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Language control and parallel recovery of language in individuals with aphasia

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Background: The causal basis of the different patterns of language recovery following stroke in bilingual speakers is not well understood. Our approach distinguishes the representation of language from the mechanisms involved in its control. Previous studies have suggested that difficulties in language control can explain selective aphasia in one language as well as pathological switching between languages. Here we test the hypothesis that difficulties in managing and resolving competition will also be observed in those who are equally impaired in both their languages even in the absence of pathological switching.

Aims: To examine difficulties in language control in bilingual individuals with parallel recovery in aphasia and to compare their performance on different types of conflict task.

Methods & Procedures: Two right-handed, non-native English-speaking participants who showed parallel recovery of two languages after stroke and a group of non-native English-speaking, bilingual controls described a scene in English and in their first language and completed three explicit conflict tasks. Two of these were verbal conflict tasks: a lexical decision task in English, in which individuals distinguished English words from non-words, and a Stroop task, in English and in their first language. The third conflict task was a non-verbal flanker task.

Outcomes & Results: Both participants with aphasia were impaired in the picture description task in English and in their first language but showed different patterns of impairment on the conflict tasks. For the participant with left subcortical damage, conflict was abnormally high during the verbal tasks (lexical decision and Stroop) but not during the non-verbal flanker task. In contrast, for the participant with extensive left parietal damage, conflict was less abnormal during the Stroop task than the flanker or lexical decision task.

Conclusions: Our data reveal two distinct control impairments associated with parallel recovery. We stress the need to explore the precise nature of control problems and how control is implemented in order to develop fuller causal accounts of language recovery patterns in bilingual aphasia.

Keywords: Language control; Bilingual aphasia.

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A language task, such as describing an event, is a process in which alternative formulations and expressions compete for selection. Understanding the control processes involved is important for accounts of performance post-stroke in monolingual speakers (see, for example, Dean & Black, 2005) and is core to theoretical accounts of recovery patterns in bilingual aphasia (Abutalebi, Miozzo, & Cappa, 2000; Fabbro, Skrap, & Aglioti, 2000; Green, 1986, 1998; Green & Price, 2001; Paradis, 1998, 2004; Pitres, 1895). Different patterns of language recovery in bilingual individuals (Paradis, 1998, 2001, 2004; see also Fabbro, 1999) reflect the ease with which individuals can select and control language representations following damage to frontal-parietal-subcortical networks mediating language selection and control (Abutalebi & Green, 2007; Green & Price, 2001).

Problems controlling language selection may underlie reported cases of selective recovery of one language (Fabbro & Paradis, 1995; García-Caballero et al., 2007; Ku, Lachman, & Nagler, 1996), or pathological language mixing (Abutalebi et al., 2000), and of inadvertent switching between languages in the absence of any other deficits in production or comprehension (Fabbro et al., 2000). To our knowledge, however, the nature of language control in parallel recovery has not been addressed empirically even though this pattern of recovery could reveal different control problems. We hypothesise that problems of language control are relevant to understanding the parallel pattern of language recovery where there is no difficulty selecting or maintaining the language in use (Green, 2005; Green & Price, 2001; Paradis, 2004).

In parallel recovery both languages are recovered to the same degree relative to their pre-morbid levels. Using explicit tests of verbal and non-verbal control, we examined the performance of two individuals who had aphasia in their main two languages following stroke. Our aim was to determine if the parallel pattern of recovery reflects a general problem of control, one primarily restricted to the verbal domain, or one associated with different impairments of control in different individuals. We rely on the distinction between representation and control but do not explore the more specific conjecture that inhibitory processes are central to such control (Green, 1998).

Our basic idea was that if language performance in individuals with aphasia (whether monolingual or bilingual) reflects their ability to control aspects of language use by, for example, selecting relevant words in the face of competition from other words, then any difficulty in verbal control should be most evident in tasks that explicitly demand such control. In order to measure language performance we asked participants with aphasia to describe a depicted event (a composite picture) in English and a second depicted event in their first language (L1), which was also their other main language. We scored their spoken descriptions using a standard system (see *Comprehensive Aphasia Test*; Swinburn, Porter, & Howard, 2004). Next, each participant completed three explicit conflict tasks (two verbal and one non-verbal) and a short test of general cognitive ability (Raven, 1938).

Before we describe the explicit conflict tasks that we used and their explanatory value, we discuss the nature of language control in unimpaired speakers of more than one language. In order to understand the patterns of language recovery we need to understand the nature of the cognitive-linguistic system in such speakers. We contend that there are processing costs and processing benefits associated with the use of two languages in unimpaired speakers. There are costs in terms of lexical access and naming and benefits deriving from the need to manage competition between two (or more) languages.

LANGUAGE CONTROL IN BILINGUAL SPEAKERS

Consider the task of describing a depicted event. Speakers select the appropriate language and construe the event in a language appropriate manner ("thinking for speaking"; Slobin, 1996). They must then express that construal by selecting appropriate words and organising these words grammatically (Dean & Black, 2005). In order to do so they must select between alternative object and action names. When speaking in their second language, there is the additional challenge of managing competition from the first language (Green, 1998).

Research with unimpaired bilingual speakers indicates processing costs associated with knowing another language attributable, at least in part, to competitive effects. Relative to monolingual speakers, bilingual speakers are slower at naming objects (Kaushanskaya & Marian, 2007) and experience more "tip of the tongue" states (Gollan & Acenas, 2004). Bilinguals are also slower to make lexical decisions about words even in their first language (e.g., Ransdell & Fischler, 1987) and experience greater difficulty identifying words in noise (Rogers, Lister, Febo, Besing, & Abrams, 2006).

Differences in the relative use of words in each language compared to monolingual speakers may be one source of differences. But there is also experimental evidence that interference from the other language is a major source in production. When a person is speaking in their second language, the first language name of the object competes for production (see Kroll, Bobb, & Wodniecka, 2006, for a review). In a lexical decision task in which bilinguals have to decide if a presented letter string is a word in their second language or not, the time required to correctly reject a letter string as a non-word in the second language depends on whether it is a possible word in the first language (Altenberg & Cairns, 1983; Von Studnitz & Green, 1997; for a model see Dijkstra, 2005; Dijkstra & Van Heuven, 2002). Likewise the time required to accept a letter string in the second language depends on whether it is also a real word in the first language (Dijkstra, Van Jaarsveld, & ten Brinke, 1998; Von Studnitz & Green, 2002). In short, bilingual readers of a second language must manage interference from their first language. Data from speech processing in bilinguals leads to the same conclusion: non-native speakers suffer increased lexical competition (Weber & Cutler, 2004).

Interestingly, bilingual speakers acquiring both languages early and using both languages on a regular basis are less affected by conflicting information in a non-verbal flanker task compared to monolingual speakers (Costa, Hernandez, & Sebastián-Gallés, 2008). Bialystok (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004) has argued that practise in handling verbal conflict has made these individuals more skilled at suppressing interfering information. It is reasonable, therefore, to expect that bilinguals might also be better at handling certain types of verbal interference.

Recent work shows that bilingual speakers show less Stroop interference compared to monolingual speakers (Bialystok, Craik, & Luk, 2008). Arguably, bilingual speakers have less automatic word-reading skills and the reduced interference is simply a by-product of this phenomenon. However, the advantage remained even when reading speed was taken into account. Bilingualism may thus convey a general advantage in suppressing conflicting information. If so, it enhances an important aspect of executive functioning (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000).

One challenge to the view that bilingual speakers are more skilled at suppressing interfering information, is that bilinguals show a *disadvantage* in English lexical decision

(e.g., Ransdell & Fischler, 1987; Von Studnitz & Green, 2002). It is conceivable that a bilingual advantage on tasks of executive function may be restricted to contexts where there is a single dominant competitor as in the Stroop and flanker tasks. More plausibly, however, bilinguals experience greater competition than monolinguals in lexical decision because of activation of words in L1. Indeed, bilinguals might experience an even greater disadvantage on the lexical decision task were it not for their enhanced skill in suppressing interference.

In order to examine language control in our participants with aphasia we used an English lexical decision task, a verbal Stroop task (in English and in L1) and a non-verbal flanker task. We outline our predictions below. For each task we contrasted performance of unimpaired European bilingual controls and monolingual English speaking controls and then compared the performance of two participants with aphasia to the bilingual controls. Given the possibility that participants with aphasia might differ in their overall reaction times and accuracy from bilingual controls, we also assessed proportional changes as a function of conflict. We describe these "conflict ratios" in the Results section.

EXPLICIT CONFLICT TASKS

In the English lexical decision task individuals decide whether a presented letter string is a word in English or not. To indicate their response, participants use two fingers of their preferred hand and press one of two response buttons mounted on a single response box. Non-words are possible words in English; that is, they are consistent with English spelling and are pronounceable (e.g., "fict", "pell", "settion"). We had two aims in using this task. First, accuracy in identifying English words is an indicator of word knowledge and the time required to do so provides an index of reading speed. Second, the time and accuracy to correctly reject possible words in English (non-words), provides a measure of the ability to handle lexical conflict. Given prior research we expected that, relative to monolingual English speakers, our unimpaired bilingual speakers, who used English as a second language, would be less accurate when identifying real words and would show a greater increase in the time required to correctly reject non-words relative to accepting real words. In the case of participants with aphasia, we expected a substantial increase in reaction time, or a substantial decrease in accuracy, to correctly reject non-words resulting from a problem in handling lexical competition. Critically, this outcome should be observed with relatively unimpaired word recognition, which would demonstrate a reasonable knowledge of English words.

We used the colour-word version of the Stroop task to examine control of conflict in a verbal task that requires a vocal rather than a manual response (Stroop, 1935; for a review see MacLeod, 1991). We contrasted naming time on conflict trials (naming the ink colour of a word representing a different colour, for example the word RED printed in green) with naming time on neutral trials (naming the ink colour of a string of Xs). We used an equal number of neutral and conflict trials to minimise strategic effects (Long & Pratt, 2002). This task allowed us to assess the ease with which individuals can suppress interference when there is an explicitly presented interfering word that is part of the response set. Our expectation was that our bilingual controls would show less Stroop interference in English compared to the monolingual controls even when effects of word reading time were removed, as indexed by reaction time to identify words correctly in the lexical decision task. For

our participants with aphasia, impaired control would be indexed by an above average increase in the time required to respond on conflict relative to neutral trials and/or an above average decrease in accuracy.

We also used a non-verbal flanker task to examine if participants had a general executive problem, which could lead to a difficulty in control of verbal interference (Fan, McCandliss, Sommer, Raz, & Posner, 2002). This task required participants to determine whether a target arrow presented centrally on a screen pointed to the left or right. Participants used the fingers of their preferred hand to press one of two response buttons mounted on a single response box to indicate their response. The target arrow was accompanied by flanking arrows that pointed either in the same direction as the target arrow (congruent trials) or in the opposite direction to the target arrow (incongruent trials). Given prior research, and assuming commonality with previously tested groups, we expected bilingual speakers, relative to monolingual speakers to show either less interference (Costa et al., 2008) or faster responses to both congruent and incongruent trials (Bialystok et al., 2008). Impaired control in participants with aphasia would then be indexed by an above average increase in responding to incongruent trials and/or by an above average decrease in accuracy. Alternatively, there may be large increases in latency to both types of trial and decreased accuracy relative to the control participants.

PREDICTED PATTERNS OF PERFORMANCE ON THE EXPLICIT CONFLICT TASKS

Overall, we expected bilingual speakers to show increased effects of conflict in the English lexical decision task (because of increased competition from words in their first language) and a decreased effect of conflict in the English Stroop task (because of their greater experience in controlling interference) relative to monolingual controls. Finally, we expected that if bilingual speakers were better able to control conflicting information, they might show a decreased effect of conflict in the non-verbal flanker task. For participants with aphasia, we supposed two possibilities. First, we expected impaired verbal control (evident by increased effects of conflict in the lexical decision task and the English Stroop task) but no general executive impairment indicated by a normal effect of conflict in the flanker task. Second, we expected that impaired verbal control might reflect a more general executive problem. In that case, impaired performance on the two verbal tasks would be associated with impaired performance on the non-verbal flanker task.

METHOD

Participants

We report data from two female, right-handed individuals with aphasia, Pt1 and Pt2, who fulfilled the following inclusion criteria: (a) first language (L1) was European but not English; (b) English was the second best language after their L1 and in use prior to brain damage; (c) language performance was impaired in both English and the first language as assessed by the Comprehensive Aphasia Test (CAT, Swinburn et al., 2004) and the Bilingual Aphasia Test (BAT: Paradis & Libben, 1987); (d) able to complete the picture description task in English and their L1, were above chance on the conflict tasks and on Raven's test (Raven, 1938); (e) were at the chronic stage

after stroke (more than 2 years) and (f) showed no evidence of difficulty selecting or maintaining the language in use. The participants could therefore be categorised as showing parallel recovery of English and their first language. Table 1 reports relevant details of their case histories. Both had normal or corrected vision and acquired English relatively late.

Pt1 had a large subcortical left hemisphere stroke that removed most of her left lentiform nucleus (putamen and globus pallidus), see Figure 1. She was a housewife prior to her stroke and is now a full-time carer for her husband. On subtests from the CAT, Pt1 scored below the fifth percentile of unimpaired performance on picture naming, written sentence comprehension, and word reading, but not single word comprehension or non-word reading, see Table 2. On subtests from the French BAT, Pt1 also performed poorly on the complex commands and written sentence comprehension (Table 3). Pt1 was also more impaired when translating both words and sentences from French to English than vice versa despite intact performance in recognising the translation of words.

Pt2 had several thrombo-embolic strokes over a 2-day period after a heart attack and thrombolysis treatment. There was extensive left middle cerebral artery damage that primarily destroyed her left parietal lobe but also impinged on her left frontal and temporal cortices with additional damage in the bilateral occipital lobes, see Figure 2. Her basal ganglia appeared intact. Pt2 communicates effectively with limited verbal

TABLE 1
Language background information for the participants with aphasia and bilingual controls

Participants	*Pt1*	*Pt2*		
Age at testing:	65	47		
Time post stroke:	11 years, 8 months	6 years, 1 month		
Native language:	French	Spanish		
Age English acquired:	12	28		
Resident in UK:	40+ years	19 years		
	Current usage[1]	*S.R.P*[2]	*Current usage*	*S.R.P*
French:	40	8	–	–
English:	40	7	95	5.5
Spanish:	10	7	5	8
Hebrew:	10	3	–	–
Controls ($N = 12$)	*M*	*Range*		
Age at testing	34.8	24–59		
Age English acquired	10.5	3–26		
Number of languages	3.5	2–5		
	Current usage		*S.R.P*	
	M	*Range*	*M*	*Range*
English[3]	52.5	20–70	7.6	5–9
L1	46.3	30–80	8.9	8.3–9

[1]Current daily usage in %. [2]SRP = Mean self-rated proficiency (/10): premorbid level for each participant with aphasia. [3]Based on $n = 9$.

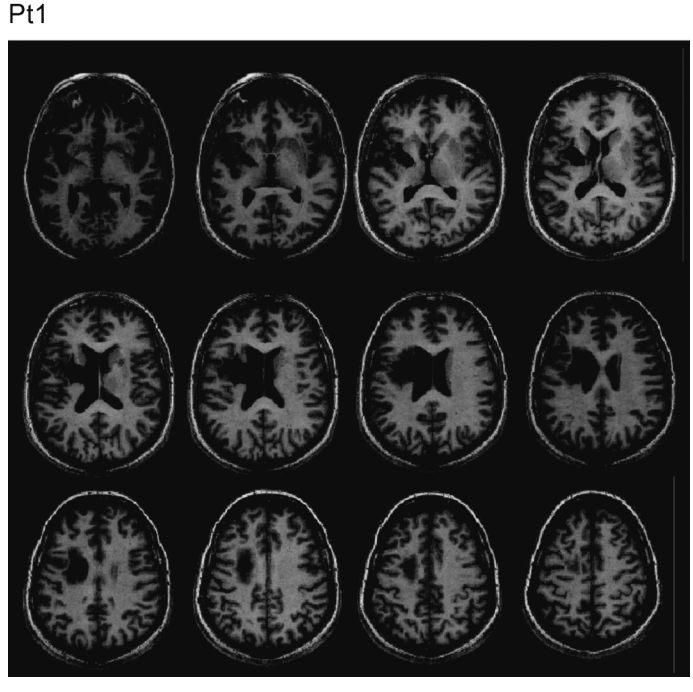

Figure 1. Stroke damage in Pt1.

output skills and excellent non-verbal communication skills, functions independently at home and runs her own company (premorbidly she was a doctor).

On subtests from the CAT, Pt2 scored below the fifth percentile of unimpaired performance on all writing and speaking tasks except non-word reading, see Table 2. There was no evidence of memory impairments. On subtests from the Spanish BAT, Pt2 had considerable difficulty understanding complex commands and written paragraphs (Table 3). Her difficulty in translating English sentences into Spanish (Table 4) most likely reflects impaired comprehension in English.

We recruited 12 unimpaired bilingual speakers who were non-native speakers of English. This group consisted of individuals with a range of European languages as their first language (French/German/Spanish/Greek) and mostly with English as a late acquired second language. They differed in the number of languages spoken (to cover the number of languages spoken by the participants with aphasia) but for simplicity's sake we refer to them as bilingual controls rather than bi-/multilingual controls. Table 1 summarises the language information for these participants. We also recruited 14 unimpaired monolingual native English speakers to complete the explicit conflict tasks. This was a second control group, which enabled us to assess the impact of bilingual experience on performance in the explicit conflict tasks.

Procedure

Participants with aphasia and bilingual controls completed a Language Background Questionnaire that covered acquisition and use of each language. Proficiency in reading, writing, speech understanding, and comprehension was estimated on a 10-point

TABLE 2
Scores for Pt1 and Pt2 on the Comprehensive Aphasia Test (CAT)

	Pt1	*Pt2*	*Cutoff*
Cognitive			
Line bisection	53	53	41
Semantic memory	60	60	51
Recognition memory	59	48	48
Total memory	62	54	50
Gesture	68	55	55
Arithmetic	65	53	44
Repetition			
Total	60	**46***	60
Words	65	46	57
Complex words	62	38	62
Non-words	58	53	53
Sentences	63	**48***	63
Naming			
Total	**60***	**62***	63
Objects	**61***	**58***	62
Actions	**49***	**54***	63
Comprehension			
Spoken total	61	**45***	57
Spoken words	60	**51***	53
Spoken sentences	63	**42***	61
Spoken paragraphs	49	**43***	49
Written total	**56***	**50***	60
Written words	65	65	55
Written sentences	**54***	**46***	59
Reading			
Total	61	61	61
Words	**58***	61	62
Complex words	67	61	61
Function words	62	62	49
Non-words	61	58	58
Writing			
Picture names	62	**54***	55

All scores are *t*-scores. Those in bold with an asterisk are below the cut-off for unimpaired performance.

scale from 1 (very low proficiency) to 10 (very high proficiency). Mean values are shown in Table 1. Participants also completed the composite picture description task in English and in their L1, together with the explicit conflict tasks (a lexical decision task in English; a Stroop test in English and in their L1; and the non-verbal flanker task). Composite picture descriptions were elicited by native speakers and scored by the person administering the test using the guidelines set out in the CAT manual. Tests for each of the languages were completed in different sessions on the same day with a break between the different languages.

Participants with aphasia also completed sections from the CAT and subtests of the relevant bilingual aphasia tests. Both participants were tested in English by the same native speaker and tested in their first language by native speakers. These

TABLE 3
Bilingual Aphasia Test (BAT) scores for Pt1 and Pt2 in English and in L1

	Pt1		*Pt2*	
	English	*French*	*English*	*Spanish*
Expression				
Sentence construction (/31)	29	27	20	24
Repetition				
Words (/30)	–	30	–	25
Comprehension				
Pointing (/10)	10	10	10	10
Simple and semi-complex commands (/10)	10	10	7	9
Complex commands (/20)	12	11	11	5
Spoken commands total (/40)	32	31	28	24
Spoken paragraph (/5)	–	5	–	4
Written words (/10)	10	10	9	8
Written sentences (/10)	–	4	–	6
Written paragraph (/6)	6	6	3	1
Reading				
Lexical decision (/30)	–	30	–	27
Words (/10)	–	10	–	10
Sentences (/10)	10	10	10	10

confederates had observed a testing session (in English) and read the BAT before testing. Monolingual speakers completed explicit conflict tasks. All participants completed Raven's Progressive Matrices Test.

Materials and tasks

Picture description. In separate sessions, participants with aphasia completed a picture description task describing one picture in English for 1 minute and a second different picture for 1 minute in their first language (their other best language). The pictures were taken from the CAT and the Boston Diagnostic Aphasia Examination (BDAE; Goodglass & Kaplan 1972). The picture descriptions were scored according to criteria in the CAT manual, in English and in the other language by native speakers. The picture description score covered both content and manner of expression. The content measure is the sum of appropriate information carrying words minus inappropriate information carrying words. To this are added values for syntactic variety (on a scale of 0 to 6), grammatical well-formedness (on a scale of 0–6) and speed of speech production (on a scale of 0–3). Inspection of the scores from the bi/multilingual controls showed no differences between the two pictures in English or the other best language (L1). Both participants with aphasia also completed additional sections of the CAT and the BAT (see Tables 2, 3, and 4). Sections from the CAT provided a cognitive screen as well as providing tests of language. Sections of the BAT were selected to avoid overlap with the CAT. Two tests in the BAT require comment. In the comprehension of commands test the participant performs various tasks in response to commands that range in complexity from simple (e.g., "put the fork in the glass") to more complex (e.g., "open the first envelope, turn over the cup

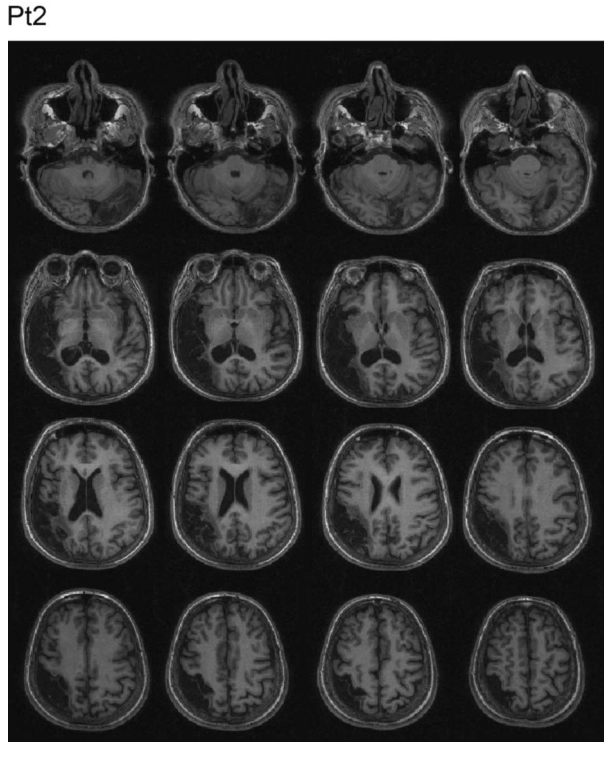

Figure 2. Stroke damage in Pt2.

TABLE 4
Bilingual Aphasia Test (BAT) scores on translation for Pt1 and Pt2

	Pt1		*Pt2*	
	English to French	*French to English*	*English to Spanish*	*Spanish to English*
Translation recognition				
Word (/5)	5	5	5	5
Translation production				
Word (/10)	8	5	9	10
Sentence (/18)	15	10	6	10

and pick up the spoon"). If performance is not correct overall on the complex command, the participant is given a score for each single command performed correctly regardless of whether it was performed in the correct sequence. In the sentence construction task, the participant creates a sentence using single words read aloud to them.

Explicit conflict tasks. The lexical decision task was adapted from materials taken from the Psycholinguistic Assessment of Language Processing in Aphasia (PALPA; Kay, Lesser, & Coltheart, 1992). Non-words were possible words in English derived

from real words (but not words presented in the task) by changing one or more letters. Following a practice block (10 words/10 non-words), participants completed an experimental session comprising 60 word and 60 non-word trials in a random sequence and divided into six blocks of 20 trials. Each letter string was displayed on a computer screen, and participants used fingers of their preferred hand to press one of two response buttons mounted on a response box to indicate if it was a word or not. The programme recorded reaction time and accuracy and the task, with between-block breaks, took approximately 20 minutes.

The Stroop task was presented to participants in English and in their L1. This task contrasted performance on neutral trials with conflict trials. A neutral trial consisted of five capital Xs printed on a black background in a single colour: red, yellow, blue, or green. A conflict trial consisted of a capitalised colour word, red, yellow, blue, and green or the L1 translation equivalent for each participant in an incongruent colour on a black background. Following a practice block of 12 trials participants completed two blocks of 24 experimental trials (half neutral, half conflict). Trials occurred in a pseudo-random sequence such that each colour and colour name appeared equally often with no repetition of a colour name on adjacent trials (i.e., the design avoided negative priming from a previous trial) and no occasion in which a colour word was the name of the hue on the current trial. Stimuli were displayed such that the first letter of the colour word (for conflict stimuli) or the first X (for neutral stimuli) was centred on the screen. Each stimulus remained on the screen until a vocal response was detected by the voice-activated relay. The response-stimulus interval was 1 second. All naming latencies were recorded and one of the experimenters observed the session and noted errors. With a short-break half way through the experimental trials, each Stroop task took about 8 minutes.

In the flanker task participants used fingers of their preferred hand to press one of two response buttons mounted on a single response box to indicate whether a central arrow pointed left or right. The arrow appeared above or below fixation and was accompanied by flanking arrows pointing in the same direction (congruent trials) on half the trials and arrows pointing in the opposite direction on half the trials (incongruent trials). In addition, in the version of the task we used (Fan et al., 2002), there were three warning conditions: no cue, centre cue, and a spatial cue that signalled the location of the trial (above or below fixation). Spatial cues were always valid. Accuracy and reaction time for congruent and incongruent trials were summed over the cueing conditions. Following a practice session with feedback, participants completed 140 trials, half of which were congruent and half of which were incongruent. The task, with breaks, took approximately 30 minutes.

Raven's progressive matrices

As a basic screen for general cognitive impairment we used the 12 items of set A from Raven's coloured progressive matrices (Raven, 1938).

RESULTS

Our primary interest was in patterns of performance on picture description and the verbal and non-verbal conflict tasks. Composite picture description and explicit conflict

task scores for the participants with aphasia and the bilingual controls are summarised in Table 5. The monolingual control data are also included enabling us to assess the impact of bilingual experience on performance in the explicit control tasks. First we will consider the performance of participants with aphasia in the composite picture description task, and then we will consider the performance of all participants on the explicit conflict tasks.

Composite picture description task

The picture description scores of participants with aphasia in English and in L1 are in line with pre-morbid ratings of proficiency and indicate a parallel recovery pattern. Each scored below the normal range ($M = 44.4$, $SD = 13.6$) for picture descriptions in English (Pt1 scored 12 and Pt2 scored 24). Each also scored below the normal range for L1 ($M = 45$, $SD = 13.6$) where Pt1 scored 26 and Pt2 scored 25. Neither participant mixed or switched languages inadvertently though Pt1 made one exclamation in German when she couldn't think of an English word ("*Oh Gott*"), and when after several attempts she couldn't retrieve the English word for bookcase/shelf, she produced it in French ("*des étagères*") in an attempt to retrieve it. It should be noted that current use of both languages as well as premorbid proficiency might be relevant to performance. As shown in Table 1, Pt1 used both languages with equal frequency but was more impaired in English than L1. In contrast, Pt2 used English practically all the time and showed a minimal difference in composite picture description scores for English and L1. Next we consider performance of all participants on the explicit conflict tasks with a view to examining the role of control problems in parallel recovery. We report the data on each conflict task separately and then consider the pattern overall.

Explicit conflict tasks

For each task we first discuss the reaction time and accuracy data for unimpaired bilingual controls and the monolingual controls in order to assess whether or not there is an effect of acquiring another language in this task. In these analyses of variance we included age as a covariate. Next, given the likelihood of overall differences in reaction time and accuracy between the groups, we examined proportional changes in conflict effects. For each task we calculated a conflict ratio (CR), one for reaction time and one for accuracy. For reaction time this ratio is the difference between performance on a conflict trial and a non-conflict trial divided by performance on the non-conflict trial. For the accuracy of responses, we calculated accuracy differences on non-conflict compared to conflict trials and divided this by accuracy on non-conflict trials based on the assumption that accuracy would typically be less on conflict trials. Having identified the nature of bilingual cost or benefit, we consider the performance of participants with aphasia with respect to their bilingual controls.

Lexical decision task. We first analysed mean correct reaction times for word and non-word decisions and percent accuracy for word and non-word decisions as a function of control group (monolingual vs bilingual controls). In the accuracy analysis the bilingual group was significantly less accurate than the monolingual group, $F(1, 23) = 8.36$, $p = .008$, although their accuracy was greater than 80% for both

TABLE 5
Mean reaction times and accuracy for the conflict tasks

Participant group			*Composite picture description task*		*Lexical decision task*						*Stroop task*												*Flanker task*					
											English						*Other language (L1)*											
Aphasia					*RT(ms)*			*Accuracy%*			*RT(ms)*			*Accuracy%*			*RT (ms)*			*Accuracy%*			*RT (ms)*			*Accuracy%*		
	Age	*Raven*	*English*	*L1*	*W*	*NW*	*CR*	*W*	*NW*	*CR*	*N*	*I*	*CR*	*N*	*I*	*CR*	*N*	*I*	*CR*	*N*	*I*	*CR*	*C*	*I*	*CR*	*C*	*I*	*CR*
Pt1	65	11	**12**	26	**1262**	**2489**	**.97**	97	**80**	**.18**	**2286**	**3572**	**.56**	93	**67**	**.28**	**1753**	**2267**	.29	93	96	−.03	**1016**	**1024**	.01	92	94	−.03
Pt2	47	**8**	**24**	25	**1450**	**2190**	.51	93	**43**	**.54**	892	966	.08	82	71	**.14**	837	879	.05	96	88	.08	**1319**	**1246**	−.06	**82**	**35**	**.54**
Bilingual controls																												
1	31	10	35	34	898	1011	.13	88	88	.03	667	829	.24	96	100	−.04	656	803	.22	86	92	−.07	703	770	.10	97	94	.03
2	41	11	31	30	986	1232	.25	92	85	.08	913	1105	.21	96	100	−.04	851	953	.12	100	100	0	581	665	.15	98	90	.08
3	40	11	36	35	754	960	.27	100	95	.05	1225	1028	−.16	96	95	.01	894	1014	.13	89	75	.16	586	646	.10	97	99	−.01
4	39	12	37	38	723	763	.06	100	95	.05	704	751	.07	61	54	.11	631	855	.35	82	79	.04	599	662	.10	97	96	.01
5	45	11	51	29	892	989	.11	97	90	.07	859	1026	.20	79	88	−.11	755	948	.26	78	79	−.01	670	814	.22	99	94	.04
6	36	11	46	67	670	759	.13	85	87	−.02	856	703	−.15	100	100	0	871	789	−.09	100	100	0	481	575	.20	90	89	.02
7	28	11	25	69	976	1374	.41	97	90	.07	981	1057	.08	100	100	0	881	1062	.21	100	100	0	490	530	.08	89	89	0
8	59	8	52	52	752	894	.19	88	83	.06	844	992	.17	100	100	0	1175	1237	.05	100	92	.08	659	696	.06	97	96	.01
9	24	12	45	49	814	948	.16	87	93	−.07	770	867	.13	100	100	0	705	797	.13	100	100	0	485	553	.14	100	94	.06
10	24	12	45	51	904	920	.02	97	88	.09	984	1158	.18	100	100	0	885	1058	.20	96	100	0	461	509	.10	100	96	.04
11	24	11	49	37	759	1061	.40	85	83	.02	759	815	.07	100	100	0	909	938	.03	100	100	0	603	695	.15	97	99	−.01
12	26	12	44	50	813	1343	.65	98	83	.15	1364	1265	−.07	100	100	0	1251	1290	.03	100	100	0	555	632	.14	100	94	.06

M	34.8	11	41.4	45.0	828	1021	.23	93	88	.05	911	966	.08	94.0	94.8	–.01	872	979	.14	94.3	93.1	.02	573	646	.13	97	94	.03
SD	*10.7*	*1.1*	*8.4*	*13.6*	*101*	*201*	*.18*	*5.9*	*4.5*	*.06*	*207*	*173*	*.14*	*12.0*	*13.3*	*.05*	*187*	*164*	*.12*	*8.2*	*9.8*	*.06*	*80.6*	*93.0*	*.05*	*3.6*	*3.4*	*.03*
Normal cut off			*24.5*	*18.1*	*1032*	*1424*	*.59*	*81*	*80*	*.16*	*1324*	*1312*	*.36*	*70.1*	*68.1*	*.09*	*1246*	*1307*	*.38*	*77.8*	*73.4*	*.13*	*734*	*832*	*.22*	*90*	*87*	*.09*
Mono-lingual controls (n = 14)																												
M	45.0	11			723	805	.11	97	92	.05	739	893	.21	99	98	.01							632	717	.14	99	94	.04
SD	*17.1*	*.7*			*109*	*136*	*.05*	*1.4*	*1.8*	*.03*	*101*	*133*	*.10*	*3.8*	*4.4*	*.04*							*119*	*130*	*.04*	*1.6*	*3.9*	*.04*
Age range: 21–69																												

Mean reaction times and accuracy for the conflict tasks (lexical decision, Stroop and the non-verbal flanker task) for Pt1 and Pt2 and bilingual controls together with their composite picture description scores in English and the first language, L1, age and Raven scores. Monolingual data for the conflict tasks are reported in the final row. Figures in bold for the participants with aphasia indicate the scores beyond the normal cut-off.

RT = reaction time, *M* = mean, *SD* = standard deviation; Normal cut off = 2 *SD* above the normal mean for RT and conflict ratios and below the normal mean for accuracy. W = word, NW = non-word; N = neutral trial, I = incongruent trial; C = congruent trial; CR = conflict ratio –please see text for descriptions.

words and non-words. These data reflect poorer knowledge of English words for non-native relative to monolingual native English speakers (see also Portocarrero, Burright, & Donovick, 2007). In the reaction time analyses bilingual participants were slower than monolingual participants $F(1, 23) = 10.83$, $p < .005$. Critically, however, the increase in response times for bilingual relative to monolingual participants was greater for non-words than real words as indicated by a significant interaction between group and lexicality, $F(1, 23) = 5.44$, $p < .05$. Such an increase cannot be attributed merely to decreased automaticity when reading English words because speed of processing letter strings will affect both real words and non-words equally.

The proportionally longer response times for non-words relative to words in the bilingual group resulted in a significantly higher conflict ratio (CR) for the bilingual than monolingual controls, $F(1, 23) = 4.36$, $p < .05$ (CR = 0.23 for the bilingual controls and CR= 0.11 for the monolingual controls). This outcome is consistent with the notion that bilingual speakers have to discriminate from a wider set of potential candidates in order to respond correctly to non-words. Participants with aphasia performed the task abnormally slowly but were at the top end of the range with accuracy for real words. Pt1 was just below the normal cut off for non-word accuracy and twice as slow for non-words than real words. This resulted in abnormally high conflict ratios in both accuracy (CR = 0.18; control mean CR = 0.05, $SD = 0.06$) and response times (CR = 0.97; control mean CR = 0.23, $SD = 0.18$). Pt2 was even more impaired with non-words and the discrepancy between her word and non-word performance resulted in an abnormally high conflict ratio for accuracy (CR = 0.54; control mean CR = 0.05, $SD = 0.06$). These data indicate participants with aphasia showed substantial conflict effects in lexical decision despite a reasonably good knowledge of English.

Stroop tasks. Analysis of data from the English Stroop task as a function of control group showed no significant effects in the accuracy data and one marginally significant interaction in the reaction time data. Relative to the monolingual controls, the bilingual controls showed a reduced effect of conflict on their reaction times, $F(1, 23) = 4.08$, $p = .06$ albeit in the context of slower, but not significantly slower, overall response times $F(1, 23) = 2.66$, $p = .12$. In proportional terms, the relative increase in reaction time on incongruent trials compared to neutral trials was significantly less for the bilingual control group (CR = 0.08) compared to the monolingual group (CR = 0.21), $F(1, 23) = 5.71$, $p = .025$.

This outcome is open to interpretation. One possibility is that reading an English word even one from a small set of colour words is less automatic for non-native English speakers and so there is less conflict with the required naming response. However, we note that, in this sample, there was no significant difference between the conflict ratio in English and in the first language ($F < 1$), which this notion predicts. We also examined this possible interpretation more directly by performing a further analysis of the conflict ratios in which we included an index of reading speed as a second covariate in addition to age. The reading speed index was each participant's mean reaction time to make correct lexical decisions about English words. The analysis showed no effect of age as before ($F < 1$) but a significant effect of our index of reading speed, $F(1, 22) = 4.98$, $p < .05$. Inspection of the data showed that the conflict ratio increased as correct lexical decision time increased. Such an outcome is opposite to that predicted by the reading speed account. But, more to the point, including this additional covariate did not abolish the difference between the two groups: there was

a highly significant difference between conflict ratios, $F(1, 22) = 11.34$, $p < .01$. This further analysis supports the alternative interpretation: unimpaired bilinguals show an advantage in the Stroop task because of their expertise in handling conflict.

Participants with aphasia showed a different pattern. Pt1 showed abnormally high conflict in reaction time (CR = 0.56) and in accuracy (CR = 0.28) for English Stroop. In each case her conflict ratio was more than double that of any control. In her first language her accuracy was within the normal range but her reaction times were more than 4 standard deviations above the normal mean for both conflict and non-conflict trials. However, despite these slow and accurate responses, the conflict effect in reaction time (CR = 0.29) was greater than that for all but one control participant. In other words, Pt1 showed a strong effect of conflict in English and a weaker effect in her L1. Considered over both languages, errors consisted of reading the word rather than naming the colour, producing filled hesitations on incongruent trials and a few colour naming errors on neutral trials (as a proportion of total error the values for the three types of error were, respectively: 0.54, 0.31, and 0.15). Pt2 showed a similar though less marked pattern. She had an abnormally high conflict ratio for accuracy during the English Stroop task (CR = 0.14) but her response times and conflict ratio for reaction time were within the normal range (CR = 0.08). For her first language the conflict ratios for reaction time and accuracy both lay within the normal range. Considered over both languages, her errors consisted of naming the word on incongruent trials and filled hesitations on neutral and incongruent trials (as a proportion of total error the values for the two types of error were, respectively, 0.19 and 0.81). In summary, both Pt1 and Pt2 showed abnormal difficulty with Stroop conflict in English relative to their first language. The effect of Stroop conflict in English was most marked for Pt1 and was evident in both reaction time and accuracy. For Pt2 the impact of Stroop conflict in English was confined to reduced accuracy.

Flanker task. Analysis of data from the Flanker task showed that conflict trials were less accurate $F(1, 23) = 13.35$, $p = .001$ and slower $F(1, 23) = 18.07$, $p < .001$ than non-conflict trials but these effects did not interact with control group (bilingual/monolingual). Latency increased with age $F(1, 23) = 18.14$, $p < .001$ and effects of conflict decreased with age $F(1, 23) = 3.97$, $p = .06$) suggesting that older participants were more careful rather than merely slower to respond on this task. Analysis of proportional changes in accuracy found no evidence that bilingual speakers were better at resolving conflict in a non-verbal task. Both participants with aphasia performed the non-verbal flanker task more slowly than any bilingual controls with their response times more than 4 standard deviations above the normal mean on both conflict and non-conflict trials. Pt1 performed the task accurately and showed no evidence of conflict on either the accuracy of responses or response times. In contrast, Pt2 showed an abnormally high conflict ratio for accuracy of responses. Her performance was below chance on conflict trials despite performance well above chance (80%) on non-conflict trials (CR = 0.54) suggesting problems handling conflict despite abnormally slow responses.

Comparison of the conflict ratios in the explicit conflict tasks

Our aim in requiring participants to complete three explicit conflict tasks was to identify the pattern of costs and benefits, and then, for participants with aphasia, to

look at the association and dissociation with performance on composite picture description. In this section we review the pattern of performance over the three tasks.

Monolingual and bilingual controls. Analysis of the conflict ratios for reaction time as a function of control group (monolingual vs bilingual) with age as a covariate confirmed a significant interaction between type of conflict ratio (lexical decision task, English Stroop, flanker task) and group, $F(2, 46) = 5.78$, $p < .025$ with no main effects (Fs < 1). This interaction reflects the increased conflict ratio for non-native speakers of English in lexical decision and decreased conflict ratio in the Stroop task, $F(1, 23) = 7.11$, $p < .025$. A similar analysis of the conflict ratios for accuracy showed just one significant effect: a main effect of type of conflict ratio, $F(2, 46) = 3.56$, $p < .05$. The effects of conflict on accuracy were similar for lexical decision and the flanker task (CR = 0.05 and CR = 0.04, respectively) and least for the English Stroop task (CR = 0.001). In this analysis there was no interaction between type of ratio and group, $F < 1$. Taken together, and consistent with expectations, the reaction time data indicate that non-native speakers of English, relative to monolingual controls, incur a cost in deciding that a letter string is not a word in English but show a benefit in suppressing the production of an irrelevant word in English Stroop. There was no significant benefit in the flanker task.

Participants with aphasia. Relative to bilingual controls, Pt1 was abnormally slow on conflict and non-conflict trials for all tasks. In addition, conflict scores were abnormally high in both verbal tasks but not in the non-verbal flanker task. Pt2, by contrast, showed abnormally high conflict during lexical decision and the non-verbal flanker task but speed, accuracy and conflict scores were normal during Stroop in her first language with evidence of abnormal Stroop conflict only in English Stroop accuracy. We consider the implication and interpretation of these patterns in the Discussion.

DISCUSSION

We used three explicit conflict tasks to explore differences in the management of interference in two participants with aphasia who showed parallel recovery in English and in their first language. In order to interpret performance we identified the nature of costs and benefits associated with acquiring a further language in unimpaired bilingual controls. We discuss these data first.

In line with expectation, unimpaired bilingual controls, relative to monolingual English speakers, showed greater interference in correctly rejecting non-words in English lexical decision but reduced interference in an English Stroop task. Contrary to expectation, they showed no clear benefits in the non-verbal flanker task. How are these data to be understood? On the supposition that bilingual speakers must regularly handle competition between their languages (Green, 1998) we expected them (see Bialystok et al., 2004) to gain expertise in suppressing interference. The bilingual advantage in the English Stroop task is consistent with this possibility especially as it is retained when reading speed, as indexed by the time required to identify real words correctly in the lexical decision task, is taken into account. If they gain expertise in suppressing interference why do they show increased interference in the lexical decision task? The most parsimonious account is that non-native speakers of English suffer from increased lexical competition making it more difficult to reject non-words

that are possible words in English (see also Weber & Cutler, 2004). Given the high-level of correct word recognition, this cost is not easily explained by assuming that their word knowledge is poor.

Overall, our data indicate that knowing and using a second language increases the effects of lexical competition (as in English lexical decision) but reduces effects of verbal interference when there is a single dominant competitor (as in the English Stroop task). It seems reasonable to expect then that impairment in verbal control will be most marked in lexical decision rather than in the Stroop task. One unexpected finding was our bilingual speakers showed no clear benefit in the non-verbal flanker task. Our sample sizes were very much smaller than those used by Costa et al. (2008) (100 Spanish-Catalan bilinguals vs 100 Spanish monolinguals) and so had less power to detect a significant effect given variability in response times. With smaller sample sizes, benefits of bilingual experience may only be evident in older participants (see Bialystok et al., 2004).

Turning to the participants with aphasia, we presume that abnormal interference, exemplified by large conflict ratios in either reaction time or accuracy data, relative to the bilingual controls, reflects impaired control. Pt1 and Pt2 displayed different patterns of interference on explicit conflict tasks and we summarise their data separately. For Pt1 conflict scores were abnormally high in lexical decision and the Stroop task but not the non-verbal flanker task. The pattern of task-dependent conflict difficulties was observed in the context of abnormally high response times for all tasks with normal performance on Raven's matrices. We interpret this pattern as evidence of impaired verbal, but unimpaired non-verbal control. Poor verbal control in English was associated with severely impaired picture description performance in English. Second, for Pt2 the pattern of abnormal conflict was different to Pt1, conflict scores were more abnormal in the non-verbal flanker task than the verbal Stroop task. However, Pt2 also showed abnormal conflict in lexical decision, which, like the non-verbal flanker task, requires a manual rather than articulation response.

As the tasks in which Pt2 showed substantial interference both involved a manual response, perhaps Pt2 simply had a problem dealing with conflict in selection of a manual response. However, the process of mapping a decision onto a response cannot completely explain the effects of conflict in these tasks as a mapping problem would apply to non-conflict as well as to conflict trials but Pt2 was much more impaired on the conflict trials.

Challenges to the language control account

Our argument is that both participants with aphasia meet the operational definition of parallel recovery of their languages but show (a) problems in managing interference and (b) a (double) dissociation in their control problems. Our interpretation relies on a number of assumptions that may be contested. First, we compared performance of participants with aphasia to an unimpaired bilingual control group. Is that comparison justified? The control group varied in a number of socio-demographic factors: age at test, age of second language acquisition, and number of languages spoken. These factors inter-correlated positively but not significantly (range: $r = .252$ to $r = .460$). Inspection of scatter plots of each factor with reaction times, accuracy data and conflict ratios for each of the conflict tasks showed no robust relationships. Nor did any of these factors predict composite picture description performance. Ideally each of our participants with aphasia would have a closely matched control

group but that was not feasible. Instead, variance in the control group scored offers a reasonable range of these socio-demographic factors and provides a conservative test of the performance of participants with aphasia. Second, although participants with aphasia showed a parallel pattern of language recovery and they acquired the English language relatively late, they differed in the age at which they acquired English and the number of years using English. Do these pre-morbid differences compromise our account of the data and make Pt1 and Pt2 too different clinically for a unitary account of their performance?

It is conceivable that the age at which a second language is learned affects its neural representation (Ullman, 2001, 2005). However, it is more plausible to suppose languages are mediated by a common neural network that adapts to acquisition of a second language, based on theoretical models (Green, 2003, 2005) and empirical data (Abutalebi & Green, 2007; Perani & Abutalebi, 2005). Residence in a country is likely to be one factor affecting language proficiency but the requirement to achieve proficiency is likely more critical. Pt2 despite fewer years in the UK than Pt1 achieved a sufficient proficiency in English to practise as a doctor. Nor do pre-morbid factors provide an obvious account of the pattern of performance on conflict tasks where Pt1 is more impaired in English Stroop compared to Pt2 but less impaired in English lexical decision.

Our account of control problems in Pt1 and Pt2 relies critically on the interpretation of conflict scores. Pt1 showed impaired control on the verbal conflict tasks but not on the non-verbal flanker tasks. As Pt1 took longer than the unimpaired bilingual controls on the non-verbal flanker task, it might be argued that she avoided the effects of conflict by delaying her response. However, this explanation fails because she was substantially slower in the Stroop task and in lexical decision, and yet in these tasks she showed a substantial effect of conflict. We interpreted the conflict effects in the Stroop and lexical decision tasks as indicative of a problem with verbal control. In the case of the Stroop task this account seems straightforward. For example, Pt1 knew, and could produce the colour names, but showed a marked delay in naming the colour correctly on incongruent trials and a marked increase in error rate on trials where she might read the colour word instead or produce a filled hesitation consistent with response conflict.

Are the data from lexical decision amenable to the same interpretation? That is, are the conflict ratios in the lexical decision task a reflection of lexical competition or might they rather reflect a deficit in word knowledge? In the assessments from participants with aphasia, using the CAT, Pt1 scored marginally below the unimpaired cut-off in reading words (score 58: cut-off 62); however she was not below cut-off in understanding words (score 65: cut-off 55). Nor does her performance on the lexical decision task obviously reflect a deficit in word knowledge. She scored 90% overall and was 97% correct on real words. Her difficulty rejecting non-words must therefore reflect a problem resolving competition from lexically or sub-lexically similar real words in English or from words in her first language (see Weber & Cutler, 2004, for experimental evidence of such an effect in unimpaired bilingual speakers). The merit of the verbal control account is that it provides an explanation for the performance in lexical decision and on the Stroop task.

Further considerations

Both participants with aphasia could use each of their languages appropriately. There was, for instance, no problem in language selection and no evidence of involuntary

language switching. However, they both showed impairments in other aspects of language control indicative of damage to distinct components of the control network. The data from Pt1, with left subcortical damage to the putamen and globus pallidus, is consistent with a specific problem of verbal control. In contrast, the data from Pt2, who had substantial left parietal damage, argue for an association between verbal and non-verbal control.

Do we need to propose a dissociation between verbal and non-verbal control in order to account for the double dissociation observed in the two participants with aphasia or could there be a simpler account? It may be that a control problem, reflecting damage to a general executive function, underlies both patterns. Pt1 may, for instance, suffer a mild executive impairment (not detected on Raven's matrices), which is revealed in language tasks but not in the flanker task, because the conflict evoked in language tasks, especially in the second language, is more difficult to resolve. In the verbal tasks (both the composite picture description and the explicit control tasks) there are more potential competitors evoked by a current stimulus than in the flanker task. In the lexical decision task all words evoked by the non-word letter string are potential competitors and these may include words from the other language. In the English Stroop task, for instance, there is competition from the written colour word and potential competition from its translation in the other language. In the flanker task, by contrast, there is just one competing response. If this alternative account is correct, then markedly poor performance on the flanker task (the easier task from the point of view of resolving conflict) should always be associated with markedly impaired performance on the Stroop task; the potentially more difficult task. Pt2 was markedly impaired on the flanker task but only somewhat impaired in the English Stroop task. Further her impairment was poorer than Pt1 who was unimpaired on the flanker task. Nonetheless, these considerations suggest it is important to probe the precise nature of the control problems in bilingual speakers post-stroke by using a range of different tasks and isolating precisely the nature of competitive effects in lexical decision and word production (Apfelbaum, Blumstein, & Kittredge, 2007, for an indicative study in monolingual cases).

Conclusion

Our conflict tasks required participants to suppress competing responses. However, other executive processes need to be studied including switching between tasks (mental sets) and updating information in working memory (Miyake et al., 2000). Each of these processes is relevant to conversation. There is increased recognition that "non-linguistic" executive processes are relevant to understanding aphasia in monolinguals (Frankel, Penn, & Ormond-Brown, 2007). We endorse this view. The present study shows that studying such processes is vital if we are to understand language recovery patterns of bilingual speakers following stroke.

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