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BILINGUAL APHASIA: ADAPTED LANGUAGE NETWORKS AND THEIR CONTROL

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This review focuses on the nature of language recovery in bilingual individuals post-stroke and on the effectiveness of treatment. We consider neuropsychological and neuroimaging papers on bilingual aphasic individuals in the period 2003-2007. We examine the extent to which current evidence supports the notion that different languages are represented in distinct processing areas or are distributed in shared areas with common organizing principles. We argue for the second possibility with the extent of recovery affected by prior proficiency and current usage. We also argue that certain patterns of deficit indicate a problem in controlling the language in use rather than a representational deficit *per se*. Most studies concern chronic aphasic patients and detailed studies of the effects of treatment and any plastic changes in response to such treatment remain sparse. We conclude with suggestions to further our understanding of recovery and treatment. In order to advance further we need to understand the range of pathways in normal bilinguals that support a given language task so that neural patterns associated with task performance post-stroke can be properly interpreted. Imaging regional changes in blood flow immediately post-stroke can help identify the regions and pathways associated with the recovery of function. Functional imaging studies of recovery and treatment in the chronic stage are also critical.

Introduction

Increased migration and mobility of labour mean that there are increased numbers of bilingual and multilingual individuals. Increasingly then, aphasia which is one of the commonest outcomes following stroke, will be found in bilingual and multilingual individuals. Such an increase poses a challenge for support services and a challenge to researchers to improve theoretical understanding of the various patterns of language recovery in order to develop effective treatments.

A number of different patterns of recovery have been described since the early work of the French neurologist Pitres (1895). The recovery of both languages in line with their premorbid proficiency may well be the most common (i.e., parallel recovery, Paradis, 1998; 2004) but published case reports indicate other patterns (Fabbro, 1999; Paradis, 2004). These include the differential recovery of the two languages with selective recovery of just one language as the extreme. Ribot (1882) supposed that the first acquired language would be least affected whereas Pitres (1895) proposed that the language most used at the time of aphasia onset would be best recovered. But such conjectures cannot explain the full set of reported patterns. Recovery may also reveal a temporal pattern, viz: successive recovery (i.e., after the recovery of one language, the other language recovers), alternating recovery (i.e., the language that was first recovered is lost again due to the recovery of the language that was not first), alternating antagonistic recovery (i.e., on one day the patient is able to speak in one language while the next day only in the other). Finally, the aphasic individual may show pathological mixing of two languages (i.e., the elements of the two languages are involuntarily mixed during language production).

Patterns of recovery are likely to reflect many factors including ones relating to the languages in question, their acquisition and usage prior to the onset of aphasia and the nature of the damage to the neural networks underpinning their representation and control. In lieu of deep theory to account for the different patterns by, for example, parameterising the relevant variables, researchers have adopted different approaches to understanding single cases.

A traditional 'localizationist' view argued that loss of one language occurs because the bilingual's languages are represented in different brain areas or even in different hemispheres. A focal brain lesion within a language-specific area could then affect one language only leaving the other language intact (Albert & Obler, 1978). The claim that different brain areas mediate syntax in L1 and in L2 lies within this tradition (e.g., Ullman, 2001; 2005). An alternative, dynamic view, attributes the different patterns of language recovery to alterations in the system of language control (e.g., Abutalebi & Green, 2007; Green, 1986; Green & Price, 2001; Paradis, 1998; 2004)[1]. In fact, Pitres himself (Pitres, 1895) proposed a 'dynamic' explanation of language recovery in bilingual aphasia: language recovery could occur only if the lesion had not entirely destroyed language areas, but only temporarily inhibited them through a sort of pathological inertia.

We frame our review in terms of this approach. We emphasize the need to distinguish, when discussing the bilingual brain, between devices responsible for language representations (i.e., the language network) and devices involved in controlling these representations (i.e., language control).

An Adaptive Network View of the Neural Representation of Languages and their Control

From a neurocomputational point of view it makes sense that the procedures designed to process specific aspects of a linguistic message (e.g., word order, morphology and syntax, prosody) are utilized to process such signals in a second language (Green, 2003; 2005). In consequence, it is reasonable to infer that acquisition of a second language will lead to its representation in a common network of regions. This view has implications for the nature of the network. First, the neural representation of each language must be distinctive in some fashion. Second, a shared network must adapt to the demands of each language (e.g., De Bot, Verspoor & Lowie, 2007; Green, 2005; Hernandez, Li & MacWhinney, 2005). A bilingual, in Grosjean's felicitous phrase, is not "two monolinguals in one body" (Grosjean, 1998).

Normal, proficient bilingual speakers are able to use each of their languages appropriately, and switch, and perhaps translate, between them. It follows that within shared processing areas there may be distinct but interleaved microanatomical circuits for each language (see Paradis, 2004, p. 127) that can be selectively activated or neurons whose functional role (e.g., activating an L1 word form or an L2 word form) changes with different input patterns (i.e., with what else is co-active). The demonstration of such circuits, or such neural dependency, remains a task for the future, but current neuroimaging research is consistent with the broad position that languages are represented in shared processing regions (e.g., Abutalebi, Cappa, & Perani, 2001). For instance, the meanings of words in different languages (English and Japanese) have a common substrate (e.g., Crinion, Turner, Grogan, Hanakawa, Noppeney, Devlin, Aso, Urayama, Fukuyama, Stockton, Usui, Green & Price, 2006). There is evidence too of common regions mediating syntax (e.g., Golestani, Alario, Meriaux, Le Bihan, Dehaene, & Pallier, 2006). In addition, there are circuits involved in language control outside the classical language areas (Abutalebi & Green, 2007; Crinion et al., 2006).

Neuropsychologically, the contrast between the language network and circuits involved in its control would be supported by cases in which there is normal comprehension and production in L1 and L2 but a difficulty in controlling the use of one language over another. S.J. is one clear example (Fabbro, Skrap, & Aglioti, 2000.) S.J.'s lesion included the left prefrontal cortex, part of anterior cingulate and the left striatum. S.J. showed normal comprehension in both Italian and Friulian and intact clausal processing in both languages. However, S.J. was unable to avoid switching into Friulian (his L1) even when addressing an Italian speaker who spoke no Friulian. Likewise, when required to speak Friulian only, S.J. would switch into Italian (his L2) (see Riccadi, Fabbro, & Obler, 2004 for an alternate case of a patient with Wernicke's aphasia who nonetheless switched appropriately).

Current neuroimaging data on normal bilinguals cannot be interpreted too far. Neuroimaging data mostly cover group results where individual variability is treated as noise. But such variability is really critical to our understanding of language in the brain because it points to the different ways in which a given language task can be performed (see Green, Crinion & Price, 2006). The failure to address this adequately may be one reason why some researchers are unimpressed by the achievements of neuroimaging research (see Paradis, 2004; chapter 6 for a critique of the enterprise, and De Bot, 2008, for sustained doubts). Individual variability will not be unconstrained, and by examining it we will be in a position to identify subgroups of normal bilingual speakers.

When we think of the consequences of stroke for a bilingual, individual variability is clinically crucial. In a recent meta-analysis of neuroimaging studies on bilinguals, Indefrey (2006) noted that although there may be no regions that are exclusively necessary for word production in one language across individuals, there do appear to be sites that are only necessary for word production in one language. Relevant data come from studies using electrical stimulation to map eloquent language areas prior to surgery (e.g., Lucas, McKhann & Ojemann, 2004). Interference of object-naming at a given site is interpreted as indicating that the site is necessary for production in that language. A stimulation-sensitive site in naming in one language does not imply that one language is represented in a distinct region from another. Stimulation can disrupt the circuit for producing that word.

One region that is reliably activated more strongly for L2 than for L1 naming is the left-inferior frontal cortex which, in the data of Lucas et al. (2004), only contains L1-specific sites. Indefrey (2006) offered a plausible interpretation of such data: individuals seek to adapt existing representations or processes to produce words in L2. The network adapts to the demands of L2.

The extent to which proficient bilinguals converge in the way in which they process language with the processing profile of monolingual speakers of that language remains contentious, but aspects of native-like performance can be achieved early in the process of acquisition. Understanding the nature of such adaptation is important for developing a causal account of recovery patterns –an account that currently eludes us. We turn now to consider the impact of the mode of acquisition of a language on its neural representation or, in our terms, on the adaptive response of the network.

<u>Effects of Different Acquisition Trajectories</u>

A standard assumption is that a second language acquired early may be represented rather differently from one acquired late. For example, a language acquired in the home may be acquired implicitly whereas one acquired at school may be learned with explicit reference to identified regularities in the language and by means of explicit vocabulary learning. The manner and/or age of acquisition may modulate the way in which L2 is represented neurally compared to L1. The effects of stroke may then have differential effects for L1 compared to L2.

Both the wide-ranging neurolinguistic theory of bilingualism proposed by Paradis (2004) and the account of L2 representation proposed by Ullman (2005) rely on the notion of two distinct memory systems. Both proposals agree that words are represented in one system and implicit grammatical competence in another and that there are differences in the representation of syntax in L2 compared to L1.

What grounds are there for believing that there are distinct memory systems in the brain that may mediate different aspects of a person's knowledge of language? Traditionally, the key data in favour of distinct memory systems derived from neuropsychological dissociations. The classic dissociation evidence that is most pertinent here is the finding of impressive skill-learning in patients despite profound amnesia, that is, despite their marked inability to recall words, sentences, faces or scenes.

Evidence of dissociation does not require that we postulate distinct systems. Dissociations may arise because of different processing demands on a unitary system. So, for instance, differences between skill learning and recognition memory may reflect differences in the demands of the tasks at study and test (Roediger, 2000). Undeniably, different memory tasks require different processes but the crucial issue is whether there are different forms of memory that are mediated by different systems. Current evidence suggests that there are.

<u>Explicit versus Implicit Memory</u>

One construal of the dissociation evidence holds that patients with amnesia are selectively impaired in their ability to *consciously* recollect prior study episodes. They have a deficit in explicit memory and the hippocampal system, damaged in amnesic patients, is selectively involved in such memory (Graf & Schachter, 1985). In contrast, skill learning does not involve explicit memory but invokes implicit memory.

Declarative and Procedural Memory

Another prominent account of the classical dissociation evidence and, one we focus on, distinguishes between declarative and procedural memory (e.g., Cohen & Squire, 1980). Declarative memory supports the memory for words, facts and events including the memory for arbitrary relations (e.g., between individuals and their phone numbers). Procedural memory, by contrast, supports the acquisition and expression of a skill. Amnesia on this account is a selective deficit of declarative memory occasioned by damage to a hippocampal-based memory system.

These two construals are frequently confounded because any explicit memory test involves a declarative memory for relations. However, Ryan, Cohen and colleagues (see Ryan & Cohen, 2003 for a review) used an eye movement procedure (i.e., an implicit task) and showed that patients with amnesia were selectively impaired in their memory for relations but only when there was a delay between viewing a scene and subsequently viewing an altered version of it.

Declarative and Procedural Memory: Implications for L2 Processing

Both Paradis (2004) and Ullman (2005; see also an earlier paper, Ullman, 2001) propose that the vocabulary of a language, whether that of L1 or of L2, is represented in a declarative memory system along with other facts of the world. In contrast, grammatical and morphological processes, at least for L1, are mediated by the procedural system that handles other cognitive and motor skills. For L2, the declarative system plays a key role in the representation of grammar. Paradis (2004) emphasizes the role of conscious, metalinguistic knowledge of L2 in guiding the acquisition, through practice, of implicit grammatical competence (Paradis, 2004; p. 50) and in the role of such metalinguistic knowledge in supporting recovery of L2 (Paradis, 2004; p. 87).

Conceptually, as Paradis (2004) argued convincingly, the procedural and implicit aspects of language use are fundamentally distinct from any metalinguistic knowledge a person has of the language. Individuals may possess metalinguistic knowledge of L2 that they do not possess of their L1. In contrast, their knowledge of L1 may be entirely implicit and embodied in computational procedures that allow them to speak it and of which they are unaware. It is plausible to infer that such knowledge is represented in distinct systems. Specifically, metalinguistic knowledge ("knowing that") is subserved by a declarative memory system to which one has conscious access and that is supported by a medial-temporal (hippocampal) system. This aspect of the proposal relates to the claims of Graf and Schacter (1985). In contrast, implicit linguistic competence ("knowing how") refers to a set of computational procedures. It is mediated by a procedural memory system as proposed by Cohen and Squire (1980) that encompasses the striatum, cerebellum and frontal structures.

Selective damage to such systems will have consequences for the recovery of languages post-stroke. To the extent a speaker has metalinguistic knowledge of L2 (i.e., explicit and conscious declarative knowledge of it), but not of L1, then such knowledge may be available to compensate for loss in the case of L2, but not in the case of L1. Consider the impact of damage to frontal, basal ganglia and cerebellar circuits following stroke. On the assumption that individuals will have more metalinguistic (i.e., explicit and conscious declarative knowledge) of a later learned language, then Paradis (2004, p.

87) predicts that a later learned language is more likely to be affected in an older patient. Individuals with memory deficits will cease to be able to recruit their metalinguistic knowledge to compensate for any loss.

Ullman (2001) developed his view of the implications of the procedural/declarative distinction for L2 processing from research on the processing of regular and irregular English verbs. The supposition was that the production of the past tense of a regular verb (e.g., "walk") is computed by the procedural system whose properties can be captured by a rule such as add "-ed" to the stem ("walk") whereas the past tense of an irregular verb (e.g., teach => taught) must be retrieved from the declarative memory system that will also store other idiosyncratic combinations (such as idioms).

On the assumption that a fronto-striatal network (i.e., one that includes the basal ganglia) mediates the use of grammatical rules (i.e., computes regular forms for production and decomposes such forms for comprehension) and a temporo-parietal memory system subserves the storage of irregular verbs, patients with striatal dysfunction should show abnormal performance on regular but not on irregular verbs.

However, Longworth, Keenan, Barker, Marslen-Wilson and Tyler (2005) found no association between striatal dysfunction and selective impairment in the ability to form regular past tense in patients with Parkinson's disease and genetically-proven Huntingon's disease. Such data undermine the attempt to link the processing of regular forms to a specific component of the procedural system. Further, prior studies have assumed that regular and irregular verbs differ solely in the way in which their past tenses are computed, but recent data indicate that they differ also in their semantic properties and that when they are matched on these properties there is no evidence of different processing mechanisms in their production (see Basnight-Brown, Chen, Hun, Kostić, Feldman, 2007). An alternative view of the role of the basal ganglia in language processing is that they have an inhibitory function (see, for example, Longworth et al., 2005; Abutalebi & Green, 2007) and so modulate both syntactic and lexico-semantic processing (see, for example, Kotz, Frisch, von Cramon & Friederici, 2003).

As applied to bilingual speakers, a key implication of the declarative/procedural distinction is that when an L2 is acquired relatively late the declarative system will play an important role in the production of syntactic forms that rely on the procedural system in L1. Such a view predicts differential effects of brain-damage on L1 and L2. Damage to the procedural system will impair L1 more than L2. In Ullman (2005, see also Ullman, 2001) an increase in L2 proficiency can be associated with increased use of the procedural system. But this means that for high proficiency bilinguals there is no motivation to predict that damage to the procedural system will impair performance more for L1 than for L2. There is also a computational question. How does grammatical processing increase its dependence on the procedural system? The suggestion proposed by Paradis (2004) provides an answer: conscious metalinguistic knowledge can guide the practice of L2 syntactic forms and so, in principle, give rise to implicit L2 syntactic competence over time.

The single adaptive network view makes a slightly different claim: individuals use, right from the start of L2 acquisition, existing systems mediating the combinatory process of syntax or morphology. Changes in proficiency are associated with shifts from more-controlled to more-automatic processing (Abutalebi & Green, 2007). In fact, current neuroimaging data and ERP data, do indicate rapid convergence with the neural patterns shown by native speakers (see Golestani et al., 2006 for relevant fMRI data; Osterhout, McLaughlin, Pitkanen, Frenck-Mestre & Molinaro, 2006 for relevant ERP data) though the extent and rapidity of such convergence may depend on the languages involved (see Chen, Shu, Liu, Zhao, & Li, 2007). In any case, the observation of different patterns of activation in performing a language task needs to be understood in the context of likely variations within normal, monolingual speakers.

This adaptive network view does allow for one critical difference in the representation of L1 and L2. In line with the proposals of Paradis (2004), individuals may have conscious, metalinguistic knowledge for L2 that they do not possess for L1. If such metalinguistic knowledge is indeed the source of advantage for the differential or selective recovery of L2 over L1, then this view clearly predicts that the processing of L2 will differ from that of normal proficient bilinguals who are using implicit procedures of the procedural system. Testing such a prediction requires a neuroimaging study using a speech production task in a patient with differential recovery of L2 over L1. Unfortunately, no such study exists to our knowledge.

Neuropsychological Studies of Bilingual Patients with Aphasia

The notion of a single adapted language network that mediates the representation of the meanings of words and grammar in each language presumes that common underlying principles of organization apply for each language. Where both languages can be produced, a common pattern of effects should be found subject to any structural differences between the languages, even if one language is recovered better than another. A problem in retrieving the names of objects or actions (anomia) is a common feature of aphasia and in this review we focus on such studies.

<u>Distinct Representations for L1 and L2?</u>

Kiran & Tuctenhagen (2005) tested a 53-year old female Spanish-English bilingual patient who was born in Mexico, moved to the USA at 21 years and then married a monolingual English-speaking individual. She suffered a left hemisphere stroke (middle cerebral artery) 9 months prior to testing. Premorbidly proficient in both languages, testing (first in one language and then the other in the same session) revealed a significant advantage for naming words to definition if they referred to concrete entities, for example, “sword” (53% - 63% accuracy) as opposed to abstract entities, for example, “doctrine” (0-3% accuracy). They proposed that the retrieval of concrete word forms was spared because of conceptual specificity of the mental representation of such words. In contrast, the content of the definitions provided insufficient contextual information for the retrieval of abstract words (see van Hell & De Groot, 1998). Consistent with the single adapted network, there was no effect of language. Nor in this study was there any effect of cognate status.

De Diego Balaguer, Costa, Sebastián-Galles, Juncadella, and Caramazza (2005) analyzed the responses of two bilingual patients with aphasia on a morphological transformation task. The contrast between regular and irregular verb forms exists in both Spanish and Catalan and so it should be the case according to the declarative/procedural proposal that Spanish and Catalan agrammatic patients with anterior lesions should be poorer at producing the forms of regular verbs rather than those of irregular verbs. Premorbidly, J.M. was a fluent Spanish/Catalan bilingual with Spanish as L1 whereas M.P. was a fluent Catalan/Spanish bilingual with Catalan as L1 and educated in Spanish as L2. In the transformation task, the patients completed an auditorily-presented sentence frame with a suitable spoken verb form. For instance, in response to a statement, glossed in English, as "Today I eat, yesterday I .." they would complete with the verb form "ate". Both in Spanish and Catalan, the patients were better at producing regular compared to irregular forms. Accordingly, De Diego Balaguer et al. argue that these two bilingual patients with agrammatism have a deficit at the level of morphosyntactic processing independent of the regularity or irregularity of the verb. As in the classical view, frontal structures are involved in morphosyntactic processing and not just rule-based processing. Regular verbs may be easier to produce for a number of reasons. One possibility is that regular transformations are more frequent than irregular transformations. However, the interpretation of these data is complicated by the fact that in Catalan and Spanish the irregular stem as well as the regular stem must be inflected according to person and number (Paradis, 2008). It is therefore more grammatically complex than the regular form. As Paradis (2008) notes predictions derived from the procedural/declarative distinction must reflect the structural properties of the language in question. As indicated above, matching the semantic properties of regular and irregular verbs will also be important in future studies (see Basnight-Brown et al., 2007)

The results of De Diego Balaguer et al. are relevant to the single network view: Common tissue is recruited to perform comparable functions in the two languages though, as De Diego Balaguer et al. note (p. 221), it remains to be seen whether selective deficits would be observed in patients speaking two languages that differ markedly in their morphosytnax (as in the case of English and Spanish).

Other research has examined evidence for the representation and processing of verbs and nouns. Verbs are arguably more representationally complex than nouns and so potentially more vulnerable to damage (see Black & Chiat, 2003 for an analysis of the multiple factors contributing to noun-verb dissociations). Poncelet, Majerus, Raman, Warinbaire, and Weekes (2007) asked three patients to name actions and objects (from the Action and Object naming battery, Druks & Masterson, 2000) first in L1 and then a week later in L2. Overall, naming in L1 was better than in L2 and objects were named better than actions. Regression analyses established that imageability was a more potent predictor for object naming than for action naming (cf. Kiran & Tuctenhagen, 2005).

Although our focus is on studies of aphasic patients, it is noteworthy that the study of a bilingual patient with Alzheimer's disease, L.P.M. also revealed comparable deficits in her two languages but she showed the reverse dissociation to the three patients reported by Poncelet et al. (2007). L.P.M had greater difficulty in naming objects compared to actions (Hernández, Costa, Sebastián-Galles, Juncadella & Reñé , 2007) L.P.M. was a 74 year-old right-handed, Catalan-Spanish speaker, highly-proficient in both languages pre-morbidly, who had acquired both languages early in her life. In Catalan, L.P.M. showed severely impaired performance in using nouns compared to verbs. So, for example, she was better at naming the action associated with a depicted object (e.g., "brushing") compared to naming the object of the action (i.e., "broom"). A similar result was obtained in Spanish: L.P.M. found it more difficult to retrieve nouns compared to verbs.

Taken together these findings of grammatical-category specific deficits in both languages suggest that common principles underlie the representation of words in the two languages and that a common neural tissue underlies both. Hernandez et al. (2007) note two caveats. First, Spanish and Catalan, along with other Romance languages, have similar grammatical and morphological properties and so it remains to be determined whether or not selective deficits exist when bilinguals have learned languages that differ more markedly in their grammatical and morphological properties. Second, L.P.M. acquired both languages early and so it is possible that the common principles of organization are restricted to circumstances in which this is the case. We do not consider this likely given our theoretical position and neuroimaging data that indicate convergence with native speakers even for late learners of that language. A further relevant factor affecting the retrieval of a verb in aphasia is likely to be its precise nature.

Kambanaros and van Steenbrugge (2006) asked twelve late Greek-English bilinguals (aged between 60 and 84 years) with anomic aphasia to complete a verb and noun picture-matching task and a verb and noun picture naming task. Comprehension relative to a matched Greek-English control group was spared in both languages, but verb and noun production in picture naming was worse in both languages with greater impairment in the production of verbs in Greek (L1) and in English (L2). Production of instrumental verbs such as "to cut" that reference an instrumental noun (e.g., knife) was better than that for non-instrumental verbs such as "to read" that do not. Such an effect may reflect the coactivation of the verb lemma via the instrumental noun leading to easier access to the phonological representation of the verb. On the assumption that the lexeme or word form of the instrumental noun is also activated, the name or phonological relation between the noun and verb should also affect the ease of production. Kambanaros & van Steenbrugge (2006) also contrasted instrumental verbs that shared a phonological relation with the instrumental noun (e.g., to hammer-hammer) with those that did not (to sweep- broom). The former were significantly more difficult to produce in L2 – the weaker language. Conceivably, such an effect reflects the need to select the correct form and reflects the problem in handling competitive effects in the weaker language (see Kambanaros & van Steenbrugge, 2006, p. 175).

If common organizational principles mediate the representation of words in each language, as we have argued, then individuals should show comparable patterns of effects modulated by the precise properties of the language. The results of a single case study reported by Alexiadou and Stavrakaki (2006) are consistent with this idea. K.S., a 32-year-old, late bilingual patient with Broca's aphasia, pre-morbidly fluent in Greek (her L1) and English (her L2), completed a sentence anagram task and a grammaticality judgment task in English and in Greek. Alexiadou and Stavrakaki observed comparable effects in the two languages and attributed differences to the inflectional properties of the two languages.

A similar conclusion can be drawn from a study of compound nouns. Jarema, Perlak, & Semenza (2007) tested two right-handed chronic aphasic bilingual patients who were premorbidly proficient in English and French before a left CVA 5 years previously. They repeated, read and translated compound nouns (e.g., avion-suicide/suicide plane) or adjective noun compounds (e.g., feuille morte/dead leaf). In French, such compounds are right-headed (e.g., the adjective follows the noun) whereas in English they are left-headed (e.g., the adjective precedes the noun). Analysis of the data for both patients showed fewer errors (e.g., phonemic paraphasias, semantic paraphasias, and deletions of the first or second constituent) for the first constituent (the head) in French compared to the second constituent. There was no difference for English. The authors concluded that bilinguals with aphasia are sensitive to the internal structure of compounds in a language-appropriate manner. They interpreted the null effect of constituent position in English as reflecting a combination of a first-position effect and an effect of the head's position. In these data there was no significant effect of cognateness.

Anomia in bilingual speakers provides an opportunity and a threat to communicative success. It provides an opportunity in the sense that the person can switch into their other language in the event of a failure of lexical access in the current language. It provides a threat in that switching into the other language to circumvent a problem in word retrieval can only be successful if the addressee speaks the other language. However, a speaker may also use such retrieval deliberately to cue the retrieval of the correct word. When a speaker is aware of such a possibility and uses it then they can filter out the non-target words and so avoid inappropriate intrusions. This was true for the patient in the next study.

Goral, Levy, Obler, & Cohen, (2006) examined the factors affecting word retrieval in a patient with trilingual aphasia. E.C. was a 46 year-old, right-handed male who suffered a left fronto-temporo-parietal infarct 4 years prior to their study. Premorbidly fluent in Hebrew (his mother tongue), English (L2) and French (L3) and with a functional knowledge of Spanish, Italian and German, E.C. continued to use French with his immediate family in Geneva, and English and Hebrew with friends. On test (using relevant portions of the Bilingual Aphasia Test, Paradis & Libben, 1993), E.C. revealed mild impairments in Hebrew and English and mild to moderate impairment in French. In normal conversation when he was unable to immediately retrieve a word, E.C. would retrieve the word in another language with the expectation that it might cue the correct retrieval of the target word. He voluntarily avoided actually producing the non-target word. For purposes of their study, Goral et al., asked E.C. to produce such "intrusions" as part of prompted naturalistic conversation. Overall incidence was highest for French, then English and then Hebrew. Further, English was the primary source of interference in French and in Hebrew. French was the primary source of interference in English. In short, the least well-recovered language (French, L3) suffered the most intrusions from the second acquired language (English). Such a pattern suggests that involuntary intrusions may reflect the acquisition history with later learned languages linked more closely together (cf. Kroll & Stewart, 1994). Difficulty in securing lexical access and in controlling an intended language is the most likely cause of the recovery pattern observed in the final case we report in this section.

García-Caballero, Garcia-Lado, González-Hermida, Area, Recimil, Juncos Rabadán, Lamas and Jorge (2007) reported the case of a 91 year-old, right-handed female Galician-Spanish bilingual who stopped speaking her L1 (Galician) and started speaking Spanish (L2) following damage to the structures of the basal ganglia (although the head of caudate was apparently spared, there was right capsuloputaminal atrophy and small lesions of subcortical white matter). Her everyday behaviour indicated mild disinhibition such as asking her guests for coffee rather than offering it to them. Language testing showed spared comprehension in both L1 and L2. She was fluent in L2 but not in L1 and showed impaired repetition in L1 sometimes translating into L2. When spoken to in L1 she replied in L2 though in context such behaviour is not entirely inappropriate as both languages are spoken. Verbal fluency was impaired as reflected in a reduced ability to name instances of a given semantic category. One year after initial testing, her spontaneous speech in L1 remained minimal and she showed a small disadvantage in auditory comprehension in L1 but she was able to name objects in her L1.

García-Caballero et al. (2007) proposed that the data from this patient are consistent with the differential representation of L2 (citing Ullman, 2001). In line with Ullman's account, they proposed that L1 may be represented more implicitly with the structures of the basal ganglia playing a key role. Certainly, formal education in her L1, Galician, was prohibited under the Franco regime and so the patient never learned to read or write in her L1 and was not exposed to Spanish (her L2) until 8 years of age. However, she was relatively proficient in her L2 - it was the language she used for reading and watching television and so, according to Ullman (2001, 2005), there should be increased reliance on the procedural system. If so, L2 should be impaired along with L1. There are reasons to doubt then that the selective recovery of L2 in this patient reflects the declarative representation of L2 grammar, especially as neuroimaging data cited above indicate use of a common substrate in the acquisition of L2 grammar early in the process of acquisition.

It is conceivable that her production in L2 benefitted from metalinguistic knowledge of L2. However, García-Caballero et al. noted that her mild disinhibition might reflect disruption of fronto-subcortical circuits and, indeed, in our view this case is better interpreted as indicating a loss of control of L1 (i.e., an inability to select it) that may have been occasioned by a temporary problem in accessing words in L1 (e.g., a failure to inhibit L2 competitors) and a decision to talk only in L2 that led to improved restitution of function in that language.

Imaging Studies of Recovery

The single case studies discussed above are consistent with the neuroimaging data on normal subjects suggesting a single adapted language network controlled by frontal-subcortical circuits. However, it is clearly desirable to determine if recovery is, or is not, supported by premorbid neural regions involved in language processing. Studies on monolingual aphasic patients continue to examine the role of the right hemisphere in language recovery. Functional imaging studies in normal individuals confirm activation in right hemisphere homologues of Broca's or Wernicke's area in naming and listening tasks. However, it has proved difficult to establish whether in aphasic patients such activation is really supporting recovery or hindering it Saur, Lange, Baumgaertner, Schraknepper, Willmes, Rijntjes, & Weiller (2006) studied a group of monolingual patients at three time points post-stroke (after 2, 12 and 320 days) using a paradigm designed to activate classical language areas. At 12 days post-stroke, patients activated right inferior frontal gyrus (the homologue of Broca's area) more than matched normal controls and activation in this region correlated with a compound aphasia score. Patients continued to improve by the final time point although activation in this region had declined. Interpretation is problematic (see Hillis, 2006) as changes in the compound aphasia score could reflect recovery of different language functions or of language control.

Evidence that right inferior frontal gyrus does not take over function derives from research using repetitive transcranial magnetic stimulation (rTMS). rTMS involves focusing magnetic pulses on the scalp and can temporarily disrupt the function of the underlying neural tissue. Winhuisen, Thiel, Schumacher, Kessler, Rudolf, Haupt, Heiss (2007) found that rTMS disrupted verb generation performance when applied over left IFG both at 10 days and eight weeks post-stroke, but did not disrupt it when applied over right IFG at either time point. Such a result suggests that right IFG does not take over function but may support it. Comparable studies have yet to be carried out with bilingual aphasic patients.

It is difficult to study recovery of function using fMRI or PET in the first week post-stroke as local vasculature dilates maximally and so alters normal neurovascular coupling. One approach that circumvents this difficulty correlates changes in blood flow to an area with recovery of function. Hillis, Kleinman, Newhart, Heidler-Gary, Gottesman, Barker, Aldrich, Llinas, Wityk, & Chaudhry (2006) showed that recovery of naming was dependent on the restoration of blood flow to three main areas of the cortex that included Broca's area (Brodmann area 44/45), Wernicke's area (Brodmann area 22) and one further area, a posterior inferior part of the temporal lobe (Brodmann area 37). Of the three areas Brodmann area 37 (the largest) is probably the most important as 50/60 patients who failed to restore blood flow to this area showed no improvement in naming. In contrast, single word auditory comprehension improvements correlated with restoration of blood flow to left Wernicke's area only. However, other areas are likely to be critical to auditory comprehension because damage in Wernicke's area may disrupt functioning in other more anterior areas usually spared by stroke (see Crinion, Warburton, Lambon-Ralph, Howard & Wise, 2006).

There is still a dearth of studies of bilingual patients with aphasia that chart the course of recovery using neuroimaging or perfusional changes. One ground breaking study is by Mariën, Abutalebi, Engelborghs and De Deyn (2005). They reported that improved functioning of the fronto-subcortical circuit coincided with relief of symptoms. E.M. was a 10 year-old, right-handed boy with English (L1) and with Dutch as L2. Oral proficiency was good in both languages premorbidly. Following a left thalamic lesion, L1 recovered, but fluent aphasia persisted in L2 despite speech therapy in L2 and greater exposure to L2. Five months post-stroke recurrent bleeding led to fluent aphasia in both L1 and in L2. Further, when speaking to monolingual speakers of either language, E.M. showed pathological language switching and mixing. L2 intrusions were common in a task requiring the use of L1 only. Perfusion imaging showed a decrease in blood flow in the left fronto-parietal and temporal regions and a region of the left basal ganglia (the left caudate nucleus). Remission of the symptoms of language mixing and switching was associated with increased blood flow to left frontal lobe and left caudate nucleus. In this later phase, where switching occurred it was under conscious control as a means to overcome word-finding difficulties (see patient E.C., in the study by Goral et al., 2006, above). However perfusion abnormalities remained in the left temporo-parietal areas and left thalamus. Indeed, E.M continued to display fluent aphasia in L1 and in L2 and could not perform the Stroop task. He also showed impaired translation at the single word and sentence level in both directions. Such data support the view of the necessity of frontal-basal ganglia circuits in the control of language. Further work is required to understand the precise nature of translation problems. For instance, it would be theoretically significant if translation was impaired even when the patient was able to name a given object in each language as it would support the view that translation involves distinct circuits of control.

Treatment Studies

Studies to date with monolinguals and bilinguals suggest that recovery and learning is often specific to the items trained. On the positive side, studies indicate that behavioural intervention can be effective in the chronic stage (i.e., months or years post the onset of aphasia) suggesting continuing plasticity.

In the treatment of bilingual aphasic patients, one of the central issues is the extent to which training in one language generalizes beyond that treatment set and to the translation equivalents in the other language and, in particular to cognates. In fact, the outcome remains unclear and may reflect the timing of an intervention, the extensiveness of training and the circumstances of language use. We consider studies that have looked at behavioural changes following an intervention and then consider work that relates behavioural change to neural substrate.

Hinckley (2003) did show generalization to novel items. Semantic and phonemic cues were used to aid picture naming in L1 and L2 in a patient who had suffered a left hemisphere stroke four months previously which had induced transcortical motor aphasia (deficits in naming and in expressive language but relatively preserved repetition in both languages). Treatment effects in Spanish and English were established using untrained items from standard tests, the PALPA (Kay, Coltheart & Lesser, 1992) and the BAT (Paradis & Libben, 1993). There was improvement in both languages and the greatest effects were for L1 (Spanish) compared to English (learned late in adolescence).

Kiran and Edmonds (2004) also found a degree of generalization to novel items. They examined two premorbidly right-handed English-Spanish bilinguals with aphasia following onset at least 8 months previously. Unfortunately, no lesion site information is supplied but premorbidly, patient 1 was more proficient in English whereas patient 2 was balanced. They used a semantic-based naming treatment that drew attention to the attributes of objects. Treatment effects varied with premorbid levels of proficiency. For the premorbidly balanced bilingual, training generalised to translation-equivalents in the other language and to semantically-related items. Performance on unrelated control items did not vary. For the English-dominant patient, untrained semantically-related items benefitted but there was no generalization to Spanish either for the translation-equivalents or for semantically-related items. The study suggests that treatment effects are rather restricted and the generalization of any benefit is modulated by prior levels of proficiency. However, for purposes of interpretation, it is also important to know about current language usage.

Kohnert (2004) showed generalization for cognates (words that look and sound similarly across languages) but not for non-cognates. Kohnert treated D.J., a 62 year-old Spanish-English male bilingual with severe non-fluent aphasia, following a single left embolic CVA a year previously. D.J. lived with his bilingual Spanish-English wife and son (primarily English-speaking). Conversational utterances were infrequent and restricted to 1-3 words, mainly in Spanish. In contrast to pre-morbid use, D.J. mixed utterances with unintended intrusions of words or phrases from the other language. On test, D.J. showed marked deficits in naming and in expressive language but relatively preserved repetition in both languages (the classic symptoms of transcortical motor aphasia). Cognitively, and arguably consistent with unintended intrusions, he showed poor performance on the Wisconsin Card Sorting task (0/7). Kohnert devised two successive treatments; a cognitive treatment that trained D.J. in non-verbal skills (e.g., card sorting tasks; single-digit addition and subtraction) and, a cognate treatment, which targeted 20 Spanish-English translations. Half of these were cognates (rosa/rose) and half were non-cognates (escoba/ broom). The intervention first in Spanish, and then in English, involved tasks such as identifying pictures of the training items from distractors and completing a cloze test ("She sweeps the floor with a ___________"). In addition to the training set, D.J. was tested on confrontational naming with 20 Spanish-English word pairs on four occasions; that is, before and after treatment in each language.

The cognitive training improved test performance speed and accuracy. D.J. also showed modest gains, relative to baseline, in confrontation naming in both Spanish and English tested using items that were not part of the treatment schedule. Enhanced information processing or general stimulation may have contributed to this.

The cognate training improved performance on untrained items in both Spanish and English. Naming cognates post-treatment in Spanish carried over to naming the same pictures in English a week later. There was no advantage, however, having previously named the non-cognate items. Kohnert argues that exploiting cross-language lexical-semantic links might be a way to maximize treatment gains especially in severe cases of aphasia (Paradis, 1993).

As discussed above, bilinguals can use their other language to aid communication in the event of a failure of lexical access. But this possibility is not always advantageous if the addressee does not speak that language. Ansaldo, Marcotte, Scherer and Raboyeau (in press) report on the case of E.L., a 56-year-old Spanish-English male with anomia and pathological language mixing and switching between languages following a left subcortical lesion. Ansaldo et al., used the best preserved ability (translation from English into Spanish) to overcome inappropriate language switching (i.e., switching into English when addressing a monolingual Spanish speaker-) in order to solve the lexical access problems in L1 (Spanish). The method 'switch-back through translation' worked by the speech and language therapist prompting EL immediately after an inappropriate switch from Spanish into English with the words "..que quiere decir ..?" (in English "which means..?) and so prompting E.L. to return to Spanish - the language of the conversation. Fading-out by the therapist and self-cuing by EL resulted in significant improvements.

Treatment can be effective even with chronic patients but is likely to be constrained to items in the trained set or to their semantic associates or cognates. In the next section we consider what is known about the neural basis of treatment effects.

Examining the Effects of an Intervention Using fMRI

Recent work examining treatment effects on speech output in monolingual patients have reported change in neural activity in tissue surrounding the lesion in the left-hemisphere, in right-hemisphere homologues and bilaterally (see Crinion & Leff, 2007 for a review) and in non-language related areas (see Fridriksson, Moser, Bonilha, Morrow-Odoma, Shaw, Fridriksson, Baylis, & Rorden, 2007). However, as Crinion and Leff note, larger numbers of patients are needed to establish the generality of any findings linking lesion site and behaviour and to rule out the possibility of differences in premorbid lateralization patterns.

An important line of work in bilinguals is to examine neural correlates of an intervention by using fMRI. Unfortunately, work of this type is still very rare with bilingual aphasia patients. In a pioneering example, Meinzer, Obleser, Flaisch, Eulitz, Rockstroh, (2007) examined treatment effects in C.Q.; a highly-educated, right-handed, 35-year old man, premorbidly highly proficient in both German and French that he had acquired early. C.Q. also spoke English and Italian. C.Q. suffered a left hemisphere stroke that damaged large parts of the fronto-temporo and parietal lobes, the posterior part of the insula and also included the putamen. Post-stroke C.Q. was rehabilitated in German (3 hours per week) but 32 months post-stroke C.Q., showed syntactic impairments and word-retrieval problems in German. Meinzer et al., tested C.Q. in an overt fMRI picture naming task in both German and French prior to, and after, short-term intensive language training in German (Constraint-Induced Aphasia Therapy, CIAT –see Pulvermueller et al., 2001).

Improved performance was restricted to pictures named in the training set. Out of a set of 80 pictures, C.Q. named 34 pictures correctly prior to training compared to 54 pictures post-training. Semantic paraphasias decreased from 22 to 10. In contrast there was no performance improvement on the untrained French items pre/post: 4/6). The results revealed a bilateral (fronto-temporal) increase in neural activity associated with improved naming ability following short-term intensive training only in the trained (German) language. No differences were found for picture-naming in French.
It is worth noting that 26/80 pictures were cognates but there was no transfer here (p. 1254) contrary to Kohnert (2004). A further important point, and one deserving of further study, is that during this intensive training, our understanding is that the patient continued to use German exclusively outside the clinic. Conceivably then French remained inhibited. Certainly French testing always followed German testing and so the French names would be in competition with the German names. We emphasize the need to take account of the precise nature of language use because this helps determine the way in which language control is exercised.

Future Directions

Research to date on bilingual speakers with aphasia has yet to get the heart of an important aspect of normal language use: our construal of events. We use language to refer to states of affairs and to event sequences in the world, but such events can be construed in different ways and such construals are constrained by language. English, for instance, emphasizes the motion aspects of an event whereas Spanish emphasizes the resultant state. A difficulty in retrieving verbs may reflect a difficulty in retrieving the word form. Alternatively, it may reflect a deficit at the level of construal, that is at the level of conceptual preparation (Levelt, Roelofs & Meyer, 1999) or 'thinking for speaking' (Slobin, 1996). Deficits at the level 'thinking for speaking' may be especially problematic for bilingual aphasic patients where the languages they speak differ in the construal of events that they demand. Further, problems in word retrieval may compound the difficulty of construing events in a language-relevant manner (see Dean & Black, 2005; and also for novel techniques for exploring 'thinking for speaking').

Much more work is needed to understand which regions and networks mediate recovery. Understanding the relationship between changes in regional blood flow post-stroke and the recovery of function is a vital step. The work of Hillis et al. (2006) in a large sample of monolingual patients and the single case study of a bilingual child by Mariën et al. (2005) are exemplary. Functional imaging studies are also important because they can help tackle theoretical predictions that are difficult to address in another way. For instance, if bilingual aphasics with better recovery of L2 compared to L1 make use of L2 metalinguistic knowledge in producing sentences in L2, then the neural pattern should differ from that evoked when speaking in L1. On the other hand, a proper interpretation of any such finding depends on establishing the variety of patterns in normal bilingual speakers (see Green et al., 2006). Only such information allows us to rule out the possibility that unusual patterns post-stroke reflect reorganisation of function rather than an example of an unusual, but normal, pre-morbid pattern.

We have focused in this review on neuropsychological and neuroimaging studies of single cases. But an important goal is to establish the nature of the correlations between lesion site and behavioural deficit. Lesions can now be described at the voxel-level (just as in functional imaging research) and voxel-based data can be related to continuous behavioural data (see Bates, Wilson, Saygin, Dick, Sereno, Knight, & Dronkers, 2003, for a pioneering example with monolingual aphasic patients). Voxel-based morphometry (VBM) identifies differences in grey or white matter based on structural MRI images. It has been used to examine the neuroanatomical bases of the different pattern of deficit in semantic dementia and herpes simplex encephalitis (e.g,, Noppeney, Patterson, Tyler, Stamatakis, Bright, Mummery, & Price, 2007) and it would be useful to extend it to examine the effect of grey-matter changes on task performance in bilinguals. To the extent a set of regions is necessary for performance of a task, such as generating instances of a semantic category or generating words beginning with a particular letter or phoneme), grey matter density should be predictive of relative differences in task performance in both languages of a bilingual aphasic patient. Current data are in line with this expectation (e.g., Grogan, Crinion, Ali, Green, & Price, 2007).

One value of this larger samples approach is that the relationship between grey-matter density and performance on a task can be used to estimate recovery. It could then provide an indicator of the extent of long-term support that might be needed but also offer a way to assess the effectiveness of any intervention. Success would be relative to the predicted recovery without the intervention.

As in the case of monolingual patients with aphasia, small amounts of therapy are unlikely to be effective. On the basis of a meta-analysis, Bhogal, Teasell, Foley and Speechley (2003) concluded that trials involving less than 52 hours of treatment never result in improvements whereas those with 60 hours or more always showed evidence of improvement.

Which aspects of treatment are efficacious is an important theoretical and practical matter. It would seem necessary to explore alternative ways to deliver treatment (other than therapist delivered) if large-scale trials are to be conducted. Pharmacological adjuncts to therapy may also improve the effectiveness of treatment (e.g., Berthier, Green, Higueras, Fernandez, Hinojosa, & Martin, 2006) and offer a further way to explore the dynamics of recovery when their use is combined with an examination of perfusional changes and fMRI studies to examine the nature of the plastic changes during the performance of language tasks.

Conclusions

A detailed neurocomputational understanding of the causal basis of different patterns of recovery remains to be developed. However, current data are consistent with the view that the acquisition of another language involves adapting an existing network. Different languages are represented in shared neural areas with common organizing principles. It is also important to consider how individuals control the use of their languages. Certain patterns of deficit reflect problems of control rather than of deficits of representation. There is still a dearth of studies examining neural changes over the course of recovery and treatment studies also remain sparse. But there is every prospect that progress can be made by combining neuropsychological and neuroimaging techniques and using these to examine the adaptive response of the brain to recovery and to treatment.

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NOTES

1. For instance, selective loss of a language may arise because of an inability to inhibit the schema for producing speech in one language rather than another (Green, 1986) or to raise the activation of the alternative sufficiently (see, Paradis, 1998). On similar lines, as outlined by Paradis (1998), parallel recovery would then occur when both languages are inhibited to the same degree. When inhibition affects only one language for a period of time, and then shifts to the other language (with disinhibition of the prior inhibited language) a pattern of antagonistic recovery occurs (Green, 1986). Pathological mixing among languages would occur when languages cannot be selectively inhibited (see Green & Abutalebi, in press, for an extended presentation on language control and bilingual aphasia).

ANNOTATED BIBLIOGRAHPY

Ansaldo, A. I., Marcotte, K., Scherer, L., & Raboyeau, G. (2008). Language therapy and bilingual aphasia: Clinical implications of psycholinguistic and neuroimaging research. *Journal of Neurolinguistics*. Doi: 10.1016/j.neuroling.2008.02.001.

This paper reports on the treatment of patient who showed pathological language mixing and switching between languages (Spanish and English). Ansaldo and colleagues used the patient's involuntary translation to switch back him back into the required language (Spanish) and so overcome lexical access problems in Spanish

Kohnert, K. (2004). Cognitive and cognate-based treatments for bilingual aphasia: A case study. *Brain and Language*, *91*, 294–302.

Naming cognates post-treatment in Spanish carried over to naming the same pictures in English a week later. There was no advantage having previously named the non-cognate items. Kohnert argues that exploiting cross-language lexical-semantic links might be a way to maximize treatment gains especially in severe cases of aphasia.

Mariën, P., Abutalebi, J., Engelborghs, S., & De Deyn, P.P. (2005). Acquired subcortical bilingual aphasia in an early bilingual child: pathophysiology of pathological language switching and language mixing. *Neurocase*, *11*, 385-398.

Exemplary use of brain imaging to chart course of recovery. Brain imaging showed a decrease in blood flow to the left fronto-parietal and temporal regions and in the left caudate nucleus. Remission of the symptoms of language mixing and switching was associated with increased blood flow to left frontal lobe and left caudate nucleus.

Meinzer, M., Obleser, J., Flaisch, T., Eulitz, C., & Rockstroh, B. (2007). Recovery from aphasia as a function of language therapy in an early bilingual patient demonstrated by fMRI. *Neuropsychologia*, *45*, 1247-1256.

Bilateral fronto-temporal increase in neural activity was associated with improved naming ability following short-term intensive training only in the trained (German) language. No differences were found for picture-naming in French. Such selectivity in treatment effect may reflect the support for linking meaning and word form in German in contrast to the lack of support offered for such links in French. It is noteworthy that naming in French always followed naming in German and that the patient used German only outside the clinic.

Paradis, M. (2004). *A neurolinguistic theory of bilingualism*. Amsterdam: John Benjamins

A scholarly, succinct and eminently readable review and theoretical account and critique that covers the fundamental issues in bilingualism and bilingual aphasia.

Ullman, M. T. (2005). A cognitive neuroscience perspective on second language acquisition: The declarative/procedural model. In C. Sanz (Ed.), *Mind and Context in Adult Second Language Acquisition: Methods, Theory and Practice* (pp. 141-178). Washington, DC: Georgetown University Press.

This chapter provides a wide-ranging review on the application of the declarative/procedural model to second-language acquisition

OTHER REFERENCES

Abutalebi, J., & Green, D.W. (2007). Bilingual speech production: The neurocognition of language representation and control. *Journal of Neurolinguistics*, *20*, 242-275.

Abutalebi, J., Cappa, S., & Perani, D. (2001). The bilingual brain as revealed by functional neuroimaging. *Bilingualism: Language and Cognition*, *4*, 179-190.

Albert, M.L., & Obler, L.K. (1978). *The bilingual brain: neuropsychological and neurolinguistic aspects of bilingualism.* London: Academic Press.

Alexiadou, A., & Stavrakaki, S. (2006). Clause structure and verb movement in a Greek–English speaking bilingual patient with Broca's aphasia: Evidence from adverb placement. *Brain and Language*, *96*, 207–220

Basnight-Brown, D.M., Chen, L., Hun, S., Kostić, A., Feldman, L.B. (2007). Monolingual and bilingual recognition of regular and irregular verbs: sensitivity to form similarity varies with first language experience. *Journal of Memory and Language*, *57*, 65-80.

Bates, E., Wilson, S., Saygin, A.P., Dick, F., Sereno, M., Knight, R.T., & Dronkers, N. (2003). Voxel based lesion-symptom mapping. *Nature Neuroscience*, 6, 448-450.

Bhogal, S.K., Teasell, R.W., Foley, N.C., & Speechley, M.R. (2003). Rehabilitation of aphasia: more is better. *Topics in Stroke Rehabilitation*, *10*, 66-76.

Berthier, M.L., Green, C., Higueras, C., Fernandez, I., Hinojosa, J., & Martin, M.C. (2006). A randomized, placebo-controlled study of donepezil in poststroke aphasia. *Neurology*, *67*, 1687-1689.

Black, M., & Chiat, S. (2003). Noun-verb dissociations: a multi-faceted phenomenon. *Journal of Neurolinguistics, 16*, 231-250.

Chen, L., Shu, H., Liu, Y., Zhao, J., & Li, P. (2007). ERP Signatures of Subject-Verb Agreement in L2 Learning. *Bilingualism: Language and Cognition*, *10*, 161-174.

Cohen, N.J., & Squire, L.R. (1980). Preserved learning and retention of pattern-analyzing skill in amnesia: dissociation of knowing how and knowing that. *Science*, *210*, 207-210.

Crinion, J.T., & Leff, A.P. (2007). Recovery and treatment of aphasia post stroke: functional imaging studies. *Current Opinion in Neurology*, *20*, 667-673.

Crinion, J.T., Warburton, E.A., Lambon-Ralph, M.A., Howard, D., & Wise, R.J. (2006). Listening to narrative speech after aphasic stroke: the role of the left anterior temporal lobe. *Cerebral Cortex*, *16*, 1116-1125.

Crinion, J., Turner, R., Grogan, A., Hanakawa, T., Noppeney, U., Devlin, J.T., Aso, T., Urayama, S., Fukuyama, H., Stockton, K., Usui, K., Green D.W., & Price C.J . (2006). Language control in the bilingual brain. *Science*, *312*, 1537-1540.

Dean, M., & Black, M. (2005). Exploring event processing and description in people with aphasia. *Aphasiology*, *19*, 521-544.

De Bot, K. (2008). Review article: The imaging of what in the multilingual mind? *Second Language Research*, *24*, 111–133.
De Bot, K., Verspoor, M., & Lowie, W. (2007). A dynamic systems theory approach to second language acquisition. *Bilingualism, Language and Cognition, 10*, 7–21.
De Diego Balaguer, R., Costa, A., Sebastián-Gallés, N., Juncadella, M., & Caramazza, A. (2005). Regular and irregular morphology and its relation with agrammatism: Evidence from Spanish and Catalan. *Brain and Language*, *91*, 212-222.
Druks, J., & Masterson, J. (2000). *An object and action naming battery*. Hove,England: Psychology Press.
Fabbro, F. (1999). *The neurolinguistics of bilingualism: An introduction*. Hove, Sussex: Psychology Press.
Fabbro, F., Skrap, M., & Aglioti, S. (2000). Pathological switching between languages following frontal lesions in a bilingual patient. *Journal of Neurology, Neurosurgery and Psychiatry*, *68*, 650-652.
Fridriksson, J., Moser, D., Bonilha, L., Morrow-Odoma, K.L., Shaw, H., Fridriksson, A., Baylis, G.C., & Rorden, C.(2007). Neural correlates of phonological and semantic-based anomia treatment in aphasia. *Neuropsychologia*, *45*, 1812–1822.
García-Caballero, A., Garcia-Lado, I., González-Hermida, J., Area, R., Recimil, M.J., Juncos Rabadán, O., Lamas, S., & Jorge, F.J. (2007). Paradoxical recovery in a bilingual patient with aphasia after right capsuloputaminal infarction. *Journal of Neurology, Neurosurgery and Psychiatry*, *78*, 89-91.
Golestani, N., Alario, F-X., Meriaux, S., Le Bihan, D., Dehaene, S., & Pallier, C. (2006). Syntax production in bilinguals. *Neuropsychologia*, *44*, 1029-1040.
Goral, M., Levy, E.S., Obler, L.K., & Cohen, E. (2006). Cross-language lexical connections in the mental lexicon: Evidence from a case of trilingual aphasia. *Brain and Language*, *98*, 235–247.
Graf, P., & Schacter, D.L. (1985). Implicit and explicit memory for new associations in normal and amnesic patients. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *11*, 501-518.
Green, D.W. (1986). Control, activation and resource: a framework and a model for the control of speech in bilinguals. *Brain and Language*, *27*, 210-223.
Green, D.W. (2003). The neural basis of the lexicon and the grammar in L2 acquisition: the convergence hypothesis. In R. van Hout, A. Hulk, F. Kuiken and R. Towell (Eds.), *The interface between syntax and the lexicon in second language acquisition*. (pp. 197-218). Amsterdam: John Benjamins.
Green, D.W. (2005). The neurocognition of recovery patterns in bilingual aphasics. In J.F. Kroll & A. M.B. de Groot (Eds.). *Handbook of bilingualism: psycholinguistic approaches*. (pp.516-530). Oxford: Oxford University Press.
Green, D.W., & Abutalebi, J. (2008). Understanding the link between bilingual aphasia and language control. *Journal of Neurolinguistics*. Doi: 10.1016/j.neuroling.2008.01.02
Green, D. W., & Price, C. J. (2001). Functional imaging in the study of recovery patterns in bilingual aphasics. *Bilingualism: Language and Cognition*, *4*, 191-201.
Green, D.W., Crinion, J., Price, C. J. (2006). Convergence, degeneracy and control. *Language Learning*, *56* (s1), 99-125.
Grogan, A. , Crinion, J., Ali, N., Green, D.W., & Price, C.J.(2007). A VBM study of semantic fluency in the normal and damaged brain. *Human Brain Mapping Conference*, Chicago, IL, USA, 10th.-14th. June, 2007.
Grosjean, F. (1998). Studying bilinguals: methodological and conceptual issues. *Bilingualism: Language and Cognition*, *1*, 131-140.

Hernandez, A., Li, P., and MacWhinney, B. (2005). The emergence of competing modules in bilingualism. *Trends in Cognitive Sciences,* 9, 222-225.

Hernández, M., Costa, A., Sebastián-Gallés, N., Juncadella, M., & Reñé. R. (2007). The organization of nouns and verbs in bilingual speakers: A case of bilingual grammatical category-specific deficit. *Journal of Neurolinguistics*, *20*, 285-305.

Hillis, A.E. (2006). The right place at the right time? *Brain*, *129*, 1351-1356.

Hillis, A.E., Kleinman, J.T., Newhart, M., Heidler-Gary, J., Gottesman, R., Barker, P.B., Aldrich, E., Llinas, R., Wityk, R., & Chaudhry, P. (2006). Restoring cerebral blood flow reveals neural regions critical for naming. *Journal of Neuroscience*, *26*, 8069-8073.

Hinckley, J. (2003). Picture naming treatment in aphasia yields greater improvement in L1. *Brain and Language*, *87*, 171–172.

Indefrey, P. (2006). A meta-analysis of hemodynamic studies on first and second language processing: Which suggested differences can we trust and what do they mean? *Language Learning*, *56*, 279–304.

Jarema, G., Perlak, D., & Semenza, C. (2007). The processing of compounds in bilingual aphasia. *Brain and Language*, *103*, 22-23.

Kambanaros, M. & van Steenbrugge, W. (2006). Noun and verb processing in Greek–English bilingual individuals with anomic aphasia and the effect of instrumentality and verb–noun name relation. *Brain and Language*, *97*, 162–177.

Kay, J., Coltheart, M., & Lesser, R. (1992). *Pyscholinguistic Assessment of Language Processing in Aphasia*. Hove: Sussex; Psychology Press

Kiran, S., & Edmonds, L.A. (2004). Effect of semantic naming treatment on crosslinguistic generalization in bilingual aphasia. *Brain and Language*, *91*, 75–77.

Kiran, S. & Tuctenhagen, J. (2005). Imageability effects in normal bilingual adults and in aphasia: evidence from naming to definition and semantic priming tasks. *Aphasiology*, *19(3/4/5)*, 315-325.

Kotz, S.A., Frisch, S., von Cramon, D.Y., Friederici, A.D. (2003). Syntactic language processing: ERP lesion data on the role of the basal ganglia. *Journal of the International Neuropsychological Society*, *9*, 1053-1060.

Kroll, J.F., & Stewart, E. (1994). Category interference in translation and picture naming: Evidence for asymmetric connection between bilingual memory representations. *Journal of Memory and Language*, *33*, 149-174.

Levelt, W.J.M., Roelofs, A., & Meyer, A.S. (1999). A theory of lexical access in speech production. *Behavioural and Brain Sciences*, *22*, 1-75.

Longworth, C.E., Keenan, S.E., Barker, R.A., Marslen-Wilson, W.D., & Tyler, L.K. (2005). The basal ganglia and rule-governed language use: evidence from vascular and degenerative conditions. *Brain*, *128*, 584-596.

Lucas, T. H., McKhann, G. M., & Ojemann, G. A. (2004). Functional separation of languages in the bilingual brain: A comparison of electrical stimulation language mapping in 25 bilingual patients and 117 monolingual control patients. *Journal of Neurosurgery*, *101*, 449–457.

Noppeney, U., Patterson, K., Tyler, L.K., Moss, H., Stamatakis, E.A., Bright, P., Mummery, C., & Price, C. (2007). Temporal lobe lesion and semantic impairment: a comparison of herpes simplex virus encephalitis and semantic dementia. *Brain*, *130*, 1123-1147.

Osterhout, L., McLaughlin, J, Pitkanen, I., Frenck-Mestre, C., & Molinaro, N. (2006). Novice learners, longitudinal designs, and event-related potentials: A means for

exploring the neurocognition of second language processing. *Language Learning, 56*, 199-203.
Paradis, M. (1993). Bilingual aphasia rehabilitation. In M. Paradis (Ed.), *Foundations of aphasia rehabilitation* (pp. 413-419). Oxford: Pergamon Press.
Paradis, M. (1998). Language and communication in multilinguals. In B. Stemmer and H. Whitaker (Eds.), *Handbook of Neurolinguistics* (pp. 417-430). San Diego, CA: Academic Press.
Paradis, M. (2008). Language communication disorders in multilinguals. In B. Stemmer and H. Whitaker (Eds.), *Handbook of the Neuroscience of Language.* (pp.341-349). London: Elsevier Science/Academic Press.
Paradis, M., & Libben, G. (1993). *The assessment of bilingual aphasia*. Hillsdale: NJ: Lawrence Erlbaum Associates.
Pitres, A. (1895). Etude surl'aphasie chez les polyglottes [Aphasia in polyglots]. *Revue de médecine*, *15*, 873-899. [Translated in M.Paradis (Ed.), Readings on aphasia in bilinguals and polyglots (pp. 26-48). Montral: Marcel Didier].
Poncelet, M., Majerus, S., Raman, I., Warinbaire, S., & Weekes, B.S. (2007). Naming actions and objects in bilingual aphasia: a multiple case study. *Brain and Language*, *103*, 158-159.
Pulvermueller, F., Neininger, B., Elbert, T., Mohr, B., Rockstroh, B., Koebbel, P., et al. (2001). Constraint-induced therapy of chronic aphasia after stroke. *Stroke*, *32*, 1621–1626.
Ribot, T. (1882). *Disease of memory: An essay in the positive psychology*. London: Paul.
Riccardi, A., Fabbro, F., & Obler, L.K. (2004). Pragmatically appropriate code-switching in a quadrilingual with Wernicke's aphasia. *Brain and Language*, *91*, 54-55.
Roediger, H. L., III (2000). Why retrieval is the key process in understanding human memory. In E. Tulving (Ed.), *Memory, consciousness, and the brain: The Tallinn Conference* (pp. 52-75). Philadelphia: Psychology Press.
Ryan, J.D., & Cohen, N.J. (2003). Evaluating the neuropsychological dissociation evidence for multiple memory systems. *Cognitive, Affective, & Behavioral Neuroscience*, *3*, 168-185.
Saur, D., Lange, R., Baumgaertner, A., Schraknepper, V., Willmes, K., Rijntjes, M., & Weiler, C. (2006). Dynamics of language reorganization after stroke. *Brain*, *129***,** 1371-1384.
Slobin, D.I. (1996). From 'thought and language' to 'thinking for speaking'. In J.J. Gumperz & S.C. Levinson (Eds.), *Rethinking linguistic relativity*. (pp. 70-96). Cambridge: Cambridge University Press.
Ullman, M.T. (2001). The neural basis of lexicon and grammar in first and second language: the declarative/procedural model. *Bilingualism: Language and Cognition, 4*, 105-122.
Van Hell, J.G., & De Groot, A.M.B. (1998). Conceptual representation in bilingual memory: effects of concreteness and cognate status in word association. *Bilingualism*, *1*, 193-211.
Winhuisen, L., Thiel, A., Schumacher, B., Kessler, J., Rudolf, J., Haupt, W.F., & Heiss, W.D. (2007).The right inferior frontal gyrus and poststroke aphasia: a follow-up investigation. *Stroke*, *38***,** 1286-1292.