Domain-general cognitive control and domain-specific language control in bilingual aphasia: a systematic quantitative literature review

Domain-General Cognitive Control and Domain-Specific Language Control in Bilingual Aphasia: A Systematic Quantitative Literature Review

Given name (Vishnu), Family name (KK Nair)[1]

1. Assistant Professor, Department of Communication Sciences and Disorders, Allen Hall, West Virginia University, WV 26505, USA

Email: vishnu.nair@mail.wvu.edu

Given name (Tegan), Family name (Rayner)[2]

2. Undergraduate student, College of Medicine and Public Health, Flinders University, Sturt Road, Bedford Park, Adelaide, SA 5042, Australia

Email: tegan.rayner@flinders.edu.au

Given name (Samantha), Family name (Siyambalapitiya)[3]

3. Senior Lecturer, School of Allied Health Sciences – Speech Pathology, Griffith University, 170 Kessels Road, Nathan QLD 4111, Australia

Email: s.siyambalapitiya@griffith.edu.au

Given name (Britta), Family name (Biedermann)[4]

4: Senior Lecturer, Curtin School of Allied Health – Speech Pathology, Curtin University, Kent Street, Bentley, WA 6102, Australia

Email: b.biedermann@curtin.edu.au

Correspondence concerning this article should be addressed to Vishnu KK Nair, Department of Communication Sciences and Disorders, West Virginia University, Morgantown, WV 26505

Email: vishnu.nair@mail.wvu.edu

Abstract

For successful language production in a target language, bilingual individuals with aphasia must inhibit interference from the non-target language. It is currently unknown if successful inhibition of a non-target language involves general cognitive control (domain-general cognitive control) or whether it is control specific to linguistic mechanisms (domain-specific language control) during language production. The primary aim of this systematic quantitative literature review was to identify and synthesize available evidence, in relation to bilinguals with aphasia, for these two mechanisms. We conducted a literature search across five databases using a set of inclusion/exclusion criteria designed for the review. We extracted data from twenty studies reporting original research in bilinguals with aphasia. The results provided evidence for both domain-general cognitive control and domain-specific language control mechanisms, although most studies showed the involvement of domain-general cognitive control. Available neuroimaging data indicated that the neural regions involved in domain-general language control in bilinguals with aphasia were the anterior cingulate cortex, caudate nucleus, basal ganglia, and the frontal lobe. Theoretical implications for the bilingual inhibitory control model, clinical implications for assessment and treatment of cognitive control abilities in bilinguals with aphasia as well the need for future research are discussed.

1.1 INTRODUCTION

In the past two decades, there has been growing interest in research focusing on understanding the relationship between cognitive control and language production in bilingual speakers (e.g., Kroll et al., 2014; Abutalebi & Green, 2007). One critical finding from this large body of research is that bilinguals activate a domain-general cognitive control mechanism to control interference from the non-target language to achieve successful target language production (Green, 1998; Abutalebi & Green, 2007; Abutalebi & Green, 2008; Kroll & Bialystok, 2013). The term domain-general cognitive control mechanism refers to a wide range of general cognitive functions such as attention, problem solving, working memory and inhibition that monitor and control goal-driven behavioural responses (Mackie et al., 2013). Domain-general cognitive control mechanism is activated in both healthy bilinguals (e.g., Abutalebi & Green, 2008) and Bilinguals with Aphasia (BwA) (Goral et al., 2013), although the nature of these mechanisms has been investigated more in healthy bilinguals than BwA. Available evidence indicates that domain-general cognitive control mechanism can be impaired in BwA resulting in significant language interference errors during language production (Green, 2008; Abutalebi et al., 2009).

Although there is evidence for the activation of domain-general cognitive control mechanism during language production in BwA, it is debated whether language control in BwA is achieved by a domain-specific language control mechanism rather than domain-general cognitive control mechanism (Gray & Kiran, 2016; Liu et al., 2014). Domain-specific language control mechanisms refer to an underlying language control network that operates separately from domain-general cognitive mechanisms to control bilingual language production (Liu et al., 2014). While the activation of both mechanisms is reported in the literature, the evidence for domain-general cognitive control mechanism and domain-specific language control mechanism in BwA is not clear. The present systematic quantitative literature review aimed to investigate evidence relating to these mechanisms in BwA. We were particularly interested in identifying evidence for domain-general cognitive control and domain-specific language control mechanisms in BwA. Although these systems have been investigated in the past literature, there is no consensus regarding the operational definition of these terminologies. Past studies have utilised a number of different terminologies such as domain-general inhibitory control, general purpose cognitive control, cognitive control linguistic control and language control to explain domain-general cognitive control and domain-specific language control in BwA (e.g., Abutalebi et al., 2009; Dash & Kar, 2014; Gray & Kiran, 2016; Radman et al., 2016). In our review, we categorised articles under these two domains based on the tasks used and their results. If the task involved non-linguistic cognitive control (e.g., Simon or Flanker), we considered this to be investigating the domain-general cognitive control mechanism. In contrast, if the task measured linguistic control (e.g., word/semantic translation task), we interpreted this to be examining domain-specific language control. If there was a positive relationship between domain-general cognitive control (e.g., Flanker task) and the linguistic task (e.g., translation task), this would indicate that successful completion of linguistic tasks requires activation of domain general cognitive control abilities. However, a dissociation between domain-general cognitive control (e.g., Flanker task) and a linguistic task (e.g., translation task) would suggest the activation of an independent language control providing evidence for domain-specific language control.

1.1.1 Domain-General Cognitive Control Mechanism

It is likely that a domain-general cognitive control mechanism would involve several executive functioning abilities rather than solely inhibition (Bruin et al., 2014). Abutalebi and Green (2007) argued that a combination of skills such as inhibition, decision making, response selection and working memory may be involved in a bilingual cognitive control network. Although a domain-general cognitive control mechanism encompasses a wide range of cognitive skills, one of the most discussed skills in bilingual literature is inhibitory control. Inhibitory control abilities are argued to be critical for spoken language production (Green, 1998).

One key model that explains activation of language control abilities during bilingual language production is the Inhibitory Control Model (ICM) (Green, 1998). This model specifically focuses on inhibition, a critical cognitive control skill, and proposes that interference from the non-target language is resolved through the purposeful inhibition of the lexicon of the non-target language. The model has three core features that are involved in language processing and control – (i) the lexico-semantic system, (ii) language task schema and (iii) the supervisory attentional system (SAS). The lexical-semantic system is a core subcomponent of language in which each lexical concept is mapped onto a lemma. The lemmas are language specific and carry information related to its word syntax. The activation of a lemma leads to the activation of word forms, and it is argued that the conceptual system is in communication with the relevant lemmas whenever there is an intention to speak a specific language. The language task schema ensures successful inhibition of non-target lemmas both within and between languages. While the SAS is not directly responsible for inhibiting non-target lemmas, it releases attentional resources and oversees the successful inhibition of non-target lemmas. It is also responsible for commanding, modifying, and monitoring the performance of a variety of language production tasks such as language switching and translation.

Evidence for activation of inhibitory control is reported during a variety of language tasks such as language switching (Kroll et al., 2014; Linck et al., 2009), visual word recognition (Martin et al., 2010), spoken word recognition (Blumenfeld & Marian, 2011) and spoken word production in healthy bilingual individuals (Misra et al., 2012).

In BwA, evidence for the presence of inhibitory control mechanisms stems from studies examining *language recovery* and *pathological switching* (Abutalebi & Green, 2007). For instance, Green (1986) described a case of *language recovery* in which an Arabic-French bilingual individual acquired Global aphasia, following damage to the left tempo-parietal area of the brain. This individual presented with an antagonistic recovery pattern, with reasonably good comprehension in both Arabic and French, however, fluctuated in expressive abilities in both languages. This pattern of recovery is associated with pathological inhibition of one language for a certain period, before spontaneously suppressing the other language. Green (1986) argued that the inability to produce both languages simultaneously is a consequence of poor inhibitory control abilities.

Failures in bilingual language control can lead to undesired language switching, referred to as *pathological language switching*, a common characteristic of bilingual aphasia (Pak-Hin Kong et al., 2014). Pak-Hin Kong et al. (2014) investigated the performance of BwA on standardised tests of executive control and functions. The authors reported a strong association between pathological language switching and reduced control over task switching. Poor task switching abilities demonstrate reduced inhibitory control abilities to supress the non-relevant competing task. This provides further evidence to the activation of inhibitory control during bilingual language production.

Neuroimaging data also provides evidence for the activation of domain-general cognitive control mechanism by bilinguals during language processing. Abutalebi and Green (2008) reviewed relevant functional neuroimaging studies and found language processing in L2, involved increased activation of these mechanisms compared to the L1 processing. Bialystok et al. (2005) found greater involvement of the prefrontal cortex and Anterior Cingulate Cortex (ACC) during non-linguistic inhibitory control tasks and conflict management in linguistic tasks. Kroll and Bialystok (2013) suggested that the ACC is involved in the monitoring of interference from the non-target language. Lee et al. (2016) indicated activation of the prefrontal cortex, ACC, inferior parietal cortex, and basal ganglia inhibitory mechanisms in the control of language selection during bilingual language production.

1.1.2 Domain-Specific Language Control Mechanism

The existence of a functionally independent mechanism for language control is debated in the literature (Gray & Kiran, 2016). Studies have found a dissociation between language production and general cognitive control tasks in healthy adults (e.g., Calabria et al., 2012) and BwA (e.g., Gray & Kiran, 2016; Faroqi-Shah et al., 2018) indicating evidence for a partial or fully independent domain-specific language control mechanism for linguistic control. Calabria et al. (2012) used a linguistic and non-linguistic switching task in a group of Catalan-English bilingual speakers. In the linguistic switching task, the participants performed a naming task either in Catalan or in Spanish. In the non-linguistic task, participants had to match colour or shape and switch matched depending on the word cue appearing in the computer monitor. Results indicated that the magnitude of the linguistic and non-linguistic switching costs were in different directions indicating no correlation between linguistic and non-linguistic switching. In BwA, Gray and Kiran (2016) examined domain-general and domain-specific language control mechanism in BwA using a non-linguistic Flanker task and a linguistic semantic word-pair judgment task. The results indicated that BwA demonstrated no congruency effect on the semantic-word pair task but showed a congruency effect on the non-linguistic Flanker task. The absence of congruency effect on the linguistic task is interpreted as evidence towards an impaired linguistic control (domain-specific language control). Although these results do not directly provide evidence against a domain-general cognitive control mechanism, it indicates an existence of shared, partial, or a fully independent cognitive mechanism specifically devoted for language control.

Currently, most research on bilingual language production and cognitive control stems from monolingual and bilingual healthy individuals. In contrast, there is a significant gap in our understanding of the nature of cognitive control mechanisms in monolingual speakers with aphasia (MwA) and BwA, with less studies published on the latter group. Impairments in cognitive control mechanisms are reported in both MwA and BwA, although in MwA attentional mechanisms are more commonly investigated (e.g., Murray, 2012). It is reported that only a subgroup of MwA show impairments in attention, however, deficits in attention can be associated with impairments in language processing (e.g., Murray, 2012; Villard & Kiran, 2017). In BwA, it has been reported that impairments in cognitive control resulted in larger interference effects on the ANT compared to healthy bilinguals (e.g., Dash et al., 2020). Faroqi-Shah et al (2018) indicated that impairments in cognitive control can negatively impact language production tasks in BwA (e.g., Faroqi-Shah et al., 2018). For example, poorer performance in verbal and category fluency tasks have been attributed to a weaker activation in inhibitory control (Faroqi-Shah et al., 2018). Patra et al. (2020) reported that BwA performed significantly worse on letter fluency tasks compared to healthy bilinguals. BwA who had difficulty with letter fluency tasks also struggled with executive control tasks. However, their results also reported one bilingual with aphasia, who performed similarly to healthy bilingual adults indicating that impairments in verbal fluency and executive control are not observed in all BwA. Carpenter et al. (2020) found that BwA showed comparable performance to healthy bilinguals in tasks requiring lesser cognitive control, however, performed worse on tasks needing increased cognitive control. Neuroimaging studies have also indicated overlapping neural regions for language control and domain-general cognitive and damage to the frontal lobe can result in impaired executive control and pathological code switching (Pak-Hin Kong et al., 2014). Radman et al. (2016) also suggested a similar overlap between language control and domain-general cognitive control brain areas (e.g., inferior prefrontal cortex, left inferior frontal gyrus pars orbitalis, anterior cingulate cortex and basal ganglia) in BwA. Taken together, these findings indicate that impairments in cognitive control are reported in the literature, however, these impairments are likely to vary depending on individual performance and task type. Furthermore, neuroimaging evidence provide support to cognitive control impairments in BwA. Although studies indicate a certain degree of overlap between domain-specific language control and domain-general cognitive control, given the heterogeneous nature of bilingual aphasia, it is likely that not all participants will show impairments in this domain. Most critically, recent findings from BwA indicate a dissociation between domain-specific language control and domain-general cognitive control suggesting the activation of a domain-specific language control in BwA (e.g., Gray and Kiran, 2016). However, the extent of evidence for domain-general cognitive control mechanism or domain-specific language control mechanisms in BwA is currently unknown. It is also unclear if these mechanisms are supported by separate neural regions. Evidence for a domain-general cognitive control mechanism or a domain-specific language control mechanism will lead to better understanding about the activation of these mechanisms, gather theoretical evidence that test the prediction of the ICM, as well as provide clinical implications for the remediation of impairments in these cognitive control mechanisms.

1.2 Aim of the current study

The current review aimed to investigate evidence for a domain-general cognitive control mechanism or a domain-specific language control mechanism in BwA and their neural regions involved during the activation of these mechanisms by asking the following research questions:

1) Is language control in BwA domain-general or domain-specific?

2) What are the neural regions associated with domain-general cognitive control or domain-specific language control in BwA?

1.3 METHOD

This review followed the process for a systematic quantitative literature review developed by Pickering and Byrne (2014) and where possible is reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA). A systematic quantitative literature review searched and categorised the available and relevant literature, to provide quantitative and qualitative summaries of the current status of this area of research (see Pickering, 2016; Pickering & Byrne, 2014 for more details).

1.3.1 Search strategy

Five scholarly electronic databases (Medline, CINAHL, LLBA, Proquest and PsychInfo) were searched to identify original research papers related to language control in BwA. Studies published up to December 2020 were included in the review. The following keywords were used for the search: 'bilingual', 'aphasia', 'language control', 'linguistic control', 'non-linguistic control', 'cognitive control', 'executive control' and 'inhibit'. An example search string in CINAHL was "bilingual aphasia AND (((linguistic or language or non-linguistic or "nonlinguistic" or cognitive or executive) adj3 control) OR inhibit*))". Additional manual searches were conducted as well as review of the reference lists of the papers identified from the database search.

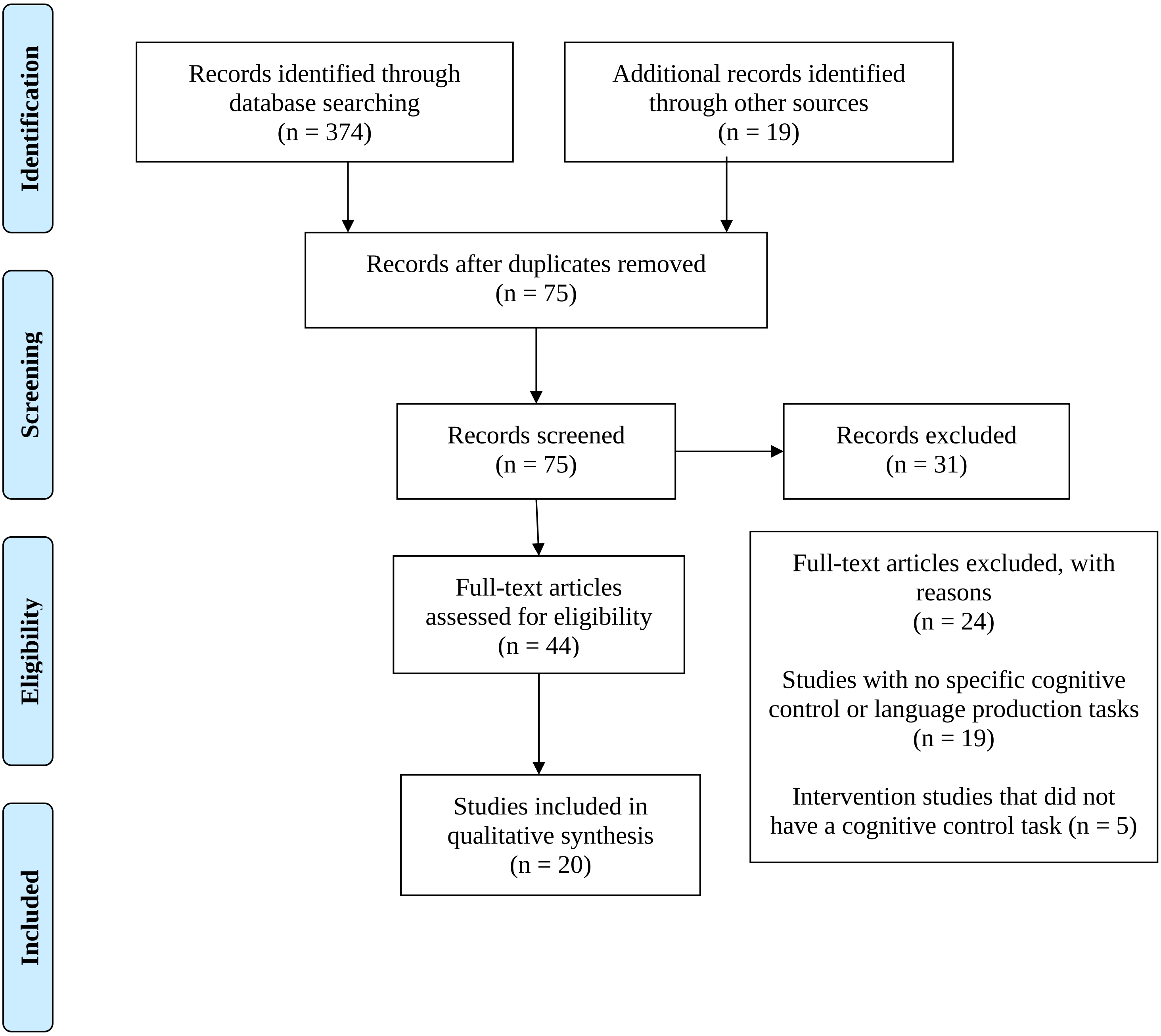
1.3.2 Inclusion and exclusion criteria

Given the novelty of this topic, it was important that only studies reporting original data on language production and cognitive control abilities in BwA were included in the review. A study was included if it reported any aspects of language production such as naming single words, verb retrieval, as well as a cognitive control task (e.g., Stroop task, Simon task). The study included investigation of BwA from all language backgrounds. We excluded papers that focused on language production and cognitive control in monolingual individuals with aphasia. Additionally, we excluded any studies that had no full text available, or literature reviews that were not presenting original research data or grey literature such as conference abstracts, dissertations, etc.

1.3.4 Data extraction

From each original research paper investigating language control mechanisms in BwA, the following categories of data were extracted and recorded in a Microsoft Excel spreadsheet: i) study information, ii) participant information, iii) bilingual language control in aphasia information, iv) outcome measurement information, v) results, and vi) summary. The study design for each selected study was identified using the Australian National Health and Medical Research Council (NHMRC) study guidelines (Merlin et al., 2009). All identified papers were reviewed for data extraction by the first and second authors. The categories for data extraction were reviewed by three reviewers. Two reviewers (first author and last author) separately extracted data from 50% of the papers. A reliability check was done for the extracted data by the second author and the reviewers. The reliability check resulted in an 85% match of the extracted data between the second author and the reviewers and the mismatches were resolved reaching a consensus. Figure 1 represents the data selection and extraction process in a PRISMA flow diagram.

*Figure 1:*PRISMA flow diagram explaining the methodological process



1.4 Results

We conducted a systematic quantitative literature review to examine evidence for activation of domain-general cognitive control or domain-specific language control mechanisms in BwA. Our literature search resulted in the inclusion of twenty papers in the review. These studies reported findings from BwA participants in the age range of 27-79 years. There were several native languages spoken by BwA across all studies. These languages included Bengali, Dutch, French, Persian, Spanish, etc. English was the most common second language spoken by the studied participants. Table 1 provides an overview of the studies included in the review.

Insert Table 1 here

Is language control in BwA mediated by domain-general or domain-specific?

The overall total of BwA across studies in this review comprised N=120. The majority of papers (16) reviewed in this study supported domain-general language control in BwA, while only four studies supported domain-specific bilingual language control. Sixteen studies that supported domain-general cognitive control included a total of 91 BwA, whereas an overall of 29 BwA spanning across four studies showed evidence for the activation of a domain-specific language control. A variety of tasks have been used to measure linguistic and non-linguistic control. For instance, non-linguistic control was measured using tasks such as Flanker and Stroop tasks. Linguistic control tasks included lexical decision, semantic naming, and letter fluency tasks. Table 2 provides information on the studies that support either of these mechanisms along with other details such as the linguistic and non-linguistic outcome measures assessed in these studies.

Insert Table 2 here

What are the neural regions associated with language control in bilingual individuals with aphasia?

There were five studies that included neuroimaging data, the majority of studies focussed on behavioural data. The neuroimaging evidence identified the following neural regions as being key areas involved in bilingual language control in aphasia (Table 3).

a) Anterior Cingulate Cortex (ACC)

b) Basal Ganglia

c) Caudate Nucleus as part of the basal ganglia

d) Frontal Lobe

Insert Table 3 here

1.5 DISCUSSION

This systematic quantitative literature review investigated the existing research evidence for the type of language control in BwA and the neurological origin of these mechanisms. Twenty papers were identified for inclusion in the review and indicated mixed findings in relation to the presence of domain-general cognitive control or domain-specific language control mechanisms in BwA. We applied the Australian National Health and Medical Research Council (NHMRC) levels of evidence to identify the type of research design for the studies included in this review. The NHMRC levels of evidence considers a systematic review and randomised control trials as the highest form evidence followed by pseudorandomised control trials, non-randomised experimental trials, case control studies and case studies. Eleven studies included in our review were non-randomised experimental trials (comparative study with control group), six studies did not have a control group (comparative study without concurrent controls) and three studies were case controls. Together these studies constituted level 3 evidence with levels 1 and 2 being systematic reviews and randomised control trials. This is not uncommon in the bilingual aphasia literature, given most study designs are quasi-experimental or single case experimental design rather than randomised control trials.

As can be taken from the results, the majority of studies provided evidence for the involvement of a domain-general cognitive control mechanism in BwA. For instance, Adrover-Roig et al. (2011), Van der Linden et al. (2018), Penn et al. (2010), Verreyt et al. (2013), Penn et al. (2016), Abutalebi et al. (2009), Goral et al. (2013) and Kohnert (2004) used behavioural outcome measures to investigate the involvement of a domain-general cognitive control mechanism. These studies measured the performance on domain-general control tasks and performance on linguistic tasks, such as verbal expression tasks (e.g., naming common objects) as well as non-linguistic executive function and control tasks (e.g., the Flanker Task, Eriksen & Eriksen, 1974). Results showed that a weakness in domain-general control mechanisms leads to poor performance in lexical decision tasks (Verreyt et al. 2013). Penn et al. (2010) showed that the impairments in response inhibition and interference control can affect beyond lexical decision or naming and create deficits in conversational tasks such as turn taking or topic maintenance.

While these results point towards a positive relationship between a domain-general cognitive control mechanism and linguistic tasks, it must be noted that only a few studies have carried out a direct correlational analysis between these two, and the results are not straight forward. Faroqi-Shah et al. (2018) correlated the performance of a linguistic Stroop task with category fluency task. It was reasoned that category fluency relies heavily on cognitive control skills such as goal directed inhibition and suppression. Contrary to their prediction, their correlation results showed no association between the Stroop task and the category fluency task. Faroqi-Shah et al. (2018) suggested that the lack of association between tasks could be due to factors such as an impaired cognitive control system that is minimally activated during category fluency. Given Faroqi-Shah et al. (2018) used a linguistic Stroop task, and the results indicated a non-significant association, we have interpreted their results as evidence *against* domain-specific-language control. In contrast, in a more recent study, Patra et al. (2020) examined the association between linguistic Stroop task and verbal fluency in Bengali-English BwA. The participants were asked to produce words that belong to semantic categories (e.g., animals or vegetables) or words that begin with the same letter/sound. The results indicated that participants with smaller Stroop ratio (a measure of better inhibitory control) were faster in their first response and produced more correct responses for the verbal fluency task in both languages. While this provides evidence for a domain-specific language control mechanism, it must be noted that results from Faroqi-Shah et al. (2018) and Patra et al. (2020) do not offer an unequivocal evidence for domain-general cognitive control or domain-specific language control in BwA. It is hard to dissociate these two mechanisms given that they overlap and might be activated jointly in a linguistic Stroop task. These findings are complex, and caution must be applied before interpreting findings from BwA because of the heterogeneous nature of this speaker group.

On the other hand, Dash and Kar (2014), Green et al. (2010) and Gray and Kiran (2019) all measured the participants' functional language skills using a variety of standardised and experimental linguistic tasks, as well as the participants' non-linguistic inhibition and interference control skills. The participants' accuracy and reaction time during completion of both linguistic and non-linguistic tasks was compared to measure the activation of a domain-general cognitive control mechanism. For instance, Gray and Kiran (2019) indicated that BwA exhibit a different pattern of performance than healthy adults in non-linguistic and linguistic control tasks. The healthy controls in their study showed congruency effects (faster reaction times for congruent trials than incongruent trials) in both high complexity non-linguistic and linguistic tasks, whereas BwA exhibited congruency effects only in a high complexity non-linguistic task. A lack of congruency effect in the linguistic control task would indicate that BwA had difficulty managing the congruent and incongruent stimuli suggesting an impaired linguistic control mechanism. Dash and Kar (2014) have also indicated that all participants in their study have shown a congruency effect for non-linguistic Flanker tasks, however an absence of a congruency effect for linguistic Flanker task was seen in some participants. This indicates that while domain-general cognitive control tasks such as interference control or inhibition can be impaired in BwA, some participants demonstrate a selective impairment in a domain-specific language control suggesting a dissociation between linguistic and non-linguistic inhibitory control in BwA supporting the involvement of a domain-specific language control mechanism.

In this review, we included two recent articles that introduced another control mechanism known as ‘semantic control’ (Calabria et al., 2019; Gray, 2020). However, it has been argued that there is a degree of overlap between brain areas responsible for semantic control and bilingual language control network for conflict monitoring and language selection (Calabria et al., 2019). Although semantic control has been investigated in healthy adults, recent findings indicate activation of this mechanism in BwA (e.g., Calabria et al., 2019). Semantic control is argued to be a core feature of semantic cognition (Chiou et al., 2018). It has been suggested that semantic cognition consists of a representational system and a control mechanism that oversee access. The semantic control mechanism is responsible for semantic retrieval depending on the cognitive load associated within a given semantic context (e.g., Chiou et al., 2018; Calabria et al., 2019). Gray (2020) investigated language control, semantic control and nonverbal control in BwA. Although there was a correlation between language control and nonverbal control, the results did not find any significant relationship between semantic and nonverbal control. Calabria et al. (2019) investigated the relationship between semantic control and non-linguistic control in BwA. Their results indicated a positive correlation between the two control mechanisms in the non-dominant language. Semantic control in this study was measured using a blocked cyclic naming task and bilingual picture-word matching task. A Flanker task was used to measure non-linguistic control. A task such as blocked cyclic naming could be considered as an example of domain-specific language control since it involves naming of words from a list of semantically related and unrelated items. However, it is likely that both ‘domain-general cognitive control’ and ‘domain-specific language control’ are activated in this task given it requires activation of both linguistic and non-linguistic features. Although there could be an overlap between ‘semantic control’ and the two control mechanisms, it remains to be seen if semantic control is any different from two major control mechanism discussed in this review.

The five studies presenting neuroimaging data were analysed to compare the neural regions activated during the undertaking of linguistic and/or non-linguistic control tasks (Cahana-Amitay & Albert, 2014). Abutalebi et al. (2000) used computed tomography scan (CT), Radman et al. (2016) and Abutalebi et al. (2009) employed functional Magnetic Resonance Imaging (fMRI), Van der Linden (2018) used resting stating-fMRI, and Pak-Hin Kong et al. (2014) utilised a combination of both CT and fMRI to gather neurological data. These studies indicate evidence for the activation of domain-general cognitive control mechanism. For example, Abutalebi et al. (2000) reported that damage to the caudate nucleus, a part of the basal ganglia, during a neurological injury that results in aphasia, may lead to pathological language mixing and impaired domain-general cognitive control mechanism. Pak-Hin Kong et al. (2014) used their CT and fMRI data to conclude that the neurological mechanisms in the frontal lobe and basal ganglia that provide language control in BwA were partially overlapping with the neurological pathways underlying domain-general cognitive control mechanism. Radman et al. (2016) argued that the ACC is involved in domain-general control functions, and change in connectivity between the ACC and

Brodmann area 45 was associated with the impairment of language control in BwA providing further support for the role of activation of domain-general cognitive control mechanism.

Abutalebi et al. (2009) applied deficit-specific language therapy in the second language to a bilingual participant with aphasia and reported changes in Broca's area and the fusiform gyrus, both known for their involvement in language processing, as well as the ACC and left caudate nucleus, already identified as part of neural network for bilingual language control. The strength of the neural connections between the language production and control areas of the brain increased for the treated second language, however decreased for the individual's native language. The changes in the neural regions post therapy indicates the activation of brain areas associated domain-general cognitive control mechanism, and its role in inhibiting L1 during therapy in L2.

No neuroimaging studies have examined or reported the activation of domain-specific language control mechanism in BwA. Therefore, the neural regions underlying domain-specific language control are currently unknown. Van de Cavey and Hartsuiker (2016) argued for an overlap of the neural structures underlying domain-general and domain-specific processing mechanisms across linguistic and non-linguistic tasks. This implies that it may be difficult to independently tease apart the neural networks underlying these two mechanisms in BwA, due to the potential overlap and simultaneous activation.

Although there is no clear pattern of neurological damage exhibited for domain-general and domain-specific language control, most studies supporting domain-general cognitive control mechanism appears to be reporting left hemisphere MCA or haemorrhagic stroke, affecting the basal ganglia, parietal, temporal and frontal lobes (e.g., Penn et al., 2016). Domain-specific language control mechanism in BwA appears to be predominantly supported by studies involving participants that experienced traumatic or inflammatory brain injuries, as well as large haemorrhagic strokes in the left hemisphere of the brain (e.g., Dash

& Kar, 2014). It is likely that some of the cases supporting domain-specific language control mechanism in aphasia did not have damage to the neural regions suggested to be involved in domain-general control regions of the brain, such as basal ganglia and anterior cingulate cortex. This may explain the dissociation between these participants' performance on linguistic and non-linguistic control tasks, as they generally experienced impaired linguistic control, while showing relatively spared non-linguistic cognitive control skills. However, more evidence is needed to support these findings in the future.

Overall, this literature review uncovered the available evidence to support both domain-general and domain-specific language control mechanisms in BwA. Although both mechanisms are supported, most papers reviewed provided evidence for the involvement of domain-general than domain-specific language control mechanism. However, evidence for domain-specific language control, despite it being from only four studies, indicate not all BwA exhibit an impairment in the domain-general cognitive control mechanism. Future research is needed to understand how BwA differ from healthy controls in their performance of non-linguistic and linguistic cognitive control using different tasks. It is likely that both types of control mechanisms are activated in BwA, however, the impairments in these mechanisms may vary depending on the type of neurological damage.

It is critical to point out that varied terminologies have been used to explain domain-general cognitive control and domain-specific language control. Studies have used both 'domain-general cognitive control' and 'domain-general inhibitory control' synonymously (e.g., Gray & Kiran, 2016; Dash & Kar, 2014). Other terminologies that are widely used in the literature include general purpose cognitive control and cognitive control system (e.g., Dash & Kar, 2014). Similarly, domain-specific cognitive control and domain-specific language control have also been used interchangeably. Terms such as linguistic control and language control are also indicative of activation of this mechanism (e.g., Abutalebi et al., 2009; Radman et al., 2016). It would be desirable for future studies to come to a general agreement regarding these terminologies in order to better operationalise them.

The results of the current literature review have theoretical and clinical implications. The theoretical implications are for Green's (1998) ICM, since the majority of reviewed papers support the involvement of domain-general cognitive control mechanism. These studies measured domain-general mechanisms through a range of cognitive control skills such as attention (Adrover-Roig et al., 2011; Kohnert, 2004; Penn et al., 2016; Radman et al., 2016), task switching (Adrover-Roig et al., 2011; Kroll & Bialystok, 2013; Penn et al., 2016; Radman et al., 2016), short-term phonological memory (Adrover-Roig et al., 2011), working memory (Penn et al., 2010), problem solving (Penn et al., 2010), and perception and categorisation (Kohnert, 2004). This demonstrates that past studies have investigated a variety of cognitive functions to understand the involvement of domain-general cognitive control mechanism in BwA. ICM is underspecified to account for all these executive functions since it is primarily focused on inhibition. Further investigation of these wide range of domain-general control functions could help better understand the role of individual cognitive functions beyond inhibitory such as task switching or perception and categorisation during language production in BwA.

Based on the evidence from this review, it is suggested that both domain-general cognitive control and domain-specific language control mechanisms should be assessed in BwA. A cognitive neuropsychological battery for executive functioning can capture a range of domain-general cognitive control skills assessing its intactness and additionally underpin the language impairment[1]. A number of assessment batteries such as Birmingham Cognitive Screen (BCoS) (Bickerton et al., 2015; also see Dash & Ansaldo, 2017) have already been

[1] Readers are encouraged to refer special issue articles reported in Murray (2017) for a comprehensive review of impairments in executive functioning, its assessment and treatment in individuals with aphasia.

developed for screening cognitive abilities in individuals with stroke. In BwA, Penn et al. (2016) have assessed shifting, updating and inhibition using tests such as Wisconsin Card Sorting Test (Grant & Berg, 1948) and Victoria Stroop Colour-Word Interference Test (Strauss et al., 2006). Studies have included a combination of verbal and non-verbal processing tasks such as linguistic Stroop tasks which measures both domain-specific and domain-general cognitive/language control mechanisms (e.g., Faroqi-Shah et al., 2018).

For treatment, it is important to adopt a case-by-case approach (Howard et al., 2015) given these mechanisms are complex and large inter-individual differences can be expected given the many variables such as extend of neurological damage, variability in language abilities and cognitive impairment are at play (e.g., Ansaldo, Saidi, & Ruiz, 2009). Most commonly used tasks such as the Simon Task (Simon & Rudell, 1967) and the Attentional Network Task (Fan et al., 2002) are experimental in nature and have not been designed for cognitively impaired populations and rather examine cognitive abilities in healthy individuals using an experimental group design. There are only a few treatment studies that have directly targeted to improve cognitive skills in BwA. Kohnert (2004) trained BwA using a computer based cognitive task (Scarry-Larkin, 1999) and found improvements in confrontation naming. Mayer et al. (2017) suggest the use of three major intervention strategies that are commonly reported in the previous literature for addressing non-linguistic impairments in aphasia. First, a process-based intervention that targets to improve impairments in abilities such as working memory may be beneficial although the evidence for such treatment is not always unequivocal. Second, self-monitoring or regulatory strategies on the other focuses on executive functioning skills that are relevant to real life situations such as working on self-efficacy (e.g., individual’s belief about his or her potential to complete a task). Mayer et al. (2017) argued that this approach has more evidence than the process-based intervention and is widely used as an intervention strategy in individuals with traumatic brain injury. Finally, language intervention strategies that are more holistic (e.g., conversational coaching) are likely to improve cognitive abilities such as attention and memory (see Mayer et al., 2017 for a review on these different intervention strategies). The treatment strategies listed in Mayer et al. (2017) have focused primarily on monolingual individuals with language impairment (e.g., aphasia, traumatic brain injury); however, we suggest that these strategies are useful for developing different activities targeting to improve domain-general cognitive control and domain-specific language control in BwA too.

1.6 Limitations and future research

This systematic quantitative literature review included twenty original research papers. Although this is a good sample size for conducting a systematic quantitative literature review, the results of the current literature are drawn from studies that employed wide range of different linguistic and non-linguistic tasks and participants, making it difficult to dissociate a definite evidence for the activation of the control mechanisms. Another significant challenge was the lack of clarity in terminologies explaining the two control mechanisms, making it difficult to operationalise them. Further, it was hard to isolate the specific effects of two control mechanisms since the tasks employed in studies (e.g., linguistic Stroop task or letter fluency task) is likely to have jointly activated domain-general cognitive control and domain-specific language control. More research is needed especially with tasks that can activate these two mechanisms separately or manipulate contexts that require greater or lesser activation of one control mechanism so isolated effects can be better examined. Critically, it is important to note that the tasks used (e.g., Stroop and Flanker tasks) in the literature are better suited to experimentally investigate control mechanisms in healthy adults. It is therefore recommended to use tasks to capture individual differences in BwA rather than experimental tasks that are based on group averages (see Murray, 2017 for a list of everyday control tasks relevant to aphasia). Additionally, it would be beneficial for both clinicians and researchers if future research consistently included neuroimaging measurements or brain scans of all participants to better understand if there are separate brain regions activated for tasks associated with domain-general cognitive control and domain-specific language control.

1.7 Conclusions

The results from sixteen research papers indicated involvement of domain-general cognitive control mechanism in BwA. Evidence from the remaining four papers lend support to the involvement of a domain-specific language control mechanism indicating the activation of a functionally specific mechanism for language control. Neuroimaging data identified ACC, caudate nucleus, basal ganglia, and the frontal lobe as the neural regions involved in the domain-general cognitive control mechanism. The findings also suggest that not all BwA show deficits in domain-general cognitive control and can show a selective impairment in one of the mechanisms. Whilst the results support routine clinical application of domain-general cognitive control and domain-specific language control mechanism as an assessment and treatment modality in BwA, more research is needed examining the two control mechanisms utilizing single subject experimental designs as well as tasks that align better with real life situations relevant to aphasia.

References

Articles included in the review

Abutalebi, J., Della Rosa, P. A., Tettamanti, M., Green, D. W., & Cappa, S. F. (2009). Bilingual aphasia and language control: A follow-up fMRI and intrinsic connectivity study. *Brain and Language, 109* (2-3), 141–156. doi:10.1016/j.bandl.2009.03.003

Abutalebi, J., Miozzo, A., & Cappa, S. F. (2000). Do subcortical structures control 'language selection' in polyglots? evidence from pathological language mixing. *Neurocase, 6*(1), 51-56. doi:10.1080/13554790008402757

Adrover-Roig, D., Galparsoro-Izagirre, N., Marcotte, K., Ferré, P., Wilson, M. A., & Ansaldo, A. I. (2011). Impaired L1 and executive control after left basal ganglia damage in a bilingual Basque–Spanish person with aphasia. *Clinical Linguistics & Phonetics, 25*(6-7), 480-498. doi:10.3109/02699206.2011.563338

Calabria, M., Grunden, N., Serra, M., García-Sánchez, C., & Costa, A. (2019). Semantic processing in bilingual aphasia: Evidence of language dependency. *Frontiers in Human Neuroscience*, *13*, 205. doi.org/10.3389/fnhum.2019.00205

Dash, T., & Kar, B. R. (2014). Bilingual language control and general purpose cognitive control among individuals with bilingual aphasia: evidence based on negative priming and flanker tasks. *Behavioural Neurology*, *2014*, 679-706. doi:10.1155/2014/679706

Faroqi-Shah, Y., Sampson, M., Pranger, M., & Baughman, S. (2018). Cognitive control, word retrieval and bilingual aphasia: Is there a relationship?. *Journal of Neurolinguistics,*45 *, 95*-109. doi:10.1016/j.jneuroling.2016.07.001

Goral, M., Naghibolhosseini, M., & Conner, P. S. (2013). Asymmetric inhibitory treatment effects in multilingual aphasia. *Cognitive Neuropsycholgy*, *30*(7-8), 564-577. doi:10.1080/02643294.2013.878692

Gray, T. (2020). The relationship between language control, semantic control and nonverbal control. *Behavioral Sciences*, *10*(11), 169. doi.org/10.3390/bs10110169

Gray, T., & Kiran, S. (2019). The effect of task complexity on linguistic and non-linguistic control mechanisms in bilingual aphasia. *Bilingualism: Language and cognition*, *22*(2), 266-284. doi:https://doi.org/10.1017/S1366728917000712

Gray, T., & Kiran, S. (2016). The relationship between language control and cognitive control in bilingual aphasia. *Bilingualism: Language and Cognition, 19*(03), 433-452. doi:10.1017/s1366728915000061

Green, D. W., Grogan, A., Crinion, J., Ali, N., Sutton, C., & Price, C. J. (2010). Language control and parallel recovery of language in individuals with aphasia. *Aphasiology, 24*(2), 188-209. doi:10.1080/02687030902958316

Kohnert, K. (2004). Cognitive and cognate-based treatments for bilingual aphasia: a case study. *Brain and Language, 91*(3), 294-302. doi:10.1016/j.bandl.2004.04.001

Pak-Hin Kong, A., Abutalebi, J., Sze-Yan Lam, K., & Weekes, B. (2014). Executive and language control in the multilingual brain. *Behavioural Neurology*, 1-7. doi:http://dx.doi.org/10.1155/2014/527951

Patra, A., Bose, A., & Marinis, T. (2020). Lexical and cognitive underpinnings of verbal fluency: evidence from Bengali-English bilingual aphasia. *Behavioral Sciences*, *10*(10), 155. doi.org/10.3390/bs10100155

Penn, C., Barber, N., & Fridjhon, P. (2016). Early recovery profiles of language and executive functions after left hemisphere stroke in bilingualism. *Aphasiology*, *2016,* 1-24. doi:10.1080/02687038.2016.1258538

Penn, C., Frankel, T., Watermeyer, J., & Russell, N. (2010). Executive function and conversational strategies in bilingual aphasia. *Aphasiology, 24*(2), 288-308. doi:10.1080/02687030902958399

Radman, N., Mouthon, M., Di Pietro, M., Gaytanidis, C., Leemann, B., Abutalebi, J., & Annoni, J. M. (2016). The role of the cognitive control system in recovery from bilingual aphasia: A multiple single-case fMRI study. *Neural Plasticity*, *2016*, 1-22. doi:10.1155/2016/8797086

Van der Linden, L., Dricot, L., De Letter, M., Duyck, W., de Partz, M. P., Ivanoiu, A., & Szmalec, A. (2018). A case study about the interplay between language control and cognitive abilities in bilingual differential aphasia: Behavioral and brain correlates. *Journal of Neurolinguistics*, *46*, 37-68. doi: https://doi.org/10.1016/j.jneuroling.2017.12.011

Van der Linden, L., Verreyt, N., De Letter, M., Hemelsoet, D., Mariën, P., Santens, P., Stevens, M., Szmalec, A., & Duyck, W. (2018). Cognate effects and cognitive control in patients with parallel and differential bilingual aphasia. *International Journal of Language & Communication Disorders*, *53*(3), 515-525. doi: https://doi.org/10.1111/1460-6984.12365

Verreyt, N., De Letter, M., Hemelsoet, D., Santens, P., & Duyck, W. (2013). Cognate effects and executive control in a patient with differential bilingual aphasia. *Applied Neuropsychology*, *20*(3), 221-230. doi:10.1080/09084282.2012.753074

***All other references**

Abutalebi, J., & Green, D. W. (2008). Control mechanisms in bilingual language production: Neural evidence from language switching studies. *Language and Cognitive Processes, 23*(4), 557-582. doi:10.1080/01690960801920602

Abutalebi, J., & Green, D. (2007). Bilingual language production: The neurocognition of language representation and control. *Journal of Neurolinguistics, 20*(3), 242-275. doi:10.1016/j.jneuroling.2006.10.003

Ansaldo, A. I., Saidi, L. G., & Ruiz, A. (2010). Model-driven intervention in bilingual aphasia: Evidence from a case of pathological language mixing. *Aphasiology, 24(2), 309-324.* doi.org/10.1080/02687030902958423

Bialystok, E., Craik, F. I., Grady, C., Chau, W., Ishii, R., Gunji, A., & Pantev, C. (2005). Effect of bilingualism on cognitive control in the Simon task: evidence from MEG. *Neuroimage, 24*(1), 40-49. doi:10.1016/j.neuroimage.2004.09.044

Bickerton, W. L., Demeyere, N., Francis, D., Kumar, V., Remoundou, M., Balani, A., Harris.L., Williamson, J., Lau, L.K., Samson, D., Riddoch, M. J., & Humphreys, G.W. (2015). The BCoS cognitive profile screen: Utility and predictive value for stroke. *Neuropsychology*, *29*(4), 638. doi: 10.1037/neu0000160

Blumenfeld, H. K., & Marian, V. (2011). Bilingualism influences inhibitory control in auditory comprehension. *Cognition, 118*(2), 245-257. doi:10.1016/j.cognition.2010.10.012

Bruin, de A., Roelofs, A., Dijkstra, T., & FitzPatrick, I. (2014). Domain-general inhibition areas of the brain are involved in language switching: FMRI evidence from trilingual speakers. *NeuroImage, 90*(2014), 348-359. doi: 10.1016/j.neuroimage.2013.12.049

Cahana-Amitay, D., & Albert, M.L. (2014). Brain and language: evidence for neural multifunctionality. *Behavioural Neurology, 2014*, 1-16. doi: https://doi.org/10.1155/2014/260381

Calabria, M., Hernández, M., Branzi, F. M., & Costa, A. (2012). Qualitative differences between bilingual language control and executive control: Evidence from task-switching. *Frontiers in psychology*, *2*, 399. doi.org/10.3389/fpsyg.2011.00399

Carpenter, E., Rao, L., Peñaloza, C., & Kiran, S. (2020). Verbal fluency as a measure of lexical access and cognitive control in bilingual persons with aphasia. *Aphasiology*, *34*(11), 1341-1362. doi.org/10.1080/02687038.2020.1759774

Chiou, R., Humphreys, G. F., Jung, J., & Ralph, M. A. L. (2018). Controlled semantic cognition relies upon dynamic and flexible interactions between the executive 'semantic control' and hub-and-spoke 'semantic representation' systems. *Cortex, 103*, 100-116. doi.org/10.1016/j.cortex.2018.02.018

Dash, T., Masson-Trottier, M., & Ansaldo, A. I. (2020). Efficiency of attentional processes in bilingual speakers with aphasia. *Aphasiology*, *34*(11), 1363-1387. doi.org/10.1080/02687038.2020.1719970

Dash, T., & Ansaldo, A. I. (2017). Clinical Implications of Neurocognitive Control Deficits in Bilingual Adults with Aphasia. *Perspectives of the ASHA Special Interest Groups, 2(2), 117-125.* doi.org/10.1044/persp2.SIG2.117

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon identification of a target letter in a non- search task. *Perception and Psychophysics*, *16*, 143–149. doi: https://doi.org/10.3758/BF03203267

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive. Neuroscience., 14*, 340–347. doi: 10.1162/089892902317361886

Golden, C. J., & Freshwater, S. M. (1978). Stroop color and word test. Stoelting Company, Chicago, IL.

Grant, D. A., & Berg, E. (1948). A behavioral analysis of degree of reinforcement and ease of shifting to new responses in a Weigl-type card-sorting problem. *Journal of experimental psychology, 38*(4), 404. doi:https://doi.org/10.1037/h0059831

Green, D. W., & Abutalebi, J. (2008). Understanding the link between bilingual aphasia and language control. *Journal of Neurolinguistics, 21*(6), 558-576. doi:10.1016/j.jneuroling.2008.01.002

Green, D. W. (1998). Mental control of the bilingual lexico-semantic system. *Bilingualism: Language and Cognition, 1*(02), 67. doi: https://doi.org/10.1017/S1366728998000133

Green, D. (1986). Control, activation, and resource: A framework and a model for the control of speech in bilinguals. *Brain and Language, 27*, 210-223. doi: 10.1016/0093-934x(86)90016-7

Howard, D., Best, W., & Nickels, L. (2015). Optimising the design of intervention studies: Critiques and ways forward. *Aphasiology*, *29*(5), 526-562. doi.org/10.1080/02687038.2014.985884

Kertesz, A. (2007). Western aphasia battery-revised. *San Antonio, TX: PsychCorp*.

Kertesz, A. (1980). *Western Aphasia Battery*. The University of Western Ontario: London, Canada.

Kroll, J. F., Bobb, S. C., & Hoshino, N. (2014). Two languages in mind: Bilingualism as a tool to investigate language, cognition, and the brain. *Current Directions in Psychological Science*, *23*(3), 159-163. doi:10.1177/0963721414528511

Kroll, J. F., & Bialystok, E. (2013). Understanding the consequences of bilingualism for language processing and cognition. *Journal of Cognitive Psychology*, *25*(5), 497-514. doi:10.1080/20445911.2013.799170

Lee, B., Moon, H. I., Lim, S. H., Cho, H., Choi, H., & Pyun, S. B. (2016). Recovery of language function in Korean-Japanese crossed bilingual aphasia following right basal ganglia hemorrhage. *Neurocase*, *22*(3), 300-305. doi:10.1080/13554794.2016.1141966

Linck, J. A., Kroll, J. F., & Sunderman, G. (2009). Losing access to the native language while immersed in a second language: Evidence for the role of inhibition in second-language learning. *Psychological Science*, *20*, 1507–1515. doi: 10.1111/j.1467-9280.2009.02480.x

Liu, H., Rossi, S., Zhou, H., & Chen, B. (2014). Electrophysiological evidence for domain-general inhibitory control during bilingual language switching. *PLoS One*, *9*(10), e110887. doi:10.1371/journal.pone.0110887

Mackie, M.A., Van Dam, N.T., & Fan, J. (2013). Cognitive control and attentional functions. *Brain and Cognition*, *82*(2013), 301-312. doi: 10.1016/j.bandc.2013.05.004

Martin, M. C., Macizo, P., & Bajo, T. (2010). Time course of inhibitory processes in bilingual language processing. *British Journal of Psychology*, *101*, 679-693. doi: https://doi.org/10.1348/000712609X480571

Mayer, J. F., Mitchinson, S. I., & Murray, L. L. (2017). Addressing concomitant executive dysfunction and aphasia: previous approaches and the new brain budget protocol. *Aphasiology*, *31*(7), 837-860.

Merlin, T., Weston, A., Tooher, R., Middleton, P., Salisbury, J., Coleman, K., Norris, S., Weston, A., Grimmer-Somers, K., & Hillier, S (2009). *NHMRC evidence hierarchy: designations of 'levels of evidence' according to type of research question*. Retrieved September, 18, 2017, from http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=AEFFDA62A5245D6D07F060B56789ED5A?doi=10.1.1.177.4984&rep=rep1&type=pdf

Misra, M., Guo, T., Bobb, S. C., & Kroll, J. F. (2012). When bilinguals choose a single word to speak: Electrophysiological evidence for inhibition of the native language. *Journal of Memory and Language, 67*(1). doi:10.1016/j.jml.2012.05.001

Murray, L. (2017). Focusing attention on executive functioning in aphasia. *Aphasiology*, 31 (7), 721-724. doi: 10.1080/02687038.2017.1299854

Murray, L. (2012). Attention and other cognitive deficits in aphasia: Present and relation to language and communication measures. *American Journal of Speech-Language Pathology*, 21, 51–64. doi.org/10.1044/1058-0360(2012/11-0067)

Paradis, M., & Libben, G. (1987). *The assessment of bilingual aphasia*. Hillsdale, N.J: Lawrence Erlbaum Associates.

Pickering, C. (2016). *Systematic quantitative literature reviews: What are they and why use them? Course notes*. Griffith University: QLD.

Pickering, C.M**.**, & Byrne, J. (2014). The benefits of publishing systematic quantitative literature reviews for PhD candidates and other early career researchers. *Higher Education Research and Development*, *33*, 534-548. doi: https://doi.org/10.1080/07294360.2013.841651

PRISMA. (2009). *PRISMA 2009 flow diagram.* Retrieved September 18, 2017, from http://prismastatement.org/documents/PRISMA%202009%20flow%20diagram.pdf

Scarry-Larkin, M. (1999). Attention and memory (Vol. 1). *LocuTour Multimedia Cognitive Rehabilitation*. San Luis Obispo, CA.

Simon, J. R., & Rudell, A. P. (1967). Auditory S-R compatibility: the effect of an irrelevant cue on information processing. *Journal of Applied Psychology, 51*, 300-304. doi: 10.1037/h0020586

Strauss, E., Sherman, E. M., & Spreen, O. (2006). *A compendium of neuropsychological tests: Administration, norms, and commentary*. American Chemical Society (3rd ed.). Oxford University Press: New York, NY

Van de Cavey, J., & Hartsuiker, R. J. (2016). Is there a domain-general cognitive structuring system? Evidence from structural priming across music, math, action descriptions, and language. *Cognition, 146*, 172-184. doi:10.1016/j.cognition.2015.09.013

Villard, S., & Kiran, S. (2017). To what extent does attention underlie language in aphasia?. *Aphasiology*, *31*(10), 1226-1245. doi.org/10.1080/02687038.2016.1242711

Table 1: Overview of the studies included in the review

Study	NHRMC Level of Evidence	Number of Participants	Language L1	Language L2	Brain Lesion	Aphasia Diagnosis
Patra, Bose & Marinis, 2020	Comparative study with control group	8 BwA & 8 HB	Bengali	English	Left CVA	Non-fluent aphasia
Gray, 2020	Comparative study with control group	12 BwA & 20 HB	Spanish	English	Left MCA and TB1	Not specified
Calabria, Grunden, Serra, Garcia-Sanchez, & Costa (2019)	Comparative study with control group	11 BwA & 13 HB	Spanish/Catalan	Catalan/Spanish	Brain tumor, Cerebrovascular ischemic or hemorrhagic stroke	Conduction, Wernicke's and Anomic
Gray and Kiran, 2019	Comparative study with control group	13 BwA & 20 HB	Spanish/English	English/Spanish	CVA	Not specified
Van der Linden, Verreyt, De Letter, Hemelsoet, Marien, Santens, Stevens, Szmalec & Duyck, 2018	Comparative study with control group	15 BwA & 19 controls	Dutch or French	English, Dutch, or French	Complete MCA, Anterior MCA, Posterior MCA, Cortical and subcortical lesions	Differential and parallel aphasia
Van der Linden, Dricot, De Letter, Duyck, de Partz, Ivanoiu, & Szmalec, 2018	Comparative study with control group	1 BwA, 10 control group and 26 neurotypical individuals	French	English	TBI - left-sided skull fracture; left-sided parenchymal damage to the parietal lobe with prominent corticoclastic	Differential aphasia

					encephalomalacia, resulting in focal loss of brain tissue together with secondary ex vacuo enlargement of homolateral ventricular trigone	
Faroqi-Shah, Sampson, Pranger and Baughman, 2016	Comparative study with control group	18 MwA & 20 BwA	English/Tamil	Russian, French, Hungarian, or Spanish/English (for BwA)	Left MCA stroke	Broca's, anomia and other
Gray and Kiran, 2016	Comparative study with control group	10 BwA & 30 HB	Spanish/English	English/Spanish	Left CVA, left basal ganglia intracranial hemorrhage, left MCA and basal ganglia, left fronto temporal lesion, focal lesion in the left internal capsule, left pontine hemorrhage	Not specified
Penn, Barber and Fridjhon, 2016	Case-control study	10 BwA & 19 HB	South African languages (Sepedi, Zulu, Setswana, Xhosa, Afrikaans, & Tswana)	English	Left MCA stroke, left CVA, other brain lesions affecting left hemisphere	Severe and Broca's aphasia
Radman, Mouthon, Di Pietro,	Comparative study without	5 BwA	French/Italian	English/French	Focal left-hemisphere brain lesion	Transcortical sensory aphasia,

Gaytanidis, Leeman, Abutalebi, and Annoni, 2016	control group					Anomia, Global aphasia
Dash and Kar, 2014	Comparative study without control group	4 BwA	Telugu, Hindi/Urdu	English, Tamil, Kannada (L3)	Bacterial meningitis, CVA and Trauma	Anomic, Broca's aphasia
Pak-Hin Kong, Abutalebi, Sze-Yan Lam and Weekes, 2014	Comparative study with control group	1 BwA	Cantonese	English, Mandarin (L3)	TBI lesions left frontal and temporoparietal lobes	Moderate Wernicke's fluent aphasia
Goral, Naghibolhosseini and Conner, 2013	Comparative study without control group	1 BwA	Persian	German, English (L3)	CVA affecting left hemisphere, including frontal lobe	Differential aphasia
Verreyt, De Letter, Hemelsoet, Santens and Duyck, 2013	Comparative study without control group	2 BwA	French	Dutch	Acute left thalamic hemorrhagic stroke	Differential aphasia with more preserved L1
Adrover-Roig, Galparsoro-Izagirre, Marcotte, Ferré, Wilson and Ansaldo, 2011	Comparative study without control group	1 BwA	Basque	Spanish	Haemorrhage of the left basal ganglia	Anomia
Green, Grogan, Crinion, Ali, Sutton and Price, 2010	Comparative study with control group	2 BwA	French, Spanish	English	(1) large subcortical left hemisphere stroke in particular affecting left lentiform nucleus (2) several thrombo-embolic	Not specified

					stroke left MCA primarily affecting left parietal lobe, as well as frontal and temporal cortex and occipital lobes.	
Penn, Frankel, Watermeyer and Russell, 2010	Comparative study with control group	1 BwA	English	Afrikaans, Tswana, Zulu, Shangaan, Xhosa, Afrikaans, Sotho, French & Russian	Left fronto-parietal lesion and left temporo- parietal lesion	Anomia and conduction aphasia
Abutalebi, Della Rosa, Tettamanti, Green and Cappa, 2009	Case control study	1 BwA	Spanish	Italian	Left cerebral hemorrhage	Severe global aphasia, fluent aphasia
Kohnert, 2004	Case control study	1 BwA	Spanish	English	Embolic left CVA	Severe transcortical motor aphasia
Abutalebi, Miozzo and Cappa, 2000	Comparative study without control group	1 BwA	Armenian	English, Italian (L3)	Left hemisphere stroke, affecting caudate nucleus	Non-fluent aphasia

Notes
Monolinguals with Aphasia (MwA), Bilinguals with Aphasia (BWA), Cerebrovascular Accident (CVA), Middle Cerebral Artery (MCA), Traumatic Brain Injury (TBI),
The Australian National Health and Medical Research Council (NHMRC) has given different levels of evidence for a study design depending on the clinical questions. The levels of evidence can be accessed through the following link:
https://www.nhmrc.gov.au/sites/default/files/images/appendix-f-levels-of-evidence.pdf

Table 2: Summary of the studies supporting domain-general cognitive control and domain-specific language control in BwA

Study	Linguistic Outcome Measures	Non-linguistic Outcome Measures	Domain Specific/Domain General
Patra, Bose & Marinis, 2020	Letter and semantic fluency task	Stroop task	Domain General
Gray, 2020	Language control task and semantic control task	Nonlinguistic control task	Domain General[a]
Calabria, Grunden, Serra, Garcia-Sanchez, & Costa (2019)	Semantic blocked cyclic naming and bilingual word-picture matching	Flanker task	Domain General
Gray and Kiran, 2019	Linguistic Flanker and linguistic triad tasks	Non-linguistic Flanker and triad tasks	Domain Specific
Van der Linden, Verreyt, De Letter, Hemelsoet, Marien, Santens, Stevens, Szmalec & Duyck, 2018	Generalised lexical decision task	Flanker task	Domain General
Van der Linden, Dricot, De Letter, Duyck, de Partz, Ivanoiu, & Szmalec, 2018	Lexical decision task (generalised and selective language)	Flanker task	Domain General
Faroqi-Shah, Sampson, Pranger and Baughman., 2016	Western Aphasia Battery (WAB) - R and WAB-Tamil (object naming and category fluency subtests)	Stroop Color Word Test (English and Tamil)	Domain General
Gray and Kiran, 2016	Identifying word-pair relationships (semantic word-pair judgement task)	Flanker task	Domain Specific

Penn, Barber and Fridjhon, 2016	Comprehensive Aphasia Test	Informal non-verbal executive functioning battery (N-back test, Stroop task, Wisconsin Card Sorting Test, self ordered pointing task, complex figures task, tower of London, Raven’s progressive matrices, five point test and design fluency task	Domain General
Radman, Mouthon, Di Pietro, Gaytanidis, Leeman, Abutalebi, and Annoni, 2016	Bilingual Aphasia Test (naming automatic speech, repetition, object recognition, following oral and written instructions, description and verbal fluency), Mississippi Aphasia Screening Test (yes/no questions)	Non-linguistic switching task (4 images - name the colour of the image on upper screen, and shape of image on lower screen)	Domain General
Dash and Kar, 2014	Erikson's Flanker Task incorporating letters from both the languages	Non-linguistic negative priming task and non-linguistic flanker task	Domain Specific
Pak-Hin Kong, Abutalebi, Sze-Yan Lam and Weekes, 2014	WAB and Bilingual Aphasia Test (BAT)	Symbol trials of the cognitive linguistic qick test, modified stroop colour-word test and Wisconsin card sorting test.	Domain General
Goral, Naghibolhosseini and Conner, 2013	Picture-sequence description task from BAT	Not applicable	Domain General
Verreyt, De Letter, Hemelsoet, Santens and Duyck, 2013	Lexical decision task (generalised and selective language)	Flanker task	Domain General
			Domain General

Adrover-Roig, Galparsoro-Izagirre, Marcotte, Ferré, Wilson and Ansaldo, 2011	Bilingual Aphasia Test, Boston Naming Test, verbal fluency and semantic fluency	Forward and backward digit spans, stroop test (Basque and Spanish), Trail Making Test	
Green, Grogan, Crinion, Ali, Sutton and Price, 2010	Comprehensive Aphasia Test and BDAE and lexical decision task from PALPA	Stroop and Flanker tasks	Domain Specific
Penn, Frankel, Watermeyer and Russell, 2010	Conversational Sample	Stroop color word test, Trail making test, self-ordered pointing test, complex figures, Wisconsin card sorting test, tower of London, five point test, and design fluency	Domain General
Abutalebi, Della Rosa, Tettamanti, Green and Cappa, 2009	Bilingual Aphasia Test - Part B and Snodgrass Naming Battery	Not applicable	Domain General
Kohnert, 2004	Sentence repetition, sentence comprehension, receptive vocabulary, confrontation naming and picture description	Test of Nonverbal Intelligence	Domain General
Abutalebi, Miozzo and Cappa, 2000	Naming in the participant's three languages	Not applicable	Domain General

Note
[a]Although there was a correlation between non-verbal control and language control measures, the author argued that this could be due to increased cognitive load associated with the linguistic task rather than a direct one on one relationship between the linguistic and the non-linguistic task.

Table 3: Summary of neuroimaging evidence for domain-general cognitive control in BwA

Study	Neuroimaging Evidence	Task completed during neuroimaging	Neural Regions Activated	Bilingual Language Control Mechanism
Van der Linden, Dricot, De Letter, Duyck, de Partz, Ivanoiu, & Szmalec, 2018	resting state -fMRI	NA	Left head of caudate and left Broca's area	Domain General
Radman, Mouthon, Di Pietro, Gaytanidis, Leeman, Abutalebi, and Annoni, 2016	fMRI	Picture naming in L1 (French and Italian) and L2 (English and French)	Anterior Cingulate Cortex	Domain General
Pak-Hin Kong, Abutalebi, Sze-Yan Lam and Weekes, 2014	CT and MRI	NA	Frontal Lobe and Basal Ganglia	Domain General
Abutalebi, Della Rosa, Tettamanti, Green and Cappa, 2009	fMRI	Picture naming in L1 (Spanish) and L2 (Italian)	Anterior Cingulate Cortex and Left Caudate	Domain General
Abutalebi, Miozzo and Cappa, 2000	CT	NA	Caudate Nucleus	Domain General

Notes
CT = computed tomography scan, (f)MRI = functional magnetic resonance imaging.
Only Abutalebi, Della Rosa, Tettamanti, Green and Cappa (2009) and Radman, Mouthon, Di Pietro, Gaytanidis, Leeman, Abutalebi, and Annoni (2016) have carried out a linguistic task during neuroimaging. Van der Linden, Dricot, De Letter, Duyck, de Partz, Ivanoiu, & Szmalec, 2018 conducted a resting state fMRI, whereas Abutalebi et al (2000) and Pak-Hin Kong, Abutalebi, Sze-Yan Lam and Weekes (2014) have provided neural scans of the lesion area.