A "CORE SKILLS" APPROACH TO THE ASSESSMENT OF ACQUIRED LANGUAGE DISORDERS: EXPLORATION AND CROSS-VALIDATION

BY

VICTORIA ELIZABETH LEE

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Abstract

The majority of diagnostic assessments of *aphasia*—an acquired language disorder that commonly occurs after stroke or brain injury—are based upon the classical model of language. A major limitation of these diagnostic assessments is that they are based upon a very simple neuroanatomical model of language function. In the decades since the classical model, cognitive theories of language function have developed considerably, which provides a much richer framework for the assessment of acquired language disorders. On the basis of this framework, Faulkner, Wilshire, Parker, and Cunningham (2015) developed the *Brief Language Assessment for Surgical Tumours* (*BLAST*) for the assessment of language function in brain tumour patients, based upon the notion that language can be decomposed into core cognitive skills. In the current thesis, we evaluate the efficacy of the BLAST in individuals with chronic post-stroke aphasia, cross-validate the core cognitive skills identified by the BLAST with independent measures argued to index the same theoretical construct, and evaluate whether an individual's linguistic profile on the BLAST is predictive of performance on a more naturalistic sentence production task. The results from the current research can be divided into three primary findings. First, we found that the BLAST could be administered to individuals with post-stroke aphasia, and that the linguistic profiles provided by the BLAST extend far beyond the predictions derived from neural localization and classical diagnostic assessments. Second, we found support for the validity of five of the core cognitive skills. Third, we found some support for the notion that performance on the BLAST may be predictive of performance on a more naturalistic sentence production task. In short, the current findings suggest that the BLAST holds potential as a clinical tool for the assessment of language function in a range of different neurological populations.

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Chapter 1: Introduction

Aphasia is an acquired language disorder that commonly occurs after stroke or other neurological disorder. The majority of diagnostic assessments of aphasia are based upon the classical model of language, which centres upon the notion of two key language areas: *Broca's area* and *Wernicke's area*. Based upon the observation that damage to anterior left hemisphere regions– in particular, the left inferior frontal gyrus (LIFG) resulted in a difficulty with speech articulation, yet not auditory comprehension, Broca (1861) postulated that the LIFG (Broca's area) is the storage site for *articulatory representations of words.* Conversely, based upon the observation that damage to posterior left hemisphere regions– in particular, the posterior superior temporal gyrus (pSTG) resulted in a difficulty with auditory comprehension, yet fluent (but often nonsensical) speech, Wernicke (1874) postulated that the left pSTG (Wernicke's area) is the storage site for *auditory representations of words*. In addition, a bundle of white matter fibres, the arcuate fasciculus, which connects Broca's area to Wernicke's area, has also been classically implicated in language function. Specifically, damage to these association tracts has been found to result in *conduction aphasia*, an acquired language disorder characterized by severe repetition deficits and phonological paraphasias (e.g., *fan* → /flæn/), yet fluent speech and intact auditory comprehension (Wernicke, 1874; Lichtheim, 1885; Geschwind, 1965) (see Figure 1.1. for a schematic diagram of the approximate locations of the classical language areas/tracts).

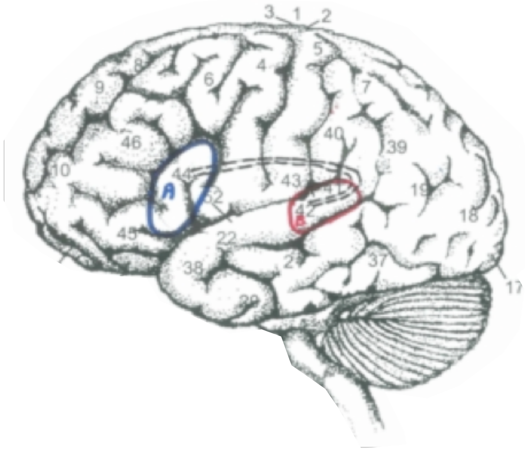

Figure 1.1. A schematic diagram of the approximate locations of the classical language regions: A: Broca's area; B: Wernicke's area; Dotted lines: trajectory of the arcuate fasciculus. This diagram is courtesy of Wilshire (2009).

The classical model of language still remains influential within clinical settings, with three of the most prominent diagnostic assessments based upon its core principles: the Boston Diagnostic Aphasia Examination (BDAE; Goodglass, Kaplan, & Barresi, 2001), the Western Aphasia Battery (WAB; Kertesz, 1982), and the Aachen Aphasia Test (AAT; Huber, Poeck, Weniger, & Willmes, 1983). Such assessments still identify the three key subtypes of aphasia—Broca's, Wernicke's and conduction—as well as several other subtypes derived from the classical model (e.g., the transcortical motor and sensory aphasias); however, there have been a number of amendments since the original model. First, two new subtypes have been added: *anomic aphasia*– characterized by a selective word-finding deficit, yet fluent speech, intact comprehension, and intact repetition skills; and *global aphasia*– a severe form of nonfluent aphasia with impairment in virtually all language domains. Second, the assessment criteria for the aphasia subtypes have been updated to include additional features commonly observed in each syndrome, such as the omission of grammatical function words in Broca's aphasia and word substitution errors in Wernicke's aphasia. Third, the subtypes have been classified into two major subgroups—*fluent* and *nonfluent*. The fluent aphasias are characterized by fluent, well-articulated and effortless speech, yet poor repetition (conduction aphasia), word-finding (anomic aphasia), or comprehension (Wernicke's aphasia). The fluent aphasias are typically associated with damage to posterior left hemisphere regions (e.g., temporal and temporoparietal areas) (Wernicke, 1874; Damasio, 1998). The nonfluent aphasias, on the other hand, of which the most common form is Broca's aphasia, are characterized by fragmented and effortful speech, which often lacks function words (e.g., *the, from, an*) and inflectional morphology (e.g., -*s*, -*ed*, -*ing*). The nonfluent aphasias are typically associated with damage to anterior left hemisphere regions, particularly the LIFG (Broca, 1861; Damasio, 1998) (see Figure 1.2 for a schematic diagram of the various subtypes of aphasia identified by the BDAE). Importantly, these assessments have typically been designed for—and validated on—individuals with post-stroke aphasia.

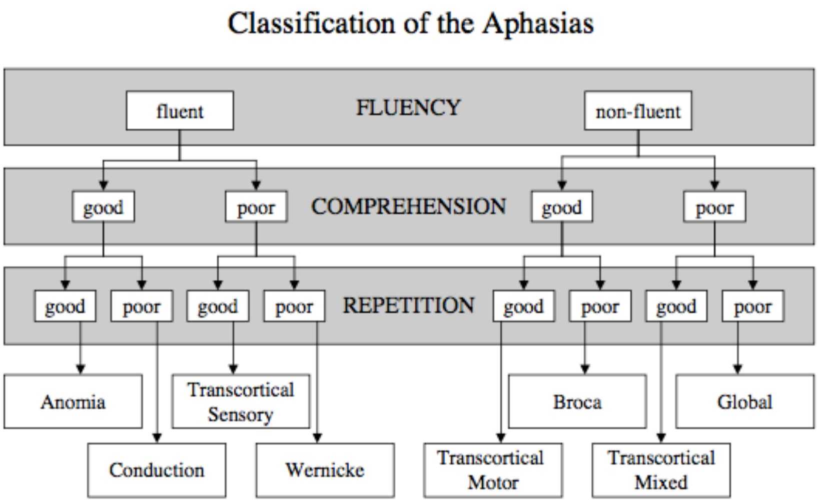

Figure 1.2. A tree diagram of the subtypes of aphasia identified by the Boston Diagnostic Aphasia Examination (BDAE; Goodglass et al., 2001). This diagram is courtesy of Wilshire (2009), which was based upon Melfi and Garrison (2006).

A major limitation of these classical diagnostic assessments is that they are based upon a very simple neuroanatomical model of language function. First, recent neuroimaging and lesion studies have indicated that a vast number of additional neural regions are involved in language production and comprehension, beyond those identified by the classical model (e.g., Peterson, Fox, Posner, Mintun, & Raichle, 1988; Damasio, Grabowski, Tranel, Hickwa, & Damasio, 1996; Dronkers, Wilkins, Van Valin Jr., Redfern, & Jaeger, 2004). Second, it has become apparent that even Broca's area and Wernicke's area are responsible for a great deal more than articulation and auditory comprehension, respectively (e.g., Novick, Trueswell, & Thompson-Schill, 2010; Scott & Wilshire, 2010; Hamilton & Martin, 2005; DeWitt & Rauschecker, 2013). For example, in the Stroop task, where participants are presented with coloured words written in either congruent (e.g., *PURPLE*)) or incongruent ink (e.g., BLUE), individuals with damage to Broca's area typically demonstrate disproportionately prolonged naming latencies and/or decreased accuracy compared with age-matched controls (Hamilton & Martin, 2005; Scott & Wilshire, 2010). Third, our understanding of the cognitive processes involved in language and its neural underpinnings has developed considerably in the decades since the classical model (Hickok & Poeppel, 2004; Poeppel et al., 2012; Damasio, Tranel, Grabowski, Adolphs, & Damasio, 2004). For example, the dual-stream model of speech processing (Hickok & Poeppel, 2004; 2007) postulates the existence of two functionally distinct computational/neural networks that process language information: a *dorsal* stream that maps acoustic speech signals to frontal lobe articulatory networks, and a *ventral* stream that processes speech signals for comprehension. Indeed, numerous additional cognitive processes beyond speech articulation and auditory processing have been identified as essential for effective language function, the majority of which have been associated with neuroanatomical substrates distinct from the key classical language areas (e.g., Poeppel, Emmory, Hickok, & Pylkkänen, 2012; Damasio & Tranel, 1993; Gvion & Friedmann, 2012).

In short, recent advances in cognitive theories of language function provide a much richer framework for the assessment of acquired language disorders, which may not only be more comprehensive, but may also be suitable for the assessment of language in other neurological populations.

On the basis of this framework, Faulkner, Wilshire, Parker, and Cunningham (2015) developed the *Brief Language Assessment for Surgical Tumours* (*BLAST*) for the assessment of language function in brain tumour patients. The BLAST is comprised of nine separate subtasks: picture naming, verb generation, picture-word verification, real and nonword repetition, Stroop, letter fluency, category fluency, and articulatory agility. Based on performance across these subtasks, scores can be derived for eight core cognitive skills: *accessing semantic knowledge*, *lexical selection*, *phonological encoding*, *auditory word recognition*, *verb retrieval*, *goal-driven response-selection*, *phonological short-term memory (STM)*, and *articulatory-motor planning*. The current research involved three primary aims. The first aim was to evaluate the efficacy of the BLAST as a clinical tool within the stroke population (Chapter 2). The second aim was to cross-validate the core cognitive skill measures used in the BLAST with independent measures that can be argued to index the same theoretical constructs (Chapter 3). The third aim was to evaluate whether an individual's linguistic profile on the BLAST is predictive of their performance on a more naturalistic sentence production task– the Quantitative Production Analysis (QPA; Saffran, Berndt, & Schwartz, 1989) (Chapter 4). The following two sections provide a brief overview of the research that has examined language function in brain tumour patients using classical diagnostic assessments and tailored neuropsychological protocols. Following this, contemporary theories of language function are discussed, which provides the theoretical basis for a more detailed discussion of the "core skills" approach. Finally, the rationale and aims of the current study are explored in further detail.

Brain Tumours and Language Testing: Standard Aphasia Protocols

The majority of research into acquired language disorders has typically focused upon individuals with post-stroke aphasia. However, it is increasingly recognized that other forms of brain damage, such as brain tumours, can have a significant impact upon language function. The majority of research into tumour-associated aphasia has used diagnostic assessments based upon the classical model, such as the BDAE, WAB, and AAT. In a study of 40 individuals undergoing surgery for a left supratentorial tumour, Whittle, Pringle, and Taylor (1998) found 63% scored below the normal range on the Aphasia Quotient (AQ) in the WAB– a global measure of aphasia severity. In addition, 63% scored below the normal range on the Boston Naming Test (BNT), a 60-item confrontational naming task (Kaplan, Goodglass, & Weintraub, 1983). Similarly, in a preoperative assessment of 100 individuals with primary static or metastatic tumours, Wacker and colleagues (2002) found 50% of patients with left hemisphere tumours (and 36% of patients with right hemisphere tumours) were classified as impaired on the AAT, which is defined as a deficit on at least one of the five subtests (Wacker, Holder, Will, Winkler, & Ilmberger, 2002)

However, some studies have obtained much lower estimates of the incidence of tumour-associated aphasia. In a preoperative study of 149 individuals undergoing surgery for an untreated or recurrent tumour near or within a suspected language area, Ilmberger and colleagues (2008) found only 18.9% of patients scored below the normal range on the AAT (Ilmberger et al., 2008). However, it should be noted that individuals with severe preoperative aphasia were excluded from the study, which makes it difficult to determine the true incidence of aphasia in the sample population. In a study of 115 individuals undergoing intraoperative cortical stimulation mapping (CSM) for resection of a Grade II glioma in a language area, Duffau and colleagues (2008) found only 10% scored below the normal range on the BDAE (Duffau, Gatignol, Mandonnet, Capelle, & Taillandier, 2008). In short, it is apparent that the incidence of tumour-associated aphasia varies significantly between studies, which is likely influenced by the characteristics of the sample population, the test protocol, and the precise definition of language impairment.

Brain Tumours and Language Testing: Specific Neuropsychological Protocols

Over the last few years, there has been increasing consensus that classical diagnostic assessments of aphasia may not be appropriate for use within the tumour population (e.g., Papagno et al., 2012; De Witte et al., 2015; Miceli, Capasso, Monti, Santini, & Talacchi, 2012). Indeed, there have been two recent attempts to develop language protocols that are more suitable for individuals with brain tumours: the *Dutch Linguistic Intraoperative Protocol* (DuLIP; De Witte et al., 2015) and the *Milano-Bicocca Battery* (MIBIB; Papagno et al., 2012). The DuLIP is based upon a linguistic framework that identifies three domains of language: phonology, semantics, and syntax. The MIBIB, on the other hand, investigates a range of neuropsychological functions: language, memory, executive function, apraxia, and spatial cognition. The MIBIB and the DuLIP are undoubtedly crucial steps towards the development of an effective language assessment for the tumour population; however, there are a number of limitations inherent within the two protocols. For example, the total administration time for each test protocol is 1½-2 hours, an extensive period of time considering the high levels of cognitive demand required to complete each subtask. Further, only five of the twelve tasks in the MIBIB were found to be sensitive enough within the tumour population. Recent advances in cognitive theories of language function provide a novel framework for the development of an alternative type of assessment. Indeed, this type of approach may be more sensitive to mild language deficits, such as those typically observed within the tumour population.

Post-Stoke Aphasia and Tumour-Associated Aphasia: Similarities and Differences

Over the past few decades, a small body of research has suggested that tumour-associated aphasia substantially differs from post-stroke aphasia. For example, Davie and colleagues (2009) compared the linguistic profiles of 63 individuals with malignant left hemisphere tumours who had been referred for speech pathology evaluation to individuals with acute post-stroke aphasia (Davie, Hutcheson, Barringer, Weinberg, & Lewin, 2009). Interestingly, the tumour patients exhibited low rates of global aphasia (3%) and high rates of anomic aphasia (49%) on the WAB, whilst the stroke patients exhibited higher rates of global aphasia (20-40%) and lower rates of anomic aphasia (9-28%). These differences persisted regardless of lesion location, intraoperative CSM, and tumour grade. It is important to note, however, that individuals with mild aphasia tend to fit the classification of anomic aphasia on classical diagnostic assessments, which makes it is difficult to determine whether the results reflect a difference in the incidence of aphasia subtype or aphasia severity.

In a seminal study by Anderson and colleagues (1990), 17 individuals with a unilateral glioma or meningioma were matched to individuals with a similar location and size of lesion resulting from stroke (Anderson, Damasio, & Tranel, 1990). The objective of the anatomical matching was to match the location and size of the stroke lesion to the tumour case, with the requirement that the stroke lesion must be *as large as* or *smaller than* the matched tumour lesion. On several measures, a significant proportion of the stroke cases were clinically impaired, whilst the matched tumour cases were unimpaired. For example, six of the seven individuals with vascular damage to Wernicke's area (i.e., the left pSTG) had paraphasic speech, five had impaired sentence repetition, and all seven performed below normal limits on the Token Test of auditory comprehension. In contrast, none of the tumour patients with lesions in the same region (i.e., Wernicke's area) had paraphasic speech or impaired sentence repetition, and only two performed below normal limits on the Token Test. As a result, Anderson et al. (1990) concluded that the linguistic profiles of individuals with brain tumours are unequivocally different from those individuals with vascular damage, with the cognitive sequelae of a brain tumour typically more mild and variable than that resulting from vascular damage.

Given their distinct neuropathological mechanisms, it is perhaps unsurprising that language deficits caused by brain tumours appear to significantly differ from those caused by stroke. Unlike vascular damage, which causes rapid destruction of neuronal tissue, brain tumours begin by slowly displacing neuronal structures, which can remain functional for a significant period of time (e.g., Noll, Sullaway, Ziu, Weinberg, & Wefel, 2014; Miceli et al., 2012). As a result, there is greater potential for *neuroplasticity*– the functional reorganization of cognitive skills through the recruitment of perilesional areas, which can minimize neurocognitive impairment. Indeed, in a recent study of seven individuals with gliomas in Broca's area, Benzagmout and colleagues (2007) found strong evidence for functional reorganization, with the recruitment of perilesional areas during language tasks, as evidenced by preoperative functional magnetic resonance imaging (fMRI) and intraoperative CSM (Benzagmout, Gatignol, & Duffau, 2007). Interestingly, a recent study found that the neuropsychological profiles of individuals with *fast*-growing tumours often more closely resemble those of vascular damage, due to decreased potential for functional reorganization (Noll et al., 2014). Indeed, in individuals with brain tumours, language disturbance has been found to be better predicted by tumour grade than tumour location (Haas, Vogt, Schiemann, & Patzold, 1982; Bello et al., 2007; cf. Ilmberger et al., 2008). In short, it is likely that assessments primarily designed to assess post-stroke aphasia might not be optimal for the assessment of language function in other aetiologies. The following section will examine current neuropsychological theories regarding the four major language domains: *single word production, sentence production*, *single word comprehension*, and *sentence comprehension*.

Contemporary Theories of Language

Single Word Production

First, let's consider a simple language skill– the ability to provide the name of an object or item. The majority of contemporary theories conceptualize lexical retrieval within a *spreading activation* framework, which postulates the existence of three interconnected levels of network units: semantic, lexical, and phonological (e.g., Caramazza, 1997; Rapp & Goldrick, 2000; Roelefs, 2004) (see Figure 1.3).

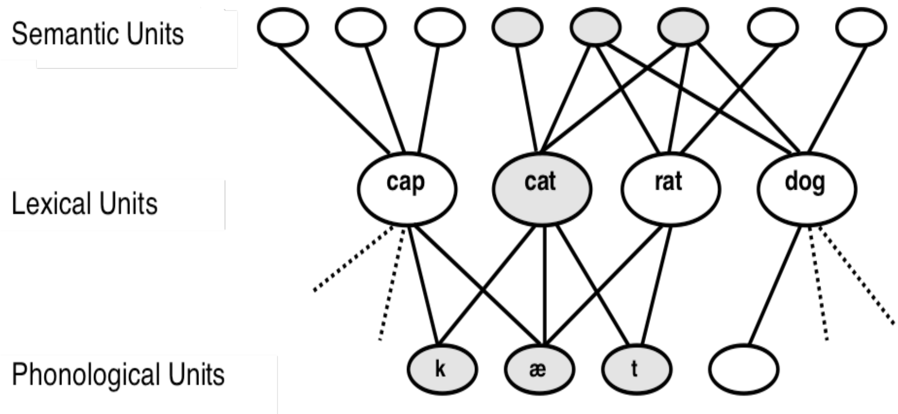

Figure 1.3. A schematic diagram of the spreading activation network of single word production. The diagram depicts a generic version of the model; individual models differ in their specific details. The diagram is courtesy of Wilshire (2009), based upon Dell and O'Seaghdha (1991, 1992).

The first stage of processing—*accessing semantic knowledge*—involves retrieving information about relevant concepts and facts for a target word from the mental lexicon (Tulving, 1972). Within a spreading activation framework, successful retrieval of such information will result in the activation of semantic units that correspond to the semantic features of the object or item to be named (Collins & Loftus, 1975; Neely, 1977). For example, if the target item is a cat, the units corresponding to the semantic features "*furry*", "*four-legged*", and "*meows*" will become activated. A difficulty at this stage is likely to result in the failure to produce the target word (i.e., an *omission error*), or the production of a word that shares some of the semantic properties of the target (i.e., a *semantic paraphasia*: e.g., *camel* → "giraffe"). Impairment at this stage would also impact upon the ability to comprehend auditory words, as evidenced by an inability to generate word meanings and semantic confusions in word-picture matching tasks. *Accessing semantic knowledge* has been frequently localized to left anterior temporal regions in *voxel-based morphometry* (VBM) and *voxel-based lesion-symptom mapping* (VLSM) studies (e.g., Schwartz et al., 2009; Mummery et al., 2000; Baldo, Schwartz, Wilkins, & Dronkers, 2006). It has been suggested that *semantic dementia* may reflect a selective impairment at this stage (e.g., MY: Goodglass et al., 2001).

The second stage of processing—*lexical selection*—involves selecting an appropriate word (*lexical representation*) for the desired concept. Within a spreading activation framework, the lexical unit corresponding to the target word must be sufficiently activated above that of other non-target lexical units. Due the nature of the interconnections between the semantic and lexical units, lexical units representing items that are semantically similar to the target also become activated during this process (e.g., Caramazza, 1997; Dell, 1986; Levelt, Roelofs, & Meyer, 1999; cf. Mahon, Cost, Peterson, Vargas, & Caramazza, 2007). For example, if the target item is a cat, semantic units representing its features ("*furry*", "*four-legged*", "*meows*") will not only activate the lexical unit for *cat*, but also those of other items that share one or more of the same properties (e.g., *four-legged* → *dog, pig, cow*). However, in this example, since "*cat*" shares the most properties, its corresponding lexical unit will receive the most activation and will be selected for production. However, if the target lexical unit does not receive sufficient activation, the speaker may either fail to produce the word, or may produce a word that is semantically similar to the target word, since the next most highly activated unit is likely to correspond to a semantically related item. A difficulty at the *lexical selection* stage has been associated with damage to left posterior temporal regions (e.g., DeLeon et al., 2007; Baldo, Arévalo, Patterson, & Dronkers, 2013). It has been suggested that *anomic aphasia* may reflect a selective impairment at this stage (e.g., NP: Wilshire, Keall, Stuart, & O’Donnell, 2007).

The third cognitive skill—*phonological encoding*—involves retrieving information about the selected word’s phonological form from the mental lexicon. Within a spreading activation framework, activation spreads from the target lexical unit to the corresponding phonological units. The phonological encoding stage is complete when all of the phonemes have been selected for each position in the target word. A difficulty at this stage is likely to result in the production of phonological errors, whereby one or more of the target word’s phonemes are incorrect or absent (*phonological paraphasias*; e.g., *hippopotamus* → /hɪtopɒtəsʊs/). Impairment at this stage would also impact upon the ability to repeat single words– particularly those with multiple syllables, as the ability to encode phonological information is a prerequisite for the subsequent processes involved in word repetition. It has been suggested that *conduction aphasia* may reflect a selective impairment at this stage (e.g., CSS: Rapp & Goldrick, 2000). *Phonological encoding* has been frequently localized to left superior temporal/inferior parietal regions in VLSM and fMRI studies (e.g., Schwartz, Faseyitan, Kim, & Coslett, 2012; Baldo, Katseff, & Dronkers, 2012; Buchsbaum, Hickok, & Humphries, 2001).

The fourth and final cognitive skill involved in single word production—*articulatory-motor planning*—involves the translation of the phonemic code into a motor plan for articulation (McNeil, Doyle, & Wambaugh, 2000). A difficulty at this stage is likely to result in distorted speech, characterized by sound substitutions and inaccurate assignment of stress (e.g., *electric drill* → /lotɪk dʒɪl/), as well as slowed articulation and a significantly reduced rate of speech (Dronkers, 1996). A difficulty at the *articulatory-motor planning* stage has been associated with damage to the left insula and left inferior frontal regions (e.g., Henseler, Regenbrecht, & Obrig, 2014; Dronkers, 1996; Hillis et al., 2004). It has been suggested that *apraxia of speech* may reflect a selective impairment at this stage (Dronkers, 1996).

Sentence Production

In reality, single word production typically occurs within the context of a larger utterance, which requires the recruitment of numerous additional cognitive skills. Indeed, individuals with nonfluent aphasia often have preserved single word production skills, yet struggle to integrate these same lexical items into a sentence (e.g., Williams & Canter, 1982). The production of nonfluent speech does not seem to be simply a way of coping with the articulatory-motor demands of connected speech, but rather is likely to reflect the recruitment of additional cognitive skills involved in sentence formation. For example, it has been suggested that the construction of a syntactic frame for a sentence may rely heavily upon the ability to retrieve the key verb, such that a difficulty with this process may impose powerful constraints on the production of the sentence (Garrett, 1975; Levelt, 1989). In line with this, individuals with nonfluent aphasia, particularly those with an agrammatic pattern of speech, typically have greater difficulty with naming verbs than nouns, whilst individuals with anomic or Wernicke’s aphasia typically exhibit the opposite pattern (Breedin, Saffran, & Schwartz, 1998; Zingeser & Berndt, 1990; Miceli, Silveri, Villa, & Caramazza, 1984). A difficulty with *verb retrieval* has been associated with damage to left inferior frontal regions (Damasio & Tranel, 1993; Piras & Marangolo, 2007; 2010).

In addition to *verb retrieval*, effective sentence production is also likely to require a considerable degree of cognitive control. Indeed, in order to ensure that the various lexical items that have been retrieved for inclusion in the sentence are produced in the correct order, a speaker needs to ensure that items only become highly activated when they are required for production. In other words, a speaker must manage competition between simultaneously activated lexical representations. In fact, recent studies have found that individuals with nonfluent aphasia are often disproportionately impaired on tasks that are designed to induce high levels of competition between lexical items, even in the absence of integration into syntactic phrases (such as naming semantically related picture sets; see Hamilton & Martin, 2006; Biegler, Crowther, & Martin, 2008; Schnur, Schwartz, Brecher, & Hodgson, 2006; Thompson-Schill et al., 1998; Scott & Wilshire, 2010). It has been postulated that there could be a mechanism, localized to the LIFG, which modulates the flow of activation throughout the lexical network, thereby minimizing the competitive effects of non-target lexical items (Schnur et al., 2009; Thompson-Schill, D’Esposito, Aguirre, & Farah, 1997). Accordingly, the poor spontaneous speech observed in nonfluent aphasia could be interpreted as a way of coping with unresolved lexical competition, by limiting the number of words produced per utterance.

Single Word Comprehension

So far, we have considered the cognitive processes involved in language production– both at the single word level and at the sentence level. However, the ability to comprehend language is an equally important requisite for effective communication. The recognition of a spoken word requires a complex process of mapping from sound to meaning. The majority of neuropsychological theories assume that *auditory word recognition* occurs in at least two major stages (McClelland & Elman, 1986; Marslen-Wilson, 1987; Luce & Pisoni, 1998). According to the cohort model, the first step is the association of specific phonemes to a specified word from the mental lexicon, and the second is the linking of the known word to its semantic attributes (Marslen-Wilson, 1987). According to this model, a ‘cohort’ of words that share the same onset are activated as soon as the speaker initiates production of an auditory word. As successive segments of the word are produced, the cohort is reduced accordingly, until only one candidate—the target word—is left. In other words, a target word can only be identified after all other potential word candidates have been eliminated. For example, the word "*trespass*" (/trɛspəs/) will only be recognized once it has surpassed the segment /trɛsp-/ as until such point, cohorts such as "*trestle*" have not yet been eliminated. In some versions, sentential context may also be used to eliminate words from the cohort (e.g., *the poacher ignored the sign not to tres-*) (Marslen-Wilson & Welsh, 1978).

A selective difficulty with auditory word recognition is observed in *pure word deafness*, a disorder in which an individual cannot comprehend spoken words, despite intact language production, reading abilities, and nonlinguistic auditory analysis (Auerbach, Allard, Naeser, Alexander, & Albert, 1982). It is often suggested that pure word deafness is one of the characteristics of Wernicke's aphasia (Auerbach et al., 1982). In line with this, auditory word recognition has been frequently localized to Wernicke's area (i.e., the pSTG) in neuroimaging and lesion studies (e.g., Buchsbaum et al., 2001; Dronkers et al., 2004; cf. DeWitt & Rauschecker, 2013). Individuals with a difficulty at this stage, such as those with Wernicke's aphasia/pure word deafness, should be significantly impaired on tasks that involve phonetic manipulation and analysis, such as discrimination of minimal word pairs (e.g., *cap-cab*), auditory lexical decision, and single word repetition.

Sentence Comprehension

In the previous section, we discussed the cognitive processes involved in single word comprehension. However, in reality, single word comprehension typically occurs within the context of a larger utterance, such as a phrase or sentence. The comprehension of a sentence not only involves retrieving semantic and phonological information about the target words, but it also involves utilizing information about word order/sentence structure, in order to understand interrelations between the lexical items. Accordingly, sentence comprehension is likely to make greater demands on verbal short-term memory (STM) than single word comprehension (Martin & Romani, 1994; Vallar & Baddeley, 1984). Accordingly, individuals with impaired verbal STM would be likely to have difficulty with sentence comprehension, particularly when the thematic relations among the various elements cannot be inferred by context alone (e.g., *the man serves the woman*).

According to some models, verbal STM is comprised of a collection of different maintenance capabilities, some of which operate on phonological information, and others on lexical or semantic information (Martin, Lesch, & Bartha, 1999; Martin & Saffran, 1997). In the current thesis, we focus on the maintenance of phonological information—*phonological STM*—as this set of skills appears to be particularly important for the maintenance of verbatim information (Baldo, Klostermann, & Dronkers, 2008). Traditionally, *phonological STM* is measured by the digit span task; however, nonword repetition has recently been considered a purer measure, particularly when the focus is on the maintenance of phonological information (Gathercole & Baddeley, 1989). Individuals with damage to posterior temporo-parietal regions, such as those with *conduction aphasia*, typically perform poorly on these tasks. In a VLSM study, Baldo and colleagues (2012) found that left posterior temporo-parietal regions, rather than the arcuate fasciculus, were critical for *phonological STM* tasks, such as nonword repetition and digit span (Baldo, Katseff, & Dronkers, 2012). Specifically, real and nonword repetition showed maximal foci in the left pSTG, whilst number-word repetition, word span, and digit span were localized to the left middle temporal gyrus-STG border.

Table 1.1.

Summary of the core cognitive skills identified from the four language domains.

Language Domain	Core Cognitive Skill	Associated Aphasia Subtype	Language Profile	Critical Neural Region(s)
Single Word Production	*Accessing Semantic Knowledge*	Semantic Dementia	High rate of semantic errors in picture naming. Low category fluency score relative to letter fluency. Semantic confusions in word-picture matching tasks.	*Left anterior temporal regions* (Schwartz et al., 2009; Mummery et al., 2000; Baldo et al., 2006)
	Lexical Selection	Classical Anomia	Significant frequency effect and high rate of omission errors in picture naming. Normal performance on comprehension tasks.	*Left posterior temporal regions* (DeLeon et al., 2007; Baldo et al., 2013)
	Phonological Encoding	Conduction Aphasia	Significant length effect and high rate of phonological errors in picture naming. Poor single word repetition.	*Left posterior temporal-parietal regions* (Schwartz et al., 2012; Baldo et al., 2012)
	Articulatory-Motor Planning	Apraxia of Speech	Slow rate of speech and frequent articulatory errors.	*Left insula and left inferior frontal regions* (Henseler et al., 2014; Dronkers, 1996)

Table 1.1. (Cont.)

Language Domain	Core Cognitive Skill	Associated Aphasia Subtype	Language Profile	Critical Neural Region(s)
Sentence Production	*Verb Retrieval*	Broca's Aphasia	Disproportionately impaired on action naming relative to object naming. Impaired ability to produce sentences with multiple argument structures.	*Left inferior frontal regions* (Piras & Marangolo, 2007)
	Goal-Driven Response-Selection	Broca's Aphasia	Deficits in tasks that require the resolution of competition (e.g., Stroop, blocked-cyclic naming) or a strategic search through the mental lexicon (e.g., letter fluency).	*Left inferior frontal regions* (Baldo et al., 2006; Tsuchida & Fellows, 2013; Schnur et al., 2009)
Single Word Comprehension	*Auditory Word Recognition*	Wernicke's Aphasia; Pure Word Deafness	Impaired on single word repetition and auditory comprehension tasks (e.g., lexical decision, phoneme discrimination).	*Left posterior temporal-parietal regions* (Robson, Sage, & Lambon Ralph, 2012)
Sentence Comprehension	*Phonological Short-Term Memory*	Conduction aphasia	Reduced digit span. Disproportionately impaired on nonword repetition relative to real word repetition.	*Left posterior temporal-parietal regions* (Baldo et al., 2012)

The Brief Language Assessment for Surgical Tumours (BLAST)

Recently, Faulkner and colleagues (2015) developed the BLAST for the assessment of language function in brain tumour patients (Faulkner, Wilshire, Parker, & Cunningham, 2015). The BLAST adopts a “core skills” approach, which assesses core cognitive skills that have each been identified as essential for the production and/or comprehension of language. The BLAST is comprised of nine separate subtasks, which incorporate manipulations that are designed to further tease apart any source of difficulty (e.g., manipulations of word length and frequency in the picture naming task). From an individual’s overall performance, it is possible to derive numerical scores for eight core cognitive skills: *accessing semantic knowledge*, *lexical selection*, *phonological encoding*, *auditory word recognition*, *verb retrieval*, *goal-driven response-selection*, *phonological STM,* and *articulatory-motor planning*. In this way, the administration time of the BLAST is kept to a minimum (i.e., 20-30 minutes), yet the subtasks still provide a rich indication of an individual’s linguistic profile.

In a preoperative sample of 53 individuals undergoing surgery for undifferentiated cerebral tumours, Faulkner et al. (2015) found that 53% of patients scored below the normal range on at least one core cognitive skill in the BLAST, relative to healthy age-matched controls. Importantly, performance on the core cognitive skill measures was consistent with hypotheses based upon the tumour location. For instance, individuals with left posterior tumours exhibited significantly lower scores on *accessing semantic knowledge*, *lexical selection*, *phonological encoding,* and *phonological STM* than the other three anatomical groups (left frontal, right posterior, and right frontal). Conversely, individuals with left frontal tumours exhibited significantly lower scores on *goal-driven response-selection* and *articulatory-motor planning* compared with the other three anatomical groups (left posterior, right frontal, and right posterior). The results from the VLSM analyses further supported this conclusion.

Rationale for the Current Study

Although the BLAST holds potential as a clinical tool for the assessment of language function in the tumour population, there are a number of important limitations and unresolved questions. First, the operational measures for the core cognitive skills were derived from theoretical conceptualizations of the skill in question. Although the linguistic profiles of individuals with chronic post-stroke aphasia were used to guide the selection of measures that contributed to core cognitive skill scores, the core skills have not yet been validated on a population with known language deficits. A study of this kind is particularly important, since various arbitrary decisions were made concerning which types of measures would be included in each core score, and how each measure would be weighted. Second, on some of the core cognitive skills, very few tumour patients scored significantly below controls (e.g., less than 20% of the tumour patients were impaired on real word repetition, nonword repetition, and articulation). At present, it is unclear whether this paucity reflects a limitation of the core cognitive skills, or a genuine absence of impairment in the sample population. In short, cross-validation of the core cognitive skills against independent measures in a population with known language deficits would be particularly valuable.

A further limitation of the BLAST is that it restricts itself to the single word level. Whilst it has recently been suggested that deficits at the sentence level are often discernible at the single word level (e.g., Hamilton & Martin, 2005; Scott & Wilshire, 2010; Biegler et al., 2008; Schnur et al., 2006; Wilshire & McCarthy, 2002), a direct comparison between performance at the single word level and the sentence level would be particularly valuable. A study of this kind would help to determine whether language can be reduced to isolated components of a neuropsychological theory, and whether an individual’s linguistic profile on the BLAST is indeed predictive of their performance at the sentence level.

The Current Study

The current research involved three primary aims. The first aim was to examine the performance of individuals with chronic post-stroke aphasia on the BLAST. In this way, we aimed to evaluate the efficacy of the BLAST as a clinical tool within the stroke population (Chapter 2). The second aim was to cross-validate the core cognitive skill measures used in the BLAST with independent measures that can be argued to index the same theoretical constructs, again using a population of individuals with known language deficits (Chapter 3). The third aim was to evaluate whether these individuals’ linguistic profiles on the BLAST are predictive of their performance on a more naturalistic speech production task– the QPA (Chapter 4).

Chapter 2: Performance of Individuals with Chronic Post-Stroke Aphasia on the BLAST

The aim of this study was to assess the applicability of the BLAST to individuals with chronic post-stroke aphasia. We administered the BLAST to 12 individuals with chronic post-stroke aphasia, who represented a range of aphasia subtypes and severity levels. Given that the current thesis seeks to overcome the limitations of classical diagnostic assessments, the current hypotheses are based upon neuroanatomical regions of interest (ROIs), as opposed to the classical subtypes of aphasia. However, it is important to note that the ROIs are not intended to disregard a neurocognitive network perspective of language—an approach that emphasizes the contribution of several brain regions organized into a large-scale network via long-distance association pathways (cf. Mesulam, 1990; Damasio, 1991)), but rather to provide tentative hypotheses that align with the exploratory nature of the current study. Accordingly, it is predicted that individuals with damage to the left temporal lobe will score below the normal range on *accessing semantic knowledge* (anterior regions) and/or *lexical selection* (posterior regions); individuals with damage to left temporal-parietal regions will score below the normal range on *phonological encoding* and *phonological STM*; and individuals with damage to the superior temporal gyrus will score below the normal range on *auditory word recognition* (posterior regions). Finally, it is predicted that individuals with damage to left inferior frontal regions will score below the normal range on *verb retrieval*, *goal-driven response-selection,* and *articulatory-motor planning*.

Method

Participants. Twelve participants with chronic aphasia arising from a cerebrovascular accident (CVA) and/or subarachnoid haemorrhage were recruited from a register of past research volunteers at Victoria University of Wellington. Six of the participants had previously been classified as having nonfluent Broca's aphasia, and the remaining six participants had been classified as having fluent aphasia: three with conduction aphasia, two with anomic aphasia and one with Wernicke's aphasia. All participants met the following inclusion criteria: 1) their stroke occurred at least twelve months prior to the commencement of the current study; 2) all were native speakers of English, and 3) all had normal or corrected-to-normal vision.

Background, medical, and diagnostic information for each participant is presented in Table 2.1. This data was gathered between two and six years prior to the current study (Speer, 2014). Eight of the participants had undergone a structural MRI scan within the past two years; lesion maps are presented in Figure 2.1 (see Speer, 2014 for detailed lesion analyses). A sample of each participant's spontaneous speech from the Cookie Theft picture description task (Goodglass et al., 2001) is presented in Table 2.2. A detailed case description for each participant is provided in Appendix A.

Table 2.1.

Background, medical, and diagnostic information for each individual with aphasia

	Patient	Age*	Gender	Years post CVA	Lesion site/aetiology	BDAE Diagnosis
Nonfluent	BY	58	Male	6 & 36	Subarachnoid haemorrhage, subsequently operated upon, large lesion extending from anterior horn of L lateral ventricle to L parietal lobe	Broca’s
	DA	71	Male	13	Isch. CVA, L inferior frontal, L temporal, and L inferior parietal lobe	Broca’s
	JG	72	Female	5	Isch. CVA, L MCA region	Broca’s
	JHM	51	Female	12	Isch. CVA, extensive L MCA region	Broca’s
	RB	80	Male	6 & 8	Isch. CVA, L MCA region	Broca’s
	RP	69	Male	10 &11	Unspecified CVA, L frontal, L parietal and R medial frontal infarct	Broca’s
Fluent	DW	57	Male	10	Medical notes not available	Conduction
	IC	71	Male	4	Unspecified CVA, R frontoparietal infarct and possible L MCA thrombus	Conduction
	NP	75	Male	16	Isch. CVA, several foci in L occipital and temporal lobes	Anomia
	STR	81	Female	11	Isch. CVA, possibly multiple, infarcts in R occipital and L parietal lobe	Anomia
	SW	81	Female	4	Haem. CVA, L posterior temporal lobe	Wernicke’s
	WL	63	Male	2	Isch. CVA, L parietal and L posterior temporal lobe	Conduction

Note. Isch. = ischaemic; Haem. = haemorrhagic; CVA = cerebrovascular accident; MCA = middle cerebral artery; L = left; R = right.
*Age at time of BLAST administration. Note that for some participants, the cross-validation assessment was completed 1-4 years prior to, or following the BLAST (with the exception of the PWIT, which three participants completed 7-8 years prior to the BLAST (DA, JHM, STR), and the real word reading and repetition tasks, which one participant completed 6-7 years prior to the BLAST (STR)).

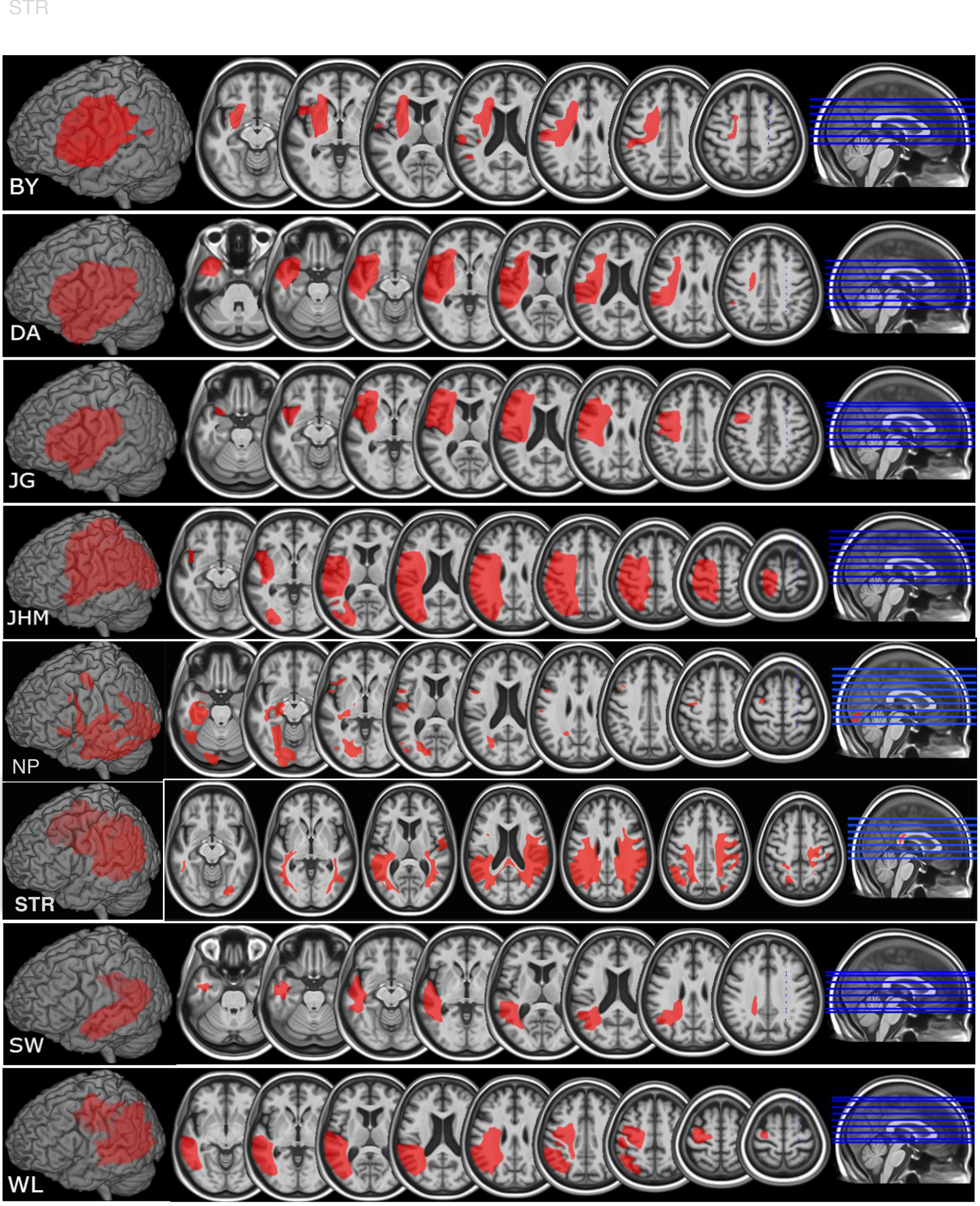

Figure 2.1. Lesion maps for the individuals with aphasia, depicting the lesions on a standard template (Colin27; Holmes et al., 1998), and axial slices of the brain on a standard template (Rorden, Bonilha, Fridriksson, Bender, & Karnath, 2012). Slices were selected as a representative display of the individual lesions. The lesion maps are courtesy of Speer (2014).

Table 2.2.

Extracts from the Cookie Theft picture description task (Goodglass et al., 2001) for each individual with aphasia. (Dots = pauses over one second; commas = pauses less than one second).

Nonfluent	
BY	Um… oh god, I dunno… it's it's waiting for it to come… uh… and that … (sighs)… god, I can't say it it's overflowing… [long pause] and she's washing dishes and... with her back to the… child getting the… cookies… [truncated]
DA	Um...the the the the /tʌd/ the tub was on yeah... um yeah... oh... behind /bihænd/ behind... her children... um... um... [long pause] were reaching... [long pause] reach reaching... into a cookie jar... in the... in the...um... the cupboard [truncated]
JG	Um, a child… and, cookie- jars… um… washing /wɪt/ um the tap… /wɒʃssss/… I dunno yeah (laughs)… /n-/ spilling /ɪ- ʌnn/… /lɪ/ floor… um… garden [truncated]
JHM	Ok… the the woman ah ah ah| dreaming ah dreaming uh uh ah um… she uh d:ry a plate um…um... the water… over:flow uh…. to the floor um…[long pause] um the- the boy… stealing a cookie… and um… uh the boy is… giving a…girl /g-/ giving a cookie a /g-, gɔ:/ [truncated]
RB	He th- th- th- the the cookie jar and the /spʌntʃ,bʌntʃ/ th- th- the water out the sink… um… um… /ɛbəʃ/… [Ex: can you say anything about what's happening here?] /əs/ uh th- tree uh th- tree… [Ex: and do you think anything's going to happen to these?] /əs…s/ fall /aʊv/ a go [Ex: yeah]… um… [Ex: anything else? Can you see anything out here?] yeah it's um… yeah
RP	Cookie jar… boy… girl… /t/ tip over… washing the dishes… [long pause] pill… floors is spill… and gardening… and /tuː/… uh… uh… kitchen…and… cups... plates… cupboards… uh curtains… trees… [long pause] curtains again… shrubs… uh lawns

Table 2.2. (Cont.)

Fluent

DW	Uh the children are stealing cookies… and /rɒnso/ they're gonna drop the whole... tin to me out the cupboard… um but he's gonna fall of his chair anyway because it's /ʧitɜrıŋ/ on one leg… um mother's got problems with her /wə-/, washing… she's overflowed the sink… again and it's all splashing onto the floor.
IC	There's a /pɜzʌn / a person a a woman and the dish and a tea towel and water taps faucet cups... /tʃʊki/ a cookie jar girl boy… stool cupboards… there's a lid um... bushes curtain um there's a tree… bath… bits of her… shoes oh she's washing her washing her… dishes ah there's a floor there's ..… oh she's wearing a dress shorts t-shirt no it's not it's an ordinary shirt um…[truncated]
NP	Uh that's that's his mother… the water's… overflowing shhhh so I don't know what the hell she's doing (laughs) that's a- an apron… over a frock and shoes and she's got a dinner plate and tea towel… um… out the window that's windows uh curtains [truncated]
STR	Um… there is a um there is a mother and two children and they're in the kitchen and they are doing the washing doing washing up but the unfortunately the tap has over- /θ/ the sink has overflowed the /w/ the…/ovəəflɔ/ with the water so there's there's there's water on the floor [truncated]
SW	An /æprɒn… æpəərəən/… and he's got a little uh… car, jar… I mean cookie… I think she's going to eat something or drink something… he going fly up… you see… I can't see the word! You got it… why is it like that… him going on the… skull... Why is that? … [truncated]
WL	Ah, the man /ɒ/ or the the boy the boy is um... trying to get, uh the cookie jar, uh to give uh the girl a cookie and the the the the boy /f/-fell down the the uh the uh um The uh... the stool and uh the wife the mother the mother- was washing the dishes and uh /tuː/ /w/ ah overflowed the sink [truncated]

Materials and Procedure

The BLAST was individually administered on a MacBook computer and by experimenter instruction. The entire procedure was digitally recorded and naming latencies were manually measured using sound-editing software. Testing occurred in either one or two sessions (depending upon patient severity), and took approximately an hour to complete. The entire protocol consisted of the following tasks: picture naming, verb generation, picture-word verification, real and nonword repetition, Stroop, letter and category fluency, and articulatory agility. PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993) was used to present the computerized tasks (picture naming, verb generation, picture-word verification, Stroop). The remaining tasks were administered by experimenter instruction. Breaks were offered at the completion of each task, or if the patient experienced any discomfort or fatigue. The following sections provide a brief summary of each task; further details are available in Faulkner et al. (2015).

1. Picture Naming. In this task, participants are required to provide the name of a pictured object. The 60 items vary in both frequency and length. Specifically, items were selected to depict low frequency (with frequency rating of less than 70; *M* = 34.9, range = 4-69), medium frequency (with frequency ratings between 70-200; *M* = 129.3, range = 72-199), or high frequency nouns (with frequency ratings of more than 200; *M* = 763.0, range = 205-2441), based upon CELEX lemma frequency ratings (Baayen, Piepenbrock, & van Rijn, 1993). Each frequency group was comprised of approximately equal numbers of monosyllabic, bisyllabic, and polysyllabic items, thereby forming nine different length x frequency combinations. Pictures were presented on a computer screen, accompanied by a tone. Participants were instructed to provide the name of the pictured item. The picture remained onscreen for the duration of the trial, and participants were given unlimited time to respond. Picture presentation was self-paced; the experimenter pressed a key to initiate the next trial, after a response had been made. The test items were presented in a fixed pseudo-random order. Each session commenced with a single practice trial.

Responses for each target item were scored as either correct or incorrect. In all cases, the first attempt was scored, even if it was spontaneously self-corrected. Appendix B provides full details of the criteria used for error coding. The total number of correct responses for the entire task was calculated and converted to a percentage. Following this, the overall percentage of correct responses for each frequency and length manipulation was calculated, and used to calculate the slope of the length and frequency effects using the slope function in Microsoft Excel.

2. Verb Generation. In this task, participants must provide the name of a verb associated with a pictured concrete noun. The stimuli were 45 coloured drawings, which were organized into two groups in a previous pilot study using healthy controls, based on a measure of response-strength ratio: the frequency of the most common verb response divided by the frequency of the second most common verb response. Response strength ratios of 3.0 or less were classed as low-competition ($M = 1.68$, $SD = 0.47$, range = 1.05-2.8), and those of 5.0 as high-competition ($M = 15.93$, $SD = 12.29$, range = 5-41). Further details are available in Cameron-Jones (2008). A high response-strength ratio suggests one dominant verb associate (e.g., *ladder* → “climb”); conversely, a low response-strength ratio suggests several verb associates (e.g., *pills* → “swallow”, “dissolve”, “prescribe”). Low and high response strength pictures were balanced with respect to frequency and word length of the object’s name and also that of the dominant verb response. As with the picture naming task (Section 1), the stimuli were presented on a computer screen. Each pictured object and its written name appeared immediately, accompanied by its auditory name. Participants were instructed to provide a verb that describes what the object does or what can be done with the object. Participants were given unlimited time to respond. Picture presentation was self-paced. The stimuli were presented in a fixed pseudo-random order. Each session commenced with a single practice item. If the participant responded incorrectly on this trial, the experimenter provided the participant with feedback.

The procedure for the accuracy analyses was identical to that described for the picture naming task (Section 1). Responses for each target item were scored as either correct or incorrect. A response was considered correct if the verb was appropriate to the noun, and specific to the noun (e.g., ladder → *“climb”* would be acceptable, but not *“use”*). Inflectional verb forms were scored as correct.

3. Picture-Word Verification. In this task, participants must determine whether an auditory word matches a visually displayed pictured object. The auditory distractor words are identical, phonologically related, semantically related, or unrelated to the target picture. There were 12 target pictures, each of which belonged to one of four semantic categories: animals, food, household objects, and weapons. Each picture was presented four times, each time accompanied by a different auditory word: 1) an *identical* word (e.g., *hammer-hammer*), 2) a *phonologically related* word, which shared at least two phonemes with the target word (e.g., *hammer-hamlet*), 3) a *semantically related* word, which belonged to the same semantic category as the target word, as narrowly defined as possible (e.g., *hammer-axe*), or 4) an *unrelated* word, which bore no semantic or phonological relationship to the target word (e.g., *hammer-pearl*). Frequency and syllable length were balanced across the four conditions. Each of the 12 pictures appeared in all four conditions, which yielded a total of 48 trials.

In this task, participants were simultaneously presented with a picture and an auditory word, and had to determine whether the auditory word matched the picture (i.e., a forced-choice task, whereby participants could only respond with “*yes*” or “*no*”). The test items were presented in a fixed pseudo-random order. Each session commenced with two unrelated practice items. If the participant responded incorrectly on any of these trials, the experimenter provided the participant with feedback. Responses for each target item were scored as either correct or incorrect. As with the picture naming task (Section 1), the stimuli were presented on a computer screen, and the first attempt was scored, even if it was spontaneously self-corrected.

4. Word and Nonword Repetition. In this task, participants are required to repeat an auditory word provided by the experimenter. The task consists of two parts– real words that vary in frequency and imageability ratings, and nonwords. The stimuli consisted of 60 real words and 20 nonwords. The real words comprised of 30 low imageability and 30 high imageability words taken from the MRC Psycholinguistic database (Coltheart, 1981). The groups were further divided into 15 low frequency words (i.e., a frequency of 35 or less) and 15 high frequency words (i.e., a frequency of more than 35) based upon the Francis and Kučera (1982) word count. The nonwords differed from real words by at least one phoneme (e.g., analogy → *atalogy*). In this task, the experimenter pronounced a single word and participants were required to repeat the word. The experimenter was positioned to prevent lip-reading. The experimental blocks were presented in two separate blocks: real words and nonwords. The test items were presented in a fixed pseudo-random order. Responses for each target item were scored as either correct or incorrect. As with the picture naming task (Section 1), the first attempt was scored, even if it was spontaneously self-corrected.

5. Stroop. In this task, participants are required to ignore the identity of a written word, and name the colour that the word is presented in. The stimuli consisted of a total of 20 words with eight different colour name words: pink, black, red, blue, green, orange, yellow, and purple. The task consists of two different conditions: congruent and incongruent (Stroop, 1935). The congruent condition consisted of seven items, in which the colour of the word matched that of the written word name (e.g., *PURPLE*). The incongruent condition consisted of 13 items, in which the colour of the word did not match the written name (e.g., *BLUE*). Each target word was presented in the centre of a laptop screen, in size 60 font.

In this task, participants were instructed to ignore the identity of the word and simply name the colour in which it is presented. Instructions were presented onscreen and read verbatim by the experimenter. The task began with a single practice item from the incongruent condition, to familiarize the participant with the task procedure. If the participant responded incorrectly on this trial, the experimenter provided the participant with feedback. Prior to each trial, an array of fixation symbols appeared onscreen for 100ms. Following this, the experimental items were presented in fixed pseudo-random order, simultaneously with the marker tone. Word presentation was self-paced.

Responses for each target item were scored as either correct or incorrect. Response latencies for each target item were manually measured using sound-editing software. Correct responses were measured from the onset of the stimulus (indicated by a beep) to the onset of the participant’s response. Filler words were ignored. Values that were more than 2.5 standard deviations above an individual’s winsorized mean were removed.

6. Letter Fluency. In this task, participants are provided with a letter of the alphabet and are required to name as many words as possible that begin with that letter within 60 seconds. The task consists of three phases, each phase involving a different letter (*F, A, S*) (Spreen, 1998). Participants were told to refrain from using proper nouns (e.g., *Boston* or *Bob*) and variations of previously mentioned words (e.g., *eat, eating, eaten*). The experimenter used a stopwatch to record 60 seconds. Once the time had elapsed, the experimenter immediately provided the participant with the next letter. All responses that began with the allocated letter were scored as correct, with the exception of proper nouns and variations of the same word.

7. Category Fluency. In this task, participants are provided with a category and are required to name as many words as possible that belong to that category within 60 seconds. The procedure for this task was identical to that of the letter fluency task (Section 6), with the exception of the task instructions. The first category was *animals*, and the second category was *fruit*. Responses for this task were scored in the same way as for the letter fluency task (Section 6).

8. Articulatory Agility Test. In this task, participants are required to repeat a given word or phrase as many times as possible within five seconds. The stimuli for this task were identical to those in the verbal agility subtest of the BDAE (Goodglass et al., 2001): *mamma, tip-top, fifty-fifty, thanks, huckleberry, baseball player,* and *caterpillar.* The experimenter used a stopwatch to record five seconds. Once the time had elapsed, the experimenter immediately provided the participant with the next word.

Data and Statistical Analyses

The key performance measures listed in Table 2.3 were obtained for each patient, and converted into a z-score using the control data reported in Faulkner et al. (2015). Following this, the z-scores were combined using the formulae listed in Table 2.3, in order to derive a total score for each core cognitive skill. Finally, each patient’s cognitive skill score (expressed as a z-score) was converted to a T-score. In all cases, T-scores were capped at a minimum of -50 and a maximum of +50, so that major variations in performance did not overly inflate subsequent analyses.

Table 2.3.

Measures and formula used to operationalize the core cognitive skills in the BLAST.

Core Skill	BLAST Profile	Key Performance Measures	Formula
Accessing Semantic Knowledge	Semantic errors in picture naming Poor category fluency relative to letter fluency Semantic confusions in picture-word verification	Percent semantic errors in picture naming, expressed as a z-score (A) Category fluency z-score minus letter fluency z-score (B) Percent semantic confusions in picture-word verification/2[1], expressed as a z-score (C)	= μ (A, B, C)
Lexical Selection	Strong frequency effect in picture naming Disproportionately high production of omission and semantic errors in picture naming Normal picture-word verification	Slope of frequency effect in picture naming, expressed as a z-score (D) Percentage omission + semantic errors in picture naming) – (overall percent errors in picture-word verification), expressed as a z-score (E)	= μ (D, E)
Phonological Encoding	Strong length effects in picture naming Phonological errors in picture naming Poor nonword repetition Normal articulatory agility	Slope of length effect in picture naming, expressed as a z-score (F) Percent phonological errors in picture naming, expressed as a z-score (G) Percent errors in nonword repetition, expressed as a z-score (H) Total score articulatory agility, expressed as a z-score (I)	= μ (F, G, H) minus I, if I is lower than μ (F, G, H)
Auditory Word Recognition	Impaired single word repetition Phonological confusions in picture-word verification Reverse length effect in real word repetition	Percent errors in real word repetition, expressed as a z-score (J) Percent of phonological confusions in picture-word verification/2[1], expressed as a z-score (K) Reverse slope effect in real word repetition, expressed as a z-score[2] (L)	= μ (J, K, L)

Table 2.3. (Cont.)

Core Skill	BLAST Profile	Key Performance Measures	Formula
Goal-Driven Response-Selection	Abnormal congruency effect in the Stroop task Abnormal response-strength effect in the verb generation task Poor letter fluency	Percent increase in RT from congruent to incongruent items in the Stroop task, expressed as a z-score (M) Percent errors on incongruent items, relative to congruent items in the Stroop task, expressed as a z-score (N) Percent errors on low response-strength items, relative to high response-strength items in the verb generation task, expressed as a z-score (O) Letter fluency score, expressed as a z-score (P)	= µ (M, N, O, P)
Verb Retrieval	Poor verb generation on high response-strength items in the verb generation task, relative to high frequency items in the picture naming task	Percent errors in verb generation (high response-selection items only) minus percent errors in picture naming (high frequency items only), expressed as a z-score (Q)	= Q
Articulatory-Motor Planning	Poor articulatory agility	Total score in the articulatory agility, expressed as a z-score (R)	= R
Phonological Short-Term Memory	Poor nonword repetition	Nonword repetition accuracy, expressed as a z-score (S)	= S

[1] Due to small variability in control performance (i.e., at or near ceiling), these measures were halved so that minor variations in performance did not overly inflate the relevant z-score.
[2] This measure was set with a maximum z-score of zero so that a forward length effect did not inflate the relevant z-score.

To determine whether individuals who were impaired on a particular core cognitive skill had damage to the region(s) most commonly associated with that particular core skill, we identified a region of interest (ROI) for each core skill, based upon previous large group analyses (see Table 1.1). For three of the core cognitive skills—*goal-driven response-selection, verb retrieval,* and *articulatory-motor planning*—the ROIs were determined using the Automated Anatomical Labeling (AAL; Tzourio-Mazoyer et al. 2002) atlas as implemented in MRIcron (Rorden et al., 2007). The AAL atlas is based upon the anatomical parcellation of a spatially normalized high-resolution T1 volume single-subject provided by the Montreal Neurological Institute (MNI; Collins et al., 1998). The following regions were delineated: 1) *goal-driven response-selection*: left pars opercularis (11) and left pars triangularis (13); 2) *verb retrieval:* left pars opercularis (11), left pars triangularis (13), and left pars orbitalis (15); 3) *articulatory-motor planning*: left pars opercularis (11), left pars triangularis (13), and the left insula (29).

However, as the AAL atlas does not distinguish between anterior and posterior portions of gyri, the remaining five core cognitive skills were determined using the Brodmann Atlas as implemented in MRIcron. The following regions were delineated: 1) *accessing semantic knowledge*: BA 20, BA 21 and BA 38; 2) *lexical selection*: BA 37; 3) *auditory word recognition*: BA 22; 4) *phonological encoding* and *phonological STM*: BA 22, BA 39, and BA 40. In all cases, the ROI was considered to be damaged if there was at least 10% infarct in at least one of the key regions. Appendix C provides full details of the classification of each individual by percentage of infarct to the key regions of interest (ROIs).

Results

Individual T-scores for each of the core cognitive skills were compared with the scores of the age-matched control group, using the Crawford, Howell, and Garthwaite (1998) modified T-test. Impairment was defined as a significant difference ($p < .05$) between the patient and the age-matched control group. The T-scores for each patient on the eight core cognitive skills are presented in Table 2.4.

Table 2.4.

Individual T-Scores for each individual with aphasia on the core cognitive skills in the BLAST

		Accessing Semantic Knowledge	Lexical Selection	Phonological Encoding	Auditory Word Recognition	Goal-Driven Response-Selection	Verb Retrieval	Articulatory -Motor Planning	Phonological Short-Term Memory
BY	Broca’s	50	40.55	42.94	50	**-1.45*** **	**12.34** **	38.36	50
DA	Broca’s	50	50.00	47.90	**15.43** **	**-11.88*** **	38.60	**25.09***	**9.56*** **
JG	Broca’s	44.77	**17.77** **	35.05	50	**-24.04*** **	**19.38** **	33.05	44.89
JHM	Broca’s	47.40	50	50	50	**-5.71*** **	50	**31.06***	***12.58** ***
RB	Broca’s	33.44	50	**-23.70*** **	**-26.66*** **	**14.36** **	43.72	**31.06***	**18.39** **
RP	Broca’s	32.77	50	**-29.63*** **	**-50*** **	**-42.46*** **	**23.23***	**30.39***	**15.45** **
DW	Conduction	48.34	45.61	36.00	32.93	33.07	39.24	37.69	44.89
IC	Conduction	45.51	41.94	**20.66** **	**24.68***	48.79	**31.55***	43.00	41.94
NP	Anomia	**21.28** **	**8.61*** **	**12.80** **	**15.43** **	**17.22** **	50	50	39.00
STR	Anomia	48.77	45.58	**31.49***	43.17	**12.96** **	50	41.01	na
SW	Wernicke’s	**12.86** **	50	na	**-50*** **	43.40	**4.65*** **	na	**0.73*** **
WL	Conduction	46.76	33.34	**0.76*** **	**2.56*** **	**-50*** **	**24.51***	50	**15.45** **

* $p < .05$, ** $p < .01$, *** $p < .001$
Note. na = not available
Scores in bold denote performance at least two standard deviations below the normal range for control participants.
Score in italics denotes task performance assessed two years prior to the other core cognitive skills, which placed the individual in the 30-50 age group for this particular core skill.

As shown in Figure 2.2, the cognitive skills most commonly impaired on the BLAST were *goal-driven response-selection* and *auditory word recognition.* The cognitive skills that were least commonly impaired were *accessing semantic knowledge, lexical selection,* and *articulatory-motor planning.*

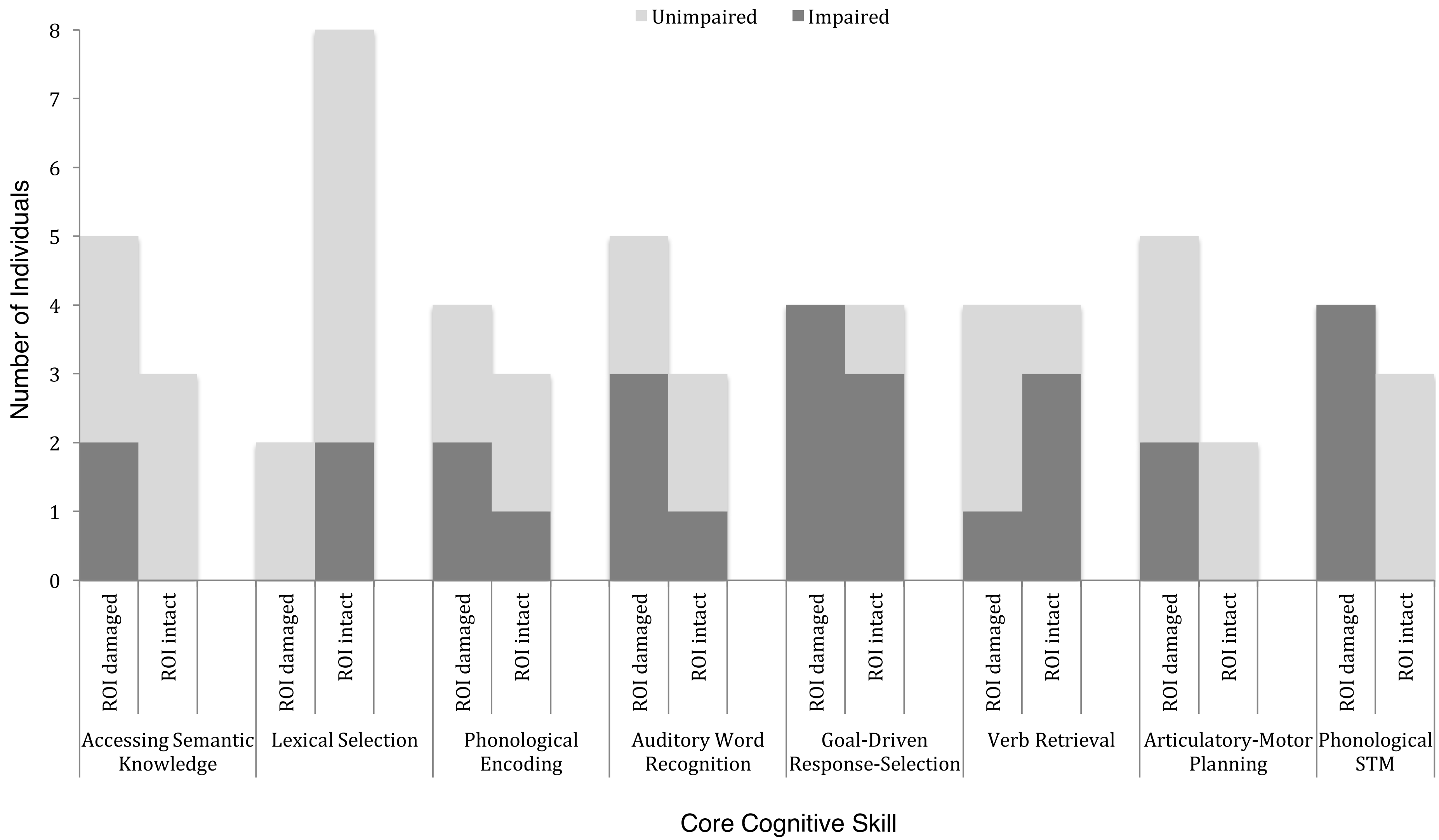

Figure 2.2. Number of patients with/without damage to the region(s) of interest (ROIs) impaired/unimpaired on each core skill in the BLAST.

Discussion

In line with hypotheses, all of the individuals who scored below the normal range on *accessing semantic knowledge, articulatory-motor planning,* and *phonological STM* had damage to the respective ROI. However, for *accessing semantic knowledge* and *articulatory-motor planning*, there was at least one individual who had damage to the ROI, but did *not* score below the normal range on the respective core cognitive skill. It is possible that our ROI-based approach defined a region that was considerably broader than that which is essential for these core skills. Indeed, a seminal study by Dronkers (1996) found that only damage to a discrete region of the precentral gyrus of the insula (directly anterior to the central sulcus) was associated with impaired *articulatory-motor planning*. An alternative possibility is that damage to the relevant ROI is necessary, but not alone sufficient to cause impairment on the particular core skill. For example, in the case of *accessing semantic knowledge,* impairment might only be observed when damage to the relevant ROI is accompanied by damage to other closely associated regions, such as the occipitotemporal area (BA 37), the STG (BA 22), and the lateral prefrontal cortex (BA 45/46) (Schwartz et al., 2009; Cloutman et al., 2009; Hillis et al., 2006).

For the remaining core cognitive skills, there was not a strong association between poor performance and damage to the corresponding ROI. In other words, some individuals who scored below the normal range did not have damage to the relevant ROI, and, conversely, not all individuals with damage to the ROI scored below the normal range on the particular core cognitive skill. Again, it is possible that other neural areas may also be crucial for these core cognitive skills. For example, language skills that involve an element of cognitive control, such as *goal-driven response-selection,* may be affected by damage not only to the key ROI, but also to any frontal region that may lie further upstream. Indeed, all of the individuals who scored below the normal range on *goal-driven response-selection* had at least some frontal lobe damage. Another possibility is that at least some of the core cognitive skills may not be sufficiently well defined to yield reliable lesion correlates. For example, a number of studies have found that selective *verb retrieval* deficits are associated with a variety of lesion sites, such as the basal ganglia, the temporal lobe, and the parietal lobe (e.g., Miceli et al., 1984; see Mätzig, Druks, Masterson, & Vigliocco, 2009 for a review). In fact, some researchers have suggested that the heterogeneity of lesion location for verb deficits may indicate that the functional basis of verbs is variable, or that certain types of grammatical knowledge might be essential for verb production (Mätzig et al., 2009). Further, it is also possible that the weak associations between performance and damage to corresponding ROIs may indicate limitations within the BLAST measures themselves. Finally, it is important to note that the current data is derived from a very small sample population, which makes it difficult to draw any solid conclusions about neural localizations. Consequently, the following chapter will address these questions more directly—by examining whether each core cognitive skill is reliably associated with an alternative independent measure of the core skill in question.

Chapter 3: Cross-Validation of the Core Cognitive Skills in the BLAST

The aim of this study was to cross-validate the core cognitive skills identified in the BLAST against independent measures that could be argued to index the same theoretical construct. It is predicted that performance on the BLAST will be predictive of performance on the cross-validation assessment, such that individuals who score below the normal range on a particular core cognitive skill in the BLAST will also score below the normal range for the same core cognitive skill on the cross-validation assessment. Conversely, it is predicted that individuals who score within the normal range on a particular core cognitive skill in the BLAST should also score within the normal range for the same core cognitive skill on the cross-validation assessment. Specifically, it is predicted that there will be significant positive correlations between scores on the BLAST and the cross-validation assessment for each of the eight core cognitive skills. The following subsections provide a brief summary of the rationale for the selection of each cross-validation measure. The primary requirement for the selection of the cross-validation measures was that they must be independent of those measures used in the BLAST. Accordingly, it should be noted that the measures selected for the cross-validation assessment were not intended to be superior to those in the BLAST, but simply provide an indication of the validity and sensitivity of the core cognitive skills.

Accessing Semantic Knowledge. The Peabody Picture Vocabulary Test (PPVT-IIIA; Dunn, Dunn, Williams, Wang, & Booklets, 1997) is a standardized assessment used to measure an individual’s receptive vocabulary. In this task, participants are required to select the most appropriate picture for an auditory word from an array of four semantically related pictures (e.g., *balloon, plane, jet, helicopter*). Individuals with impairment in *accessing semantic knowledge*, such as those with semantic dementia, should be disproportionately impaired on this task, as it requires the activation levels of the target word’s semantic units to overcome those of the semantic distractors.

Lexical Selection. A small body of research has suggested that performance in picture naming tasks has limited use in the assessment of *lexical selection*, due to the degree of similarity among aphasia subtypes in the distribution of picture naming errors (Kohn & Goodglass, 1985; Howard & Orchard-Lisle, 1984). One novel paradigm that could be used to assess this skill is the auditory picture-word interference task (PWIT). In this task, participants name a series of pictures whilst ignoring auditory distractor words. The distractor words are semantically related (e.g., *table* → "bookcase"), phonologically related (e.g., *letter* → "lettuce") or unrelated (e.g., *pocket* → "dentist") to the target word. According to the spreading activation framework, the presence of a phonologically related distractor may increase activation in the target word's phonological units, which could subsequently boost low levels of activation in the target word's lexical unit (Starreveld, 2000). Indeed, individuals with anomic aphasia often benefit from *phonological priming* (i.e., the presence of begin-related primes – e.g., *finger-finish*) and *phonemic cueing* (e.g., *cucumber* → /kju-/) (Lambon-Ralph, Sage, & Roberts, 2000; Wilshire & Saffran, 2005), which provides support for the idea that phonologically related items may boost low levels of activation in the target lexical units. Importantly, the phonological facilitation effects appear to be restricted to individuals who predominately produce semantic and/or omission errors; in other words, those individuals whose primary deficit appears to involve the lexical selection stage (Wilshire & Saffran, 2005). In the proposed task, the phonologically related distractors are begin-related (e.g., *ferry-feather*) as opposed to end-related (e.g., *brother-feather*). In a spreading activation framework, begin-related primes have more opportunity to increase the activation levels of the target lexical unit. In the key comparison, the auditory distractors will be presented just before, or simultaneously with, the target picture, in order to maximize facilitation at the lexical selection stage (Wilshire & Saffran, 2005; Schriefers, Meyer, & Levelt, 1990; Sevald & Dell, 1994). Accordingly, individuals with a difficulty at the *lexical* *selection* stage, such as those with anomic aphasia, should exhibit exaggerated phonological facilitation effects (i.e., increased accuracy and decreased naming latencies) with phonologically related distractors relative to unrelated distractors when the distractor word is presented just before (i.e., -200ms), or simultaneously with, the target picture (i.e., 0ms).

Phonological Encoding. The production of phonological errors is one of the defining characteristics of impairment at the phonological encoding stage (e.g., *hippopotamus* → /hɪtopɒtəsʊs/). Importantly, the production of phonological errors is not restricted to spontaneous speech, but rather extends to tasks that provide the target word, such as real word repetition and real word reading. Therefore, the current study will assess the proportion of phonological errors across four different tasks: connected speech production, picture description, real word repetition and real word reading. Accordingly, individuals with a difficulty at the *phonological encoding* stage, such as those with conduction aphasia, should produce a high number of phonological errors in each of these tasks, as each task requires the retrieval and selection of the appropriate phonemes in the correct order.

Auditory Word Recognition. The same-different discrimination of minimal word pairs (PALPA 2: Kay, Lesser, & Coltheart, 1992) is a standardized assessment used to measure an individual’s auditory processing skills. In this task, participants are presented with auditory word pairs, and must indicate whether the words are the same (e.g., *face-face)* or different (e.g., *cap-cab*). Individuals with impairment in *auditory word recognition*, such as those with Wernicke’s aphasia/pure word deafness, should be significantly impaired on this task, as the ability to recognize the auditory word pairs is a requisite for auditory discrimination.

Verb Retrieval. The Object and Action Naming Battery (Druks & Masterson, 2000) is a standardized assessment used to measure an individual’s ability to name nouns and verbs in isolation. Importantly, the stimulus items have been matched on psycholinguistic variables, such as frequency, imageability, and age-of acquisition, all of which have been found to be important predictors of naming performance (e.g., Hirsch & Ellis, 1994). Accordingly, individuals with a modality-specific impairment in *verb retrieval* should exhibit disproportionately poor performance on verb items relative to noun items.

Goal-Driven Response-Selection. The blocked-cyclic naming task (BCNT) is a novel paradigm that can be used to examine *goal-driven response-selection*. In this task, participants name a series of single pictures that are repeated across four successive cycles, each time in a different order. The pictures are either semantically related (e.g., *ship, truck, car*) or unrelated (*e.g., ship, cow, dress*). Recent studies have found individuals with nonfluent aphasia tend to exhibit prolonged naming latencies and/or decreased accuracy on semantically related sets compared with unrelated sets (Schnur et al., 2006; Biegler et al., 2008; Scott & Wilshire, 2010). Importantly, these exaggerated effects have not been observed in comparative cases with fluent aphasia, despite poorer picture naming overall (e.g., KV: Biegler et al., 2008). Individuals with impairment in *goal-driven response-selection,* such as those with Broca’s aphasia, should be disproportionately impaired on this task, as it requires the management of competition between simultaneously activated lexical items (Schnur et al., 2006; Wilshire & McCarthy, 2002; cf. Oppenheim, Dell, & Schwartz, 2010).

Articulatory-Motor Planning. A slowed rate of speech is one of the defining characteristics of impairment at the articulatory-motor planning stage (Ogar et al., 2006). Therefore, the current study will assess rate of speech in a sentence production task– the QPA. Individuals with impairment in *articulatory-motor planning*, such as those with apraxia of speech, should exhibit a significantly reduced rate of speech, because a difficulty in the ability to plan, articulate, and coordinate phonemes in the correct order would invariably impact upon the ability to speak at a normal rate.

Phonological STM. The auditory digit span task is the most widely used assessment of *phonological STM* (e.g., Gvion & Friedmann, 2012; Baddeley & Wilson, 1988).

Importantly, nonword repetition and digit span have been found to be highly correlated in neurologically healthy individuals, which provides support for the idea that the two tasks index the same theoretical construct (e.g., Gathercole & Baddeley, 1989). Individuals with impaired *phonological STM*, such as those with conduction aphasia, should score below the normal range on the auditory digit span task.

Method

Participants. The participants in this study were identical to those described in Chapter 2.

Materials and Procedure

The general procedure for the cross-validation assessment was identical to that described for the BLAST (Chapter 2). The entire protocol consisted of the following tasks: PPVT, same-different discrimination of word pairs, object and action naming, picture-word interference, blocked-cyclic naming, auditory digit span, connected speech production, picture description, real word repetition, and real word reading. PsyScope software was used to present the computerized tasks (PPVT, object and action naming, picture-word interference, blocked-cyclic naming). The remaining tasks were administered by experimenter instruction. The following sections provide a brief summary of each task; further details are available in each of the reference articles.

1. Peabody Picture Vocabulary Test. In this task, participants are required to select the most appropriate picture for an auditory word from an array of four semantically related pictures (PPVT-IIIA; Dunn et al., 1997). To summarize, the stimuli consisted of 204 grayscale picture arrays. Each array contained four semantically related pictures (e.g., *nostril, eye, ear, mouth*). The procedure was based upon standard administration; the experimenter presented each picture array individually and pronounced the target word. Participants were instructed to select the most appropriate picture for the auditory word by either pointing to or providing the number of the target picture. Responses for each target item were scored as either correct or incorrect. Raw scores were then converted to standard scores based upon the age of the participant.

2. Same-Different Discrimination of Word Pairs. For this task, we used the PALPA Same-Different Discrimination using Minimal Word Pairs (Kay et al., 1992). Participants are presented with auditory word pairs, and must indicate whether the words are the same or different. The stimuli consisted of 72 word pairs, which are either identical (e.g., *face-face*), or minimally different (e.g., *might-night*). The experimenter presented the word pairs with a one second interval with flat intonation. Participants were told that they would be presented with two words, and asked to say “*yes*” if the two words were the same and “*no*” if the words were different. The experimenter was positioned to prevent lip-reading. Item repetitions were not permitted. Responses for each target item were scored as either correct or incorrect.

3. Object and Action Naming. For this task, we used the Druks and Masterson (2000) Object and Action Naming Battery (List A). In this task, participants are required to provide a verb that describes what the person in the picture is doing or what is happening in the picture (verb items), or a noun that describes the pictured object (noun items). The object and action pictures are matched on the psycholinguistic variables of frequency, age-of-acquisition, and familiarity of the verbal labels of the pictures. The stimuli consisted of 100 grayscale drawings (50 objects and 50 actions). Responses for each target item were scored as either correct or incorrect. Inflectional verb forms and responses following a prompt (except for phonological prompts) were scored as correct. Phonological paraphasias were coded as correct (e.g., *comb* → /klom/).

4. Picture-Word Interference. In this task, participants name a series of single pictures whilst ignoring an auditory distractor word that is semantically, phonologically, or unrelated to the target word. The stimuli employed were identical to those in Wilshire et al.

(2007). To summarize, they consisted of 50 coloured pictures with bisyllabic names. Two exemplars of each distractor type were selected for each target picture: a) *phonological* distractors, which shared at least the first two phonemes with the target word (e.g., *finger-finish*); b) *semantic* distractors, which belonged to the same semantic category as the target word (e.g., *diamond-hexagon*); and c) *unrelated* distractors, which bore no semantic or phonological relationship to the target word (e.g., *tractor-jungle*). Each target picture appeared in each of the three distractor conditions (i.e., phonological, semantic, and unrelated) at four different SOAs: –200ms (distractor precedes target), 0ms (simultaneous presentation), +200ms, and +400ms (distractor succeeds target).

The procedure was identical to that of Wilshire et al. (2007). The target picture remained onscreen for the duration of the trial. Participants were instructed to name the target picture and ignore the distractor word. Each of the 50 target pictures appeared in all 12 conditions (three distractor types x four SOAs). As a result, there were 600 trials in total, which were divided into 12 blocks (50 trials in each). All 12 experimental blocks were completed, across a total of six sessions, separated by at least one week. Each session commenced with eight practice items. One week prior to commencing the task, each participant completed a naming test featuring all 50 pictures in a fixed pseudorandom order. If the participant did not provide the target word, the experimenter provided it for them.

Responses were scored for accuracy and naming latency. For the accuracy analyses, the first attempt was scored, even if it was spontaneously self-corrected (e.g., /p-/ *"cake"*). For the latency analyses, correct responses were measured manually from the onset of the stimulus (indicated by a beep) to the onset of the response. The data was then strictly pruned to ensure a balanced number of trials across the conditions. These procedures are described in full in Appendix D. It should be noted that although the entire task was administered to each individual, we only analysed performance on two of the distractor conditions (phonological and unrelated), and at two of the SOAs (-200ms and 0ms).

5. Blocked-Cyclic Naming. In this task, participants name a series of single pictures that are repeated across four successive cycles, each time in a different order. The pictures are either semantically related or unrelated. The stimuli employed were identical to those in Scott and Wilshire (2010). To summarize, they consisted of 72 coloured drawings, which were organized into 12 semantic categories (body parts, clothes, food, furniture, household items, people, flora, small household objects, utensils, vehicles, and animals), each of which consisted of six pictures. The picture names within each category were frequency-balanced.

Twelve unrelated sets were created by randomly reassigning the original 72 pictures into 12 new six-item sets, with the requirement that these sets must not contain any semantically related items (e.g., *fork, dress, milk, truck, cow, leaf*). Each of the 24 picture sets was used to create a single block of stimulus trials. Within each block, six pictures were presented, one at a time, four times in total, each time in a different random order (with the limitation that each picture repetition was separated by at least three other pictures) (e.g., *grass, root**, leaf**, trunk, seed, fern, **leaf**, root…*). The complete task consisted of 24 blocks—12 semantically related and 12 unrelated. The blocks were presented in a fixed pseudorandom order. The 24 blocks were administered across two sessions, separated by at least one week. Each session commenced with a single practice block of unrelated items with the identical structure as the experimental blocks. Prior to commencing the task, each participant completed a naming test featuring all 72 pictures in a fixed pseudorandom random order. If the participant did not provide the target word, the experimenter provided it for them.

Participants were instructed to name each picture as quickly and accurately as possible. Following the first perceived response of the patient, the experimenter pressed a key to initiate the subsequent trial (after an automatic delay of 100ms). If the patient failed to respond, the next trial was automatically initiated after five seconds. The procedure for the accuracy and latency analyses was identical to that described for the picture-word interference task (Section 4). These procedures are described in full in Appendix D.

6. Auditory Digit Span. For this task, we used the PALPA Auditory Digit Repetition Span (PALPA 13: Kay et al., 1992). Participants hear a sequence of digits and must repeat the sequence back in the correct order. The stimuli consisted of 60 different digit span sets, each of which had between two and seven digits. Participants start on the lowest span length (i.e., two), and, if they respond correctly, they move onto the next span length (i.e., three). If the participant responds incorrectly, the experimenter moves back to the last correct sequence length, and presents the next group of digits at that length. The experimenter presented each digit with a one second interval with flat intonation. Item repetitions were not permitted. Final digit span was defined as the length at which the majority of digit groups were repeated correctly in the correct order.

7. Production of Connected Speech. This task is based upon the standard administration procedure for the QPA (Saffran et al., 1989). Participants were instructed to re-tell a well-known story (i.e., *Cinderella*). Two measures were calculated from the speech sample obtained, using the scoring procedure outlined in Saffran et al. (1989). These were: 1) rate of speech, and 2) number of phonological paraphasias. As per protocol, rate of speech was calculated from their entire speech sample (which excludes filler words and false starts; e.g., *Cin-* Cinderella). The control data for this measure was obtained from Rochon, Saffran, Berndt, and Schwartz (2000). The number of phonological errors was calculated from the narrative transcript, as defined by Saffran et al. (1989) (i.e., the first 150 words, excluding neologisms, direct responses to the examiner, narrative/task comments, habitual starters, conjunctions, and reparations). Mixed errors were not counted. If the participant was unable to provide the full 150-word corpus, the number of phonological errors was calculated as a proportion of the total narrative words. Appendix B provides full details of the criteria used for error coding.

8. Picture Description. In this task, participants were asked to describe a pictured scene— the *Cookie Theft* scene from the BDAE (Goodglass et al., 2001). The total number of phonological errors per 50-word corpus was calculated. The picture remained available for the duration of the task, and participants were given an unlimited time to respond. If the participant failed to provide the 50-word corpus, the experimenter pointed out neglected features of the picture to prompt elaboration. The procedure for calculating the number of phonological errors for each individual was identical to that described in Section 7.

9. Real Word Repetition. In this task, participants are required to repeat an auditory word provided by the experimenter. The stimuli consisted of 180 words from the New Zealand Length by Frequency Naming Test (Wilshire, 2002), which vary in both frequency and syllable length. The experimenter was positioned to prevent lip-reading. The test items were presented in a fixed pseudo-random order. Item repetitions were not permitted. Participants were given unlimited time to respond. The procedure for calculating the number of phonological paraphasias was identical to that described in Section 7.

10. Real Word Reading. In this task, participants are required to read aloud a series of written words. The stimuli were identical to those in the New Zealand Length by Frequency Naming Test (see Section 9), with the exception that the target words were individually presented on paper in a different fixed pseudorandom order. Participants were given unlimited time to respond. The procedure for calculating the number of phonological paraphasias was identical to that described in Section 7.

Data and Statistical Analyses

The core cognitive skill calculations for the cross-validation assessment were identical to those described in Chapter 2, except that Table 3.1 describes the key performance measures and formulae used to derive the core cognitive skill scores. Again, individual z-scores were converted to T-scores using the same method described in Chapter 2. Following this, correlation coefficients were computed between scores on the BLAST and the cross-validation assessment for each core cognitive skill.

Table 3.1.

Measures used to operationalize the core cognitive skills in the cross-validation assessment

Core Skill	Key Performance Measures	Formula
Accessing Semantic Knowledge	Accuracy in the Peabody Picture Vocabulary Test (PPVT), expressed as a standard score (A)	= A
Lexical Selection	Accuracy with phonological distractors relative to unrelated distractors in the Picture-Word Interference Task (PWIT) at -200ms and 0ms (B) Naming latencies with phonological distractors relative to unrelated distractors in the PWIT at -200ms and 0ms (C)	= μ (B + C)
Phonological Encoding	Production of phonological errors in connected speech production, picture description, real word repetition, and real word reading (D)[1]	= D
Auditory Word Recognition	Accuracy on PALPA 2: Same-Different Discrimination of Minimal Word Pairs (E)	= E
Goal-Driven Response-Selection	Accuracy on semantically related sets relative to unrelated sets at cycles 2-4 in the BCNT (F) Naming latencies on semantically related sets relative to unrelated sets at cycles 2-4 in the BCNT (G)	= μ ((2 x F) + G)
Verb Retrieval	Accuracy in action naming minus accuracy in object naming (H)	= H
Articulatory-Motor Planning	Rate of speech in the QPA (I)	= I
Phonological Short-Term Memory	Final digit span on PALPA 13: Auditory Digit Span (J)	= J

[1] Due to the small variability in control performance (i.e., controls perform at or near ceiling), individual performance for this particular core skill was calculated relative to the other individuals with aphasia, such that means and standard deviations used to calculate the T-scores reflect those of the individuals with post-stroke aphasia in the current study rather than those of controls.

Results

Individual T-scores for each aphasic participant on the eight cognitive skills in the cross-validation assessment are presented in Table 3.2.

Table 3.2.

Individual T-Scores for each individual with aphasia on the core cognitive skills in the cross-validation assessment.

		Accessing Semantic Knowledge	Lexical Selection	Phonological Encoding	Auditory Word Recognition	Goal-Driven Response-Selection	Verb Retrieval	Articulatory -Motor Planning	Phonological Short-Term Memory
BY	Broca's	43.33	50	50	**30.99***	**-25.67*****	37.96	**23.29***	**9.70****
DA	Broca's	49.33	50	46.48	**1.13*****	50	42.52	**13.83****	**-5.22*****
JG	Broca's	42.00	50	43.86	50	**-9.50*****	50	**17.08****	**24.63***
JHM	Broca's	44.00	50	50	50	**-23.74*****	47.71	**15.45****	**-20.15*****
RB	Broca's	48.67	50	***26.67****	36.96	39.22	**22.59****	na	**-5.22*****
RP	Broca's	40.00	50	43.57	33.97	**-50*****	47.75	**13.56****	**-20.15*****
DW	Conduction	40.00	na	50	**27.62***	50^	45.28	38.16	**24.63***
IC	Conduction	48.00	na	50	**28.00***	50	42.83	36.81	**9.70****
NP	Anomia	38.67	**29.84***	50	**-4.84*****	36.27	40.42	38.43	**24.63***
STR	Anomia	47.33	**26.75***	47.06	**19.04****	50	37.76	49.78	**24.63***
SW	Wernicke's	**10.00*****	na	na	**-13.79*****	50	**6.31*****	na	**-20.15*****
WL	Conduction	50	38.93	48.62	39.94	**5.55****	**27.39***	**25.45***	**9.70****

* $p < .05$, ** $p < .01$, *** $p < .001$

Note. na = not available

Scores in bold denote performance at least two standard deviations below the normal range for control participants.

Score in italics includes a predicted value for the connected speech production task based upon a linear regression equation.

^ Score was derived from a subset of the original picture sets, which were presented as described in Scott and Wilshire (2010).

For some participants, the cross-validation assessment was completed 1-4 years prior to, or following the BLAST (with the exception of the PWIT, which three participants completed 7-8 years prior to the BLAST (DA, JHM, STR), and the real word reading and repetition tasks, which one participant completed 6-7 years prior to the BLAST (STR)).

As shown in Figure 3.1, the core cognitive skills most commonly impaired on the cross-validation assessment were *phonological STM, auditory word recognition,* and *articulatory-motor planning.* The cognitive skills that were least commonly impaired were *accessing semantic knowledge* and *phonological encoding,* with only one patient impaired on each core skill.

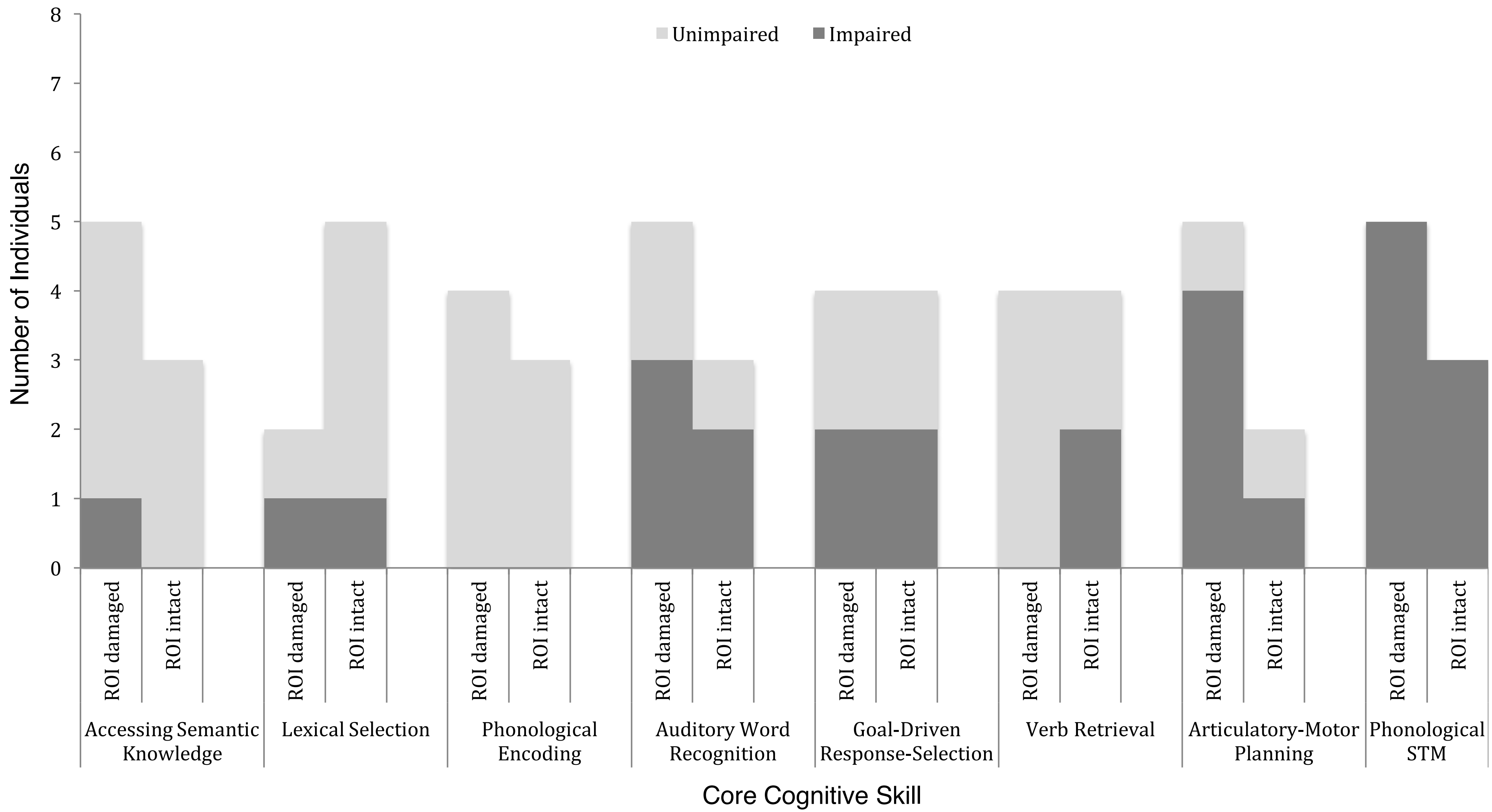

Figure 3.1. Number of patients with/without damage to the region(s) of interest (ROIs) impaired/unimpaired on each core skill in the cross-validation assessment.

As shown in Figure 3.2, the cognitive skills that were most consistently implicated in both the BLAST and the cross-validation assessment were *accessing semantic knowledge, lexical selection, goal-driven response-selection,* and *articulatory-motor planning,* with at least 65% of patients performing consistently between test protocols. The cognitive skill that was least consistently implicated between the BLAST and the cross-validation assessment was *auditory word recognition,* with only 50% of patients performing consistently between test protocols.

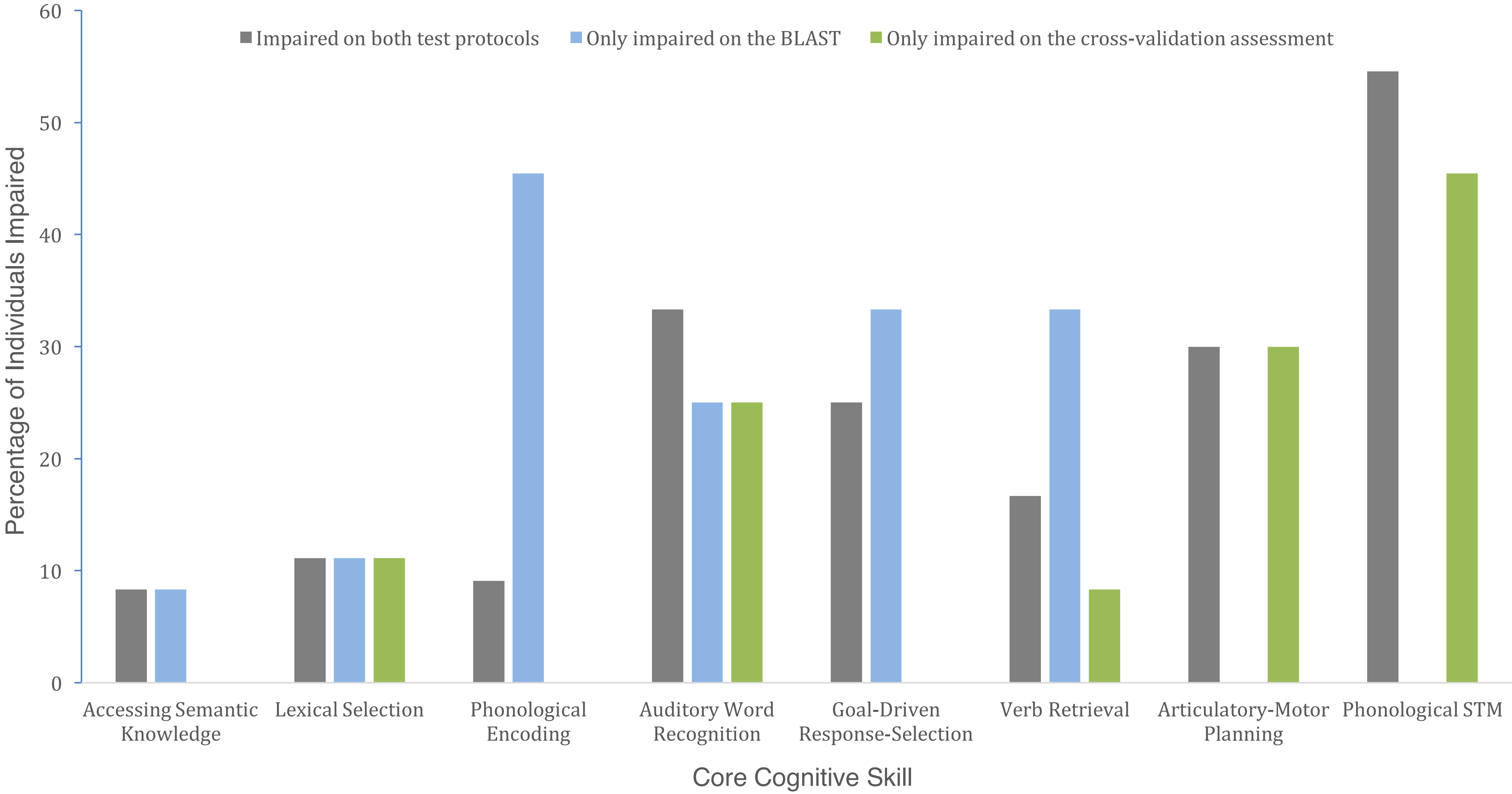

Figure 3.2. Percentage of patients impaired on both test protocols, only on the BLAST, or only on the cross-validation assessment for each core cognitive skill.

As shown in Table 3.3, there were significant positive correlations between the BLAST and the cross-validation assessment for five of the core cognitive skills: *accessing semantic knowledge* ($r(10) = .77$, $p = .004$), *phonological encoding* ($r(9) = .61$, $p = .046$), *goal-driven response-selection* ($r(10) = .71$, $p = .010$), *articulatory-motor planning* ($r(8) = .66$, $p = .037$) and *phonological STM* ($r(9) = .83$, $p = .002$)., which indicates that individuals with low scores on the BLAST tended to exhibit low scores on the cross-validation assessment for the respective core cognitive skills. The correlations between the BLAST and the cross-validation assessment for remaining three core cognitive skills (*lexical selection*, *auditory word recognition*, and *verb retrieval*) did not reach statistical significance.

Table 3.3.

Correlation coefficients between the BLAST and the cross-validation assessment for the eight core cognitive skills

	Cross-Validation Assessment							
BLAST	Accessing Semantic Knowledge	Lexical Selection	Phonological Encoding	Auditory Word Recognition	Goal-Driven Response-Selection	Verb Retrieval	Articulatory-Motor Planning	Phonological Short-Term Memory
Accessing Semantic Knowledge	0.77**							
Lexical Selection		0.41						
Phonological Encoding			0.61*					
Auditory Word Recognition				0.36				
Goal-Driven Response-Selection					0.71**			
Verb Retrieval						0.37		
Articulatory-Motor Planning							0.66*	
Phonological Short-Term Memory								0.83**

* $p < 0.05$, ** $p < 0.01$

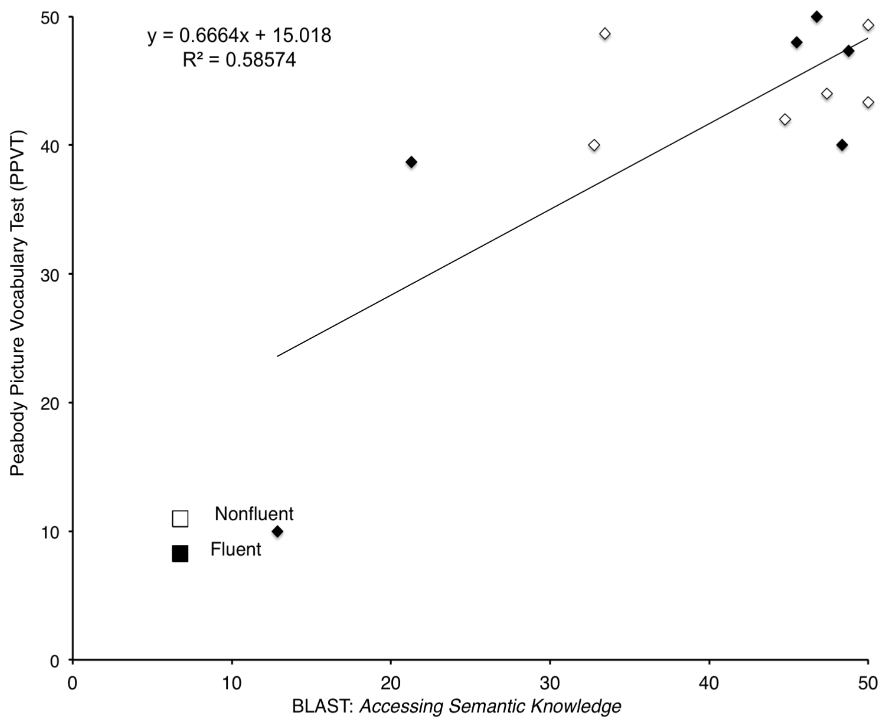

Figure 3.3. Scatterplot showing each patient's score on the BLAST measure of accessing semantic knowledge plotted against their score on the cross-validation measure (Peabody Picture Vocabulary Test). The regression line predicting cross-validation scores from the BLAST measure is displayed; the regression equation is provided in the top left. The scatterplot data points represent T-scores for the individual patients.

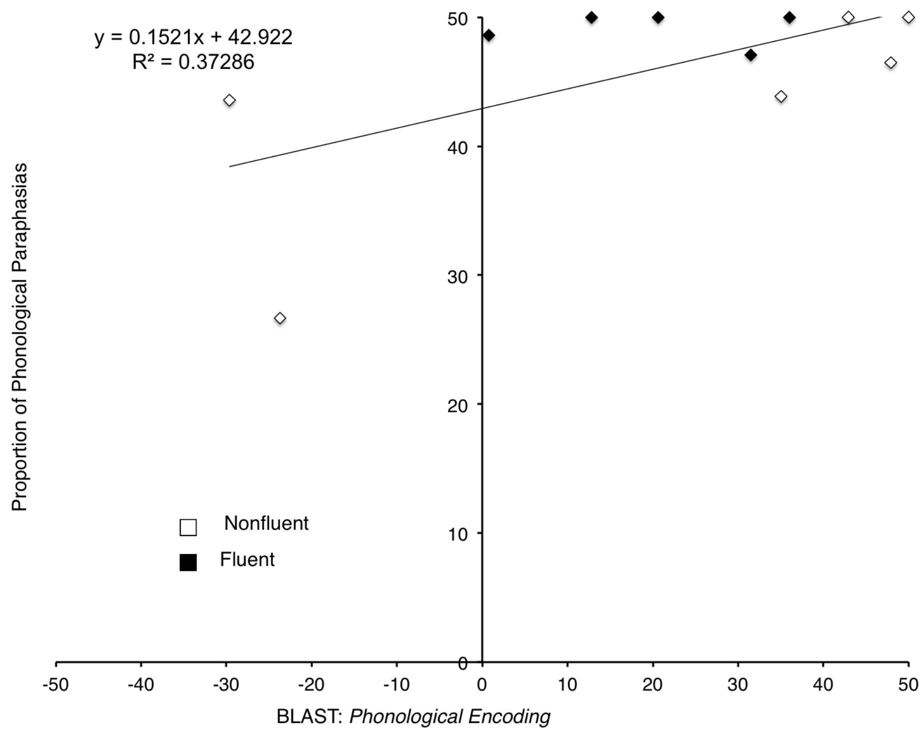

Figure 3.4. Scatterplot showing each patient's score on the BLAST measure of phonological encoding plotted against their score on the cross-validation measure (proportion of phonological paraphasias in connected speech production, picture description, real word repetition, and real word reading). The regression line predicting cross-validation scores from the BLAST measure is displayed; the regression equation is provided in the top left. The scatterplot data points represent T-scores for the individual patients.

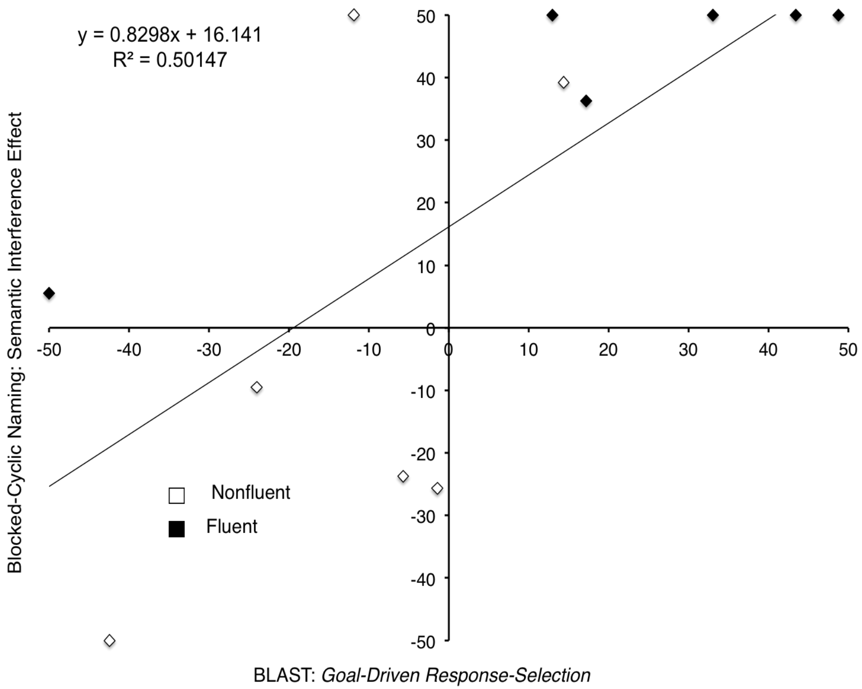

Figure 3.5. Scatterplot showing each patient’s score on the BLAST measure of goal-driven response-selection plotted against their score on the cross-validation measure (semantic interference effect in the blocked-cyclic naming task). The regression line predicting cross-validation scores from the BLAST measure is displayed; the regression equation is provided in the top left. The scatterplot data points represent T-scores for the individual patients.

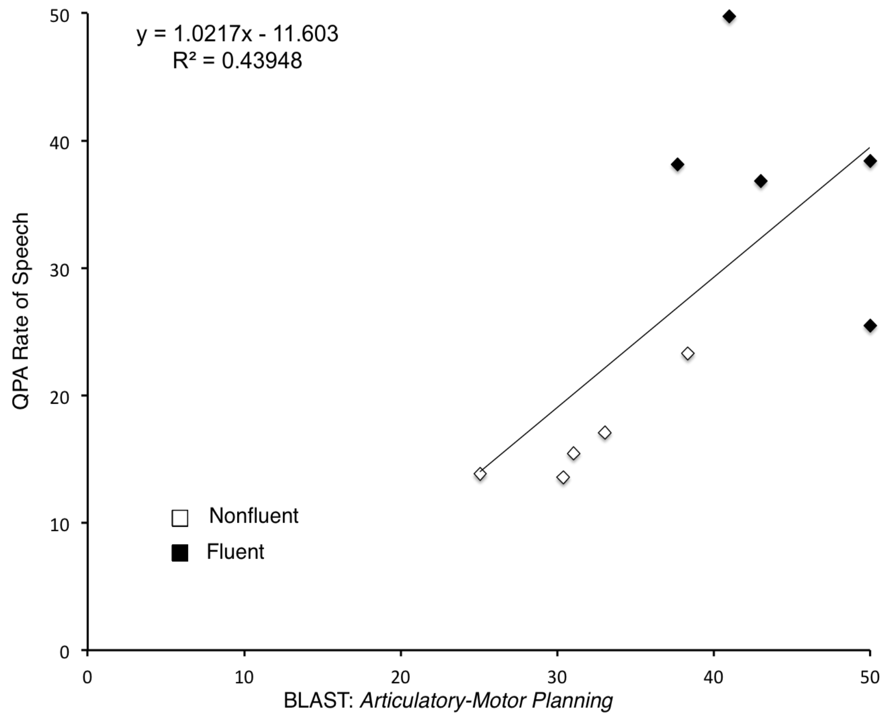

Figure 3.6. Scatterplot showing each patient’s score on the BLAST measure of articulatory-motor planning plotted against their score on the cross-validation measure (rate of speech on the Quantitative Production Analysis (QPA)). The regression line predicting cross-validation scores from the BLAST measure is displayed; the regression equation is provided in the top left. The scatterplot data points represent T-scores for the individual patients.

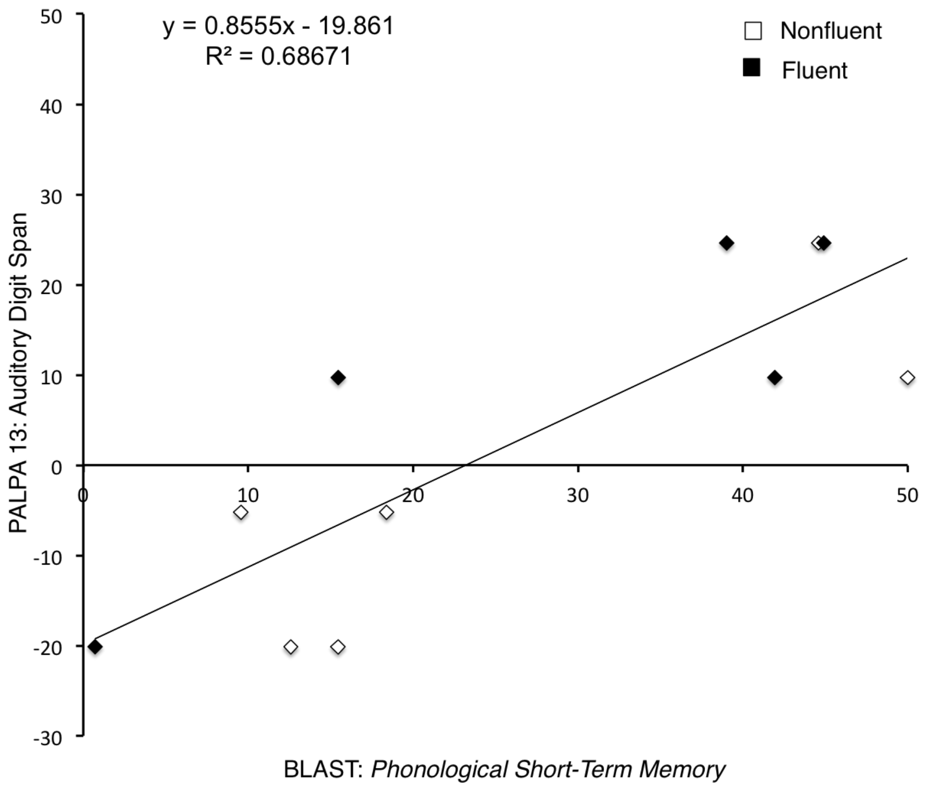

Figure 3.7. Scatterplot showing each patient’s score on the BLAST measure of phonological short-term memory plotted against their score on the cross-validation measure (PALPA 13: Auditory Digit Span). The regression line predicting cross-validation scores from the BLAST measure is displayed; the regression equation is provided in the top left. The scatterplot data points represent T-scores for the individual patients.

Discussion

As predicted, there were significant positive correlations between scores on the BLAST and the cross-validation assessment for five of the core cognitive skills: *accessing semantic knowledge, phonological encoding, goal-driven response-selection, articulatory-motor planning,* and *phonological STM.* In contrast to hypotheses, the correlations between scores on the BLAST and the cross-validation assessment for the remaining three core cognitive skills were not significant: *lexical selection, auditory word recognition,* and *verb retrieval*. However, it is important to note that the sample size was relatively small– particularly for *lexical selection* (n = 9). A small sample size would not only influence statistical power, but may also increase the influence of one or two data points on the overall correlation coefficient.

The current results also provide an indication of the relative sensitivity of each test protocol for the core cognitive skills. The BLAST was more sensitive than the cross-validation assessment for four of the core skills: *accessing semantic knowledge, phonological encoding*, *goal-driven response-selection,* and *verb retrieval.* Conversely, the cross-validation assessment was more sensitive at detecting impairment than the BLAST for two of the core cognitive skills: *articulatory-motor planning* and *phonological STM*. It is also of note that one individual (patient DW) did not exhibit any core cognitive skill deficits on the BLAST, yet demonstrated *auditory word recognition* and *phonological STM* deficits on the cross-validation assessment. Further interpretation of the current results will be explored in the General Discussion (Chapter 5).

Chapter 4: A Comparative Analysis between the BLAST and a Connected Speech Production Task

The aim of this study was to determine whether performance on the core cognitive skills in the BLAST is predictive of performance on a connected speech production task (i.e., the QPA). Specifically, it is predicted that difficulty in resolving competition among simultaneously activated lexical items would likely impact upon the ability to produce well-formed sentences at a normal rate. Consequently, individuals with impaired *goal-driven response-selection* on the BLAST would be expected to score below the normal range on *proportion of words in sentences, proportion of well-formed sentences, median length of utterance, speech rate,* and *struggle measure.* Further, according to models that view agrammatism as a compensatory strategy used to maximize the amount of information that the speaker can produce in a limited time frame (e.g., Sahraoui & Nespoulous, 2012; Kolk, 1995; Ruiter, Kolk, & Rietveld, 2010), impairment in *goal-driven response-selection* might also result in an agrammatic pattern of speech. Accordingly, we tentatively predict that individuals with low scores on the BLAST measure of *goal-driven response-selection* may also exhibit low scores on *proportion of closed-class words, proportion of verbs,* and *inflection index.* Finally, it is predicted that individuals with low scores on the BLAST measure of *verb retrieval* will score below the normal range on *proportion of verbs, inflection index*, and *proportion of words in a sentence,* as the ability to retrieve and integrate the main verb imposes powerful constraints on the production of a sentence (Miceli et al., 1984).

Method

Participants

The participants in this study were identical to those described in Chapter 2, with the exception of RB, whose speech sample did not qualify for the study.

Materials and Procedure

This task is based upon the standard administration procedure for the QPA, as described in Chapter 3. In addition to *rate of speech*, seven additional measures were calculated: *proportion of closed-class words, proportion of verbs, inflection index, proportion of words in sentences, proportion of well-formed sentences, median length of utterance,* and *struggle measure*, based upon the procedures outlined in Saffran et al. (1989). These seven measures were obtained from a corpus of the first 150 narrative words, as defined in Section 7 of Chapter 3.

Data and Statistical Analyses

The calculations for the QPA index measures were identical to those described in Chapter 2 for the BLAST, except that Table 4.1 provides full details of the procedures used to calculate the index measures. Again, individual z-scores were converted to T-scores using the same method described in Chapter 2. Following this, correlation coefficients were computed between scores on the BLAST (i.e., sentence production skills: *goal-driven response-selection* and *verb retrieval*) and the QPA index measures to determine the relationship between performance on the core cognitive skills involved in sentence production and performance on a connected speech production task.

Table 4.1.

A brief description of the key index measures in the Quantitative Production Analysis

QPA Index Measure	Response Scoring Procedure
Proportion of closed-class words	The total number of open-class words (nouns, verbs, adjectives, and adverbs) was counted, and divided by the total number of narrative words.
Proportion of Verbs	The number of verbs was calculated, and divided by the total number of nouns. All verb forms (except "*be*" in the auxiliary) were included.
Verb Inflection Index	The number of inflectable verbs that occurred in the inflected form was calculated, and divided by the total number of inflectable verbs. Irregular verb forms and verbs that occurred in syntactic contexts that required uninflected forms were excluded.
Proportion of words in sentences	The number of words in sentences was calculated, and divided by the total number of narrative words. The classification of an utterance as a sentence required conformation to one of the following structural types: [noun + main verb], [noun + copula + adjective], or [noun + copula + prepositional phrase].
Proportion of well-formed sentences	The number of syntactically well-formed sentences was counted, and divided by the total number of sentences in the narrative transcript. Semantically anomalous sentences were scored as well formed.
Median length of utterance	The number of words in each utterance was calculated, and the median length of utterance was determined.
Rate of speech	The procedure for calculating rate of speech was identical to that described in Chapter 3 (see Section 7).
Struggle measure	The number of narrative words was calculated, and divided by the total number of words uttered to achieve the narrative word sample.

Results

Individual T-scores for each aphasic participant on the eight index measures in the QPA are presented in Table 4.2.

Table 4.2.

Individual T-Scores for each individual with aphasia on the index measures in the Quantitative Production Analysis (QPA)

		Proportion of Closed-Class Words	Proportion of Verbs	Verb Inflection Index	Proportion of Words in Sentences	Proportion of Well-Formed Sentences	Median Length of Utterance	Speech Rate	Struggle Measure
BY	Broca's	50	50	50	50	**11.61****	50	**23.29***	**22.78***
DA	Broca's	**19.48****	**28.64***	48.67	**15.19****	**23.36***	**27.19***	**13.83****	**-28.34*****
JG	Broca's	**5.91****	50	50	44.91	**14.58****	**20.00****	**17.08****	**-2.16*****
JHM	Broca's	**0.11*****	31.59	**24.56***	**2.94*****	**-37.50*****	**27.19***	**15.45****	**-11.45*****
RP	Broca's	**7.00****	**13.10****	**3.48*****	**-50*****	**-43.75*****	**23.60***	***13.56*****	**24.06***
DW	Conduction	49.19	50	50	50	50	48.78	38.16	36.59
IC	Conduction	36.71	50	33.11	47.42	50	41.58	36.81	41.54
NP	Anomia	50	50	50	35.51	42.36	**27.19***	38.43	**20.25****
STR	Anomia	**27.18***	50	45.81	50	39.95	34.39	49.78	**0.79*****
SW	Wernicke's	44.70	50	45.81	**11.89****	**12.50****	**27.19***	35.99	**-10.34*****
WL	Conduction	**22.84***	42.46	50	50	41.54	41.58	**25.45***	**-9.01*****

* $p < .05$, ** $p < .01$, *** $p < .001$
Scores in bold denote performance at least two standard deviations below the normal range for control participants.
Score in italics denotes performance drawn from a different speech sample to the other index measures, which represented the longest sample of uninterrupted speech from which the measure could be more accurately calculated.

As shown in Figure 4.1, the QPA index measure most commonly impaired was *struggle measure*. Conversely, the QPA index measures that were least commonly impaired were *proportion of verbs* and *inflection index,* with only two patients impaired on each measure.

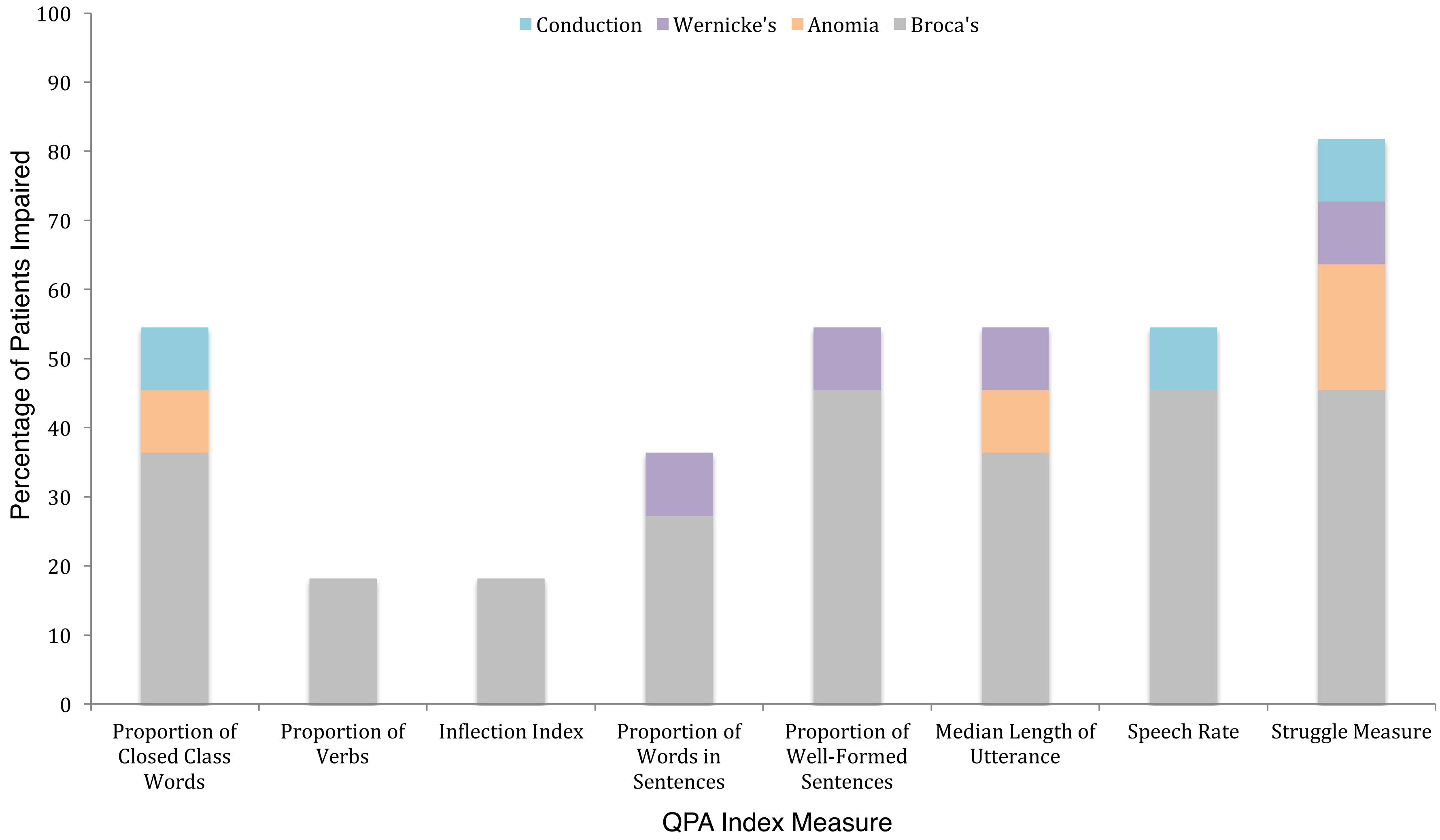

Figure 4.1. Percentage of patients impaired on each Quantitative Production Analysis (QPA) index measure.

As shown in Table 4.3, and consistent with our hypotheses, there were significant positive correlations between the BLAST measure of *goal-driven response-selection* and two of the QPA index measures: *proportion of closed-class words* ($r(9) = .66$, $p = .027$) and *rate of speech* ($r(9) = .69$, $p = .018$). However, contrary to our hypotheses, the correlations between *goal-driven response-selection* and the remaining six QPA indices did not reach statistical significance: *proportion of verbs, inflection index, proportion of words in sentences, proportion of well-formed sentences, median length of utterance,* and *struggle measure*. Finally, and again contrary to hypotheses, none of the correlations between the BLAST measure of *verb retrieval* and any of the three QPA index measures were significant: *proportion of verbs, inflection index,* and *proportion of words in a sentence*.

Table 4.3.

Correlation coefficients between the BLAST core cognitive skills and the Quantitative Production Analysis (QPA) index measures

	QPA Index Measures							
BLAST	Proportion of Closed-Class Words	Proportion of Verbs	Verb Inflection Index	Proportion of Words in Sentences	Proportion of Well-Formed Sentences	Median Length of Utterance	Speech Rate	Struggle Measure
Goal-Driven Response-Selection	0.66*	0.60	0.25	0.34	0.43	0.28	0.69*	0.38
Verb Retrieval	-0.14	-0.07	-0.04	0.09	0.15	-0.06	0.25	0.00

* $p < .05$

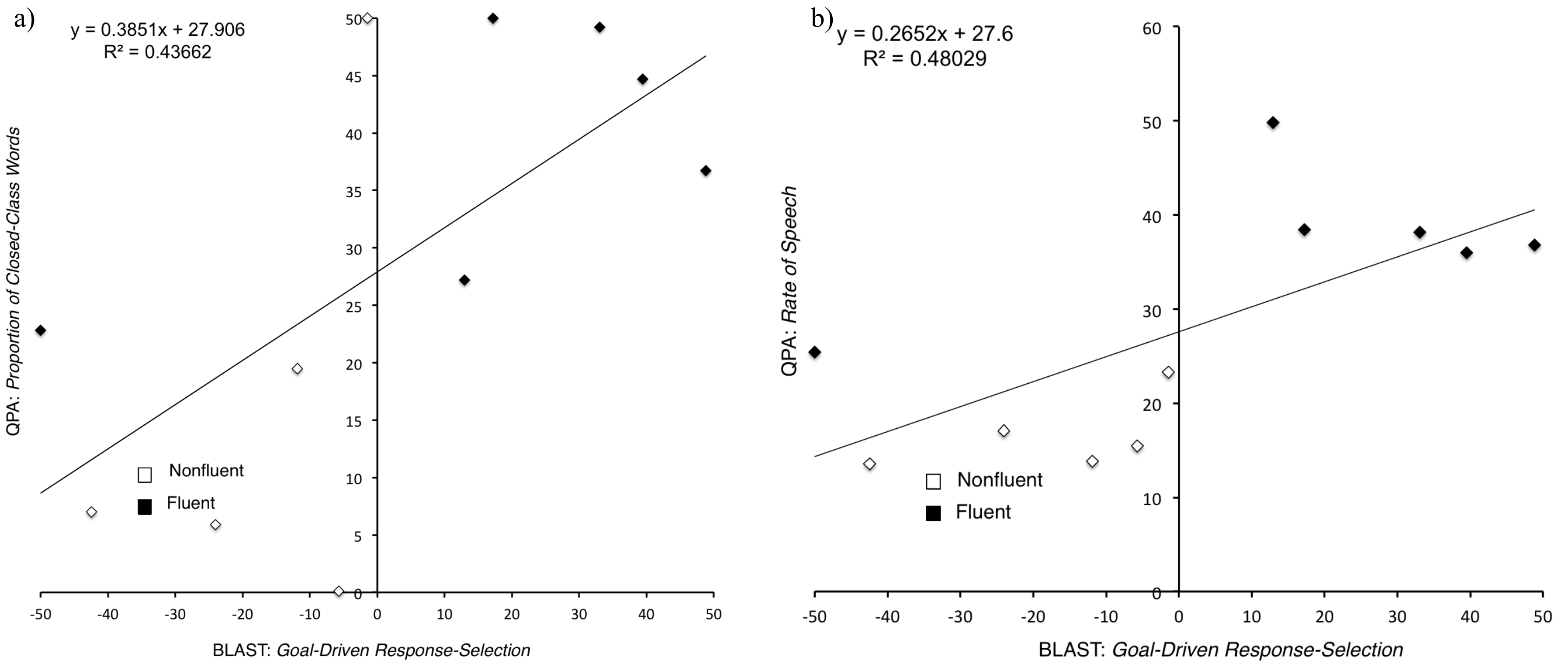

Figure 4.2. Scatterplot showing each patient’s score on the BLAST measure of goal-driven response-selection plotted against their score on the QPA measure of proportion of closed-class words (panel (a)) and on the QPA measure of rate of speech (panel (b)). Each panel also displays the regression line predicting BLAST goal-driven response-selection scores from the relevant predictor variable; the regression equation is provided in the top left of each panel. The scatterplot data points represent T-scores for the individual patients.

Discussion

As predicted, there were significant positive correlations between *goal-driven response-selection* and two QPA index measures: *proportion of closed-class words* and *rate of speech.* However, none of the other hypotheses with respect to *goal-driven response-selection* were supported, nor were any of the hypotheses regarding *verb retrieval*. Nevertheless, it is important to note that the sample size was relatively small, which would not only influence statistical power, but may also increase the influence of one or two data points on the overall correlation. Further interpretation of the current results will be explored in the General Discussion (Chapter 5).

It could be argued that the null results between the scores on the BLAST measure of *verb retrieval* and the QPA indices may reflect limitations of the BLAST measure. To explore this issue in further detail, we repeated the correlational analyses using the cross-validation measure of *verb retrieval* (action naming relative to object naming). However, as with the BLAST measure, none of the correlations were significant (see Appendix E). Indeed, a small body of research has suggested that performance on tasks that assess *verb retrieval* at the single word level may not be a very good predictor of verb production in spontaneous speech (e.g., Bastiaanse & Jonkers, 1998; Zingeser & Berndt, 1990; Berndt, Haendiges, Mitchum, & Sandson, 1997). Further interpretation of the current results will be explored in the following chapter.

Chapter 5: General Discussion

The current research had three primary aims. The first aim was to explore the efficacy of the BLAST as a tool for the assessment of language in post-stroke aphasia (Chapter 2). To this end, we examined the performance of a small but diverse cohort of individuals with chronic post-stroke aphasia. The second aim was to cross-validate the core cognitive skills identified by the BLAST with independent measures that could be argued to index the same theoretical constructs (Chapter 3). The third aim was to evaluate whether an individual’s linguistic profile on the BLAST was predictive of performance on a more naturalistic speech production task– the QPA (Chapter 4). The key findings and implications of each study will be discussed in the following sections.

Study One: Performance of Individuals with Post-Stroke Aphasia on the BLAST

The first aim of the current study was to examine the performance of individuals with chronic post-stroke aphasia on the BLAST (Chapter 2). In this way, we aimed to evaluate the efficacy of the BLAST as a clinical tool within the stroke population. A clinical assessment of language function should satisfy several key criteria (Goodglass et al., 2001; Howard, Swinburn, & Porter, 2010; Byng, Kay, Edmundson, & Scott, 1990). First, the test protocol should reveal the *nature* of an individual’s impairment, in order to provide an indication about an optimal approach to therapy. Indeed, this is one of the advantages of the core skills approach, as an individual’s linguistic profile on the BLAST provides a much more fine-grained analysis of language function than classical diagnostic assessments. To illustrate this point, consider the six individuals in the current study that had been previously classified as having Broca’s aphasia on the BDAE (see Table 2.1). On the basis of the syndrome classification, it would be predicted that all six individuals would score below the normal range on the two core cognitive skills: *verb retrieval* and *articulatory-motor planning*. However, only three of the six individuals scored below the normal range on *verb retrieval*, and only four individuals scored below the normal range on *articulatory-motor planning.* Furthermore, of these six individuals, one scored below the normal range on *lexical selection,* two scored below the normal range on *phonological encoding*, and at least three scored below the normal range on *auditory word recognition* and/or *phonological STM*. In short, it is clear that syndrome classification provides neither a complete nor an accurate interpretation of an individual's language function. The BLAST, on the other hand, is able to provide a summary profile of an individual's language abilities that neither assumes nor excludes interrelationships between core cognitive skills.

Second, a test protocol should be informed by contemporary theories of language function. The BLAST incorporates a number of psycholinguistic variables, such as frequency, imageability, and word length in the subtasks. In this way, the BLAST not only provides an indication of the *nature* of an individual's language impairment, but it can also provide an indication about the various psycholinguistic factors that may affect task performance in acquired language disorders, which can then be used to inform theories of normal language functioning. The BLAST is not the first of its kind to assess language function in this way. The Psycholinguistic Assessment of Language Processing in Aphasia (PALPA; Kay et al., 1992) is a well-established language assessment, which consists of 60 subtests, each of which aim to identify the precise point(s) of language breakdown through the examination of specific psycholinguistic variables. However, the PALPA was not designed to be administered to a single individual in its entirety, but rather to be used as a resource for a hypothesis-driven exploration of an individual's impairment. The BLAST, on the other hand, can provide an indication of the nature of an individual's impairment within a brief period of time, without any need to generate specific hypotheses. Further, as each of the core cognitive skills has been localized to distinct neural regions and the majority of the core skills in the BLAST are assessed by multiple subtasks, the associations and dissociations between neural localizations and individual performance on the subtasks within each core skill can be examined. Therefore, although the BLAST is still in the initial exploratory stage, we suggest that the "core skills" approach holds immense potential as a clinical tool.

Third, a test protocol should be able to be administered to individuals of different aetiologies and of differing levels of severity. Although the BLAST was primarily designed for individuals with brain tumours who typically have more mild language deficits, the core skills were specific enough such that none of the individuals in the current study were globally impaired across all of the core cognitive skills. In other words, none of the individuals scored below the normal range on all eight core cognitive skills, and none of the core skills yielded below normal scores in all of the individuals. In short, we suggest that the BLAST is an appropriate test protocol for individuals with post-stroke aphasia.

Study Two: Cross-Validation of the Core Cognitive Skills

The second aim of the current study was to cross-validate the core cognitive skills in the BLAST against independent measures that could be argued to tap into the same theoretical construct (Chapter 3). In this section, we discuss the results from the cross-validation assessment for the eight core cognitive skills. First, we discuss the core skill measures that significantly correlated with the cross-validation measures (*accessing semantic knowledge, phonological encoding, goal-driven response-selection, articulatory-motor planning,* and *phonological STM*). Following this, we consider those core skill measures that did not significantly correlate with the cross-validation measures (*lexical selection, auditory word recognition,* and *verb retrieval*).

Accessing Semantic Knowledge. The BLAST measure of *accessing semantic knowledge* is comprised of semantic errors in picture naming, semantic confusions in picture-word verification, and total category fluency score. To cross-validate this measure, we assessed accuracy on the Peabody Picture Vocabulary Test (PPVT). As predicted, there was a significant positive correlation between scores on these two measures. It is of interest that one of our participants was impaired on the BLAST measure, but not the cross-validation measure (NP), which suggests that the BLAST may be the more sensitive of the two. Indeed, the PPVT is a multiple-choice test, the sensitivity of which is limited by credit given for correct guesses by forced choice. The BLAST measure, on the other hand, consists of multiple subtasks, only one of which is limited by multiple-choice. It should be noted that neither the BLAST nor the cross-validation assessment considers the possibility of category-specific semantic deficits. A large body of research has found that conceptual knowledge of specific categories can be disproportionately impaired, particularly animals, fruit/vegetables, and artifacts (e.g., Warrington & McCarthy, 1987; Warrington & Shallice, 1984). Indeed, in the BLAST picture naming task, patient NP’s semantic errors were almost entirely restricted to pictures of animals, such that without these errors, he would have scored within the control range. Nevertheless, the evidence from the current study supports the validity of the BLAST measure of *accessing semantic knowledge*.

Phonological Encoding. The BLAST measure of *phonological encoding* is comprised of phonological errors and a length effect in picture naming, accuracy in nonword repetition, and a normal articulatory agility score. To cross-validate this measure, we assessed the proportion of phonological errors in four different tasks: connected speech, picture description, real word repetition, and real word reading. As predicted, there was a significant positive correlation between scores on these two measures. This provides support for the validity of the BLAST measure. Once again, the BLAST measure appeared to be the more sensitive of the two: five of our participants were impaired on the BLAST measure, but not the cross-validation measure. It is possible that the inclusion of the real word repetition task may have decreased the sensitivity of the cross-validation measure, as many individuals with conduction aphasia make fewer phonological errors in real word repetition than in picture naming (Wilshire, 2002; Wilshire & McCarthy, 1996; Caplan, Vanier, & Baker, 1986). A similar argument could be made for the real word reading task, as some individuals may be able to utilize the written orthography of the word to support phonological encoding, at least for words that provide reliable information about their phonological form (Wilshire & McCarthy, 1996; McCarthy & Warrington, 1984). Further, the picture description and connected speech production tasks are not constrained, and therefore individuals may be able to avoid troublesome items that may have otherwise resulted in phonological errors. However, as previously mentioned, the aim of the current study was to select tasks that were independent of those used in the BLAST, which meant that there were often limited alternatives. Accordingly, the measures selected for the cross-validation assessment were not intended to be superior to those in the BLAST. In conclusion, the evidence from the current study supports the validity of the BLAST measure of *phonological encoding*.

Goal-Driven Response-Selection. The BLAST measure of *goal-driven response-selection* is comprised of accuracy and naming latency on incongruent items on the Stroop (relative to congruent items), accuracy on low response-strength items in the verb generation task (relative to high response-strength items), and total letter fluency score. To cross-validate this measure, we measured accuracy and naming latency on semantically related sets in the blocked-cyclic naming task (BCNT)– a task that has been extensively studied in brain-damaged populations, and has been frequently associated with the LIFG (Schnur et al., 2009; Thompson-Schill et al., 1998; Scott & Wilshire, 2010; Wilshire & McCarthy, 2002). As predicted, there was a significant positive correlation between scores on these two measures. This provides support for the validity of the BLAST measure. Once again, four of our participants were impaired on the BLAST measure, but not the cross-validation measure, which suggests that the former may be the more sensitive of the two. However, this is not altogether surprising, given that the BLAST measure draws upon a wider range of skills associated with response selection. Using the terminology of Snyder and colleagues (2014), the tasks that contribute to the BLAST measure use two types of competition: *prepotent* and *undetermined* (Snyder, Banich, & Munakata, 2014). Specifically, the Stroop task involves prepotent competition (suppressing a highly practiced response in favour of another less practiced one), whilst the verb generation task and the letter fluency task involve undetermined competition (resolving competition between internally generated response competitors, as in the verb generation task; or a strategic search through the mental lexicon to select the most appropriate items that adhere to the goal of the task, as in the letter fluency task). The cross-validation measure, on the other hand, consisted of a single task, and used only one metric of competition (i.e., the difference between semantically related and unrelated sets). In conclusion, the evidence from the current study supports the validity of the BLAST measure of *goal-driven response-selection*, which could extend itself to include the BCNT, a task in which the source of the competition is relatively transparent and the effects have been circumscribed to the LIFG (Schnur et al., 2009; Thompson-Schill et al., 1998).

Articulatory-Motor Planning. The BLAST measure of *articulatory-motor planning* is comprised of an individual’s total score on the articulatory agility task. To cross-validate this measure, we assessed rate of speech on the connected speech production task (i.e., the QPA). As predicted, there was a significant positive correlation between scores on these two measures. This provides support for the validity of the BLAST measure. Interestingly, and in contrast to the other core skills considered thus far, three of our participants were impaired on the cross-validation measure, but not on the BLAST measure, which suggests that the former may be the more sensitive of the two. However, it is also possible that the ability to speak at a normal rate is influenced by a number of other additional cognitive factors. For example, an individual who has difficulty managing competition between simultaneously activated lexical representations may exhibit a significantly reduced rate of speech. Indeed, there was a significant correlation between *goal-driven response-selection* in the BLAST and *rate of speech* in the QPA (Chapter 4), which is consistent with this interpretation. However, once again, the measures selected for the cross-validation assessment were not intended to be superior to those in the BLAST, but simply provide an indication of the validity and sensitivity of the core cognitive skills.

Phonological STM. The BLAST measure of *phonological STM* is comprised of accuracy in the nonword repetition task. To cross-validate this measure, we assessed performance on the auditory digit span task (PALPA 13). As predicted, there was a significant positive correlation between scores on these two measures. This provides support for the validity of the BLAST measure. Similar to *articulatory-motor planning*, it appears that the cross-validation measure was more the more sensitive of the two: five of our participants were impaired on the cross-validation measure, but not on the BLAST measure. It is possible that the digit span task draws upon a number of other additional cognitive skills, aside from *phonological STM* – for example, digits belong to the same semantic category and therefore may compete with each other for selection. One method to obtain a purer measure of *phonological STM* could consider an examination of the qualitative aspects of digit span performance, rather than just performance accuracy. Indeed, a small body of research has found that individuals with impaired *phonological STM* tend to exhibit a reduced recency effect (i.e., no recall benefit for final list items: Martin & Saffran, 1997; Shallice & Warrington, 1970). Future research could utilize a quantitative measure of the recency effect.

In the following subsections, we consider the three core cognitive skills that did not significantly correlate with their respective cross-validation measure: *lexical selection, auditory word recognition*, and *verb retrieval*. These core skills deserve particular scrutiny, as the results may indicate the need to reconsider the way in which the particular core skills are measured, or perhaps even whether the underlying theoretical constructs are valid.

Lexical Selection. The BLAST measure of *lexical selection* is comprised of semantic and omission errors in picture naming (relative to errors in the picture-word verification task), and the slope of the frequency effect in picture naming. To cross-validate this measure, we assessed the effect of phonological distractors on accuracy and naming latencies in the picture-word interference task (PWIT), when the auditory distractor was presented prior to, or simultaneously with, the target picture. Contrary to our hypothesis, the correlation between scores on these two measures was not significant. There are a number of possible reasons for this. First, the premise of the cross-validation measure was that the presence of phonologically related distractor words in the PWIT would increase activation in the target word's phonological units, which would subsequently boost low levels of activation in the target word's *lexical* unit. However, one limitation of this measure is that phonological facilitation would only occur if the individual is able to adequately process and maintain the auditory distractor word; if the distractor cannot be adequately discriminated from the target word, it may act more like an identical distractor than a phonological distractor. Similarly, if the distractor's lexical representations decay rapidly, its facilitatory effects would be more restricted. Second, impairment in other core cognitive skills may also influence the potential for phonological facilitation to occur. For example, the majority of the individuals in the current study who exhibited low scores on *goal-driven response-selection* actually exhibited phonological *interference* effects on the PWIT. If some individuals exhibit phonological interference, whilst others exhibit phonological facilitation—for entirely different reasons—this would undermine the efficacy of the cross-validation measure as a valid index of *lexical selection*.

Finally, the non-significant correlation between scores on the BLAST measure of *lexical selection* and its cross-validation counterpart may actually reflect theoretical limitations of the underlying construct of *lexical selection*. Indeed, some researchers have argued that it may not be necessary to postulate a separate lexical selection stage within models of single word production (Lambon Ralph, Moriarty, & Sage, 2002; Lambon Ralph et al., 2000). According to this view, the process of mapping from semantic to phonological representations should not be seen as two dichotomous “steps”, but rather as a continuous process. Indeed, unlike other core cognitive skills, such as *auditory word recognition* and *articulatory-motor planning,* the theoretical construct of *lexical selection* has not been reliably associated with any distinct brain region (e.g., Schwartz et al., 2009; DeLeon et al., 2007; Baldo et al., 2013).

Auditory Word Recognition. The BLAST measure of *auditory word recognition* is comprised of errors in real word repetition, phonological confusions in picture-word verification, and a reverse slope effect in real word repetition. To cross-validate this measure, we assessed performance on the same-different discrimination of minimal word pairs task (PALPA 2). Contrary to our hypothesis, the correlation between scores on these two measures was not significant. There are a number of possible reasons for this finding. First, a lack of variability in control performance in the BLAST real word repetition and picture-word verification tasks could have led to excessively low z-scores in the patient population. Second, real word repetition requires the *production* of the target word; therefore, it is possible that core cognitive skills involved in the final stages of single word production, such as *phonological encoding* and *articulatory-motor planning*, may play a role in task performance. In support of this, there was a strong positive correlation between the BLAST measure of *auditory word recognition* and the BLAST measure of *phonological encoding* ($r(9) = .91$, $p < .001$). It is currently unclear as to whether this correlation reflects limitations of the two BLAST measures, or whether it may be attributable to overlapping neural regions, or perhaps even whether it reflects another property of the two core skills in question. According to interactive theories of language production/comprehension, it may not be possible to make a clear functional distinction between input and output phonological processing, as production and comprehension utilize the same lexical network, with the critical difference being the primary direction of activation flow (Martin & Saffran, 1992, Dell, 1986; cf. Levelt et al., 1999). Accordingly, ineffective flow of activation within a specific part of the network (e.g., between lexical and phonological units) could give rise to impairment on a range of different tasks (see Wilshire & Fisher, 2004 for a case example). Within this framework, poor performance on auditory word recognition tasks (e.g., auditory lexical decision), poor single word repetition, and perhaps even poor spontaneous speech production might all reflect a common underlying impairment.

Regardless of its integrity, the notion of interactivity in theories of single word production illustrates an important caveat of neuropsychological research— the interpretation of impairment on a particular task is heavily dependent upon the theoretical framework of the researcher. Therefore, the tasks selected for the assessment of a particular core cognitive skill, such *auditory word recognition,* should be as distinct as possible from other core cognitive skills. Accordingly, it would be advisable to incorporate at least one subtask into the BLAST that provides a purer measure of auditory input, such as discrimination of minimal word pairs or auditory lexical decision.

Verb Retrieval. The BLAST measure of *verb retrieval* is comprised of accuracy in the verb generation task relative to accuracy in the picture naming task (high response-strength/high frequency items only). To cross-validate this measure, we assessed action naming on the Druks Object and Action Naming task (relative to object naming). Contrary to our hypothesis, the correlation between scores on these two measures was not significant. There are a number of possible reasons for this. First, the BLAST measure of *verb retrieval* involves generating a verb in response to a pictured object, which is distinctly different from the more conventional task of naming pictured objects. Further, the BLAST compares accuracy on the verb generation task with accuracy on the picture naming task using standardized scores, rather than an object naming task that is matched with respect to a number of key psycholinguistic variables (e.g., imageability, age of acquisition, frequency).

Second, in order to minimize any contamination due to a difficulty with *goal-driven response-selection*, the BLAST measure of *verb retrieval* only considers high response-strength items (e.g., *scissors* → "cut"). Nevertheless, even the high response-strength items could make considerable demands on higher-level cognitive processes. For example, the individual still has to refrain from producing the stimulus name in favour of the associated verb, and must also inhibit any nonverb associates that may come to mind (e.g., sugar → *"sweet"*) (Martin & Byrne, 2006). Indeed, all of the individuals in the current study who exhibited low scores on the BLAST measure of *verb retrieval*—but not the cross-validation measure—produced a high proportion of nonverb associate errors (e.g., *stethoscope* → "doctor") and/or task-based errors (i.e., e.g., *stethoscope* → "stethoscope") in both of the response-strength conditions, and all had at least some damage to the posterior LIFG. In contrast, the individuals who were impaired on *both* the BLAST and the cross-validation assessment predominately produced omission errors and/or inappropriate responses (e.g., *nun* → "dream").

Third, the seemingly simple task of producing a verb makes a number of different demands, whose relative contribution varies depending on the precise task used (Black & Chiat, 2003; Gordon & Dell, 2003). For example, the production of a verb may be contingent upon an individual's ability to generate and/or simulate a mental image of the target action within the premotor cortex. Indeed, a large body of research has found that the left premotor cortex often becomes activated in tasks that involve mental imagery, such as verb generation and silent naming of tools (Grèzes & Decety, 2001; Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995). For example, a recent EEG study suggested that localization of activation might also vary according to the primary body part involved in the action (e.g., leg-related verbs, such as *to walk*, produced strongest activity close to the cortical representations of the leg) (Pulvermüller, Härle, & Hummel, 2001).

Finally, and perhaps most importantly, verb production typically occurs within the context of a larger utterance, such as a phrase or sentence. In fact, performance on action naming tasks is not a very good predictor of verb production in spontaneous speech (e.g., Bastiaanse & Jonkers, 1998; Zingeser & Berndt, 1990; Berndt et al., 1997). Viewed in this light, the verb generation task in the BLAST might actually be more—not less—representative of the processes involved in verb production within a sentence. Indeed, this is a valid limitation of the core skills approach *in general*, as it is possible that performance on the key tasks might not accurately represent performance at the sentence level– an issue that will be discussed in the next section.

Study Three: Connected Speech Production

The third aim of the current study was to evaluate whether an individual's linguistic profile on the BLAST is predictive of their performance on a more naturalistic speech production task – the QPA (Chapter 4). It was predicted that there would be significant positive correlations between the BLAST measure of *goal-driven response-selection* and five of the QPA measures: *proportion of words in sentences, proportion of well-formed sentences, median length of utterance, speech rate,* and *struggle measure,* as a difficulty in resolving competition among simultaneously activated lexical items would likely impact upon the ability to produce well-formed sentences at a normal rate. We also tentatively predicted that there would be significant positive correlations between *goal-driven response-selection* and the remaining three QPA indices: *proportion of closed-class words, proportion of verbs,* and *inflection index.* As predicted, there were significant positive correlations between *goal-driven response-selection* and two of the QPA index measures: *proportion of closed-class* *words* and *speech rate*, which provides support for the notion that the BLAST measure of *goal-driven response-selection* plays an important role in sentence production. Further, the significant correlation between *goal-driven response-selection* and *proportion of closed-class words* is consistent with the idea that at least some of the features of agrammatism may reflect strategies used to compensate for a difficulty in managing competition between simultaneously activated lexical representations. In short, the current results suggest that although the BLAST restricts itself to the single-word level, it can be a useful tool in identifying individuals who may have difficulty at the sentence level, at least for some of the features of spontaneous speech.

Contrary to predictions, the correlations between *goal-driven response-selection* and the remaining six QPA indices were not significant (*proportion of verbs, inflection index, proportion of words in sentences, proportion of well-formed sentences, median length of utterance,* and *struggle measure*). Such results could be underpinned by several factors. First, the results could indicate variability in compensatory strategies between individuals. In other words, some of the individuals may cope with lexical competition by limiting the number of words produced per utterance, whilst others may omit grammatical morphemes and/or required arguments. Second, it is possible that impairment on core cognitive skills other than *goal-driven response-selection* may contribute to performance on the QPA index measures. Indeed, in the current study, individuals who scored below the normal range on only one of these core skills were impaired on no more than five of the QPA index measures. Further, a number of correlations between *articulatory-motor planning* and QPA index measures approached significance: *proportion of closed-class words, proportion of verbs, proportion of words in sentences and proportion of well-formed sentences* ($p > 0.1$). It would be of interest to conduct a multiple regression analysis with a larger sample that incorporates both of these core cognitive skills within a single analysis.

Third, there are a number of limitations of the QPA measures, such that performance may not accurately reflect an individual's sentence production abilities. For example, the *proportion of verbs* index does not necessarily reflect the *omission* of verbs, but rather the excess production of nouns (e.g., "she got a new dress, glass slippers and a pumpkin coach with four horses"). Similarly, the *inflection index* does not necessarily reflect an individual's ability to inflect verbs, as it does not credit the total number of inflectable verbs. Therefore, if an individual produces a limited number of (albeit correctly inflected) inflectable verbs, their score would paradoxically be within the control range. It is likely that the total number of inflectable verbs produced may actually tell us more about an individual's ability to inflect verbs than the measure itself, as individuals who have trouble inflecting verbs may omit inflectable verbs entirely rather than produce them inaccurately.

So far, we have considered the relationship between the BLAST measure of *goal-driven response-selection* and performance on the QPA index measures. We turn now to the BLAST measure of *verb retrieval*, where we predicted that there would be significant positive correlations with three of the QPA index measures: *proportion of verbs, inflection index*, and *proportion of words in a sentence*. Contrary to our predictions, none of the correlations were significant. There are a number of possible reasons for this. First, it is possible that the BLAST measure of *verb retrieval* might not accurately represent performance at the sentence level. As previously noted, performance on action naming tasks is not a very good predictor of verb production in spontaneous speech (e.g., Bastiaanse & Jonkers, 1998; Zingeser & Berndt, 1990). Second, the QPA is relatively unconstrained; such that individuals can rely on high frequency, semantically empty verbs (e.g., *do, have, make*) and simple syntactic structures that do not require verb inflections. It would therefore be of interest to examine individual performance on a constrained sentence production task, such as the Sentence Production Test (SPT: Wilshire, Lukkien, & Burmester, 2014).

Limitations and Suggestions for Future Research

A critical limitation of the current study is the small sample size and range of participants. Indeed, it is likely that some of the non-significant correlations may reflect a lack of statistical power, rather than a genuine null effect. In fact, even the significant correlations cannot be considered conclusive in such a small sample, as correlation coefficients can be strongly influenced by one or two data points. The next step in the current research would be to increase the overall sample size, as well as the variability of the sample (aphasia subtype, severity level, and lesion location). Furthermore, as the individuals in the current study were pre-selected for aphasia, it is difficult to determine whether the current results reflect the characteristics of the sample, or the properties of the measures themselves. Therefore, future research could consider cross-validation of the core cognitive skills in individuals with undifferentiated post-stroke aphasia, or perhaps even in individuals with undifferentiated brain tumours, given that the BLAST was primarily designed for use within the tumour population. In fact, a study of this kind may provide a better indication of the most sensitive measures for use within this population, considering that the cognitive sequelae of a brain tumour are typically more mild and variable than those resulting from vascular damage (e.g., Anderson et al., 1990; Davie et al., 2009).

An important concern that could be raised about the current study is the possibility of recovery of language function between test protocols, due to the time lapse between the administration of the BLAST and the cross-validation assessment for some individuals. However, all of our participants were at least two years post-stroke before the administration of either test protocol. Further, although a degree of spontaneous recovery can occur years after stroke, the greatest degree of spontaneous recovery typically occurs between two and ten weeks post-onset, with the majority of long-term follow-up studies finding no further measurable improvement in language function after one year post-stroke (e.g., Pedersen, Jørgensen, Nakayama, Raaschou, & Olsen, 1995; Sarno & Levita, 1971; Kertesz & McCabe, 1977; cf. Smania et al., 2010). Future research should administer both test protocols at the same point in time, or should assess the possible contribution of language recovery by administering the test protocols across different time points. In fact, a study of this kind would not only provide insight into the BLAST measures themselves, but would also determine its ability to detect change over time.

A further limitation of the current research is that the significant correlations may reflect *anatomical* associations rather than *functional* associations, whereby the cognitive processes are functionally distinct, yet the brain regions underlying the cognitive processes are located close together (Vallar, 1999). Although this limitation is inherent within all neuropsychological research, it is particularly pertinent in research of individuals with extensive vascular lesions, such as those in the current study. For example, in the current study, there was a significant positive correlation between *goal-driven response-selection* in the BLAST and *rate of speech* in the QPA, both of which are typically associated with the LIFG (Schnur et al., 2009; Broca, 1861; Ogar et al., 2006). It could be argued that the association between these abilities is anatomical rather than functional. However, recent research has suggested that these core skills may be more functionally related than they may appear at first glance. It has recently been suggested that one of the primary functions of the LIFG is the active selection of words for production. This production may be particularly crucial in situations where multiple words have been activated, and a single target word must be selected, such as in sentence production. In the context of a sentence, multiple words must be simultaneously activated, maintained, and produced in the correct order. According to this view, impairment to this particular function may be associated with deficits across a number of ostensibly diverse tasks, including difficulty with any task where a single word item must be generated from an internal goal (whilst other non-target items must be ignored), and also a disproportionate difficulty producing words in sentences. Individuals with impairment at this level might be likely to exhibit a significantly reduced rate of speech, as more time may be required for the competition to be resolved.

Conclusion

The BLAST is based upon the notion that language can be decomposed into core cognitive skills, each of which is underpinned by distinct neural regions. In this way, the BLAST provides a novel approach to the assessment of acquired language disorders. In the current study, we found support for the validity of the BLAST as a clinical tool for the assessment of acquired language disorders. First, we found that the assessment could be administered to individuals with chronic post-stroke aphasia, and that the linguistic profile provided by the BLAST extends far beyond the predictions derived from neural localization and classical diagnostic assessments (Chapter 2). Second, we found support for the validity of five of the core cognitive skills: *accessing semantic knowledge*, *phonological encoding*, *goal-driven response-selection, articulatory-motor planning,* and *phonological STM* (Chapter 3). Third, we found that there was a significant positive relationship between scores on the BLAST measure of *goal-driven response-selection* and two of the QPA indices (*proportion of closed-class words* and *rate of speech*), which suggests that performance on the BLAST may be predictive of performance on a more naturalistic sentence production task (Chapter 4). In sum, the current findings suggest that the BLAST holds potential as a clinical tool for the assessment of language function in a range of different neurological populations.

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Appendix A: Case Descriptions

Individuals with nonfluent aphasia

BY. BY is a 58-year-old man who suffered a subarachnoid haemorrhage following a motorcycle accident thirty-six years prior to testing. He suffered a further CVA six years prior to the current study. An MRI scan performed a year after testing revealed damage exclusively to the left hemisphere, extending from the anterior horn of the left lateral ventricle to the left parietal lobe. Anteriorly, the lesion encompassed the primary motor cortex, and small portions of the pars operculum (of the LIFG), and the insula. Posteriorly, the lesion encompassed the primary somatosensory cortex and a small portion of the STG (see Figure 2.1 for a graphical depiction of BY’s lesion). Medical documentation at the time of the stroke noted dysphasia, right hemiparesis, and mild amnesia. According to the BDAE, BY was classified as having mild Broca’s aphasia.

DA. DA is a 71-year-old former telecommunications professional who suffered a CVA thirteen years prior to testing. An MRI scan performed eleven months after testing showed significant damage to the left hemisphere. Anteriorly, the lesion extended from the LIFG to the left inferior parietal cortex and parietal operculum, as well as to the primary somatosensory cortex and left insula. Inferiorly, the lesion encompassed almost the entire left superior temporal gyrus (STG) and middle temporal gyrus (see Figure 2.1 for a graphical depiction of DA’s lesion). Medical documentation at the time of the stroke noted expressive aphasia and right hemiparesis. According to the BDAE, DA was classified as having moderate Broca’s aphasia.

JG. JG is a 72-year-old woman who suffered two CVAs five years prior to testing. Following the first stroke, medical documentation noted dysphagia, incoordination, and weakness in both legs. A CT scan conducted on the day of the first stroke revealed acute right cerebellar infarction. Following the second stroke, medical documentation noted a right-sided facial droop, right-sided hemiparesis, and expressive aphasia. An MRI scan performed ten months after testing revealed damage exclusively to the left hemisphere. Anteriorly, the lesion encompassed a large portion of the LIFG, the premotor and primary motor cortices, and the insula. There was also minor damage to the primary somatosensory cortex, the inferior parietal cortex, and the parietal operculum. Posteriorly, the lesion further extended to the anterior and middle STG, yet sparing the posterior superior frontal gyrus, inferior temporal gyrus, and middle temporal gyrus (see Figure 2.1 for a graphical depiction of JG’s lesion). According to the BDAE, JG was classified as having moderate Broca’s aphasia.

JHM. JHM is a 51-year-old female who suffered an extensive CVA twelve years prior to testing. An MRI scan performed nine months after testing revealed extensive damage to the left hemisphere. Anteriorly, the lesion encompassed the posterior portion of the LIFG, the premotor and primary motor cortices, and the left insula. Posteriorly, the lesion further extended to encompass a large portion of the left parietal lobe, including the primary somatosensory cortex and the posterior two-thirds of the STG (see Figure 2.1 for graphical depictions of JHM’s lesion). Medical documentation was not available for JHM; however, it was apparent that she continued to suffer from mild right hemiparesis. According to the BDAE, JHM was classed as having moderate Broca’s aphasia.

RB. RB is an 80-year-old former distribution manager who suffered an ischemic CVA eight years prior to testing. He suffered a further CVA six years prior to the current study. No MRI scan was available for RB; however medical documentation from an earlier CT scan reported damage to the left middle cerebral artery. Following the first stroke, medical documentation noted severe expressive aphasia, speech apraxia, and a right-sided facial droop. According to the BDAE, RB was classed as having severe Broca’s aphasia, although his phrase length score slightly exceeded the range typical for individuals with Broca’s aphasia.

RP. RP is a 69-year-old former wharf labourer who suffered a CVA eleven years prior to testing. He suffered a further CVA ten years prior to the current study. Following the first stroke, medical documentation noted severe dysphasia, right leg claudication, and right-sided facial weakness. A carotid ultrasound suggested complete occlusion of the left internal carotid artery. Following the second stroke, medical documentation noted severe expressive dysphasia, mild right-sided weakness, and dysphagia. Two CT scans confirmed the findings of the previous ultrasound, and suggested further extensive infarctions to left frontal and parietal regions, as well as to the frontal horn of the left lateral ventricle and the right medial frontal region. According to the BDAE, RP was classed as having moderate Broca's aphasia.

Individuals with fluent aphasia

DW. DW is a 57-year-old former mechanic who suffered a CVA ten years prior to testing. Medical documentation and MRI scans were not available for DW; however, his wife recalled damage to left posterior regions. According to the BDAE, DW was classed as having mild conduction aphasia.

IC. IC is a 71-year-old man who suffered a CVA four years prior to testing. Medical documentation noted expressive and receptive aphasia, particularly speech sound errors, word finding difficulties, and problems with comprehending complex sentences, and written information. No MRI scan was available for IC; however, a CT scan at the time of the stroke noted a right fronto-parietal infarct, and possible thrombus within the left middle cerebral artery. According to the BDAE, IC was classed as having mild conduction aphasia.

NP. NP is a 75-year-old male who suffered a CVA sixteen years prior to testing. An MRI scan performed two years prior to testing revealed several foci of damage within the left hemisphere. The largest lesion encompassed posterior portions of the superior, middle, and inferior temporal gyri, and a small portion of the inferior parietal lobe and the lateral occipital lobe. There were also several smaller lesion foci: one located in the pars opercularis (of the

LIFG), another in the premotor and primary motor cortices, and the third affected small portions of the insula (see Figure 2.1 for graphical depictions of NP’s lesions). Medical documentation at the time of the stroke noted right hemianopia, right neglect, right hemiplegia, and expressive aphasia. According to the BDAE, NP was classed as having moderate anomic aphasia.

STR. STR is an 81-year-old female who suffered multiple CVAs eleven years prior to testing. An MRI scan performed one year after testing revealed damage to both the left and the right hemispheres of the brain. The left hemisphere lesion encompassed a large portion of the inferior parietal lobe, encompassing portions of the primary somatosensory and motor cortices, and the dorsolateral prefrontal cortex, as well as posterior portions of the superior and middle temporal gyri. The right hemisphere lesion encompassed the right inferior parietal lobe, the parietal operculum, and the occipital lobe, including the associative visual cortex (see Figure 2.1 for graphical depictions of STR’s lesions). Medical documentation at the time of the stroke(s) noted left hemiparesis, fluctuating levels of consciousness, disinhibition, left hemineglect, and expressive dysphasia. According to the BDAE, STR was classed as having mild anomic aphasia. However, immediately after her stroke, STR was diagnosed with conduction aphasia.

SW. SW is an 81-year-old female who suffered a CVA four years prior to testing. An MRI scan performed one year after testing revealed extensive damage to the left posterior lobe, including the posterior two-thirds of the superior and middle temporal gyri, further extending into the left inferior parietal lobe (see Figure 2.1 for graphical depictions of SW’s lesions). Medical documentation at the time of the stroke noted sudden onset receptive and expressive dysphasia, with no loss of consciousness or seizures. According to the BDAE, SW was classed as having moderate-severe Wernicke’s aphasia.

WL. WL is a 63-year-old former business consultancy manager who suffered an ischemic cerebrovascular accident two years prior to testing. An MRI scan performed four months prior to testing revealed extensive damage to the left inferior parietal lobe, and the parietal operculum. The lesion also encompassed the primary motor and premotor cortices, as well as the primary somatosensory cortex, and posterior portions of the superior and middle temporal gyri (see Figure 2.1 for graphical depictions of WL's lesion). Medical documentation at the time of the stroke noted severe expressive aphasia, speech dyspraxia, and a right-sided facial droop. According to the BDAE, WL was classed as having mild conduction aphasia.

Appendix B: Classification of Error Types

Error Type	Definition	Example
Phonological paraphasia	A nonword that is phonologically related to the target (i.e., has the correct first or last phoneme, or two other phonemes in their correct position, or at least 30% of the same phonemes in any position).	*boat* → “bice”
Formal paraphasia	A real word that is phonologically related to the target, by the above definition.	*boat* → “bake”
Semantic paraphasia	A real word that is semantically related to the target. The word must be from the same category (e.g. *apple* → “banana”), but not an associate (e.g., *apple* → “core”).	*boat* → “car”
Unrelated word error	A real word that is not phonologically or semantically related to the target.	*boat* → “rice”
Neologism	A nonword that is not phonologically related to the target.	*boat* → /dɛm/
Mixed error	A real word that is phonologically and semantically related to the target.	*carrot* → “cabbage”
Omission	No direct attempt at the word.	
Fragment	An aborted attempt that contains incorrect phonemes.	*cat* → /f-/ “cat”
Alternative	A word that is *entirely* appropriate, but not the target.	*couch* → “sofa”

Appendix C: Classification of Individuals by Regions of Interest (ROIs)

Table C1.

Percent infarct in neuroanatomical regions of interest for each individual with aphasia

	Percent Infarct in Neuroanatomical Regions of Interest										
	Brodmann Area 20	Brodmann Area 21	Brodmann Area 22	Brodmann Area 37	Brodmann Area 38	Brodmann Area 39	Brodmann Area 40	Pars Opercularis (11)	Pars Triangularis (13)	Pars Orbitalis (15)	Left Insula (29)
BY	-	-	-	-	-	-	-		-	-	35%
DA	14%	27%	29%	-	35%	-	-	13%	-	31%	99%
JG	-	-	-	-	-	-	-	81%	72%	19%	95%
JHM	-	-	18%	-	-	39%	35%	53%	-	-	57%
NP	12%	-	-	-	-	-	-	11%	-	-	-
STR	-	14%	24%	14%	-	50%	15%	-	-	-	-
SW	-	22%	19%	-	-	15%	-	-	-	-	-
WL	-	25%	34%	15%	-	38%	21%	-	-	-	-

Appendix C: Classification of Individuals by Regions of Interest (ROIs)

Table C2.

Classification of individuals by damage to neuroanatomical regions of interest

Core Cognitive Skill	Key Region(s) of Interest	Individuals with Damage to Key Region(s) of Interest
Accessing Semantic Knowledge	Brodmann Area 20 Brodmann Area 21 Brodmann Area 38	DA, NP, STR, SW, WL
Lexical Selection	Brodmann Area 37	STR, WL
Phonological Encoding	Brodmann Area 22 Brodmann Area 39 Brodmann Area 40	DA, JHM, STR, SW, WL
Auditory Word Recognition	Brodmann Area 22	DA, JHM, STR, SW, WL
Goal-Driven Response-Selection	Pars Opercularis (11) Pars Triangularis (13)	DA, JG, JHM, NP
Verb Retrieval	Pars Opercularis (11) Pars Triangularis (13) Pars Orbitalis (15)	DA, JG, JHM, NP
Articulatory-Motor Planning	Pars Opercularis (11) Pars Triangularis (13) Left Insula (29)	BY, DA, JG, JHM, NP
Phonological STM	Brodmann Area 22 Brodmann Area 39 Brodmann Area 40	DA, JHM, STR, SW, WL

Appendix D: Data and Statistical Analyses for Blocked-Cyclic Naming and Picture-Word Interference

Prior to latency analyses, all technical errors, incorrect responses that were not spontaneously self-corrected and outliers (defined as responses that were more than 2.5 standard deviations above the patient's winsorized grand mean) were removed. Following this, in order to eradicate bias from the missing responses and to ensure balanced numbers of trials across the conditions, the data was further pruned. The pruning process differed for each task; the procedures are described in separate sections below. Following this, all latency data was log-transformed to correct for positive skew (which can be particularly considerable in patient data). Consequently, the data presented are geometric means, which were calculated from the logged value and presented in unlogged form. This is a more suitable measure of centrality than the arithmetic mean for positively skewed data sets.

Blocked-Cyclic Naming

Due to the increased difficulty of the semantically related condition, it is more likely that these items will be omitted, which can bias the means towards the less difficult unrelated condition. All items were presented twice in each cycle number: once in the related condition and once in the unrelated condition, which meant that the target pictures could be sorted into pairs. If any given trial was failed, the corresponding trial in the opposing condition was also excluded. For example, if the target item "*cow*" was failed in cycle four of the semantically related condition, the corresponding trial for "*cow*" in cycle four of the unrelated condition would also be excluded from the latency analyses.

Picture-Word Interference

Due to the increased difficulty of the semantically related distractor condition, it is more likely that these items will be omitted, which can bias the means towards the less difficult phonologically related and/or unrelated distractor condition. All items were presented once in each distractor condition (semantic, phonological, unrelated) and once at each SOA (–200ms, 0ms, +200ms, +400ms), which meant that the target pictures could be sorted into triads. If any given trial was failed, the corresponding trials in the other two distractor conditions were also excluded. For example, if the target item "*triangle*" was failed at –200ms in the semantically related condition, the corresponding trials for "*triangle*" at –200ms in the phonologically related condition and unrelated condition would also be excluded from the latency analyses.

Appendix E:

Correlation Coefficients between the Cross-Validation Assessment and the Quantitative Production Analysis (QPA)

	QPA Index Measures							
Cross-Validation Assessment	Proportion of Closed-Class Words	Proportion of Verbs	Verb Inflection Index	Proportion of Words in Sentences	Proportion of Well-Formed Sentences	Median Length of Utterance	Speech Rate	Struggle Measure
Verb Retrieval	-0.43	-0.32	-0.31	0.08	0.20	-0.08	-0.35	0.30