Semantic processing in aphasia: evidence from semantic priming and semantic interference

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Abstract

Semantic processing theories propose activation of concepts via semantic features, with interference from semantic neighbours arising due to shared features. Semantic impairment has been explained as damage to activation and interference mechanisms, and linked to impaired semantic control. This study investigated semantic activation and interference in 20 people with aphasia. We found normal semantic priming or hyper-priming, coupled with significant semantic interference effects, in most of the participants, regardless of scores on standard semantic tasks. There was little evidence of a relationship between executive functions and semantic processing. The data indicate that semantic activation is unimpaired in most people with aphasia. Apparent difficulties with semantic processing are predominantly found when tasks involve resolving competition from close semantic neighbours. These novel findings question the use of offline tasks involving semantic competitors in diagnosis of semantic deficits in aphasia - and other conditions such as dementia - and demand revised diagnostic methods.

Keywords:

Aphasia, semantics, activation, interference, priming

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Abbreviations: Abbreviations used in this text: PWA – participants with aphasia.

Abbreviations for the three new tests used in this project are: SP – semantic priming task; WPV: word-to-picture verification task; WPM – word-to-picture matching task

Introduction

Semantic memory

Semantic memory refers to shared conceptual knowledge (Tulving, 1972), which builds over time and through multi-modality experiences of a concept. Connectionist accounts of semantic representations propose networks of semantic features instantiated in distributed neural network models. Each concept is represented by a pattern of activation across a network of semantic features (Cree & McRae, 2003; Rogers & McClelland, 2004). In such theories related concepts share features, which are activated by target concepts and by their semantic neighbours (McNamara, 2005). Selection is by interactive activation with competition (although see Oppenheim, Dell & Schwartz, 2010). Levels of processing interact to activate a set of semantic features.

These characteristics of network models explain two seemingly contradictory semantic effects, those of priming and interference. Semantic priming refers to the improved speed or accuracy of response to a target following prior exposure to a semantically related or associated stimulus (McNamara & Holbrook, 2003; Meyer & Schvaneveldt, 1971; Neely, 1991). According to network theories priming occurs due to prior activation of shared features, the target thus being partially activated prior to its appearance. Semantic interference refers to slower or less accurate processing due to the presence of a close semantic neighbour, in tasks such as picture-word interference (e.g. Damian & Bowers, 2003; Schriefers, Meyer & Levelt, 1990). As both target and neighbour are activated interference occurs due to difficulties in resolving competition.

Access vs storage deficits

Warrington (1975) reported participants with progressive cortical atrophy affecting the fronto-temporal lobes, who presented with deterioration of the ability to perform a range of semantic tasks. They showed gradual deterioration of specific knowledge, producing category co-ordinate naming errors early, and superordinate errors later in the disease. These findings have been replicated by several studies since then and the term semantic dementia used to define the condition (e.g. Hodges, Graham & Patterson, 1995; Hodges & Patterson, 2007; Schwartz, Marin & Saffran, 1979). The pattern of semantic deterioration found by Warrington (1975) contrasts in significant ways to the semantic impairment found in people with stroke aphasia, for example Howard and Orchard-Lisle (1984) described JCU who made semantic category coordinate errors and few superordinate errors, and her naming was cueable and miscuable. These two distinct patterns of presentation led Warrington and Shallice (1979) to distinguish between access and storage deficits, with the deterioration found in the participants in semantic dementia characterised as storage deficits, and the stroke aphasia participants presenting with access deficits. In a storage deficit the representations of concepts are gradually eroded, such that knowledge is not retrievable. In an access deficit damage to the mechanisms involved in retrieval and manipulation of conceptual knowledge results in specific patterns of performance, including for example positive response to cues (e.g. Jefferies & Lambon Ralph, 2006).

In a review of research into access and storage deficits Mirman and Britt (2014) identified a diverse range of phenomena which arguably distinguish the two. Participants with an access deficit respond positively to cues, show inconsistent responses to the same stimuli at different test times, are not sensitive to frequency, show effects of number and type of semantic competitors, and are sensitive to presentation rate and serial position of stimuli. They cite the connectionist account of Gotts and Plaut (2002), which simulated the two forms of semantic disorder. Gotts and Plaut (2002) identified correlative neurophysiological processes to explain access and storage deficits, with access deficits resulting from disruption to neuro-modulatory systems controlling synaptic activation and depression, and storage deficits emerging from damage to connections critical for semantic integrity of concepts. Two forms of damage to the model, simulating the neurophysiological impairments, mimicked the two patterns of deficit found in the two groups of patients. It remains the case however, as Mirman and Britt (2014) acknowledge, that the specific nature of semantic access is underspecified.

Impaired semantic control

The term semantic aphasia has been used to refer to cross-modality semantic impairment, and equates to the condition described by Mirman and Britt (2014). It involves damage to temporo-parietal and pre-frontal regions (Patterson, Nestor & Rogers, 2007). The impairment has been explained as damage to semantic control or semantic cognition, which operates over the intact semantic storage system (see Corbett, Jefferies, Ehsan & Lambon Ralph, 2009; Jefferies & Lambon Ralph, 2006; Jefferies, Baker, Doran & Lambon Ralph, 2007; Jefferies & Lambon Ralph, 2008; Noonan, Jefferies, Corbett & Lambon Ralph, 2010). Semantic control is dependent upon intact frontal executive control systems (Jefferies & Lambon Ralph, 2006; Lambon Ralph, Jefferies, Patterson, & Rogers, 2017). The evidence for the claim comes from fMRI studies with neurotypical participants showing increased activation of frontal regions during complex semantic decision-making tasks (e.g. Thomson-Schill, D'Esposito, Aguirre & Farah, 1997), from studies of participants with semantic aphasia who showed a significant relationship between semantic task performance and scores on tests of executive function (Jefferies & Lambon Ralph, 2006), and from semantic interference arising in participants with damage to left inferior frontal gyrus (Harvey & Schnur, 2015). The proposal of a deficit in semantic cognition parallels the access deficit discussed previously.

Components of semantic access

As Mirman and Britt (2014) point out there exists no explicit definition of semantic access. They note that different accounts refer to 'activation, inhibition, selection and other aspects of processing' (p10), but the exact processing systems and their functions remain underspecified. Here we focus on two of these components: activation and interference. As Oppenheim et al. (2010) note two phenomena result from the prior retrieval of a word from memory. Subsequent attempts to retrieve that word are facilitated, known as repetition priming, and there is inhibition of access for words from the same category (e.g. Howard, Nickels, Coltheart & Cole-Virtue, 2006; Schnur, Schwartz, Brecher & Hodgson, 2006).
A number of variables are known to operate over semantic access, affecting activation and interference. These are either concept-intrinsic factors or contextual factors. Intrinsic factors characterise that concept or word, and include its rated imageability, concreteness, and typicality. Contextual factors include task artefacts such as the presence of other words in a task and their relationship to a target. Both are considered below.

Activation

Interactive activation (IA) models operate by the increased excitability of sets of related nodes within a specific level of processing in response to a stimulus such as a word or picture. This activation spreads to adjacent levels, and feeds back via IA. In Dell, Schwartz, Marin et al.'s (1997) account of spoken production (see also Dell, 1986; Foygel & Dell, 2000; Oppenheim et al., 2010), activation of a target's semantic features feeds forward to the word level, activating the target's word node and semantic neighbours' word nodes. Feedback then provides a further boost to semantic features, which then feeds forward, and eventually lexical selection occurs when a threshold in activation levels is achieved. This model also incorporates interactive activation between the word and phoneme levels, hence maximising the chances of the target's word node being selected over and above the competitor word nodes. There are alternatives to this strong position on IA, with Goldrick and Rapp (2002), and Rapp and Goldrick (2000) limiting the amount if IA occurring between levels, specifically the amount of IA between the semantic and word levels. Whatever the differences between theories, a sufficient level of activation is required for targets to be selected.

In connectionist accounts of semantic processing such as that of Plaut and Shallice (1993) words with more concrete meanings are attributed more semantic features, which makes them easier to access and more resilient in the context of a damaged system. Yap, Lim & Pexman (2015: 1148) redefined semantic richness as a multi-dimensional construct including number of features and semantic neighbourhood density. Investigations into the effects of this on lexical decision found speeded lexical decision times for words with more semantically rich concepts (Pexman, Lupker & Hino; 2002; Pexman, Hargreaves, Siakaluk, Bodner, & Pope, 2008; Yap, Pexman, Wellsby, Hargreaves, & Huff, 2012).

One well researched contextual factor affecting activation is semantic priming. Words are presented for lexical decision in semantically related and semantically unrelated conditions, with the related condition yielding faster decision times than the unrelated (Meyer & Schvaneveldt, 1971; Hutchison, Balota, Neely et al., 2013; Rissman, Eliassen, & Blumstein, 2003). There is evidence of positive semantic priming effects in people with aphasia. Participants with relatively unimpaired lexical comprehension and Broca's aphasia show limited effects of semantic priming (Bushell, 1996; Del Toro, 2000), whereas those with impaired lexical comprehension and Wernicke's aphasia have shown significant semantic priming effects (Milberg & Blumstein, 1981; Blumstein, Milberg & Shrier, 1982). These findings of retained semantic activation in participants with apparent lexical-semantic comprehension deficits suggest task differences may underlie the performance difference.

Interference

Semantic inhibition has been studied experimentally with healthy participants using the picture-word interference paradigm, where participants name pictures with a written word of a semantic neighbour appearing simultaneously or at predetermined lags. Studies report slower naming in the presence of the semantic competitor word, supporting claims of semantic competition being inherent to lexical processing (e.g. Damian & Bowers, 2003; Schriefers et al., 1990).

A second method of investigation of semantic interference is the blocked cyclic naming paradigm, where stimuli are presented multiple times in related and unrelated conditions. In the related condition stimuli are semantic neighbours. Evidence from healthy control and aphasia participants has found that interference (more errors or slower responses) may occur in the related condition and may build over repeated cycles. Harvey and Schnur (2015) labelled these the relatedness effect and increasing relatedness effect respectively. This has been found with healthy speakers (e.g. Damian, Vigliocco & Levelt, 2001) and those with aphasia (e.g. McCarthy & Kartsounis, 2000; Wilshire & McCarthy, 2002; Howard et al., 2006; Schnur et al., 2006; Harvey & Schnur, 2015). The increasing relatedness effect has been termed cumulative semantic interference (e.g. Oppenheim et al., 2010: 227), but is also referred to as semantic refractory effects (e.g. Crutch & Warrington, 2008; Schnur et al., 2006; Warrington & Cipolotti, 1996), and is one of the characteristics of semantic access deficits outlined by Mirman and Britt (2014). The more semantically similar items are the greater the interference (e.g. Vigliocco, Vinson, Damian & Levelt, 2002). Using a continuous naming task Harvey, Traut and Middleton (2019) found effects of semantic interference on error types, with more semantic errors to targets presented in the related condition, and that degree of semantic similarity affected rates of semantic errors.

Similar effects have been found in lexical comprehension and recognition tasks. Campanella and Shallice (2011), Wei and Schnur (2016) and Harvey and Schnur (2016) found interference from semantic neighbours in control participants' ability to complete word to picture matching tasks. The effect has also been found in people with semantic deficits (e.g. Crutch & Warrington, 2005; Warrington & Cipolotti, 1996; Warrington & McCarthy, 1983, 1987; Thompson, Robson, Lambon Ralph & Jefferies, 2015; Harvey & Schnur, 2015). Harvey and Schnur (2015) found relatedness effects in comprehension and production with 15 speakers with aphasia, but increasing relatedness effects in production only. The mechanism for the semantic competition in network models has been thought to be within semantics for comprehension, or due to the co-activation of related words via their shared features in production tasks (Harvey & Schnur, 2015), and the closeness of the relationship appears to play a critical part. Crutch and Warrington (2005) found larger interference effects for more closely related words. Harvey and Schnur (2016) and Chen and Mirman (2012) unpacked this more closely, finding inhibitory effects of near neighbours, and facilitatory effects of distant neighbours, simulated in PDP models via the number of shared semantic features.

Activation, interference, and semantic control

To examine the relationships between activation, interference and semantic control, we have outlined three factors relevant to the tasks used to examine these (table 1). These are the appearance of the target and competitor, the type of response, and the nature of the task. The latter refers to the degree to which tasks elicit implicit or explicit knowledge. Implicit and explicit knowledge were differentiated by Schacter (1987), and from his definition terms including unconscious and unintentional have become associated with implicit processing, and conscious and intentional associated with explicit processing. Previous studies have used either offline tasks such as word to picture matching (e.g. Howard & Gatehouse, 2006; Rapp & Caramazza, 2002), or online tasks such as priming.

The semantic control hypothesis associates damage to prefrontal cortex with loss of semantic control (e.g. Jefferies & Lambon Ralph, 2006). Located within the prefrontal cortex, the left inferior frontal gyrus has been shown to resolve competition in production tasks (e.g. Pisoni, Papagno & Cattane, 2012), and activation occurs in this region in tasks requiring complex semantic decision making (Thomson-Schill et al., 1997). Such tasks typically involve inhibition of responses to competitor stimuli, and the LIFG is well recorded as being involved in inhibition of undesired responses. The importance of being able to inhibit responses differs across tasks however. For example Harvey and Schnur (2015) found larger increasing relatedness effects in production in participants with damage to the LIFG compared to those without this damage. No such difference was found for comprehension however so the involvement of this region and this function in comprehension remains unclear. It is possible also that little inhibition of responses is required in the lexical decision task used within semantic priming. Competitor stimuli are presented, but never at the same time as the target. Conversely competitor stimuli are present with the target word semantic judgement tasks and in picture-word interference. The competitors are not present in blocked cyclic naming yet still interference has been found. The difference here may lie in the task response, with naming requiring more control than does lexical decision. Naming involves selection from many, whereas lexical decision involves a yes/no choice. So the two factors may both play a part in response to semantic tasks – the presence or absence of competitors, and the type of response required, with naming demanding more decision-making within executive functions.

Table 1 here

Study focus and aims

This study aimed to examine semantic activation and interference in individuals with aphasia to identify critical factors impacting on performance, including task demands. To achieve this we recruited healthy controls and people with acquired aphasia to complete three experimental tasks: semantic priming and two semantic judgement tasks (word-picture verification, and word-picture matching). The tasks differ in terms of likely elicited effects (activation or interference), presence of competitor (prior appearance or simultaneous appearance), the response mechanism (lexical decision, semantic judgement), and the nature of the processing (implicit or explicit). The semantic priming task provides a measure of semantic activation. The difference between congruent and incongruent conditions in the word to picture verification task provides a measure of semantic interference. Accuracy scores in the semantic judgement tasks provide a measure of offline explicit processing typical of clinical assessment for diagnostic purposes. Participants with aphasia also completed a range of semantic and other language tests, and tests of executive function. Studies of lexical semantic processing have included subgroups of participants with aphasia selected to meet stringent pre-existing criteria (e.g. Jefferies & Lambon Ralph, 2006). By including people with aphasia across a range of severity in terms of aphasia and semantic deficit, we aimed to examine semantic processing afresh with no a priori assumptions regarding likely outcomes. In line with the proposal that tests of semantic processing recruit other functions in addition to semantic we also examined the relationship between performance in these semantic measures with tests of executive function, to add to the evidence base concerning the role of executive function in semantic processing.

Materials and methods

Participants

Twenty people with post-stroke aphasia and 40 healthy control participants took part. The inclusion and exclusion criteria for all participants were that they were adults aged 40 or above, monolingual literate native English speakers, no history of or current significant psychiatric illness, sufficient visual acuity either aided or unaided, no significant hearing loss, and sufficient attention. Controls also had no history of speech, language or literacy impairment, and no history of relevant neurological illness affecting cognition.

Additional criteria for the participants with aphasia were that they had sustained a single left hemisphere stroke at least six months previously, had no history of other significant neurological illness, presented with acquired aphasia as diagnosed by a speech and language therapist and corroborated by the first author, no pre-morbid history of speech, language or literacy difficulties, and were able to give informed consent to participate. The participants with aphasia were not receiving speech and language therapy during their participation.

The participants with aphasia needed to score above 20/28 on a subset of items from PALPA 25 written lexical decision (PALPA: Psycholinguistic Assessment of Language Processing in Aphasia: Kay et al., 1992) and higher than 5/15 on the CAT 7 spoken word to picture matching test (CAT: Comprehensive Aphasia Test: Swinburn Porter & Howard, 2005)[1].

[1] As the semantic priming task was central to this study screening for written lexical decision was undertaken to ensure that all participants could complete the task and were responding at rates significantly above chance. Similarly we aimed to recruit people with a range of semantic impairment hence the need to include a low cut-off score for word to picture matching to ensure those with significant deficits were included but those at floor were excluded.

Table 2 provides background details for both groups of participants. The full details of participants with aphasia are provided in Table 3.

Table 2 here

Table 3 here

Ethics recruitment and consent

Ethical approval for the project was obtained from The University of Sheffield Department of Human Communication Sciences Research Ethics Committee. Control participants were recruited via opportunistic sampling methods through social networks. Information about the study was disseminated by word of mouth, email and information flyers, and individuals contacted the researchers via phone or email if they met the criteria. Participants with aphasia were recruited via local groups, and the University of Sheffield's Aphasia Communication and Research Centre. All participants were provided with approved information sheets and consent forms, those for the participants with aphasia being designed in line with Herbert et al.'s (2012) accessible information guidelines.

Aphasia and executive function data: participants with aphasia

Participants with aphasia undertook a battery of language and executive function assessments. The data are shown in full in tables 4 and 5. Participants were allocated to aphasia syndromes based on their fluency, lexical comprehension scores (deficit assumed if the score on one or both of the CAT word-picture matching tasks was below normal range), and word repetition scores on our 182 words test, following Albyn Davis (1993). Fluency was assessed using picture description data and Goodglass, Kaplan and Baresi's (2001) criteria.

We selected specific tests of executive function in order to minimise the demands on language and semantic function, to ensure that test results were not contaminated by the aphasia. Previous studies in this field such as Jefferies and Lambon Ralph (2006) and Jefferies, Baker, Doran and Lambon Ralph (2007) used Raven's Coloured Progressive Matrices (Raven, 1956), which assesses visual spatial perception and nonverbal reasoning. Jefferies et al. (2007) also used the Brixton Spatial Anticipation Test (Burgess & Shallice, 1997) which assesses rule attainment and strategies used in response when rules change. It can be delivered more quickly and with fewer language demands than commonly used tests with similar objectives, such as the Wisconsin Card Sorting Test (Grant & Berg, 1948; 1993). We therefore selected those two tests plus one additional test, an adapted version of the Tower of Hanoi Test (M Coleman personal communication). The Tower of Hanoi task (Simon, 1975) is categorised as a planning executive function task also implicating cognitive skills of working memory, visuospatial memory and response inhibition (Lezak et al., 2004) in order to make counter-intuitive moves in support of the end goal.

Table 4 here

Table 5 here

Design

All the participants completed all three experimental semantic tasks. The tasks included one list each of 50 targets, matched across the three lists for key variables. The tasks differed in that both the Semantic Priming (SP) and the Word-Picture Verification (WPV) tasks involved two conditions and hence included two word lists, each containing all 50 target stimuli, and the Word-Picture Matching (WPM) task involved one condition and hence one list of 50 stimuli. For Semantic Priming and Word-Picture Verification each target appeared once in each list, in one of the two conditions.

Each control participant saw only one list in each task thereby ensuring they saw each target once in each of the tasks. For the Semantic Priming task this was either the related or the unrelated condition, and for the Word-Picture Verification task this was either the congruent or the incongruent condition. The participants all completed all test stimuli in the Word-Picture Matching task at one test time.

Participants with aphasia completed the above, and also the second alternative lists for the Semantic Priming and the Word-Picture Verification tasks six months later, resulting in them eventually viewing each item in both conditions. This was to allow for individual analysis of each participant with aphasia.

Design of stimuli sets for the three semantic tasks

Word lists. The word lists for the three semantic tasks consisted of three sets of 50 target concrete nouns matched across task for concreteness, imageability, age of acquisition, lexical frequency, emotional valence and word length. Semantic partners for the target words were selected which were also matched for these variables. Data relating to the stimuli are in the supplementary material online[2]. For the WPM task additional nouns were selected to act as

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[2] A full description of the test materials is provided in Dyson, L., Morgan, J. & Herbert, R. (submitted). Novel matched stimuli for assessment of lexical semantics. *Aphasiology*.

phonological distracters and unrelated distracters. Semantic partners acted as primes in the SP task and as semantic distracters in the WPV and WPM tasks.

Semantic Priming task design. Targets in the SP task were presented in two conditions, related and unrelated. In the related condition the target was preceded by its semantic prime word, and in the unrelated condition it was preceded by a semantically unrelated word from the prime list, randomly allocated to the target. The 50 targets were split into two sets of 25, half were in the related and half in the unrelated condition. Participants thus completed either the related or the unrelated condition for each target word. Each list contained 25 target word pairs in the related condition (e.g. cat-dog), 25 target word pairs in the unrelated condition (e.g. mouse/fork), 125 non-words and 25 filler words, i.e. there were 125 words and 125 non-words in each list[3]. Lists were matched for prime and target lexical frequency and imageability. The twenty-five filler words were neither semantic coordinates nor had any association to targets within the list of 50 target words. Fillers were matched in frequency and length to target items. Non-words were created by modifying 125 real words matched in length in syllables to the 125 real words in each list, changing one letter to generate a non-word. All non-words had common English spelling and none were pseudo-homophones. Within each list the 250 stimuli were pseudo-randomly ordered into five blocks of 50 items. The order of presentation of the blocks was pseudo-randomised across participants. Within each block there were five related prime-target pairs, five unrelated prime-target pairs, five fillers, and an equal number of words and non-words. No more than three words or non-words appeared consecutively. Phonologically similar items were separated by at least two

[3] Filler words were included in order to establish an acceptable relatedness proportion of 0.2 within each word list, after Neely, Keefe and Ross (1989). The relatedness proportion is calculated by dividing the number of semantically similar or associated real word prime-target partners by the total number of test stimuli i.e. 50/250.

intervening words. Prime-target pairs were separated by a minimum of two stimuli, and unrelated word-target pairs were separated by a minimum of one other stimulus.

Word-Picture Verification task design. The 50 target words and images were presented in two conditions: congruent and incongruent. In the congruent condition the target word appeared with its image. In the incongruent condition the distracter word appeared with the target image. The 50 targets were split into two lists, with each target appearing once, in either the congruent or incongruent condition. Participants were randomly allocated to word list, with the condition that 50% completed one list and 50% completed the second list. The two sets of 25 target words in the two lists were matched for distractor and target frequency and imageability. The 50 targets (25 congruent and 25 incongruent condition) were randomised within each list and then scrutinised to ensure a maximum of three consecutive yes or no responses, no two consecutive targets shared the same initial phoneme, and no two consecutive targets were semantically or phonologically related. Each set of 50 targets was split into two blocks of 25 items (A and B) and participants saw either AB or BA pseudo-randomly allocated.

Word-Picture Matching task design. The *Word-Picture Matching* task involved one set of target stimuli in one list. Each target was accompanied by a semantic distracter, a phonological distracter and an unrelated word. All three distracters were realised in the assessment as images and only the target word was visible to the participants. Targets were ordered in the list such that there were a minimum of two intervening items between semantic or phonologically related targets.

Materials and procedure

Each control participant completed one assessment session lasting one hour. This included the process of providing informed consent, and completion of the experimental semantic tasks. Participants with aphasia completed up to five sessions in which they completed the experimental tasks and additional assessments, with one session 6 months later to complete the alternate lists for the SP and WPV tasks.

Semantic Priming

Written words were presented in a continuous list requiring lexical decision to all stimuli, i.e. to primes, targets, fillers and non-words. The lists were presented on a laptop screen using the software programme Psychopy (psychopy.org). The written words were in lower case Arial font (sized to 1.9cm), centred on the screen. For control participants each word appeared for a maximum of two seconds, and the inter-stimulus interval (ISI) was 0ms. If there were no response within two seconds the word disappeared and the next appeared. For people with aphasia the word disappeared once a response had been made, however long that took. The word then disappeared and the same 0ms ISI pertained meaning the next word appeared immediately. Continuous list presentation and short ISI were selected to minimise the potential involvement of strategic processing. Participants used external switches to make their decisions. Participants were first familiarised to the task via 20 practice words and non-words not used in the main experiment. Written instructions appeared on the screen prior to the start of each block of stimuli and the researcher provided a spoken equivalent. Participants were informed that their reaction times and accuracy would be recorded but they were not made aware of the experimental aims or relationships between words.

Word-Picture Verification task

Materials consisted of 50 colour photographs or colour digital images presented on a laptop computer along with a written word, in one of two conditions. Colour photographic images were original photographs produced by the first author, images from Hemera Technologies copyright-free photographic resource, photographs purchased from a royalty-free image bank (Fotolia.com), or copyright free web-sources[4]. All images were presented in colour with a white background. All images were sized to 550 x 350 pixels. Written words were presented centrally at the top of the computer screen and were in lower case Arial font (sized to 2.4cm). The task consisted of yes/no judgements to a presented image and word pair. For each trial the written word appeared 500ms before the image. Control participants had five seconds to respond, and PWA had unlimited time. If a control participant did not respond within this timeframe the next trial started. There was a one second ISI between participant response and presentation of the next item, or between items if a control failed to respond and was timed out. There were four practice items including congruent and incongruent conditions. Participants were given verbal instructions detailing responses required for same and different pairings.

Word-Picture Matching task

In the WPM task, each written target word was accompanied by four images, as outlined above. Images were digital images to represent the target word and three distractors, sourced as per the WPV task. The written target word was presented centrally in lower case Arial font (sized to 1.9cm). Each image was centred in one quadrant of the screen, each sized to 400 x 245 pixels until one or both of the maximum diameters were reached. The written target and

[4] Websites used for copyright free images include: Morguefile (http://www.morguefile.com/); Flicker Creative Commons (http://www.flickr.com/creativecommons/ http://www.flickr.com/creativecommons/by-2.0/); and Stock.XCHNG (http://www.sxc.hu/). Photographers were contacted regarding the use of their images and will be attributed as per the guidelines of each website in any publication of materials including the images.

corresponding four images appeared simultaneously in each trial. Control participants had a maximum of five seconds to choose the matching picture and PWA had unlimited response time. There was an ISI of 1.5 seconds between trials following response or time-out for controls. There were two practice items. Participants were presented with written instructions on the laptop screen, supported by verbal instructions from the researcher.

Recording responses

All task response times and accuracy data were recorded into the software programme Psychopy. In the semantic priming and the word-picture verification tasks participants made their choices via external switches operated by one hand (Buddy Button switches: SmartboxTM). There were two switches, one positioned on the left with a symbol denoting yes (green tick), and the other positioned on the right with a symbol for no (red cross). Task responses for word-picture matching were recorded via the computer keyboard, where four centrally located keys were covered in coloured stickers, each key corresponding to the appropriate quadrant on the screen. All participants used their preferred hand to operate the switches, using one hand only. For several of the participants with aphasia with concomitant hemiplegia this was their pre-morbid non-preferred hand.

Resulting data and statistical analyses

Two forms of analysis were conducted: group comparisons, and a case series analysis of each individual with aphasia compared to the controls. In the group analyses whole group comparisons of the data from controls versus people with aphasia were compared using ANOVA or appropriate non-parametric statistics. In the individual analyses the control data as a whole were compared to the data from each individual with aphasia separately, using the Singlims_ES.exe program[5] (Crawford, Garthwaite, & Porter, 2010).

The group analyses consist of one data point for each target word from each participant, giving accuracy and response latency data, derived from one of the two experimental conditions in the task (Semantic Priming and Word-picture verification) or from the sole condition in Word-picture matching. The individual analyses differ in that they include datapoints for each target word from each participant with aphasia from both conditions in the Semantic Priming and Word-picture verification tasks.

For all analyses for all three tasks response latency data below 200ms or above 2000ms (controls) or 10,000ms (aphasia) were coded as errors and those response latency data discarded. For whole group analyses the remaining data were trimmed in line with Ratcliff's criteria (1993). Kolmogorov-Smirnov tests were conducted to assess normality of distribution for all data, and where data were non-normally distributed non-parametric tests were used. Exact significance (2-tailed) is reported throughout. Unless otherwise stated effect sizes for significant results are categorised using Cohen's (1988) criteria of small (r =.10 to .29), medium (r =.30 to .49) and large (r =.50 to 1.0) effect sizes. Where partial eta squared is reported, criteria of small (.01) medium (.06) and large (.14) effect sizes are applied (Cohen, 1988).

As the SP and WPV tasks involved yes/no responses the possibility of chance level of responding in the participants' responses was assessed using binomial tests, sensitivity index or D' which compares accuracy in detecting the incongruent pairs with false alarm or error

[5] http://homepages.abdn.ac.uk/j.crawford/pages/dept/Single_Case_Effect_Sizes.htm

rates to these pairs[6]. We also looked at bias in responses through criterion or C values which measure tendencies to one particular response. Extreme bias would mean answering yes to all trials resulting in 100% correct in condition A and 0% correct in condition B. Macmillan and Creelman (2004) report that criterion location C refers to the number of standard deviations by which a point differs from zero-bias, hence C of 1 is one standard deviation from zero bias. Values of C below 1 are deemed acceptable.

[6] According to online information from UCLA's Phonetic Lab: 'The highest possible d' (greatest sensitivity) is 6.93, the effective limit (using .99 and .01) 4.65, typical values are up to 2.0, and 69% correct for both *different* and *same* trials corresponds to a d' of 1.0.'
http://phonetics.linguistics.ucla.edu/facilities/statistics/dprime.htm#:~:text=The%20highest%20possible%20d'%20(greatest,corresponds%20to%20a%20d'%20of%201.0.

Results

Group comparisons

Semantic Priming

Accuracy. Controls produced 1% errors to target words in the related condition and 1.4% errors to target words in the unrelated condition. Participants with aphasia produced 3.6% errors to target words in the related condition and 5% errors to target words in the unrelated condition. The aphasia data were subjected to binomial tests comparing correct and incorrect rates of response to words and to non-words, and D' and C values were generated to compare responses to words and non-words. All participants with aphasia responded at rates significantly above chance for both the total set of words and the total set of non-words (all values of Binomial test $p<0.001$). Fourteen participants' D' values were above 4 which indicates near perfect performance, and the remaining six had values greater than 3.5. All values of C were lower than 1. These analyses indicate that participants with aphasia produced valid responses to the task.

Response latencies. The data for by-participant analysis are shown in figure 1. Two factor ANOVAs were conducted with Group as a between subjects factor (controls vs participants with aphasia) and condition as a within subjects factor (related vs unrelated prime condition). By-participant analysis revealed a significant main effect of condition with faster reaction times to items in the related than in the unrelated condition (F_1 (1, 58) = 11.42, p = .001, partial eta squared = .164). There was a significant main effect of group with the control group responding significantly faster than people with aphasia (F_1 (1, 58) = 38.37, p < .001, partial eta squared = .398). There was no significant interaction between condition and group (F_1 (1, 58) = 1.99, p = .164, partial eta squared = .033) with both groups responding faster to targets in the related condition to the same degree. In the by-item analysis the main effect of condition was not significant at the item level (F_2 (1, 98) = 3.813, p = .054, partial eta squared = .037). There was a significant main effect of group with control participants responding significantly faster than people with aphasia (F_2 (1, 98) = 359.06, p < .001, partial eta squared = .786). There was no significant interaction between relatedness condition and group (F_2 (1, 98) = 3.813, p = .317, partial eta squared = .010).

Figure 1 here

Word-Picture Verification

Accuracy. Data are presented in figure 2. Controls produced 1.3% errors to target words in the congruent condition and 12.3% errors to target words in the incongruent condition. Participants with aphasia produced 4.4% errors to target words in the congruent condition and 22% errors to target words in the incongruent condition. The aphasia accuracy data were analysed to check for random responding and response bias. All participants responded at above chance levels in the congruent condition (Binomial test values of p<0.001). In the incongruent condition three participants' response rates were indistinguishable from chance (JC: 14/25, p=0.345; JK: 15/25, p=.2122; PS: 14/25, p=0.345). All values of D' were greater than 1. The three participants with low scores in the incongruent condition also had C values higher than one indicating potential response bias.

Control participants were more accurate than participants with aphasia in the congruent condition (controls median 1.00, aphasia median 0.97, U=245, z=-2.73, p=0.006, r=.35), and in the incongruent condition (controls median .88, aphasia median .77, U=178, z=-3.52, p<0.001, r=.45). Controls and participants with aphasia were more accurate in the congruent than the incongruent condition (controls: median congruent 25, median incongruent 22, z=5.41, p<0.001, r=.61; aphasia: median congruent 48.5, median incongruent 38.5, z=-3.93, p<0.001, r=.62). Analysis of the interaction between group and condition was conducted by comparing the difference between congruent and incongruent accuracy scores across groups. The controls' difference values were significantly lower than those of the people with aphasia (controls median 2, aphasia median 9, U=211, z=-3.00, p=0.002, r=.39).

Figure 2 here

Response latencies. Response latency data are shown in figure 3. Comparisons of main effects of the response latency data were conducted using Mann Witney and Wilcoxon tests, and investigation of the interaction of group and condition was conducted by comparing the difference in response latencies between congruent and incongruent conditions across the two groups. In by-participant analyses controls were significantly faster than participants with aphasia in both the congruent condition (U=62, z=-5.30, p<0.001, r=.68), and the incongruent condition (U=21, z=-5.94, p<0.001, r=.77). By-item analyses revealed controls were faster than participants with aphasia in the congruent condition (z=-6.15, p<0.001, r=.62) and the incongruent condition (z=-6.15, p<0.001, r=.62). By-participant analyses revealed that both groups were faster in the congruent condition (control group: z=-5.51, p<0.001, r=.62; aphasia group: z=3.92, p<0.001, r=.62), and by item analyses revealed the same (control group: z=-4.96, p<0.001, r=.50; aphasia group: z=5.46, p<0.001, r=.55).

Figure 3 here

The interference effect hypothesised to arise in the incongruent condition was analysed by deriving the differences in response latencies between the two conditions for each group. There was significantly greater interference for participants with aphasia than for controls, significant for both by participant (U=13, z=-6.07, p<0.001, r=.78) and by item (U=509, z=-5.11, p<0.001, r=.51) analyses.

Word-Picture matching

Accuracy. The accuracy data are shown in figure 4. By participant between groups comparison of accuracy was significant with controls showing greater accuracy than participants with aphasia (control median 50, PWA median 48, U=134, z=-4.40, p<0.001, r=.57) as was the by item comparison (control median=40, PWA median=19, z=-6.23, p<0.001, r=.62).

Figure 4 here

Response latencies. Response latency data are shown in figure 5. Analysis of response latencies to accurate target responses revealed by participant between groups analysis of response latencies was significant (controls median=1886, PWA median=3648, U=17, z=-6.01, p<0.001, r=.78), as was the by item analysis (controls median=1907, PWA median=4112, Z=-6.15, p<0.001, r=.62).

Figure 5 here

Summary of group comparisons

Control participants were more accurate and faster than participants with aphasia in all three tasks. In semantic priming both groups responded faster to the targets in the related condition than in the unrelated condition, indicating an overall positive effect of relatedness on response latencies. The effect was comparable across the two groups showing a similar magnitude of prime effect. In Word-picture verification both groups responded significantly faster and more accurately to targets in the congruent condition than to targets in the incongruent condition, showing significant effects of semantic interference. Controls showed significantly less semantic interference than participants with aphasia. In Word-picture matching controls were significantly faster and more accurate than participants with aphasia.

Individual analyses: participants with aphasia

Data and analyses

Overview. Individual analyses were conducted of each person with aphasia's performance on Word-Picture Verification and Word-Picture Matching accuracy, the degree of Semantic Priming effect, i.e. the difference in response latencies between related and unrelated conditions, and the Word-Picture Verification interference effect i.e. the difference in response latencies between congruent and incongruent conditions. As the data included Semantic Priming and Word-Picture Verification data from times 1 and 2 each individual with aphasia's data were scrutinised to check response validity and response bias, to compare data from times 1 and 2 of testing for practice effects, and to ensure sufficient numbers of items entered the response latency analyses, as only items responded to accurately in both conditions were eligible.

Accuracy data. In the Semantic Priming task the participants with aphasia produced a total of 4.5% errors in the related and 4.2% errors in the unrelated condition. There was no significant difference in accuracy between conditions (t=0.326, df=19, one tailed p=0.3741, r=.06). The analyses of responses show above chance levels for all participants, with significant Binomial test results with p<0.001 in all cases, D' values of 3.9 or higher, and C values below 1. Participants' accuracy was compared across test times 1 and 2 to check for practice effects. There were no significant differences in accuracy between targets in related condition at times 1 and 2 (t=1.69, df=19, 2 tailed p =0.1074, r=.31), or targets in the unrelated condition at times 1 and 2 (t=1.165, df=19, p=0.2585, r=.29). Individual analyses of accuracy in the two conditions (comparing correct and incorrect responses within condition across test times) showed no significant difference for any participant in either condition. To enter the response latency analyses individuals' responses to the targets had to be accurate in both conditions. The total numbers of target items meeting this criterion ranged from 35-50 across participants, with a mean of 46.

In the Word-Picture Verification task the participants with aphasia produced 3.2% errors in the congruent and 23.8% errors in the incongruent condition. The total set of accuracy data for congruent and incongruent responses were analysed for response bias and validity of responding. The data for the congruent condition show reliable responses above chance levels for all participants, with significant Binomial test results of p<0.001 in all cases. The incongruent data show similar results for 17 participants, but three participants' responses in this condition do not differ significantly from chance (JC: p=0.4439; JM: p=0.1013; PS: p=0.3359). Analysis of the test as a whole, comparing responses in both conditions showed D' values of 3.5 or higher, and c values below 1 for all participants.

Participants' accuracy was compared across test times 1 and 2 to check for practice effects. Accuracy was higher in the congruent condition at time 2 (mean time 1=23.90, mean time 2 = 24.50, t=2.698, df=19, p=0.0071, r=.64). Accuracy was similar at times 1 and 2 in the incongruent condition at time 1 (mean time 1=19.50, mean time 2 = 18.60, t=1.294, df=19, p=0.1056, r=.24). Individual analyses of accuracy in the two conditions (comparing correct and incorrect within condition across test times) showed no significant difference for any participant in either condition, apart from JM who was significantly less accurate in the incongruent condition at time 2 than time 1 (chi square=4.08, df=1, p=0.043). The total number of target items correct in both conditions ranged from 23-47 across participants, with a mean of 37.

Response latency data. Individual participants' response latency data were compared at times 1 and 2. In Semantic Priming there were faster responses to target words at time 2 than time 1 with a mean of 1346 at time 1 and 1260 at time 2 but this difference was not significant (t=1.526, df=19, 2 tailed p=0.1434, r=.35). Individual analyses of response times to the 50 target words showed faster responses at time 2, significant for 10 of the 20 participants. Comparison of the size of the semantic priming effect at time 1 vs time 2 showed larger effects at time 2 (mean time 1=39, mean time 2 =71.55) but this was not significant (Wilcoxon matched pairs: z=1.06, one tailed p=0.1437, r=.35).

In Word-picture verification response latencies to target words were faster at time 2 than time 1, with a mean of 2804ms at time 1 and 2636ms at time 2, and this difference was significant (related t=2.255, df=19, two tailed p=0.0361, r=.15). The size of the interference effect (difference between congruent and incongruent conditions) did not differ across the two test times however, with a mean of 1037 ms difference at time 1 and 1098ms difference at time 2 (related t=0.297, df=19, 2 tailed p=0.77, r=.09). There was also a significant correlation between participants' congruent-incongruent differences at time 1 and time 2 (Spearman's R=0.481, df=22, two tailed p=0.017).

Summary. The above analyses were conducted in order to identify any effects of time of testing on response accuracy or latency. We found little evidence of systematic increases in accuracy or decreases in response latency at time 2 compared to time 1, hence the data do not show strong evidence of practice effects on responses. Some individuals showed accuracy that did not differ from chance in the WPV incongruent condition. This is noted in the analyses that follow.

Data analyses

Individual comparisons to control data. Analyses were conducted using the Singlims_ES.exe program available (Crawford, Garthwaite, & Porter, 2010). For each task the control sample mean, standard deviation and sample size were entered into the analyses, along with values for the participant with aphasia. The analysis generated a *t* test statistic, an effect size, and a point estimate of the atypicality of the aphasia score i.e. the percentage of the population that would be expected to score lower than that participant (95% confidence intervals)[7]. Two tailed significance levels are reported throughout. The full dataset is provided in supplementary data. The performance of controls and of each individual with aphasia is shown in figures 6-9. The striped bars indicate that the participant with aphasia's score was significantly different to the controls. The data are summarised in table 6 in terms of effect sizes and significance levels.

The accuracy data reveal two main patterns of performance, and two participants who do not fit either pattern. The accuracy data in figures 6 and 7 show nine participants whose performance does not differ from that of the control group (group 1), nine participants whose performance is significantly worse than controls (group 2), and the two who do not fit either pattern (group 3). Figure 8 shows the semantic priming effect. Group 1 participants' performance does not differ significantly from the controls' performance. Six participants in Group 2 also show priming effects that do not differ from controls, and three participants (DH, JM, TS) show significantly greater effects of semantic priming than controls. Figure 9 shows the Word-picture verification interference effect. All participants apart from DB and DW show significantly greater interference effects than controls.

Figures 6-9 here

Table 6 here

[7] Crawford and Garthwaite (2002) propose that a point estimate of less than 2.5% would be rare in the population and would represent a large deficit in performance. Hence a point estimate that is equal to or larger than 97.5% demonstrates a large advantage in performance (Burgoyne, Duff, Nielsen, Ulicheva, & Snowling, 2016).

Relationships between accuracy, priming and interference data. Correlations comparing accuracy in Word-Picture Verification and Word-Picture Matching, and response latencies in Semantic Priming and Word-Picture Verification Interference revealed significant relationships as follows. There were significant relationships between accuracy for WPV and accuracy for WPM (R=.790, P<0.001), between accuracy for WPV and semantic interference in WPV (R=-.767, p<0.001), and between accuracy for WPM accuracy and semantic interference in WPV (R=-.519, p=0.019). In contrast the semantic priming effect did not correlate significantly with any of the other variables.

Summary of individual analyses. The comparisons revealed two distinct main patterns of performance in terms of accuracy on the explicit offline tasks, with nine participants showing intact, and nine impaired processing. The majority of these 18 participants with aphasia showed semantic priming effects in line with the controls however, and three with impaired accuracy scores showed hyper-priming. All the participants bar one, regardless of their accuracy scores, also showed significant interference effects. Accuracy and interference effects correlated with each other, whereas semantic priming effects did not correlate with any other measure, indicating that it differs from the other tasks in terms of the cognitive and semantic functions it is measuring.

Executive function and semantic task performance

Participants with aphasia's data from the experimental semantic tasks were compared to their scores on three tests measuring different elements of executive functioning. This was to address the claims that executive function impairment underlies the semantic impairment in semantic aphasia (e.g. Jeffries and Lambon Ralph, 2006). The data are shown in Table 7.

Analyses were conducted using Spearman's rank order correlations, and we applied Bonferroni corrections to the significance cut-off due to completion of multiple comparisons for each semantic measure. This gave a value of alpha of 0.017 (0.05/3). Using the value of 0.017 meant that there were no significant correlations between any of the measures of semantic processing and scores on any of the tests of executive functions. There was limited evidence of a possible relationship between WPM accuracy and Raven's Coloured Progressive Matrices, and response latencies for the WPV and WPM tasks and scores on the Towers of Hanoi task, all of which had p-values below 0.05 but above 0.017.

Table 7 here

Discussion

This study provides new evidence about the semantic system and about the nature of the impairment to semantic access in aphasia, by comparing people with aphasia's performance on measures of accuracy, semantic activation, and semantic interference. It is the first study to compare these processing routines in individuals with aphasia, comparing their data to control data, and using carefully designed and matched stimuli. The findings indicate that semantic activation is either fully retained, or operates normally then fails to decay in aphasia, even in participants with apparent semantic deficits shown on accuracy scores on semantic judgement tasks. We also demonstrated that the majority of participants with aphasia show significant interference effects when compared to controls. All the participants with aphasia bar two showed this effect, regardless of their performance on semantic judgement tasks. A final novel finding from the study concerns the ongoing debate about the role of executive function in semantic processing. There is limited evidence in our dataset of a relationship between semantic processing and degree of impairment to executive function. The outcomes of this study question the use of accuracy scores from offline semantic judgement tasks as principal diagnostic markers, and argue for more refined methods of assessing semantic processing. We consider each finding in turn below.

Semantic activation

We have proposed here that the Semantic Priming task gives us the clearest window onto semantic activation, as it does not involve complex conscious semantic judgements and decision-making. We propose that semantic activation is best described within neural network accounts of the semantic system in which semantic neighbours share semantic features (e.g. Gotts & Plaut, 2002). The controls and the people with aphasia showed significant semantic priming effects, and this was of a similar size for controls and for participants with aphasia. This is in line with the findings of a number of previous studies in aphasia (e.g. Milberg & Blumstein, 1981; Blumstein et al., 1982; Hagoort, 1993; Baum, 1997; Yee, 2005; Howells & Cardell, 2015). The aphasia group were not pre-selected to meet any theoretical assumptions, nor selected by aphasia syndrome. Nevertheless, even with this heterogeneous group we found semantic priming effects. Previous studies have found effects in Wernicke's aphasia (e.g. Milberg & Blumstein, 1981; Milberg, Blumstein & Dworetzky, 1987), Broca's aphasia (Blumstein et al., 1982) and in anomic aphasia (Howells & Cardell, 2015). Of interest in particular is the finding of semantic priming, i.e. retained semantic activation, in participants with apparently impaired semantics as shown by their accuracy scores in semantic judgement tasks.

The individual analyses showed that the participants with aphasia demonstrated either normal semantic priming effects in comparison to the controls, or hyper-priming in the case of three of the 18 participants in Groups 1 and 2. All of the participants with normal accuracy scores presented with normal semantic priming. This particular subset of the data supports a unitary account of semantic activation, which can account for participants' performance in the accuracy and priming tasks, and which is unimpaired in these participants. The data from the six participants with impaired accuracy and normal semantic priming undermine this account however. Like the participants in Blumstein et al. (1982) and Milberg and Blumstein (1981), these participants show apparently impaired semantic processing on accuracy tasks, but normal priming effects, so a different account of semantic processing is required.

In terms of activation of shared features in a model such as Gotts and Plaut (2002), the prime activates semantic features, some of which pertain to the target, and hence speed up processing of the target. This explanation holds for all the people with aphasia showing typical priming effects, both those with normal accuracy and those with poor accuracy. The data from priming therefore suggest that representations in semantics can be activated normally in people with aphasia. So why is this not reflected across the accuracy data?

There are two possible explanations for this. The first relates to semantic task components. The semantic priming task we used involved continual list and lexical decision to all stimuli, so was online and implicit, involving unconscious and unintentional semantic processing. The semantic judgement tasks in contrast are offline and explicit, involving conscious and intentional processing. The latter explicit types of tasks arguably recruit additional cognitive processes outside of semantic processing. They make greater demands on attention, decision-making capacity, and working memory. It has also been argued that offline tasks measure only the end point of processing (see e.g. Shapiro, Swinney & Borsky, 1998), and reflect the interplay of a number of cognitive functions (Howells and Cardell, 2015: 745), hence are not a pure measure of semantic activation. In our Word-picture verification task for example being able to reject the word ‘otter’ in response to a picture of a badger demands retrieval of and comparison of both representations in semantic memory simultaneously. This explanation proposes therefore that the participants showed a specific difficulty with explicit offline tasks involving related stimuli. This equates to Jefferies and Lambon Ralph’s (2006) claims that the deficit lies in poor semantic control, recruited for more demanding semantic tasks. If this were the case then performance on offline explicit tasks would correlate with measures of executive function. We used similar tasks to those used by Jefferies and Lambon Ralph (2006), and found limited evidence of this relationship, with a possible significant correlation in three of the 18 comparisons, but which did not withstand Bonferroni corrections for multiple comparisons.

We recognise that there is no pure single measure of executive functions, and that domain-general tasks used in this study may not directly probe domain-specific deficits in semantic control. Like other researchers in this field we are limited to what is available. Trying to measure semantic control with semantic tasks could become a circular activity so at present existing measures which limit the involvement of language are the best available. Chapman, Hasan, Schultz and Martin (2020) also failed to find significant relationships between usual tests of executive function and semantic processing scores, but did find a relationship between tests of updating, including one back and two back where participants judge whether the new word appearing also appeared in the previous trial (one back) or trial but one (two back). All the updating tasks involved language however, which was arguably a confounding factor, as those with word processing deficits would do worse regardless of hypothesised semantic control deficits.

Our second explanation relates to the presence or otherwise of semantic neighbours in the tasks. In our semantic priming task each prime or target word appears in isolation. In semantic judgement tasks in contrast, both the target and the near semantic neighbour (the distractor word) are simultaneously present and hence presumably simultaneously activated. In the Word-picture verification task these are the only stimuli present, and, critically, they are presented in different modalities. The resulting semantic interference affects processing of the target and distracter and results in lower accuracy and slower response times. We consider this explanation more fully in the following section.

Finally with regard to activation, three participants with poor accuracy showed hyper-priming, with significantly greater priming effects than found in the controls. Similar findings have been reported in people with schizophrenia at very short SOAs (e.g. Maher, 1983; Baving, Wagner, Cohen & Rockstroh, 2001). Hyper-priming has also been found in participants with Alzheimer's Disease (Giffard, Desgranges & Eustache, 2005; Nebes, Brady & Huff, 1989). These effects have been interpreted as enhanced initial semantic activation in such participants with schizophrenia or Alzheimer's disease. For the participants with aphasia investigated here, enhanced activation of semantic features appears unlikely and inexplicable, and the effect is more easily explained as a failure of activation to decay appropriately after word selection is completed (see e.g. Dell et al.'s 1997 weight and decay account of anomia). If this latter were the case the overall response latencies in these three participants would be slower, as each preceding word's activated features would decay more slowly than normal, affecting all subsequent words. Scrutiny of the response times for these three participants shows their average responses are amongst the slowest in the group. This supports an account where activation of the prime's semantic features, then the target's semantic features, results in over-stimulation of the shared features, prohibiting the normal decay processes.

In summary the data from the semantic priming task reveal that, regardless of the nature of the participant's performance on semantic judgement tasks, semantic priming is present in the participants with aphasia to the same extent as it is for healthy controls. This indicates that speakers with aphasia on the whole do not have primary difficulties in activating semantic representations. This is in line with the access-storage dichotomy (Warrington & Shallice, 1979), where storage in aphasia is maintained but access may be impaired, and efficiency of access is task-dependent. More complex tasks such as those used by Noonan et al. (2010) reveal marked difficulties in those participants who also have difficulties in other judgement tasks such as word-picture matching. When task complexity is minimised as is the case with priming tasks, semantic activation is shown to be normal. It is feasible therefore that for many people with aphasia diagnosed with semantic impairment, activation of lexical semantics is unimpaired. The difficulties identified in testing may therefore only be revealed by semantic judgement tasks pitting two semantic neighbours against each other, hence such difficulties are task-related. Critically those showing hyper-priming are arguably the only participants with aphasia in this study presenting with a semantic activation deficit, with their semantic activation processes being affected by the failure of representations to decay, which is likely to negatively impact on semantic processing regardless of task.

Semantic interference

We identified interference effects as being present when two semantic neighbours are simultaneously present in a task. In the Word to Picture Verification task the participants with aphasia and the controls showed lower accuracy and slower response times in the incongruent condition than in the congruent condition, providing evidence of the negative impact of cross-modal semantic neighbours on processing. The interference was present for both groups but was significantly greater for the aphasia group[8]. There are few previous studies investigating semantic processing in aphasia using word-picture verification tasks (Breese & Hillis, 2004; Howard & Gatehouse, 2006; Howard & Orchard-Lisle, 1984; Morris & Franklin, 2012; Rapp & Caramazza, 2002). In Breese and Hillis' (2004) study the majority of the 122 participants with aphasia performed less well on this task than on word-picture matching, indicating that this task is more sensitive to difficulties in handling semantic

[8] Three of the participants with aphasia's accuracy responses in the incongruent condition did not differ significantly from chance and must be viewed with that in mind - participants JC, JK and PS

competitors. Previous studies have not tended to investigate response latencies as analysed here however, although see Biegler, Crowther and Martin (2008) for an exception, so our data provide a novel insight into this element of processing in aphasia and in controls.
In the individual analyses all bar two of the participants with aphasia showed significant interference effects when compared to controls[9]. The participants with normal accuracy scores and normal semantic priming effects would usually be identified as presenting with normal semantic processing. Nevertheless their response latencies are significantly slower when attempting to resolve competition between two simultaneously activated semantically related representations. Previous studies using this type of interference task have not routinely analysed response latencies (e.g. Breese and Hillis, 2004). In their aphasia study Milberg and Blumstein (1981) compared semantic priming effects with scores on a semantic judgement task (two words presented simultaneously) and found no relationship, probably because two written words can be distinguished visually without lexical or semantic involvement. The inclusion of response latency analyses is valuable in particular in interrogating semantic processing in those with high accuracy scores. The semantic interference effect from the incongruent word indicates that in most people with aphasia the capacity to inhibit the activation of a close competitor representation is impaired.

The interference findings are in line with those from previous studies of picture-word interference effects with normal controls (e.g. Schriefers et al., 1990), where target and competitor are simultaneously present, and from studies of aphasia where the competitor precedes the target such as naming and blocked cyclic naming. These studies have found increased semantic interference with increased exposure to semantic competitors, so-called semantic refractory disorder (e.g. Warrington & McCarthy, 1983; Warrington & McCarthy,

[9] DB in group 1, and DW in group 3, the anomalous subgroup

1987). In blocked cyclic naming tasks such as those reported by Harvey and Schnur (2015), McCarthy and Kartsounis (2000), Wilshire & McCarthy (2002), Howard et al. (2006), and Schnur et al. (2006) interference effects have been reported. The competitor stimuli precede the target item, yet still interference is found. This task involves spoken production however, unlike our semantic tasks, so differs in that critical way. In the naming task interference builds gradually over trials, as more shared features and more word forms activated by shared semantic features are activated. Competition presumably arises due to this activation, and to the increased demand on resources of selecting the correct word at the lexical level. This has been termed the incremental learning account of language use by researchers such as Oppenheim, Dell and Schwartz (2010). So in production tasks stimuli do not need to appear simultaneously with the target in order to cause interference, but possibly in comprehension they do. As Harvey et al. (2019: 81) point out, other tasks not requiring lexical access, such as manual semantic categorisation of pictures, also do not typically show semantic interference effects. In some cyclic naming reports interference effects emerged only at certain speeded tempos, or with repeated presentation of the stimuli (e.g. Hodgson et al., 2003), so the impact of previous items is not inevitable, but where there is additional stress on the processing system, such as selection requirements, less efficient processing ensues. Harvey and Schnur’s (2015) findings of the impact of damage to the LIFG on increased interference over cycles of naming, but not on interference in comprehension indicates again the differences between the tasks, with inhibition of competitors being of greater relevance in naming.

Like the naming task, our semantic priming task also involved listwise presentation, so why are there only priming and not interference effects in this task? Again the critical difference may be the response type, with lexical decision to each item involving only a yes/no choice incurring less complex decision making and no selection at the lexical level. Arguably the semantic priming task does not involve the same complexity of language processing that is present in semantic judgement tasks. But conversely the latter do not reflect natural language processing in everyday conversation. Semantic priming must recruit semantics, otherwise there would be no effect of semantic relatedness on response latencies. We argue that this is closer to natural language than being asked to match an image to a word in the presence of competitor stimuli.

The six participants with impairments shown in semantic judgement scores, but normal semantic priming, also showed evidence of semantic interference. This is easier to explain within neural network accounts. There is no effect of competitor stimuli when representations are activated consecutively and where semantic decision making and selection is minimal, as shown in the semantic priming task, but difficulties arise in handling simultaneously active competitor stimuli in more demanding tasks involving semantic decisions. This is apparent across tasks, leading to errors in both accuracy tasks, and significantly slower response times when competitors are present in the incongruent condition in Word-Picture Verification, than when they are not. The same explanation pertains for the hyper-priming subgroup, with the same difficulties arising due to simultaneous activation of competitors, compounded by the slowness in decay of semantic features for previously activated representations. Both factors arguably contribute to the difficulties experienced by this group.

Relationships between accuracy, activation, and interference

A clear pattern emerged in the analyses of correlations between scores on the experimental semantic tasks. Accuracy scores in the two explicit semantic decision tasks (Word-Picture

Verification and Word-Picture Matching) and the data pertaining to semantic interference from the Word-Picture Verification task, all showed significant correlations with each other. No task showed a significant correlation with the semantic priming effect however. These findings support the proposals outlined above, that the semantic priming effect shows semantic activation in its most transparent form. All the other tasks involved resolving competition between the target and a competitor activated simultaneously and demanded explicit decisions about the semantic relationship. The deficits found in people with aphasia reported in research studies and used in clinical diagnosis, relate therefore almost entirely to this epi-phenomenon of semantic processing tasks. The use of tasks which do not involve co-activation of semantic neighbours and explicit semantic decisions will likely render very different findings in future studies. Different assessment methods are therefore required in order to provide data which truly reflects the operation of the system under investigation, and thereby build appropriate theoretical models of the semantic system. Clinically these are needed to ensure accurate diagnosis and selection of appropriate intervention.

Executive function and semantic control

In the discussion above we argue for a new understanding of semantic processing in aphasia, in which initial activation of semantic representations is unimpaired, resolution of competition between simultaneously activated semantic neighbours is impaired when tasks demand conscious decision making, and in some severe cases failure of activation to decay is present leading to hyper-priming and overall slower and less accurate task performance. We now consider the role of executive functions in processing of semantic knowledge.

As outlined in the introduction, one theoretical account of semantic processing holds that semantic knowledge is regulated by a frontal executive semantic control mechanism. The degree to which the latter is involved differs depending on task demands, with simpler implicit tasks being likely to place fewer demands on executive processes. Multi-modal semantic processing impairments in participants with aphasia have been labelled semantic aphasia, and the degree of semantic deficit associated with degree of executive function impairment (e.g. Jefferies & Lambon Ralph, 2006; Noonan et al., 2010). To date few cases have been examined however, and those that have taken part have all presented with deficits in a range of accuracy tasks.

In the study reported here we found limited evidence of a relationship between semantic processing task scores and our measures of executive control. Only three of our 18 comparisons were significant (accuracy on Word-picture matching and scores on Raven's progressive matrices), and with Bonferroni corrections applied none were significant. Our data point to difficulties with handling competitor stimuli when these are simultaneously activated in tasks involving conscious decision-making. This explanation accounts for the accuracy data found in the semantic aphasia cases reported previously, where all input tests involve at least two semantic neighbour stimuli and no measures of response latencies have been analysed. Again, previous studies comparing online priming with offline metalinguistic tasks have found similar differences across tasks (e.g. Milberg & Blumstein, 1981).

Critique of methods

In our study the inclusion of data from two test times for the Semantic Priming and Word-Picture Verification tests, resulting in data points for each individual with aphasia for each target in each condition, is novel. However, it is potentially problematic, in that both accuracy and response latencies may be better at the second test time, giving skewed data. In this study there was no evidence of greater accuracy at time 2 in the Semantic Priming task, but some evidence of faster response times and a greater semantic priming effect at time 2 compared to time 1. This was not consistent across participants however, meaning that the testing procedure had a varying effect on performance and cannot in isolation account for the observed effects.

In the Word-Picture Verification task there was no clear effect of test time in the individual analyses, with accuracy for the congruent set being higher at time 2 but accuracy for the incongruent set being higher at time 1. Responses were faster at time 2 but the interference effect was the same at time 1 and time 2. This design clearly introduces a time variable however, which affects participants differently, and means data are more complex. We used this design in order to ensure sufficient power in the individual analyses, and reduce the impact of potential poor performance at time 1 due to lack of familiarity with tasks. In several previous semantic priming studies in aphasia participants have viewed targets in each condition on the same test occasion, thereby introducing potential within task priming effects (see e.g. Milberg & Blumstein, 1981; Blumstein et al., 1982). Data from studies using both methods needs to be considered in order to amass evidence of priming effects.

Conclusion and implications

This study used carefully matched stimuli to investigate semantic processing in people with a wide range of severity of aphasia. The methods used allowed the direct comparison of semantic activation with semantic interference, and with accuracy scores. The results indicate that in aphasia semantic activation is largely unimpaired. The difficulties that people with aphasia face in processing semantic stimuli relate almost entirely to the presence of competitor stimuli in neuropsychological tasks and the nature of the task with offline conscious decision making providing additional challenges to people. The findings also address claims that these difficulties are associated with damage to executive function, at least as far as we were able to assess this. The study casts new light on the nature of semantic processing in general, and semantic processing in aphasia. The development of better forms of assessment which directly assess semantics is required, using response latencies routinely in place of accuracy tasks, and minimising the impact of competitor stimuli in tasks, in order to increase our knowledge, and to provide better diagnosis for those affected by aphasia and other related cognitive-linguistic disorders.

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Declaration of interest statement

This is to certify that the authors know of no conflict of interest inherent in the publication of this report.

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Table 1. Properties of semantic tasks

	Semantic priming	Semantic judgement tasks	Blocked cyclic naming	Word-picture interference
Target and competitor presentation	Competitor then target	Simultaneous	Competitor then target	Simultaneous
Type of response	Lexical decision yes/no	Match cross modal stimuli	Spoken word retrieval	Spoken word retrieval
Type of task	Implicit	Explicit	Explicit	Explicit

Table 2. Demographic data for participants

Participants with aphasia (n=20)	Mean	Standard deviation	Range
Age (years)	66	8.82	46-84
Basic schooling (years)	10.3	.57	9-11
Enhanced schooling (years)	.85	.99	0-2
Education (years)	12	2.68	9-18
Controls (n=40)	**Mean**	**Standard deviation**	**Range**
Age (years)	63	8.26	41-81
Basic schooling (years)	10.83	.38	10-11
Enhanced schooling (years)	1.43	.84	0-3
Education (years)	14	2.87	10-18

Table 3. Background data for participants with aphasia

Participant	Age	Sex	Years in education	Employment background	Time post stroke (years; months)	Premorbid handedness	Fluency
BT	79	M	16	Teacher	13;02	pure right	F
CW	70	F	18	Researcher; administration	4;07	pure right	F
DB	46	M	11	Manual worker	7;07	mixed right	F
DH	63	M	13	Engineer	1;04	pure right	NF
DW	69	M	10	Manual worker	6;07	pure right	F
FM	75	F	12	Professional	12;07	pure right	F
GB	64	M	12	Engineer; retail	4;09	pure right	F
JC	66	M	10	Manual worker; retail	4;01	pure right	NF
JK	64	M	10	Manual worker	3;10	mixed right	F
JM	84	F	9	Manual worker	5;05	mixed right	NF
LW	67	M	10	Manual worker	0;09	mixed right	NF

NMH	70	M	11	Professional administration	6;08	mixed right	F
PG	70	M	10	Manual and trade	5;07	pure right	F
PS	69	F	10	Manual worker	11;00	mixed right	F
RP	60	M	15	Professional	8;10	pure right	F
RT	67	M	10	Professional administration	4;00	pure right	F
SE	69	M	12	Manual worker	9;06	mixed left	F
SH	52	F	16	Professional administration	18;07	pure right	NF
SL	63	F	10	Retail	4;02	mixed right	NF
TS	53	M	16	Professional	7;10	pure right	F

Table 4. Language assessment data participants with aphasia

		BT	CW	DB	DH	DW	FM	GB	JC	JK	JM	LW	NMH	PG	PS	RP	RT	SE	SH	SL	TS	Control range/ cut off
Syndrome		Co	An	Co	TM	An	TS	Co	TM	An	G	Br	An	Co	Co	W	Co	An	TM	TM	TS	
Fluency		F	F	F	NF	F	F	F	NF	F	NF	NF	F	F	F	F	F	F	NF	NF	F	
Auditory:	N=																					
ADA[1] Minimal pairs	40	1.0	.98	1.0	.90	.95	.85	.98	.10	.98	.68	.98	1.0	.78	.80	.90	1.0	.98	.98	1.0	.83	.95-1 .93
PALPA[2] Lexical decision	160	.79	.92	.96	.72	.83	.82	.94	.78	.94	.66	.96	.99	.89	.74	.81	.99	.84	.93	.94	.94	.98
High Im	40	.88	1.0	.98	.80	.98	.93	1.0	.98	1.0	.98	1.0	1.00	.98	.93	.98	1.0	.98	.95	.98	.98	.996
Low Im	40	.58	.95	.98	.53	.95	.78	.85	.85	1.0	.80	.95	1.00	.88	.68	.85	1.0	.83	.88	.88	.93	.99
Nonwords	80	.85	.86	.95	.78	.69	.79	.95	.76	.88	.43	.83	.98	.85	.68	.70	.99	.79	.95	.96	.93	.95
Lexical comprehension																						

Spoken word to picture matching (CAT[3])	30	0.9	1	0.97	0.9	1	1	0.9	0.83	0.87	0.8	0.97	1	1	0.97	0.73	0.93	0.93	0.97	0.97	0.93	0.83-1.0 0.83
Written word to picture matching (CAT[3])	30	1	0.93	0.87	0.9	0.83	0.73	0.93	0.8	0.93	0.87	0.83	0.97	0.97	0.83	0.67	0.97	1	1	0.87	0.9	0.90-1.0 0.90
Sentence comprehension:																						
CAT[3] Spoken sentence comprehension	32	.69	.97	.88	.75	.94	.59	.69	.78	.69	.69	.84	.91	.72	.69	.69	.88	.72	.69	.81	.66	.81-1 .84
CAT[3] Written sentence comprehension	32	.94	.88	.72	.56	.66	.34	.41	.66	.81	.47	.84	.72	.53	.53	.66	.88	.78	.50	.41	.59	.75-1 .72
Spoken output:																						
Picture naming (CSB[4])	64	.80	.81	.39	.31	.73	.61	.52	.64	.70	.19	.17	.64	.58	.41	.61	.59	.48	.67	.66	.67	-
Word repetition	182	.5	.97	.53	.80	.96	.80	.49	.86	.90	.08	.06	.98	.63	.49	.91	.53	.88	.89	.92	.95	.97-1 <97

Word read aloud	182	.92	.98	.56	.83	.73	.76	.63	.68	.90	.05	.04	.91	.85	.44	.99	.96	.86	.89	.76	.68	.98-1 <98
Nonword repetition	26	.15	.81	.8	.62	.88	.15	.12	.54	.65	0	.04	.85	.08	.15	.58	.77	.50	.38	.65	.73	.92-1 <.92
Nonword read aloud	26	.96	.73	.19	.58	.27	0	.12	0	.54	0	0	.65	.04	0	.58	.42	.38	.08	0	.04	.85-1 <.85

Note. Key to aphasia syndromes: An = anomic; Co = conduction; W= Wernicke's; TS = transcortical sensory; TM = transcortical motor; Br = Broca's;. G= global

All scores represent % correct. Underscore denotes scores below the test cut off for normal range. CAT cut off score and below is that which at least 95% of normal subjects exceed. Written synonym judgement norms taken from Nickels & Cole-Virtue (2004). Word and non-word read aloud and repetition tests provided by D Howard, personal communication. CSB Picture naming – no normative data available but all scores indicate deficit.

[1]ADA Action for Dysphasic Adults Comprehension Battery (Franklin, Turner, & Ellis, 1992); [2]PALPA : Psycholinguistic assessments of language processing in aphasia (Kay et al., 1992); [3]CAT Comprehensive Aphasia Test, (Swinburn et al., 2004); [4]Cambridge semantic battery

Table 5. Semantic input tests and tests of executive function for participants with aphasia

		BT	**CW**	**DB**	**DH**	**DW**	**FM**	**GB**	**JC**	**JK**	**JM**	**LW**	**NMH**	**PG**	**PS**	**RP**	**RT**	**SE**	**SH**	**SL**	**TS**	**Control range/ cut off**
Visual :	N=																					
Picture PPT [1]	52	1.00	0.98	0.94	0.96	0.92	0.96	0.98	0.9	0.96	0.79	0.96	0.92	0.98	0.73	0.96	0.90	0.96	0.96	0.90	0.88	0.94 or 49[a]
Picture CCT[2]	64	0.89	0.89	0.94	0.78	0.89	0.78	0.97	0.73	0.86	0.69	0.95	0.67	0.97	0.50	0.92	0.77	0.72	0.86	0.69	0.86	.8-.97[a]
Spoken:																						
Spoken word to picture matching (CAT) [3]	30	0.90	1.00	0.97	0.90	1.00	1.00	0.90	0.83	0.87	0.80	0.97	1.00	1.00	0.97	0.73	0.93	0.93	0.97	0.97	0.93	0.83-1, 0.83
Auditory synonym judgement (PALPA) [4]	60	0.68	0.97	0.93	0.75	0.87	0.82	0.70	0.75	0.78	0.52	0.92	0.92	0.85	0.75	0.93	0.85	0.82	0.83	0.68	0.80	Mean and SD: 56.75 (2.15) **0.87[b]**

High imageability	30	0.73	1.00	0.97	0.93	0.90	0.90	0.83	0.83	0.80	0.63	0.93	1.00	0.93	0.83	1.00	0.93	0.97	0.87	0.73	0.93	Mean 28.9 (SD 0.85)
Low imageability	30	0.63	0.93	0.90	0.57	0.83	0.73	0.57	0.67	0.77	0.40	0.90	0.83	0.77	0.57	0.87	0.77	0.67	0.80	0.63	0.67	Mean 27.85 (SD 1.69)
Spoken WPM Category comprehension (CSB) [5]	64	0.84	0.98	0.97	0.92	0.98	0.98	0.98	0.92	0.95	0.48	0.91	0.98	1.00	0.88	0.98	1.00	0.91	0.94	0.97	0.97	62 or 0.97[c]
Written:																						
Written word to picture matching (CAT) [3]	30	1.00	0.93	0.87	0.90	0.83	0.73	0.93	0.80	0.93	0.87	0.83	0.97	0.97	0.83	0.67	0.97	1.00	1.00	0.87	0.90	0.90-1.0, 0.90
Written synonym	60	0.98	0.97	0.90	0.87	0.88	0.92	0.85	0.77	0.88	0.75	0.82	0.90	0.92	0.75	0.93	0.88	0.87	0.88	0.90	0.83	Mean and SD: 56.75

judgement (PALPA)[4]																						(2.15) **0.87[b]**
High imageability	30	1.00	0.97	0.93	0.90	0.97	0.93	0.87	0.87	0.93	0.80	0.97	0.93	0.97	0.87	1.00	0.97	0.93	0.93	0.97	0.97	Mean 28.9 (SD 0.85)
Low imageability	30	0.97	0.97	0.87	0.83	0.80	0.90	0.83	0.67	0.83	0.70	0.67	0.87	0.87	0.63	0.87	0.80	0.80	0.83	0.83	0.7	Mean 27.85 (SD 1.69)
Executive function																						
Brixton Spatial Anticipation Test[6]		16	18	33	20	39	26	15	19	20	35	33	16	25	26	14	15	30	14	25	27	d
Raven's Coloured Progressive Matrices [7]		32	36	31	35	29	24	34	25	30	17	34	31	18	16	30	34	23	32	25	30	e

Towers of Hanoi [8]		4	3	3	3	6	12	3	5	3	7	3	3	7	4	3	4	5	3	3	5	f

All scores represent % correct. Underscore denotes scores below the test cut off for normal range. CAT cut off score and below is that which at least 95% of normal subjects exceed. [1]PPT Pyramids and Palm Trees test (Howard & Patterson, 1992); [2]Camel and Cactus Test from the Cambridge Semantic Battery (Bozeat, Lambon Ralph, Patterson, Garrard, & Hodges, 2000; [3]CAT Comprehensive Aphasia Test, (Swinburn et al., 2004); [4]PALPA : Psycholinguistic assessments of language processing in aphasia (Kay et al., 1992); [5]CSB Cambridge Semantic Battery (Bozeat, Lambon Ralph, Patterson, Garrard, & Hodges, 2000); [6]Brixton Spatial Anticipation Test (Burgess & Shallice, 1997; [7]Raven's Coloured Progressive Matrices (Raven, 1956); [8]Towers of Hanoi: M Coleman (personal communication)

Normative data: [a]Jefferies et al. (2007) [b]Cole Virtue and Nickels (2004) [c]Jefferies et al. (2010); [d]Brixton: 5% cut-off[6] : 18-45 >2, 46-65 > 27, 66-80 > 29; [e]Raven's: 95th centile cut-off for chronological age: 65:33, 70:31, 75: 30: 80: 29; [f]Towers of Hanoi time to complete two discs: >6.48 (control mean +2SD)

Table 6. Groups 1 and 2: semantic task scores vs controls – effect sizes and significance levels

Group 1	**WPV accuracy**	**WPM accuracy**	**Semantic priming effect**	**WPV interference**
BT	0.67	-0.31	0.98	1.933*
CW	0.00	-0.31	0.25	3.093*
DB	0.00	-0.31	-0.32	1.427
LW	-0.67	-1.27	1.94	1.873*
NMH	-0.67	-1.27	-0.51	6.972***
PG	1.33	0.64	-0.15	2.998**
RP	-0.67	-1.27	0.42	3.807***
SE	-1.67	-1.27	-0.22	2.462**
SH	-1.00	0.64	0.96	6.668***
Group 2				
DH	-4.33***	-2.22*	4.07***	12.225***
FM	-4.00***	-2.22*	1.18	16.014***
JC	-6.33***	-3.17**	0.39	15.854***
JK	-3.33***	-3.17**	0.74	8.203***
JM	-4.33***	-5.08***	2.70**	12.724***
PS	-7.00***	-12.70***	-0.22	10.839***
RT	-2.33*	-2.22*	0.34	8.405***
SL	-3.00**	-5.08***	0.98	2.861**
TS	-3.00**	-2.22*	4.04***	8.251***
Group 3				

DW	-0.67	-2.22*	-0.02	1.385
GB	-2.33*	-0.31	2.3*	5.08***

WPV: Word-Picture Verification. WPM: Word-Picture Matching. All significant WPV and WPM accuracy results represent performance which is significantly less accurate than controls All significant priming effects represent a greater priming effect than controls; All WPV interference values are significantly greater than controls. ***$p \leq .001$.**$p \leq .01$. *$p \leq .05$.

Table 7. Correlation data between experimental semantic task values and scores on tests of executive function

People with aphasia (n=20)	Brixton spatial anticipation test		Raven's coloured progressive matrices		Towers of Hanoi	
	R	p	R	p	R	p
Semantic priming effect	.013	.956	.237	.314	-.004	.985
WPV interference effect	-.198	.402	-.196	.407	.266	.257
WPV accuracy	.127	.595	.342	.140	-.193	416
WPM accuracy	.356	.124	.467	.038	-.250	.287
WPV response latencies	.038	.872	-.347	.134	.468	.038
WPM response latencies	-.048	.840	-.276	.238	.509	.022

WPV: Word-Picture Verification. WPM: Word-Picture Matching. Response latencies for the WPV task include both conditions.

Figure captions:

Figure 1 Semantic priming response latencies (ms)

Figure 2 Word-picture verification accuracy (proportion correct)

Figure 3 Word-picture verification response latencies (ms)

Figure 4 Word-picture matching accuracy (number correct)

Figure 5 Word-picture matching response latencies (ms)

Figure 6 Word-picture verification accuracy (proportion correct)

Striped bars indicate values which are significantly different to control group data

Figure 7 Word-picture matching accuracy

Striped bars indicate significantly values which are significantly different to control group data

Figure 8 Semantic priming effect (ms)

Striped bars indicate values which are significantly different to control group data

Figure 9 Word-picture verification interference effect (ms)

Striped bars indicate values which are significantly different to control group data

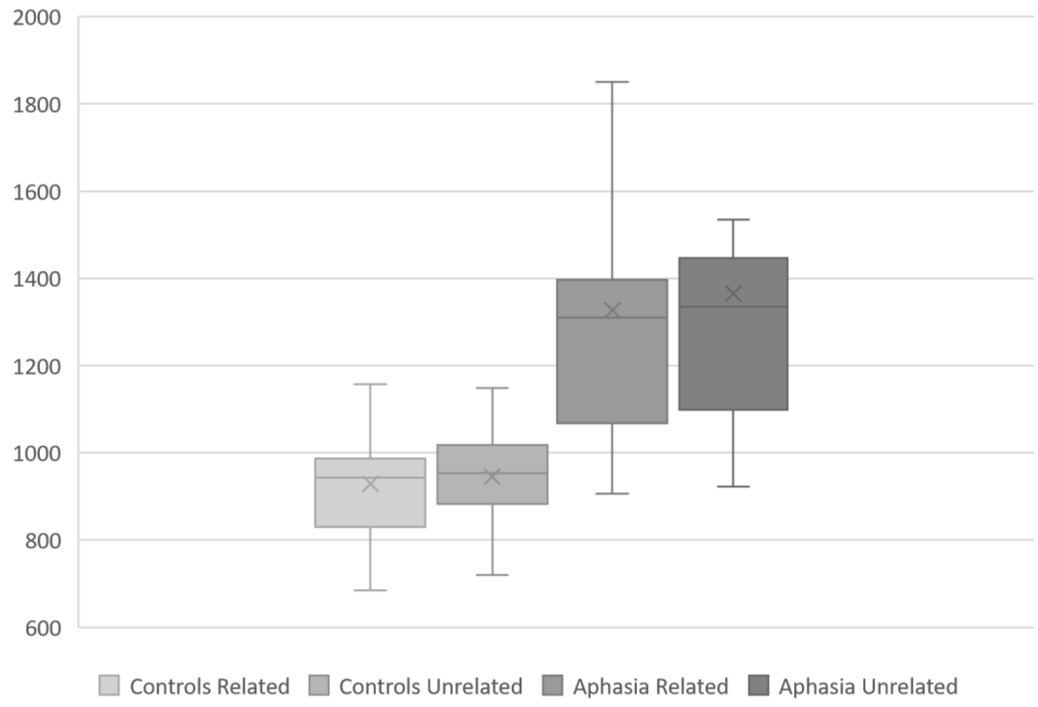

Figure 1 Semantic priming response latencies (ms)

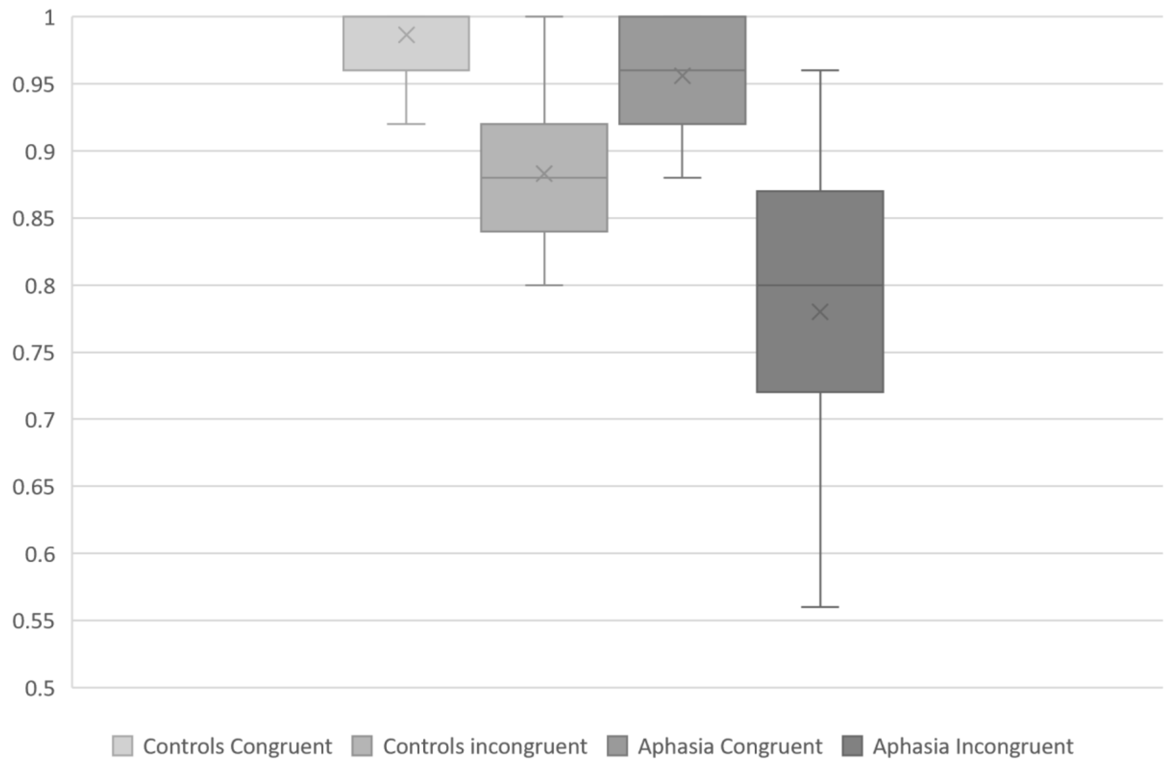

Figure 2 Word-picture verification accuracy (proportion correct)

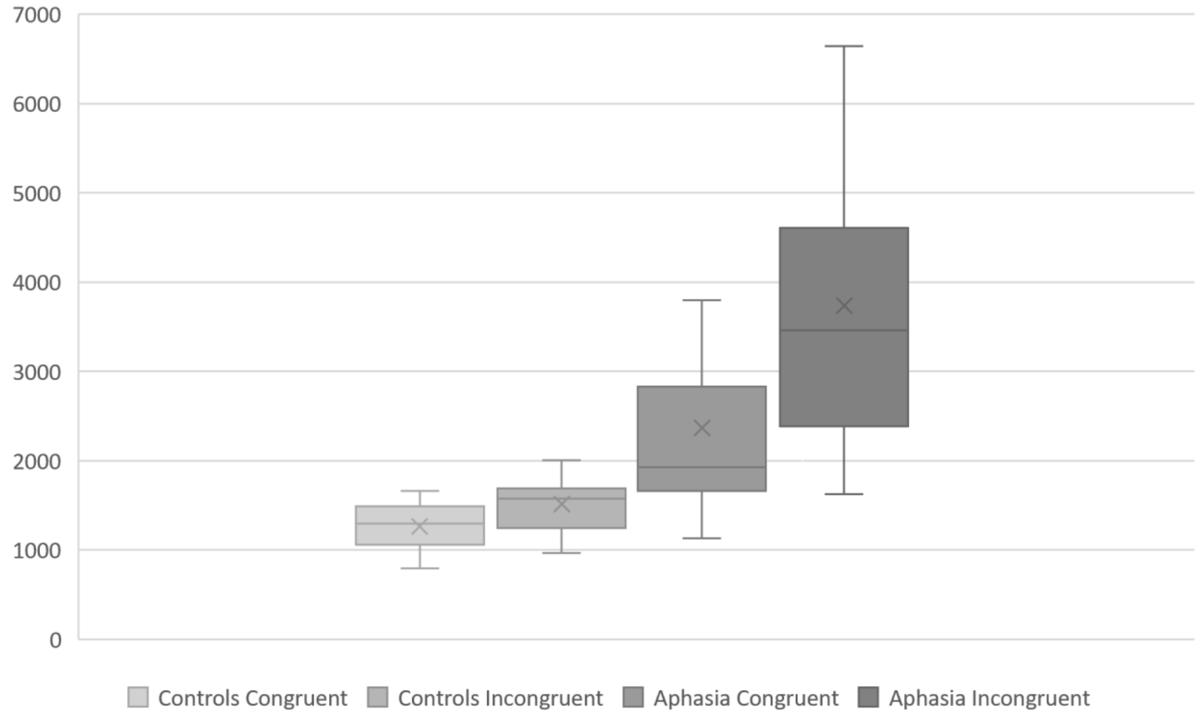

Figure 3 Word-picture verification response latencies (ms)

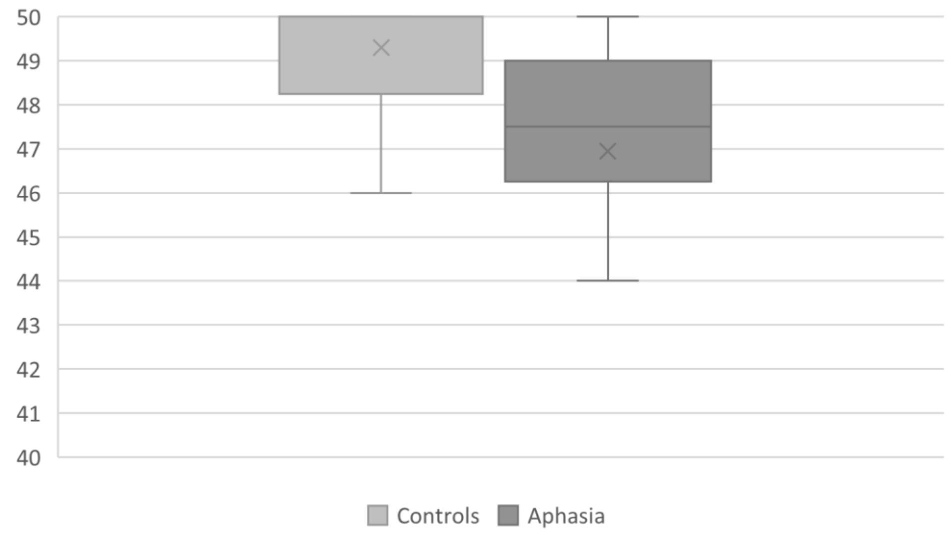

Figure 4 Word-picture matching accuracy (number correct)

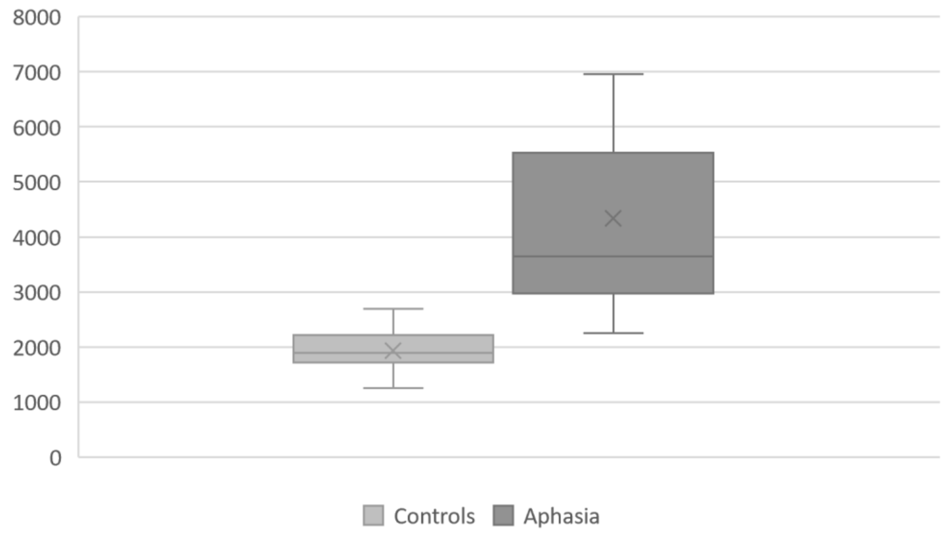

Figure 5 Word-picture matching response latencies (ms)

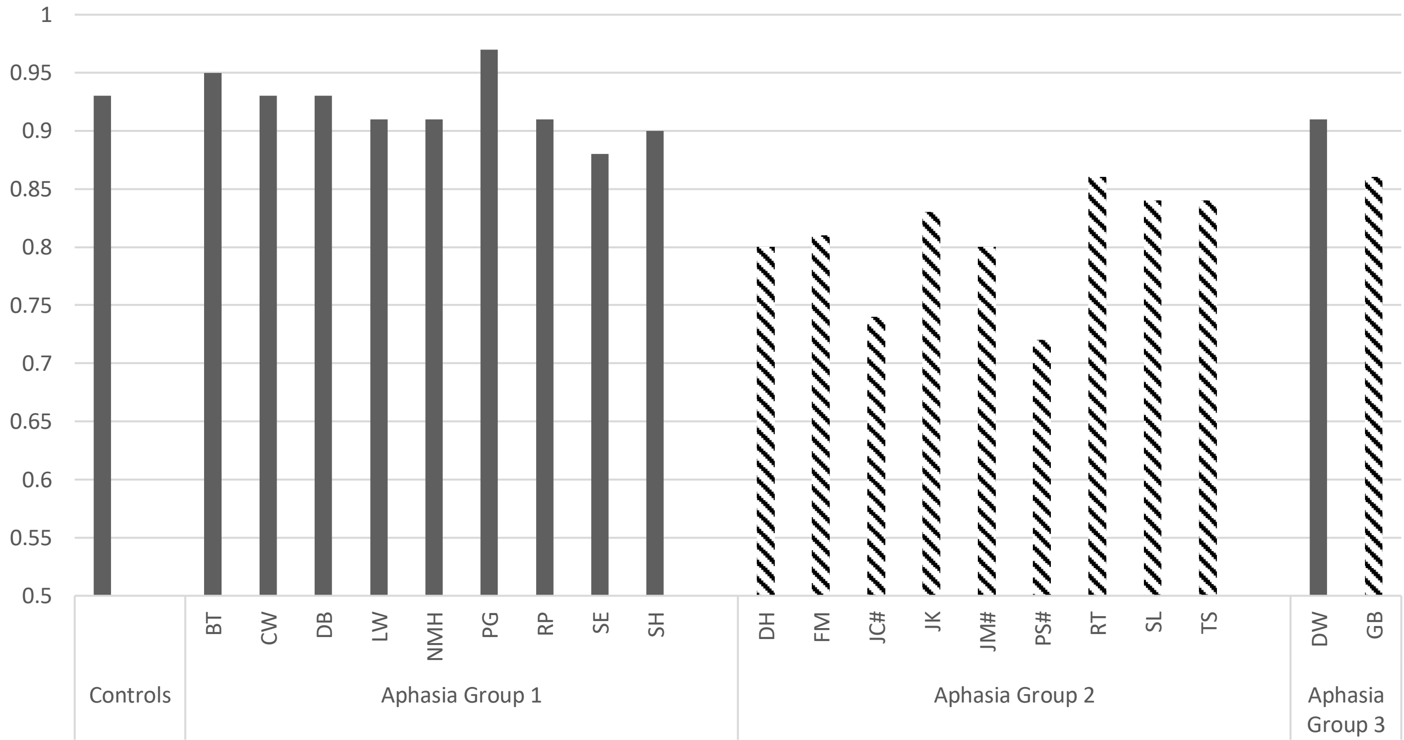

Figure 6 Word-picture verification accuracy (proportion correct)
Striped bars indicate values which are significantly different to control group data

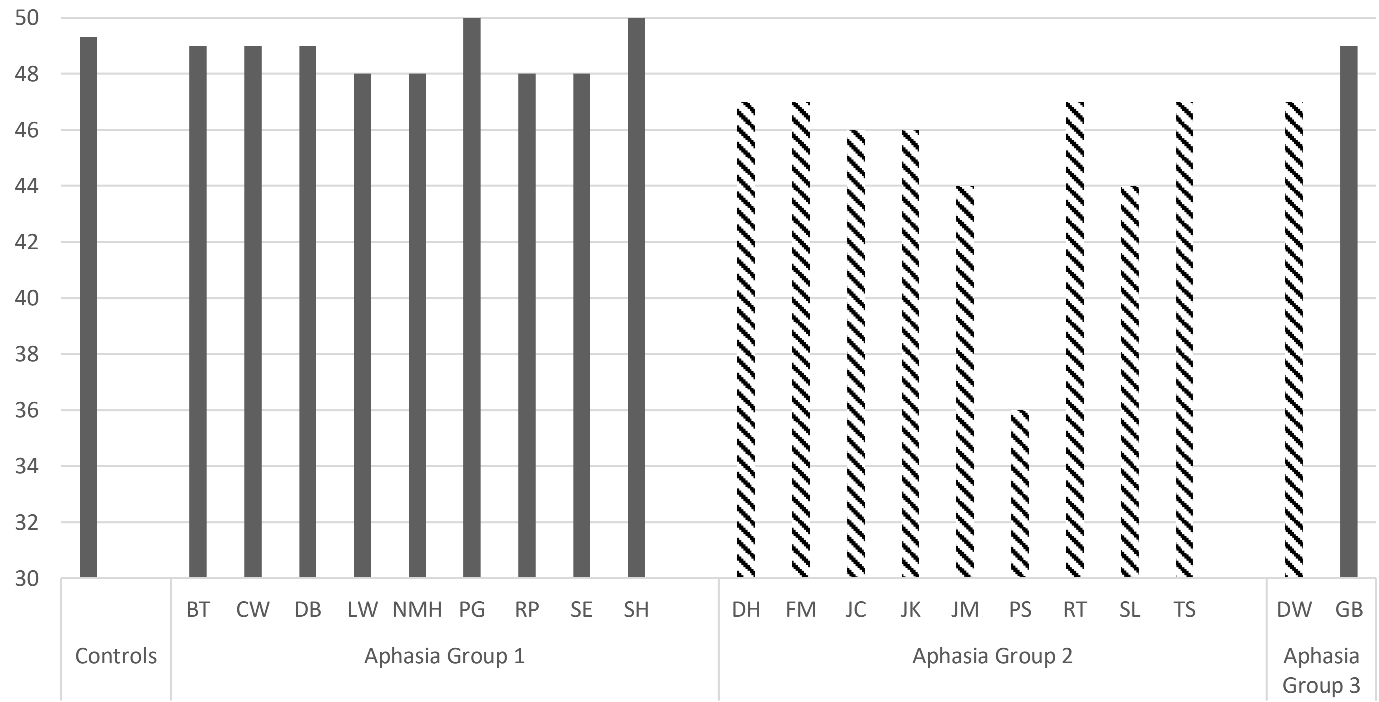

Figure 7 Word-picture matching accuracy
Striped bars indicate values which are significantly different to control group data

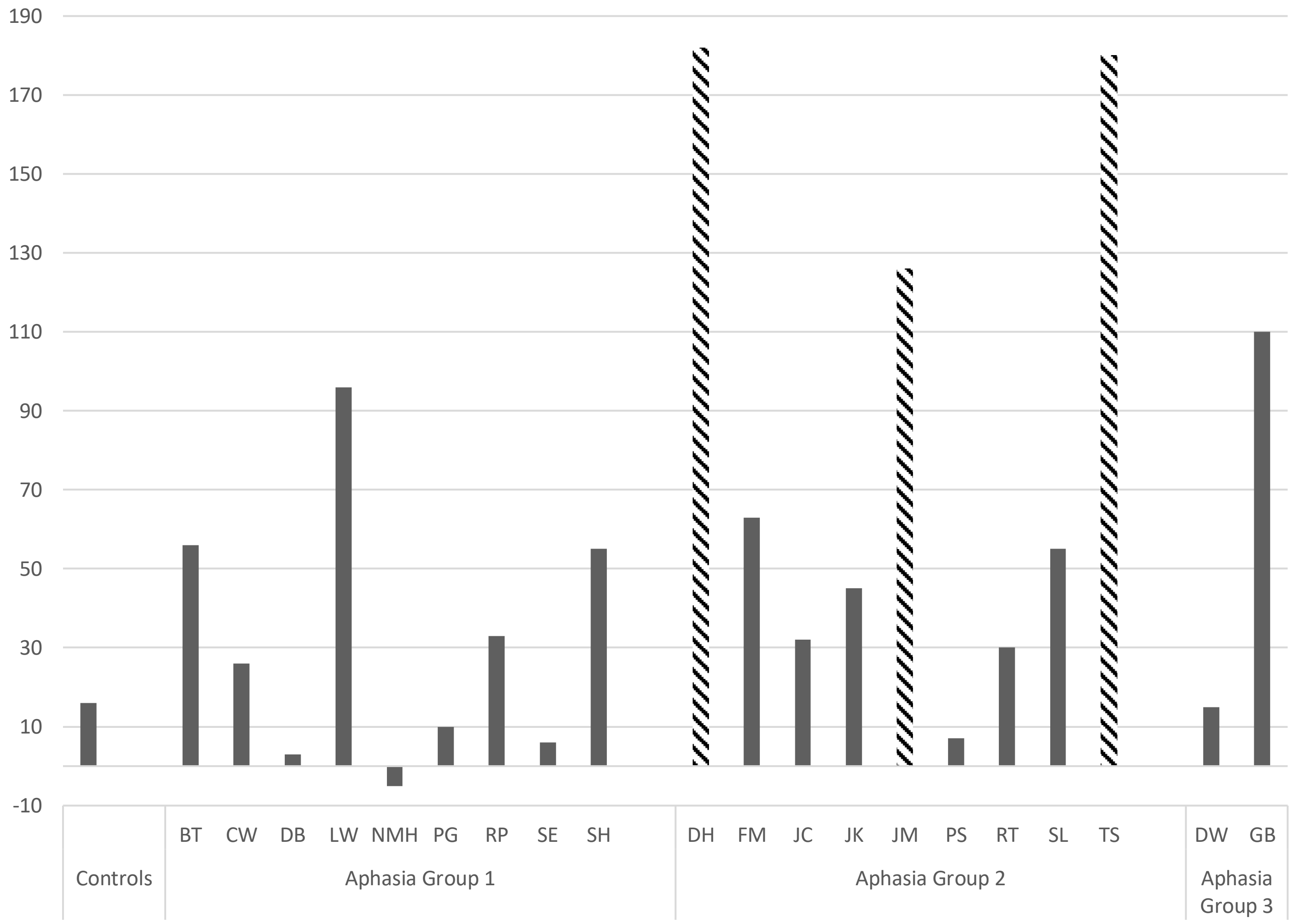

Figure 8 Semantic priming effect (ms)
Striped bars indicate values which are significantly different to control group data

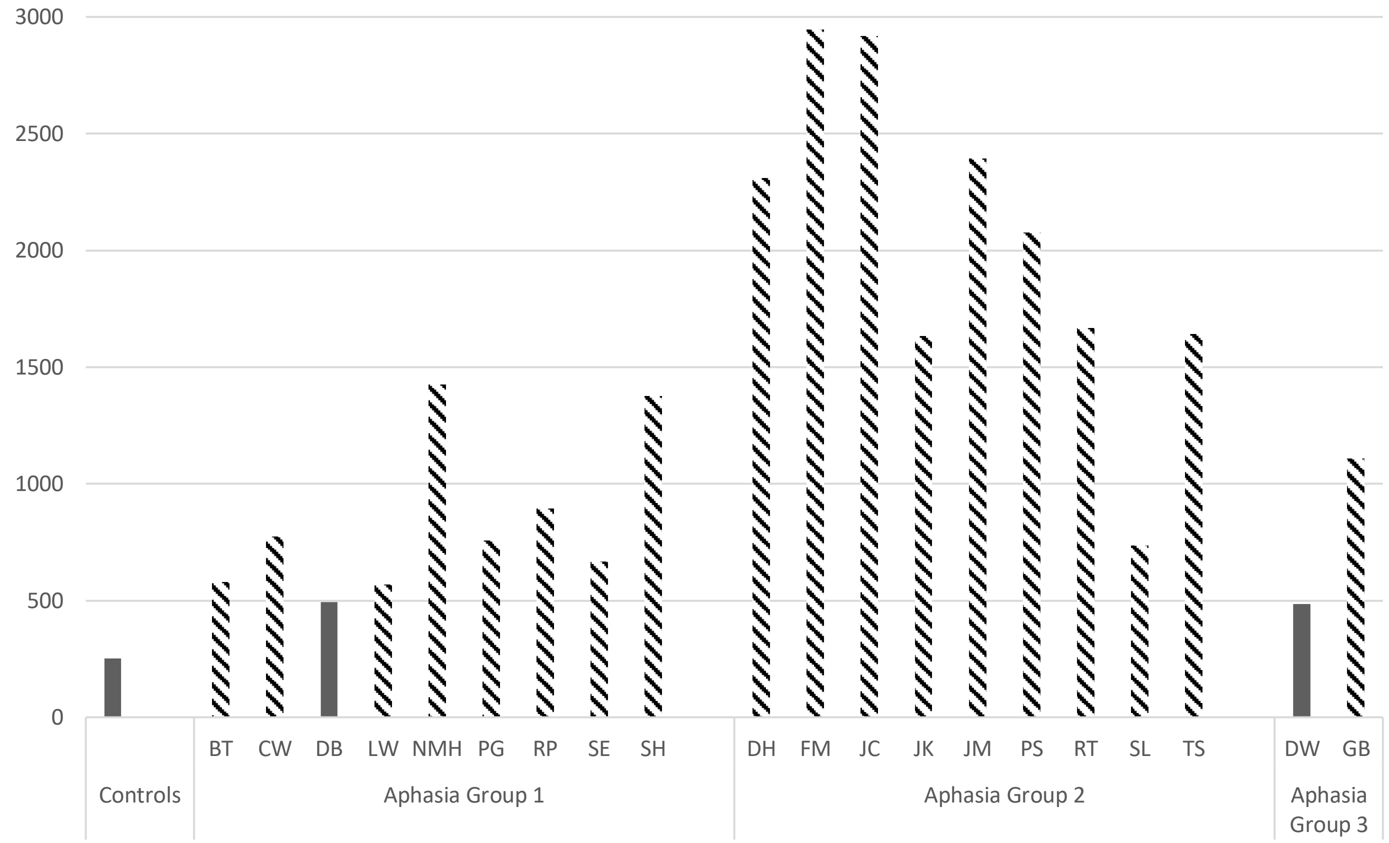

Figure 9 Word-picture verification interference effect (ms)
Striped bars indicate values which are significantly different to control group data