associated with the verbal memory processing of concrete and abstract word pairs in the native language of the subjects (Finnish) compared with a fluent foreign language (English). We tried to disentangle the neural mechanisms of encoding and retrieval in multilingual subjects who, among other languages (see below) were fluent in two widely different linguistic groups, i.e., a non-Indo-European language, Finnish and an Indo-European language, English.

Ten late Finnish-English multilinguals took part in this study. Their mother tongue was Finnish. English was acquired as a second language at school after the age of ten years. In addition to the English language all of our subjects had learnt Swedish at school. Furthermore, all but two subjects acquired a third foreign language: German, Russian or French. One subject took additional courses in Spanish. So, all of our subjects were multilinguals whereby their first and predominant foreign language
was English. In addition, our subjects reported that they were confronted with English in their daily activities (work and relaxation including music, films and television programs).

Subjects were right-handed males (age 27.3 ± 5.1 years, mean ± SD, range 22–36 years) with no known history of neurological or psychiatric illness. All but one of the subjects had undergone an MRI examination (1.5 T) of the brain, where no structural abnormalities were found. The subject, who could not take an MRI examination due to metal implants in his denture, had an unremarkable computerised tomography (CT) scan. The research project was approved by the Joint Ethical Committee of the University and University Hospital of Turku, Finland. Each subject gave informed, written consent for participation in the study according to the guide-lines of the Declaration of Helsinki.

We used a within-subject design, which meant that each subject underwent both a native language session and an English session. Subjects had to encode and retrieve four sets of 12 visually presented paired word associates. Study words were two-syllable Finnish or English words. The word pairs were semantically unrelated and, therefore, difficult to associate. “Hard” word associations (as introduced by Wechsler (1987) in his Wechsler Memory Scale, Subtest VII) were used to increase the mnemonic demands (see Fig. 1).

The stimulus words were presented on a 21" computer screen placed at a distance of about 70 cm from the eyes (Font: Times New Roman, size: 72 points). Subjects were instructed to read them aloud (duration of presentation 4 s, 1 s interval) and to learn the paired associations. In order to avoid lateralisation effects the second word was written under the first word, the letters were black on a white screen and centred. Between encoding and retrieval scans, the same word pair associates were presented in random order 1–3 times according to the number of encoding repetitions needed to retrieve at least 80% of the word pair associates. During retrieval scans, the first word of the pair was shown. The subjects had to read the first word aloud and to retrieve the associated word from memory and express it verbally. The reference task was the presentation of two-syllable non-sense words formed according to the spelling rules, but having no semantical meaning. The subjects were required to read the non-sense words aloud, but they were not requested to memorise them. The details of the experimental paradigm of paired-word association memory have been described earlier (Halsband et al., 2002).

Scanning was done on two separate days. In the first scanning session the subjects were requested to learn and to retrieve word pairs in their mother tongue; the second scanning session involved paired-word association learning in the foreign language.

Session I (Finnish): Each subject underwent twelve O-15 water PET scans. Two word pair sets consisted of highly imageable words (e.g. POLKU – small road vs. KOIRA – dog) and another two sets of abstract words (e.g. UHKA – threat vs. SUURE – unit). These words were selected on the basis of the Finnish word frequency handbook (Saikkonen et al., 1979).

Session II (English): The same subjects were scanned during the learning and retrieval of English word pairs. The technical execution of the PET scans and the principles of the experimental paradigm were the same as described above, except for the fact that the word pairs were in English. The English proficiency of the subjects was tested with an ad hoc questionnaire before starting the experimental PET sessions. The subjects had to encode and retrieve four sets of 12 English word pairs. The English words were chosen according to Paivio et al. (1966, 1968), independently of the selection of the Finnish stimulus words. In order to rule out familiarity effects, great care was taken that the same nouns were not used twice in the two different languages. For instance, if in the English condition the high frequency word “monkey” was used, the Finnish word list did not contain a noun referring to this specific animal category or a similar species (apes); instead the Finnish word list made use of the word “koira” (dog).

Scans of rCBF were obtained for each single subject using a GE Advance PET Scanner (General Motors Medical Systems, Milwaukee, Wisconsin, USA). This apparatus has been previously described (Lewellen et al., 1996). Regional cerebral blood flow (rCBF) during each cognitive task was measured by recording the distribution of radioactivity in the brain following an intravenous injection of 300 MBq of O-15-labelled water (10 ml in 10–15 s) through a forearm cannula. Twelve tasks were carried out during a three-hour session. The minimum interval between the
O-15 water injections was 10 min. As each of the twelve scans was concerned, the cognitive task began 15 s before the administration of O-15 water. Emission data were acquired in 3-dimensional mode for 90 s starting at the entry of the tracer into the brain, for which the criterion was the true coincidence rate exceeding the threshold of 15,000 counts/s. Data were framed into a single static frame of 90 s (Holm et al., 1995; Laine et al., 1994).

The data were first transformed into the ANALYSE format using a converter program especially developed for this purpose at Turku PET Centre. The actual quantitative analysis of the 90 s images was carried out with Statistical Parametric Mapping (SPM96, The Wellcome Department of Cognitive Neurology, London, UK) software (Friston et al., 1995a,b) on a SPARC 20 workstation (Sun Microsystems). Calculations were performed with Matlab version 4.2 c. Each reconstructed O-15 water scan was realigned according to the bi-commissural line into a stereotaxic space corresponding to the atlas of Talairach and Tournoux (1988) using a PET template and normalised according to Friston et al. (1995a). A Gaussian filter with a full width half maximum (15 mm) was applied to smooth each image to compensate for inter-subject noise in the images. Differences in global activity within and between subjects were removed by the analysis of covariance (ANCOVA) on a voxel by voxel basis with global counts as covariate of regional activity across subjects for each task, as inter- and intrasubject differences in global activity may obscure regional alterations in activity following cognitive stimulation. For each pixel in stereotactic space the ANCOVA generated a condition-specific, adjusted mean rCBF value (normalised to 50 ml/100 ml per min) and an associated adjusted error variance (Van den Heuvel et al., 2003). The ANCOVA allowed comparison of the means across the different conditions using t statistics. The resulting map of t values constituted a statistical parametric map (Friston et al., 1995a).

The results were analysed both using a comparison to the reference task and on the other hand, subtracting the foreign language from the mother tongue and vice versa (cognitive subtraction). Voxels were identified as significantly activated if they passed the height threshold of $Z = 3.72 \ (p < 0.0001)$ and at least belonged to a cluster of 33 activated voxels ($p < 0.05$, corrected for multiple comparisons) (Friston et al., 1994). The results were as follows:

### 5.2.2.1. High imagery word pairs: encoding

During encoding in the foreign language the prefrontal cortex (BA 10) was activated on both sides (right: $Z = 4.46$, left $Z = 3.90$), whereas the orbitofrontal cortex (BA 11) was significantly active only on the left side ($Z = 4.03$). The hippocampal formation was bilaterally activated (right: $Z = 3.44$, left: $Z = 4.50$). Furthermore, the angular/supramarginal gyrus (BA 39) was active on the left side ($Z = 3.95$) and the precuneus (BA 7) on the right side ($Z = 3.68$). Encoding high imagery word pairs in one’s mother tongue resulted in a bilateral hippocampal activation (right: $Z = 3.44$, left: $Z = 4.59$) and a predominantly right orbitofrontal activation (BA 11) ($Z = 3.80$) (see Table 1).

### 5.2.2.2. High imagery word pairs: retrieval

Both, the retrieval of word pairs in the foreign language and in one’s mother tongue resulted in bilateral increases in rCBF in the precuneus (English: BA 7: bilateral $Z = 6.35$; Finnish: BA 7: right $Z = 3.94$, left $Z = 4.84$) and in the prefrontal cortex (English: BA 10: right $Z = 6.77$, BA 10/11: left $Z = 4.54$; Finnish: BA 10/11: right $Z = 5.65$, BA 10: left $Z = 4.75$) (Fig. 2 and Table 2). In the foreign language, there was additionally a significant increase in rCBF in the right angular and supramarginal gyri (BA 39/40: $Z = 4.83$) (Fig. 2a).

### Table 1

<table>
<thead>
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![Fig. 2. Comparison of adjusted mean rCBF in ten subjects between retrieval of word pairs with high imagery content and reference. Spatial distributions of significant voxels are shown as integrated projections along sagittal, coronal and transverse views of the brain. Foreign language (a) and native language (b) compared against reference condition.](image-url)
The cognitive subtraction “foreign language minus mother tongue” just passed the height threshold and showed (Fig. 3 a and Table 5) right-sided activation of the lower medial temporal area (BA 20, Z = 3.76). In contrast, retrieval of native words activated the left cingulate gyrus (BA 25, Z = 5.50) and the left cerebellar hemisphere (Z = 4.93). The cognitive subtraction “mother tongue minus foreign language” showed an activation of Broca’s area (BA 45: left activation Z = 4.50) (Fig. 3 b and Table 3) and in the precuneus on the right side (BA 7: Z = 3.84).

5.2.2.3. Low imagery words: encoding. As a shared neural substrate of both languages, the prefrontal cortex (BA 10/47) was bilaterally activated (English: BA 9/10, right: Z = 4.37, left: Z = 3.72; Finnish: BA 10/47, right: Z = 3.24, left: Z = 3.50). Encoding the word pairs in English resulted in additional activations in the left cingulate gyrus (BA 31) (Z = 4.08) and the right precuneus (BA 7; Z = 4.02). In contrast, the cerebellar vermis (Z = 3.53) and the right secondary visual cortex (BA 19; Z = 4.43) were active in the native language condition (Table 3).

5.2.2.4. Low imagery words: retrieval. The precuneus (English: left precuneus, BA 7: Z = 5.76; Finnish: BA 7, bilateral activation, Z = 5.16), prefrontal cortex (English: bilateral prefrontal cortex, BA 10/11; right, Z = 6.69; BA 10; left, Z = 5.71; Finnish: right prefrontal cortex, BA 10: Z = 4.95) serve as common structures in the retrieval of abstract word pairs in the native and foreign language. Retrieval of foreign word pairs resulted in additional activations in the left cingulate gyrus (BA 29: Z = 4.13). The cognitive subtraction ‘foreign language minus native language’ indicated activation of the left-sided medial frontal gyrus (BA 8, Z = 5.41). In contrast, retrieving the word pairs in one’s mother tongue activated the right cerebellar hemisphere (Z = 4.99) (Fig. 4 and Table 4).

The cognitive subtraction ‘mother tongue minus foreign language’ showed activation of Broca’s area (BA 44: left activation Z = 4.42) (Fig. 5 and Table 5).

Table 2
Encoding of words with low imagery content compared to reference condition

<table>
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Table 3
Retrieval of words with high imagery content compared to reference condition

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Fig. 3. Comparison of adjusted mean rCBF in ten subjects between retrieval of word pairs and reference. Spatial distributions of significant voxels are shown as integrated projections along sagittal, coronal and transverse views of the brain. Retrieval of high imagery word pairs: Foreign language (a) and native language (b) compared against reference condition.

Fig. 4. Comparison of adjusted mean rCBF in ten subjects between retrieval of word pairs and reference. Spatial distributions of significant voxels are shown as integrated projections along sagittal, coronal and transverse views of the brain. Retrieval of low imagery word pairs: Foreign language (a) and native language (b) compared against reference condition.
The results of our encoding paradigm confirm previous findings which emphasise the role of the prefrontal cortex and the hippocampal formation (Blaxton et al., 1996; Halsband et al., 1998; Kapur et al., 1994; Krause et al., 1999a, b; Squire et al., 1992). The pivotal role of hippocampus in memory processes has been extensively documented (Eldridge et al., 2000; Mellet et al., 2000; Schacter et al., 1999).

Our study (Halsband et al., 2002) showed common cortical structures in the retrieval of Finnish and English word pairs in (1) the precuneus, and (2) prefrontal cortex. With reference to the precuneus, findings underline the important role of this structure as a module subserving verbal memory and retrieval independent of the language used and the imagery content of the presented material. Results support the hypothesis of Fabbro (1999) which suggests that the cortical representations of different languages in bi/multilingual subjects partly overlap. This does not exclude the possibility that within the same cortical areas distinct neural circuits independently subserve different language sets. Overlapping mechanisms are also in agreement with the results obtained with electro-cortical stimulation during neurosurgical operations (Ojemann, 1991; Ojemann and Whitaker, 1978).

Furthermore, a consistent prefrontal activation was found during encoding and retrieval in all but one experimental condition (encoding high imagery words in Finnish). It remains unclear why in only one condition our findings failed to reach significance. In all of our previous studies (e.g. Halsband et al., 1998; Krause et al., 1999a, b; Schmidt et al., 2002) and in 7/8 experimental conditions of the present investigation, the prefrontal cortex was active. These findings are in agreement with existing data from animals and humans (Buckner et al., 1995; Fuster, 1995; Goldman-Rakic, 1987; Goldman-Rakic et al., 1992; Halsband et al., 1998; Squire et al., 1992; Tulving et al., 1994a, b) and with neuropsychological studies of brain damaged patients (Milner et al., 1985; Moscovitch, 1992; Paradis, 1994; Schacter, 1996; Warrington and Weiskrantz, 1982). The common denominator of these studies is the pivotal role of prefrontal cortex in declarative memory.

Brain mechanisms of the two languages showed also differential activations in Broca’s area and in the cerebellum as well as in the angular/supramarginal gyri according to the language used (see below).

5.2.2.5. Dorsolateral prefrontal cortex. Our results showed that bilateral activity patterns are observed during retrieval phases with predominance for activity in the non-dominant hemispheres in the prefrontal structures. The present findings can only be partly accounted for by the model of hemispheric encoding/retrieval asymmetry (HERA). The HERA model (Tulving et al., 1994a) states that the left and right prefrontal cortices are disproportionately involved in the encoding and retrieval of episodic memories, respectively. According to HERA, the left prefrontal cortex is more involved than the right prefrontal cortex in episodic memory encoding, whereas the right prefrontal cortex is more involved than the left prefrontal cortex in episodic memory retrieval. The findings of our study

<p>| Table 4 |
|------------------|-----|----|-----------------|------------------|
| Retrieval of words with low imagery content compared to reference condition |</p>
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<td>−78 48</td>
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<td>4.95 10 Prefrontal cortex (right)</td>
</tr>
<tr>
<td></td>
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<td>−80 44</td>
<td>5.16 7 Precuneus (bilateral)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>−54</td>
<td>−8 4.99 Cerebellum (right)</td>
</tr>
</tbody>
</table>

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![Fig. 5. Cognitive subtraction “foreign language (a) minus native language (b)” : retrieval of low imagery words. Spatial distributions of significant voxels are shown as integrated projections along sagittal, coronal and transverse views of the brain.](image-url)
confirm the conclusion put forth by Fletcher and Henson (2001) “The HERA generalisation may not be sufficient, however, in that our review included many studies of verbal retrieval that activate both left and right frontal cortex, or even left frontal cortex alone”. In another review, Lee et al. (2000) concluded that between one third and a half of all functional neuroimaging studies of episodic memory encoding do not adhere to the HERA pattern.

Recently, Owen (2003) correctly put forth the critical remark that in order to establish how specific frontal regions are specialised for particular memory sub-processes one has to put forth a greater commitment to such double dissociation methodology than it is usually currently the rule. Our findings are in line with the view that interhemispheric interactions play a crucial role during the retrieval of both native and foreign word pairs. The results are in accordance with other studies which suggest that the original HERA model underestimated the role of the left prefrontal cortex during memory retrieval (e.g. Buckner, 1996; Halsband et al., 1998; Lepage et al., 2000). This points to the necessity for a revision of the retrieval-related aspects of the HERA model.

Category-related premotor and prefrontal correlates of lexical retrieval have been reported on other studies (e.g. Damasio et al., 1996; Grabowski et al., 1998; Martin et al., 1996). As the prefrontal processing of bilingual word pairs is concerned, our study did not show a significant difference between the categories “high imagery content” and “low imagery content”. This applies both to the mother tongue and the foreign language.

5.2.2.6. Broca’s area. Broca’s area (BA 44, 45) was activated both with the retrieval of concrete and abstract words as the cognitive subtraction mother tongue minus foreign language was carried out. This finding will emphasise the role of Broca’s area in the retrieval of native words, irrespective of the fact whether they are concrete or abstract. In the present study, no activation of Broca’s area was found as foreign words were retrieved from memory. As for the mother tongue, our findings support the results obtained by Kim et al. (1997) who showed with fMRI that Broca’s area is activated with the native language. On the other hand, there are also differences: Kim et al. (1997) showed that within the frontal-lobe language-sensitive regions (Broca’s area) foreign languages acquired in adulthood are spatially separated from native languages. The difference between our results and those of Kim et al. (1997) may be reconciled in part by the higher spatial resolution of the fMRI technique as compared to PET. In addition, using SPM analysis the results of several subjects were combined and averaged. This further reduces the effective resolution since individual variations in the localisation of the language areas were not taken adequately into account. Another crucial difference was that the paradigm used by Kim et al. (1997) was based on internal speech describing events that occurred during a specified period of the previous day. In contrast, in the present study, the retrieval of word pairs without syntax was investigated. One may argue that distinct activations within Broca’s area for native and second languages could be dependent on the use of different syntactic conditions rather than on the processing of phonetic structures of the different languages. This hypothesis is in accordance with the brain imaging study by Klein et al. (1995). The aim of their study was to investigate the neural substrates underlying phonological or semantic word generation in bilingual English-French speaking subjects. Their results suggest common neural substrates in phonological and semantic word generation tasks irrespective of whether subjects used their mother tongue or a foreign language.

The subtraction analysis of the two languages revealed that in Finnish the cerebellum and Broca’s area were more activated than in English. This interesting finding deserves further investigations. It remains unclear whether the linguistic/phonological characteristics of the Finnish language are more demanding or whether the native language in general uses more sophisticated networks for word production. Further experiments are needed to analyse the neurolinguistical aspects of these languages under more complex experimental conditions using whole sentence constructions.

5.2.2.7. Precuneus. This was the first study to show a consistent precuneus activation during memory retrieval of word pairs in different languages and for both highly imageable and abstract words. Our results indicate a significant and predominantly bilateral activation of the precuneus under all experimental conditions using different languages and irrespective of the imagery content of the word pair associates.

The results are in agreement with earlier brain imaging studies which showed a precuneus activation during verbal memory retrieval using the native language (Fletcher et al., 1995a,b; Halsband et al., 1998; Krause et al., 1999b; Mottaghy et al., 1999; Shallice et al., 1994). The precuneus activation occurred for words with high and low imagery content and during visual and auditory presentation modalities (Krause et al., 1999b). Our results extend the existing evidence and emphasise the role of precuneus for both foreign and native word pairs.

In spite of extensive information about lesions of the parietal lobe in various neurological disorders there are relatively few data about specific lesions of the precuneus (Cabeza et al., 1997; Ross, 1980). However, there is anatomical evidence indicating that precuneus has connections with prefrontal (Goldman-Rakic, 1988; Petrides and Pandya, 1984) and with temporal, occipital and thalamic areas (Blum et al., 1950; Pribram and Barry, 1956). This connectivity creates the basis for the functional concerted action of precuneus during retrieval.

5.2.2.8. Angular/supramarginal gyri, cingulate areas. Angular and supramarginal gyri are activated only when foreign words with high imagery content are retrieved. It has been
shown (Price et al., 1999) that switching the input language results in the activation of the supramarginal gyri, which may play an important role in the cognitive control of language processes. Using fMRI Yetkin et al. (1996) showed that the number of activated pixels was greatest for the language in which the subject was least fluent. When native concrete words or foreign abstract words are retrieved left cingulate areas (BA 25 for native concrete words and BA 29 for foreign abstract words) are activated. The functional significance of these findings is open and further data are needed. It has recently been shown that the anterior cingulate areas in the vicinity of these areas participate in the online monitoring of performance and error detection (Carter et al., 1998; Ochsner et al., 2001).

5.2.2.9. Cerebellum. There is significant cerebellar activation only concerning the retrieval of concrete and abstract native word pairs, whereas no cerebellar activation could be seen as foreign words were retrieved. This may refer to overlearnt automatic motor patterns associated with the mother tongue. The present results are in agreement with our earlier findings which indicated cerebellar activation during the retrieval of visually presented word pair associates (Halsband et al., 1998). Clinical lesion studies support the view of a critical role of the cerebellum in higher cognitive function (Bracke-Tolkmitt et al., 1989; Fiez et al., 1992).

In the present investigation the brain areas of the two languages shared common components though differential activation patterns were found in Broca’s area, the cerebellum and the angular/supramarginal gyri. Finnish and English used in the present study represent widely different linguistic groups, non-Indo-European vs. Indo-European. We presented the word pairs in the nominative case in order to avoid the extensive morphology of the Finnish language used in the present study. The human brain. In particular language experience seems to influence the functional organisation of language-relevant systems.

There is evidence that cortical cell assemblies representing action verbs include additional areas in motor and premotor cortices (Dehaene, 1995; Pulvermüller et al., 1999). In our study (Halsband et al., 2002) we used neutral, non-emotional nouns; however, it is difficult to assess the emotional value of the words; different subjects may react in various ways to the same words due to their own personal life-time memories (Dolan et al., 2000).

Further studies are needed to clarify the cerebral representation of the second language by systematically varying age of acquisition, levels of proficiency, and language exposure (Moreno and Kutas, 2005). There is recent evidence that the proficiency level may play a larger role as compared to the age of acquisition in the cerebral representation of semantic processing (Klein et al., 2006a,b; Perani et al., 1998; Wartenburger et al., 2003).

References


variability in the cortical representation of first and second language. Neuroreport 8, 3809–3815.


