Examining Inhibition During Spoken Word Production in Aphasia

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Abstract

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The nature of selective attention in people with aphasia (PWA) is currently unknown. Selective attention, or our ability to focus on relevant information and ignore distractions, is essential for everyday communication. Inhibition, or suppression of unwanted information, is an important part of selective attention. This study explored components of inhibition in spoken word production in aphasia, a language disorder impacting more than a million people across the U.S. Specifically, this study examined both interference effects and subsequent reactive inhibition, or the carryover suppression of a previous distraction.

Nineteen PWA and 20 age- and education-matched controls participated in a spoken word production task involving Stroop and negative priming experimental paradigms. Stroop color-word stimuli were used to evoke interference and facilitation effects as baseline

conditions. Stroop stimuli were also used in negative priming prime-probe pairs, where the prime distractor becomes the probe target, a method of testing reactive inhibition. Response latency and accuracy data were recorded for participants. Research questions were addressed by group-by-condition interactions, analyzed via repeated measures ANOVA and nonparametric/Mann-Whitney tests.

Results showed that while both groups demonstrated interference effects, the effects were significantly greater for PWA, as reported in previous research. Interestingly, PWA demonstrated no significant facilitation effects; Controls demonstrated significant reverse facilitation effects. This result was interpreted as PWA's inability to take advantage of contextual cues of proportion. Neither group showed statistically significant evidence of inhibitory rebound, though both groups showed surprisingly similar individual variability, suggesting inhibitory rebound for some and repeated interference facilitation for others. Lastly, PWA demonstrated a near-significant response slowing when a congruent probe had just served as prime distractor, potentially indicating diminished conflict adaptation.

These results underscore the challenges interference presents for PWA during spoken word production and indicates potentially diminished executive inhibition. However, PWA's automatic/reactive inhibition appears equivalent to controls, and therefore not a contributing factor in word retrieval impairments of aphasia. However, PWA may have difficulty adapting to contextual information compared to their neurologically healthy counterparts. These results provide direction for future research of selective attention in aphasia –aimed to improve clinical protocols for people with this language impairment.

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Chapter 1

Introduction

"Only those items which I notice shape my mind—without selective interest, experience is an utter chaos." –William James (1890)

In the United States, aphasia impacts more than a million stroke and head injury survivors who face daily life with debilitating impairments in communication (National Aphasia Association, n.d.). McNeil and Pratt defined aphasia as a multimodal physiological impairment related to language inefficiency after brain tissue damage in the language dominant hemisphere, and this impairment also impacts other language or symbol-related processes (2001; pg 907). To date, few aphasiologists agree that aphasia presents with co-occurring executive function impairments (Glosser & Goodglass, 1990; Helm-Estabrooks, 2002), including impairments of attention (Hula & McNeil, 2008; McNeil, Odell, & Tseng, 1991; Murray, 1999, 2000, 2012; Murray, Holland & Beeson, 1997, 1998). McNeil et al (1991) provided a groundbreaking argument that people with aphasia have not "lost" language (as espoused by more traditional views of aphasia), but rather demonstrate impaired language performance, characterized by impairment across domains, variability, and susceptibility to manipulation. For example, patient Bob may not be able to name "pencil" one morning, but does so easily a few hours later, or once background noise has been eliminated. The semantic, lexical or phonological representations for "pencil" are clearly not lost, but Bob's word finding problem appears to relate to processing of the item. The role of attention, the variable and flexible resource for processing (Baddeley, 1993; Cowan, 1988; Kane & Engle, 2003) may be prominent in the language impairments of aphasia (McNeil, Hula & Sung, 2010; McNeil et al, 1991). Therefore, aphasia may be classified as a disorder of performance, as diminished or misallocated attention may impede the processing of intact language representations (Hula & McNeil, 2008; McNeil et al, 1991; Tseng, McNeil & Milenkovic, 1993).

Attention is required to increase the activation of target processing pathway(s) and to actively inhibit activation of irrelevant information (Cohen, Dunbar and McClelland, 1990; Conway and Engle, 1994; Cowan, 1988; Engle, Conway, Tuholski & Shisler, 1995; Engle, Tuholski, Laughlin & Conway, 1999; Houghton & Tipper, 1994; Houghton, Tipper, Weaver & Shore, 1996; Hasher & Zacks, 1988; Kane & Engle, 2003; Miyake, Friedman, Emerson, Witzki, Howerter & Wager, 2000). However, if attention is misallocated or otherwise limited, then target inputs may not be appropriately activated and irrelevant inputs may not be appropriately suppressed (Cohen et al, 1990). Studies of aphasia have shown language processes in the presence of interference – for example, picture naming while discriminating high and low tones – are significantly slowed (Lim, McNeil, Doyle, Hula, & Dickey, 2012; Martin & Allen, 2008; McNeil, Doyle, Hula, Rubinsky, Fossett & Matthews, 2004; Murray, 2000; Murray et al, 1997, 1998). These results may also indicate a diminished capacity to inhibit or suppress irrelevant information compared to neurologically typical adults (Hamilton & Martin, 2005; McNeil, Hula & Sung, 2010; Weiner, Conner & Obler, 2004; see Martin & Allen, 2008 for a review). However, the relationship between interference and inhibitory function is a complicated one (Friedman & Miyake, 2002; Harnishfeger, 1995; Hogge, Salmon & Collette, 2008; Houghton et al, 1996; Nigg, 2000; Vitkovitch, Bishop, Dancey & Richards, 2002). Using the well-studied Stroop paradigm to evoke interference and facilitation effects and the negative priming paradigm to test reactive inhibition, this study examined components of inhibition during spoken word production in persons with aphasia (PWA) compared to age- and education-matched neurologically healthy Controls.

RESEARCH QUESTIONS

Research Question 1: Evoke interference and facilitation effects.

As a control condition, is there a significant difference between Stroop incongruent, congruent and neutral trials, in word naming latency and accuracy, for PWA and Controls? Comparisons of incongruent and neutral conditions yield interference effects, and comparisons of congruent and neutral conditions yield facilitation effects.

Research Question 2: Test reactive inhibition via inhibitory rebound.

Is inhibitory rebound significantly different, in word naming latency and accuracy, for PWA compared to Controls?

2a) Is inhibitory rebound significantly different in PWA compared to Controls <u>when tested with repeated interference/incongruent probes</u>? This negative priming task requires a significant degree of attention. It tests whether participants have inhibited the prime distractor by reactivating it using a weakly represented probe target (i.e. the prime distractor/word becomes probe target/font color), and comparing this response to the novel interference/incongruent condition (RQ1).

2b) Is inhibitory rebound significantly different in PWA compared to Controls <u>when tested using facilitation/congruent probes</u>? This negative priming task requires less attention than the previous task. It tests whether participants have supplied attention to inhibit the prime distractor by reactivating it using a strongly represented probe target (i.e. the prime distractor/word becomes congruent probe/font color and word), and comparing this response to repeated interference (2a).

2c) Is inhibitory rebound significantly different in PWA compared to Controls when tested using facilitation/congruent probes contrasted with novel facilitation/congruent condition? This question looks for the presence of inhibitory rebound by comparing two conditions that require the least attention of all tasks. It compares whether participants have supplied attention to inhibit the prime distractor by reactivating it with a strongly represented congruent probe (2b) relative to the novel facilitation/congruent condition (RQ 1).

CHAPTER 2

Background and Significance

"In a subject so wide and vague as language, it would be simple work to pile up ingenious theories, but to find a method to arrange the varying facts in many actual cases is quite a different thing." – Hughlings Jackson, 1894

Inhibition, as explored in this document, is not directly explained by parallel distributed processing (PDP) theories and models of language. However, introducing this connectionist framework and its emphasis on processing is especially useful when exploring the contributions of attention and inhibition in language (Cohen, Dunbar & McClelland, 1990; Houghton & Tipper, 1994) and subsequently, the impairments of aphasia.

2.A. LANGUAGE MODELS AND INHIBITION

In more traditional theories of language production, based on the ideas of Paul Broca, Carl Wernicke and others (Jenkins, Jiménez-Pabón, Shaw & Sefer, 1975), and further explored by Garrett (1975, 1984), Shattuck-Hufnagel (1979) and others, a lexical item is represented in whole, and language is reportedly processed serially, from one level or stage to the next. Furthermore, these models explain language impairments following neural damage in terms of a loss of language or its representations. Subsequently, rehabilitation efforts born out of these theoretical frameworks have focused on replacing lost language.

Conversely, parallel distributed processing theories of language describe more neurally plausible models of language, in which networks of numerous, neuron-like units comprise each lexical and sublexical item (Plaut, 1996; Plaut, McClelland, Seidenberg & Patterson, 1996). These networks of units are described as distributed and interactive. The theories emphasize processing within and between the networks to assemble each type of lexical unit. Networks are built through experience; the greater our experience of a lexical item, the stronger and more automatic are its distributed semantic, phonologic, lexical (etc.) networks. For example, the networks for 'water' are far stronger than the networks representing 'gruyere,' as presumably most native speakers of American English are much more familiar with the word 'water.' From our first experience of 'water,' we have been acquiring knowledge about the word, what it means, how it sounds, what it looks like when written, and how to say and write it ourselves. Each of these domains is represented and connected via overlapping networks of units (i.e. "hidden units;" Nadeau, 2001; Plaut, 1996).

As word learning occurs, each added experience is compared against that word's established networks. If the input does not exactly match the established network, due to either network damage or noise accompanying the input, a process called "graceful degradation" occurs, which aids in producing a correct, or at least rule bound, response (Nadeau, 2001; Rumelhart, Hinton & McClelland, 1986). With time and experience, this process creates an "attractor basin" of networked units, in which the most frequent experience of the word is settled toward the middle, and less frequent experiences of the word (for example, the word 'water' produced with a British accent) may include units further away from the central point of the basin (Plaut, 1996; Plaut et al 1996; Nadeau, 2001). In this way, all inputs are compared against established networks to find the best fit. When a fit is not found for novel items, new and initially weak networks and attractor basins are created.

Input items have networks that are connected to (and overlap with) related items within and across all domain planes (semantic, phonological, orthographic, etc.; Nadeau, 2001; Plaut et al, 1996). For example, the attractor basin for the concept of 'water' will share multiple units with the semantic attractor basins of concepts of 'rain,' 'liquid' and 'glass (of).' 'Water' may also share some semantic units with 'pipe,' fewer still with 'tree,' and few to none with 'book.' 'Water' shares some phonologic units with 'watch,' and likely shares both semantic and phonologic units with 'wash.'

Priming tasks offer a unique window into the processing parameters of parallel distributed processing. Priming in this context is the process by which we prepare activation networks for a specific response. For example, if we want to prime the target 'water,' we may prime the target with the target itself, or semantically related items 'rain,' 'liquid' and 'glass (of).' While the prime 'water' activates the very attractor basin we are interested in, the related primes will get us into the semantic neighborhood of 'water'-related attractor basins. In other words, these primes facilitate the target but to varying degrees. The settling into the attractor basin of water occurs very quickly when 'water' itself has served as a prime, and to a lesser degree, when the primes are semantically related to water. On the other hand, if the primes 'water,' 'rain,' 'liquid' or 'glass' are provided for an unrelated target 'book,' the activated prime attractor basins will not aid in the processing of the target. These activated prime attractor basins must be inhibited while a new attractor basin will be activated to initiate a correct response. In other words, activation must switch from the prime basin to the target basin, and the resulting response will be slowed (Plaut & Booth, 2000). Plaut and Booth describe this phenomenon as hysteresis, or the process of the activation of one attractor basin followed by the activation of another (same, related, or unrelated, depending) before the network has a chance to "settle." In this way, priming with the same or related item yields a faster (or facilitated) response. Priming with an unrelated item yields a slower response, one in which automatically activated items have likely been inhibited.

As our experience of a concept, word, and its phonology and orthography build, so do the connections between the many units of the concept and the domains in which it is represented. Furthermore, negative connection weights are built for disparate items at every level. Negative connection weights serve to guide activation toward units associated with previous experiences of the lexical item and away from wholly unconnected units. For example, we learn the words and pronunciation for ‘phone,’ ‘bone,’ ‘cone,’ ‘tone.’ With each experience, a positive connection weight is strengthened between the onset units for /f/-, /b/-, /k/-, and /t/- and the coda -/on/[1]. At the same time, and especially if we are exclusively English speakers, negative connection weights are built between these onset networks and the units that comprise the coda –/lar/. In this way, our experience provides pathways which narrow our opportunities for random error by providing an automatic and systematic inhibition of unrelated or irregular units (Plaut et al, 1996).

As mentioned previously, parallel distributed processing models of language emphasize the processing aspects of language, but do not fully describe the role of inhibition in language processes other than what is described above. However, these models emphasize that processing requires activation and inhibition, both of which require resources (Cohen et al, 1990; Houghton & Tipper, 1994; Kane & Engle, 2003). Therefore, the following sections detail

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[1] Clearly these onsets have numerous possible codas and therefore many positive connection weights to other networks.

the interface of cognitive resource and language processes within a parallel distributed processing framework.

2.B. ATTENTION, INTERFERENCE AND INHIBITION

Fundamentally based on Baddeley and Hitch's 1974 model of working memory, the domain of complex cognition, Conway and Engle (1994), Cowan (1988), Engle, Tuholski, Laughlin and Conway (1999), Hasher and Zacks (1988), and Kane and Engle (2003) have described attention as a flexible and variable component of working memory. Coupled with short-term memory, or items temporarily activated from long-term memory stores, attention boosts activation of the intended item while simultaneously inhibiting unintended items from further processing. The activation of an item from short-term memory depends on both a) our individual experience and encoding of it and b) the level of attention we allocate to its processing. Items that are more familiar have stronger inherent activation pathways than items that are less familiar (Cohen et al, 1990; Just & Carpenter, 1992; Plaut et al, 1996). Furthermore, items with strong activation pathways are believed to activate more automatically compared to weaker activation pathways. These weaker pathways may require more attention in order to reach activation threshold (Cohen et al, 1990).

When multiple or conflicting inputs are present, we resolve conflict by using attention as a contextual booster to process the target input and suppress any non-target inputs. In other words, attention is the required resource which supports and increases the activation state of the target while simultaneously dampening processing of distracting items (Conway & Engle, 1994; Cowan, 1988; Engle, Conway, Tuholski & Shisler, 1995; Engle et al, 1999; Houghton & Tipper, 1994; Houghton et al, 1996; Hasher & Zacks, 1988; Kane & Engle, 2003; Miyake et al, 2000, Neill, 1977; Tipper, 1985). Therefore, the boost in activation for the target coupled with the inhibition of activation of distracters provides a process of selection.[2] However, if attention is diminished or misallocated, target units may not be boosted and non-target units may not be inhibited, impeding successful selection. In sum, many believe inhibition is a primary component of selective attention, where irrelevant items are suppressed after all items have been activated (Neill, 1977; Neill & Westberry, 1987; Tipper, 1985; Tipper & Cranston, 1985; Tipper, Weaver et al 1991).

2.B.1. Interference and inhibition definitions

Inhibition is generally understood as the restraint or suppression of an action, behavior or state of being (Dictionary.com, n.d.). According to Miyake et al (2000), the construct of inhibition as it relates to cognition can be fragmented: 1) the suppression of activation due to negative connection weights as described by connectionism; 2) intentional inhibition, or inhibition of more dominant responses, also called "interference control" by Nigg (2000); and 3) reactive inhibition, or the automatic and residual inhibition often occurring after the suppression of a distracter, called "cognitive inhibition" by Nigg (2000).

[2] Some espouse the selection mechanism of attention as purely excitatory, wherein target items receive excitation while non-target items receive no further processing resources. Using this framework, inhibition is considered a passive process dependant on a relative lack of processing and subsequent decay. See Broadbent (1958) and Posner and Synder (1975) for the theoretical bases of this perspective.

For the remainder of this document, I will use the following terminology:

“<u>Interference control</u>” refers to the intentional inhibition of a distractor, often presented alongside a target. **“<u>Reactive inhibition</u>”** refers to automatic residual suppression of previously activated and intentionally inhibited distracting items.

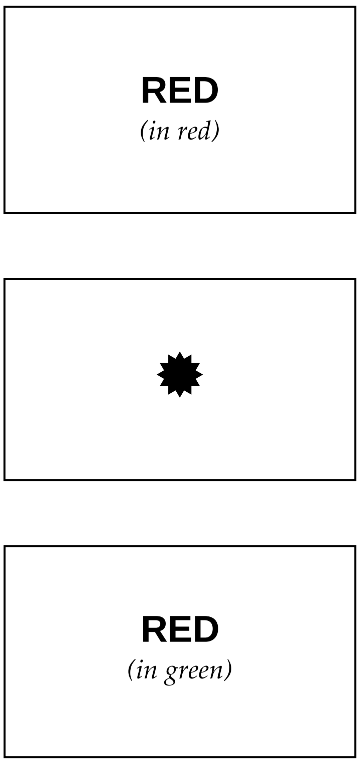

FIGURE 1. Stroop stimuli, top to bottom: congruent, neutral, incongruent.

Interference control is evident when a more dominant (and therefore more automatically activated) distractor must be deliberately overcome to process a simultaneously presented weaker target, and the resulting response is slowed. Interference control is important when faced with simultaneous inputs (a broad example is focusing on conversation, while “tuning out” other audible conversations in the surrounding environment). Cohen et al (1990; also West & Alain, 1999), described separate activation pathways that respond to simultaneously presented stimuli. The more automatic pathway is characterized by greater inherent activation strength compared to the less automatic pathway. By allocating greater attention to the weaker and less automatic target pathway, activation is boosted. At the same time, attention can also actively inhibit the non-target pathways (Kane & Engle, 2003; Hasher & Zacks, 1988; Cowan, 1988).

Interference control can be tested using the Stroop paradigm (Stroop, 1935), often presented as a color-word task. In this task, the participant is asked to name the ink/font color of an orthographically presented color-word in three general conditions (Figure 1). First, “RED” typed in a green font is considered an incongruent trial (correct response is “green”). The automatically activated word must be suppressed in favor of the more weakly activated font color. Second, the word “RED” typed in a red font is considered a congruent trial (correct response is “red”). In this trial, the weakly activated font color is boosted by the automatic activation of the word – considered “facilitation.” (See Appendix A for other examples of these stimuli.) These conditions are compared against the neutral condition, where the participant names the font color of symbols (e.g. %) or splotches (e.g. ✹), to determine interference effects (incongruent vs. neutral condition) or facilitation effects (congruent vs. neutral condition). (See Verhaeghen & DeMeersman, 1998a for a review of studies using Stroop.)

The two primary mechanisms reportedly involved in an interference task like Stroop – conflict resolution (often measured using response latency data) and goal maintenance (often measured using accuracy data) – are both influenced by working memory capacity. In fact, working memory capacity, as measured by span tasks, is reported to predict performance on Stroop-like tasks (Kane & Engle, 2003) and vice-versa.For example, “high and low span” participants – individuals grouped by working memory capacity as measured by span tests – demonstrated that interference and facilitation effects may vary with working memory capacity (see also Grandjean & Collette, 2011). In other words, limits in components of working memory capacity appear to correlate with both greater facilitation effects as well as greater interference effects.

Reactive inhibition occurs when one automatically inhibits previously activated and suppressed distraction(s). Houghton et al (1996) claimed this type of inhibition occurs after a distractor is actively suppressed and enters a state of below-threshold “inhibitory rebound,” characterized by net negative activation strength. Following its entrance into inhibitory rebound, the item is not immediately available for reactivation and selection. This phenomenon is often tested using a negative priming paradigm, where one typically responds more slowly to a target stimulus that has just served as a distractor stimulus. The resulting slowed response due to impaired reactivation is called a "negative priming effect." In negative priming paired trials, the distractor on the first/prime trial becomes the target on the second/probe trial (Figure 2). For example, using Stroop color-word stimuli, "RED" is presented in a green font on the prime trial (correct response is "green"). On the subsequent probe trial, "BLUE" is presented in a red font. The participant must correctly respond "red," though she has just suppressed red in the previous trial (see Appendix A for examples). Reactive inhibition is evident through slower reaction time on the probe trial as compared to unpaired or prime incongruent trials (see Gamboz, Russo & Fox, 2002, and Verhaeghen & DeMeersman, 1998b for meta-analyses of negative priming).

prime		probe
RED	→	**BLUE**
(in green)		(in red)

prime		probe
RED	→	**RED**
(in green)		(in red)

FIGURE 2. Negative priming stimuli, top: repeated interference, prime distractor becomes probe target; bottom: facilitation/congruent probe, where prime distractor becomes congruent probe.

Successful inhibition requires attention, though potentially to different degrees depending on type and context (Harnishfeger, 1995; Miyake et al, 2000; Nigg, 2000). Since interference control is believed to be a deliberate and intentional process, it requires more attention. Specifically, attention is allocated for inhibition in this context to suppress the activated response code after the distractor has been fully processed. On the other hand, reactive inhibition is considered the automatic residual suppression of the previous distractor which impacts the current processes (Andrés, Guerrini, Phillips, & Perfect, 2008; Catena, Fuentes, & Tudela, 2002; Hogge, Salmon & Collette, 2007; Marí-Beffa, Fuentes, Catena, & Houghton, 2000; Titz, Behrendt, Menge, & Hasselhorn, 2008). As such, reactive inhibition requires less attentional resources to operate successfully.

The construct of inhibition and its components has been widely tested and reported in the psychological literature.[3] The following sections explore its study and the resulting findings.

2.B.2. Early study of inhibition via negative priming

The phenomenon later described as reactive inhibition was first explored using a negative priming experiment by Dalrymple-Alford and Bustayr (1966). In their study, the authors used Stroop color-word stimuli to examine the nature of suppression by using the prime-probe trial sets, where the prime color-word/distractor became probe ink color/target on the immediate subsequent trial. They noted with interest the reaction time to the second of the paired trial was slower than other trial types. They interpreted this result to indicate the "temporary unavailability" of the suppressed response. Neill (1977) further tested Dalrymple-Alford and Bustayr's claim and found similar results, claiming "the data provide unequivocal evidence for the existence of inhibitory mechanisms in selective attention" (Neill, 1977, pg. 446), though potentially susceptible to contextual factors. Tipper (1985) further studied the phenomenon of the "ignored object" believing that the negative priming procedure is an

[3] Much of the inhibition and interference literature does not focus specifically on language processes, but rather includes language within complex cognition impacted by these functions. In fact, many tests of inhibition and interference occur within the language domain. Outside of spreading activation/semantic blocking and priming models, the literature isolated to language and inhibition, as defined here, is relatively sparse. However, Burke (1997) provided a useful (though outside the scope of this document) evaluation of Hasher & Zacks' Inhibitory Deficits theory of cognitive aging specific to language functions.

accurate reflection of an inhibitory mechanism of selective attention. He reported ignored items are not simply processed perceptually at the level of their features, but are fully processed and categorized, as evidenced by negative priming of categorically related items. Together, these studies hypothesized that an ignored stimulus does not simply decay, but is actively suppressed and temporarily retarded from subsequent selection.

2.B.3. Houghton and Tipper (1994) model of inhibition

The early studies just described informed a connectionist model of inhibition as a primary mechanism of selective attention. Houghton and Tipper (1994 – referred to as **H&T94** henceforth) theorized that inhibition and excitation are the central mechanisms of selection, which modulate activation stemming from perceptual inputs, based on goal-directed schemas, or packaged response programs for action and thought. Furthermore, selection occurs after perception, initial conceptual analysis and categorization. In other words, selection occurs when we link or bind a perceptual item to the goal-directed action for that item. In a sense, all perceived items "compete" for linkages to the goal-directed action, and the process of selection manages this competition in favor of the target. Houghton and Tipper also hypothesized that inhibition of a simultaneously presented distractor and inhibition of a

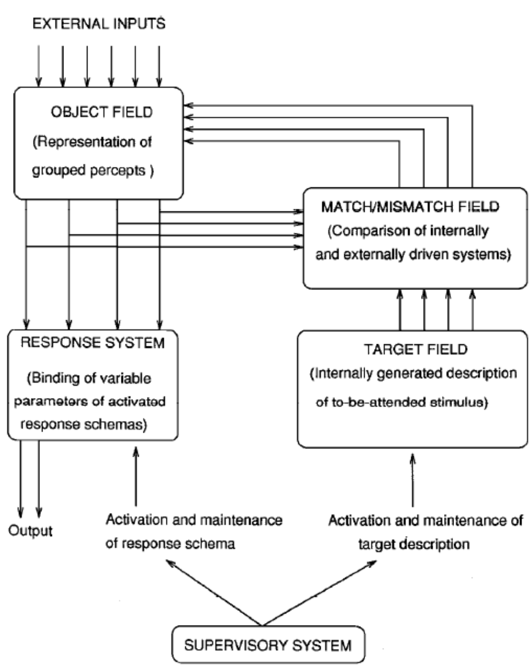

FIGURE 3. Houghton & Tipper's model of selective attention (1994), from Houghton et al (1996, pg 126).

previously presented distractor rely on different facets of the same process or mechanism.

2.B.3a. Model components

Within this framework, inhibition is integral to the mechanism of selection (Houghton et al, 1996). This selection mechanism is comprised of object and target fields, a match/mismatch detector, and response binding unit (Figure 3).

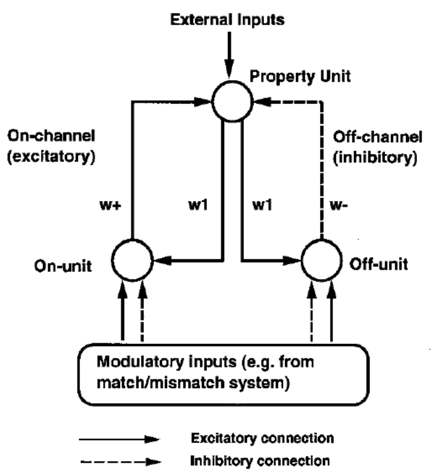

FIGURE 4. Houghton & Tipper's object field (1994), from Houghton et al (1996, pg 127).

Object fields are the activated representations based on perceptual inputs; comprised of linked "property units" where the percept's features are bound together. These units have both excitatory and inhibitory feedback loops, on-channel and off-channel respectively, which are equally weighted in their resting activation level. When a unit's on- or off-channels are activated by a match/mismatch field (described below), the unit can influence its neighbors via spreading activation/inhibition: enhanced on-channels initiate spreading activation, and enhanced off-channels initiate spreading inhibition (Figure 4).[4]

Target fields, driven by the internal goal state, are comprised of internal representations of properties of the target (sometimes called the "attentional

[4] Why a dual-mechanism within property units? Given this model is based on a connectionist framework, excitation or inhibition must operate within the limits of activation. The rate at which individual items are boosted or suppressed is finite in a single mechanism system. However, a dual-system can simultaneously boost a target and suppress a distractor much more quickly. Additionally, two equally strong (or weak) stimuli may both reach the maximum (or not achieve the minimum threshold of) response activation if selection was only an excitatory process. A simultaneously operating excitatory/inhibitory system could separate the target and distractor for selection and processing. Houghton and colleagues (1996) cite ERP data supporting the dual-mechanism framework (Luck, Hillyard, Mouloua, Woldorff, Clark & Hawkins, 1994).

trace") which are wholly separate from the perceptual representations. The target field is what informs the match/mismatch field of which property units to activate and suppress based on the target schemas. Schemas are packages of more basic motor and thought programs. Each schema has its own parameters, which are adapted to the present goal and contextual environment.

Match/mismatch fields receive input from both the perceptual system/object field and from the goal state/target fields. When there is a match between the target schema, its property units and the object field's property units, the on-channels will be enhanced and excitation will occur. When mismatched, the object field's units' off-channels will be enhanced and suppression will occur.

The response binding system is activated once the target objects are excited and non-target objects are suppressed by the match/mismatch field. Target objects are then bound to the schema provided by the target field, and the output response is initiated.

2.B.3b. Model processes

The above components of H&T94's model are at play when input stimuli are perceived. During this time, the target object is highly activated via on-channel excitation. At the same time, off-target objects are inhibited via off-channel activation, though their activation level is maintained above resting level, called "distractor equilibrium" (or "adaptation;" Houghton, Tipper, Weaver & Shore, 1996) – but again, only during perception. The amount of activation within the on- and off-channels is unequal if the distractor is more dominant or established than the target. As soon as the perceptual inputs are discontinued, distractor equilibrium becomes

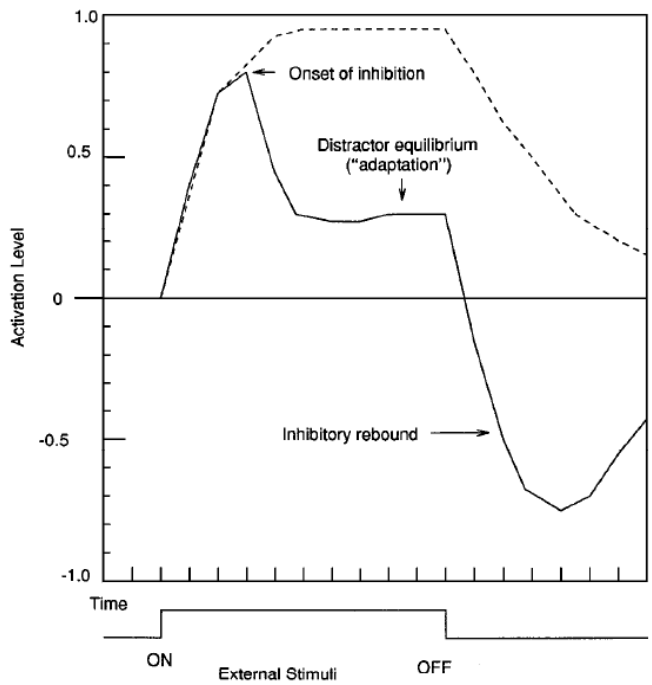

FIGURE 5. Houghton & Tipper (1994) prime stimuli activation and subsequent inhibitory rebound, from Houghton et al (1996, pg 130).

unbalanced by exclusively inhibitory activation. In other words, the strength of activation necessary to keep the distractor suppressed during distractor equilibrium overcomes the relatively weaker excitation of the target. At the offset of the stimuli, this asymmetric activation pushes the distractor object representation into a temporary activation state below resting levels called "inhibitory rebound" (Figure 5). During this time, the inhibited object's representation is unavailable for reactivation. If the now negatively suppressed object is re-presented, its selection is temporarily slowed. This slowed selection of and response to a previously suppressed representation is called "negative priming."[5] According to H&T94, the strength and "depth" of inhibitory rebound depends on the distractor object's level of

[5] Milliken, Lupianez, Debner and Abello (1999), Neill, Valdes, Terry and Gorfein (1992) and others have claimed that negative priming is not an accurate measure of inhibition, but instead of episodic retrieval. In the episodic retrieval hypothesis, a repeated stimulus automatically activates the most recent presentation of that stimulus and the related response, e.g. "ignore this stimulus" (Milliken et al, 1999; Neill et al, 1992). However, May, Kane and Hasher (1995) and others studied this claim and found ways to control for episodic retrieval and support an inhibition account of negative priming. Episodic retrieval may be evoked a) on consecutive trials in which the target repeats, b) with stimuli which are perceptually degraded, c) with stimuli with limited exposure duration, d) in tasks which require lexical decision (since episodic retrieval is considered post-lexical). Subsequently, Kane, May, Hasher, Rahhal and Stoltzfus (1997) and Tipper (2001) described a "dual-mechanism" approach which acknowledges both the episodic retrieval and inhibition accounts of negative priming depending on these contextual factors, a perspective fairly widely acknowledged in negative priming literature.

interference and its contextual environment. Its reactivation also depends on the context of its re-presentation, for example the duration of the prime stimulus, the intertrial interval, or the type of probe stimulus.

Houghton et al (1996) consider the inhibitory mechanism as described by this model as a combination of top-down and bottom-up process. Perceptual inputs drive the object field's on- and off-channels, while the target field serves as the executive management and attentional allocation of the process. In other words, these top-down functions include determining the goal-state and selecting the related targets and response sets; bottom-up processing refers to the activated representations based on perceptual inputs.

Tipper, Weaver, Cameron, Brehaut and Bastedo (1991) provided additional evidence of the nature of inhibition as tested by negative priming, particularly in regards to various types of disruption and intervening events. Specifically, inhibition does not appear to relate to the perceptual elements of the stimulus, their spatial location, or the specific motor response required, and will persist regardless of an intervening event between prime and probe trials, or other simultaneous inhibitory processes. However, inhibition may be disrupted by an "unexpected" intervening event. The authors hypothesized the resources necessary for maintaining inhibition are redirected via attentional orienting to the unexpected event.

2.B.4. The relationship between interference control and inhibition

There is ample evidence that the strength or salience of the interference has a more complicated relationship with the depth and duration of the inhibitory rebound than H&T94 originally suggested. Houghton, Tipper, Weaver and Shore (1996) emphasized that inhibition is only one component of selection involved in interference control, and the negative priming paradigm tests reactive inhibition exclusively. In other words, interference control and reactive inhibition are separate but related. Titz, Behrendt, Menge and Hasselhorn (2008) elaborated on an alternate model of inhibition and interference control (Hasher, Zacks & May, 1999) in which inhibitory functions are fragmented into three parts (similar to Friedman & Miyake, 2004, discussed previously): a) access control, which prevents irrelevant items from entering working memory (within the interference control framework), b) deletion control, which deletes once-relevant/now-irrelevant items from working memory (similar to reactive inhibition), and c) restraint control, which blocks habitual or dominant responses from working memory (also within the interference control framework). The authors explored whether these functions may be differentially impacted by normal aging. Their findings suggest that deletion control/reactive inhibition and restraint control appear to be intact and stable with age, while access control is diminished with age. The general finding that interference control and reactive inhibition are impacted differently by aging are supported by a number of studies (Andrés et al, 2008; Buchner & Mayr, 2004; Gamboz, Russo & Fox, 2002; Hogge et al, 2008; Verhaeghen, 2011; Verhaeghen, Cerella, Bopp & Basak, 2005[6]). Other studies suggest, however, that both mechanisms are impacted similarly by age (Hasher, Stoltzfus, Zacks & Rypma, 1991; Kane, Hasher, Stoltzfus, Zacks & Connelly, 1994; Mayas, Fuentes, Ballesteros, 2011; Verhaeghen & DeMeersman, 1998b)[7]. Taken together, these studies and their inconsistencies speak to a) the

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[6] See this meta-analyses review for greater depth on "Aging and varieties of cognitive control."

[7] Buchner and Mayr (2004) provided two arguments for the earlier reports of differences in inhibition between younger and older adults. First, younger participants often demonstrated more statistically significant negative priming effects compared to older participants, potentially due to the "standardized effect size measure." Effect sizes may be deluded due to greater variability and decreased accuracy (thereby eliminating trials used in statistical analyses) of older participants. Second, publication bias may inaccurately reflect effects of aging. For example, if a study yields results in which younger adults are not showing a negative priming effect, then reviewers may conclude

challenges of testing inhibition and aging, b) the complex relationship between interference control and inhibition, as well as c) the idea that inhibition is not a unitary construct but can be fragmented.

2.B.5. Interference control and inhibition in neurologically impaired populations

Several studies to date have examined interference control and reactive inhibition in specific neurologically impaired populations, namely people with Alzheimer's disease (Hogge et al, 2008), multiple sclerosis (Vitkovitch, Bishop, Dancey & Richards, 2002), Parkinson's disease (Filoteo, Rilling & Strayer, 2002) and patients with post-stroke focal lesions (McDonald, Bauer, Filoteo, Grande, Roper & Gilmore, 2005; Metzler & Parkin, 2000; Stuss, Toth, Franchi, Alexander, Tipper & Craik, 1999)[8]. Hogge et al (2008) and Vitkovitch et al (2002) reported similar results: while interference effects were more significant for the impaired participants compared to controls, reactive inhibition appeared to be roughly equivalent, after accounting for general cognitive slowing. Filoteo and colleagues (2002) reported the opposite results for their study's participants with Parkinson's disease. While no significant interference effect differences existed between groups, participants with Parkinson's did not show any negative priming effects. In the studies that examined reactive inhibition in participants with focal lesion (due mostly to stroke or tumor resection), results were mixed: participants with left frontal lesions showed positive rather than negative priming in two studies (McDonald et al, 2005; Metzler & Parkin, 2000), but only situationally diminished negative priming for the same type of participants in another (Stuss et al, 1999). Both studies found diminished or variable negative

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the experiment was not conducted properly, and the manuscript is not published. When reported in meta-analyses (e.g. Verhaeghen & DeMeersman, 1998b), younger participants therefore show larger averaged effects.

[8] While there are a number of studies that examine interference control and inhibition in people with traumatic brain injury, this population is different enough that they are not included in this focused review.

priming in participants with right hemisphere lesions (respectively), and both studies concluded that not only are interference control and reactive inhibition at least partially dissociated, but that site of lesion matters when examining these constructs.

2.C. WORKING MEMORY, INHIBITION AND NEURAL INJURY

2.C.1. Working memory and inhibition

In a study building on the work of Kane and Engle (2003) and others, Grandjean and Collette (2011) reported a positive relationship between working memory capacity and inhibitory function, as measured by an interference control task. Specifically, Grandjean and Collette attributed differences in inhibitory function to the availability of cognitive resources (i.e. attention) for working memory. These findings augment the previous reports of Jonides and Nee (2006), who explored the neural mechanisms involved in managing interference, as well as interference control's relationship to working memory. Specifically, the authors interpreted study results as evidence that people with limited working memory have greater difficulty in the presence of interference (also Conway & Engle, 1994; Daneman & Carpenter, 1980; Just & Carpenter, 1999). Activation in the left inferior frontal gyrus is one – and potentially primary – region reportedly involved in tasks that require interference control (Jonides & Nee, 2006; Jonides, Smith, Marshuetz, Koeppe, Reuter-Lorenz, 1998; Nelson, Reuter-Lorenz, Persson, Sylvester, & Jonides, 2009). Damage to this region or those connected with it is often associated with impairments in aphasia. Therefore, diminished working memory capacity and impaired inhibitory function may be challenges for individuals with acquired brain injury involving the left inferior frontal gyrus.

A number of studies have shown deficits in working memory in adults with aphasia (Wright & Fergadiotis, 2012), examined via syntactic comprehension (Miyake, Carpenter & Just, 1994; Fassbinder, McNeil, Dickey, Lim, Pratt, Kim, et al, 2011), reading comprehension (Caspari, Parkinson, LaPointe and Katz, 1998; Dickey, McNeil, Fassbinder, Pratt, Kendall, Krieger, et al, 2011; McNeil, Pratt, Fassbinder, Dickey, Kendall, Lim, et al, 2011; Sung, McNeil, Pratt, Hula, Szuminsky, & Doyle, 2009), and listening comprehension (Friedmann & Gvion, 2003; Wright, Downey, Gravier, Love & Shapiro, 2007). As suggested by Jonides and Nee (2006) and others, limitations in working memory may yield limitations in resolving interference, potentially due to or accompanied by diminished inhibitory function.

2.C.2. Attention and interference in aphasia

A number of studies have examined the impact of interference and the hypothesized diminished working memory and attention in aphasia. Some studies showed impairments in orienting of attention in aphasia, both behaviorally (Hunting-Pompon, Kendall & Moore, 2011; Petry, Crosson, Gonzalez Rothi, Bauer & Schauer, 1994; Robin & Rizzo, 1989) and electrophysiologically (Peach, Rubin & Newhoff, 1994). Other studies have focused on interference effects in comprehension (Lim et al, 2012; McNeil, Kim, Lim, Pratt, Kendall, Pompon, et al, 2010; detailed below; Wiener, Conner, Obler, 2002) and word retrieval tasks, often using a dual-task paradigm (including Murray, 2000; Murray et al, 1997, 1998; Tseng et al, 1993; see Hula & McNeil, 2008 regarding a possible confound of dual-task methodology). All of these studies reported significantly slower and less accurate target responses in the presence of interference in PWA compared to Controls. These studies hypothesize that if attentional resources are limited for PWA, then less attentional resources are available for managing interference and therefore inhibiting distractions. If true, activated distractors may prevent processing of the target item, or be processed in place of the target item. In other words, if attention is misallocated or otherwise limited in aphasia, target language processes like finding the right word during conversation may become challenging at best or impossible at worst due to the presence and processing of distractions.

Some studies of aphasia have alluded to a potential inability to inhibit irrelevant information activated during interference. For example, Wiener et al (2002) examined interference and auditory comprehension in subjects with Wernicke's aphasia using a numeric Stroop task with a manual response. Compared to controls, participants with aphasia demonstrated a larger interference effect (similar to Lim et al, 2012). The authors concluded these results indicate people with Wernicke's aphasia may not be able to adequately inhibit the automatically evoked items in favor of the less automatic items. However, the authors did not explicitly explore the components of inhibition.

Similarly, Hamilton and Martin (2005) examined interference in a participant (ML) with left inferior frontal damage and aphasic impairments. Using Stroop color-word tasks, ML demonstrated significantly larger interference effects via spoken word response when compared to controls. The authors concluded ML may have been unable to inhibit recently activated competitors from previous trials, but testing this hypothesis was outside the scope of the study.

Lastly, McNeil and colleagues (2010) studied interference and facilitation effects in PWA using a Stroop task within the CRTT-R (Computerized Revised Token Test--Reading) with 25 PWA and 29 control participants. This experiment used Stroop stimuli within the CRTT-R's self-paced sentence reading comprehension task to determine interference and facilitation effects in PWA, among other things. Overall, between-group analyses showed PWA were significantly slower and less accurate compared to Controls. In within-group comparisons of the incongruent condition to the neutral and regular reading conditions, PWA demonstrated greater interference effects relative controls. Interestingly, there was no interaction between the fade/regular reading and neutral conditions when examining reading time, interpreted to indicate little to no evidence of slowed activation of the lexical representation for PWA. Additionally, both groups showed significant facilitation effects when comparing the congruent and neutral conditions. Taken together, these results may indicate diminished inhibition in PWA, but inhibition was not addressed specifically.

2.C.3. Studies of impaired inhibition in aphasia

A study by Bartols-Tobin and Hinckley (2007) examined reactive inhibition in PWA from a spread of activation/interference perspective.[9] Using a negative priming lexical decision task with a button-press response, participants' response accuracy and reaction times were evaluated in three conditions: semantically related associates, semantically related distractors, unrelated words and non-words. The results of this study showed both older participants and PWA performed with similar response latency and accuracy scores when comparing conditions. Additionally, neither group demonstrated negative priming effects in any condition. However, the methods employed by the authors contributed to a number of confounded results. For example, it is unclear if the stimuli used (targets with flanker words and non-words) controlled

[9] "Inhibition" of a target and its relations via spread of activation, as tested using semantic blocking and priming studies, is likely related to reactive inhibition following distraction. However, this type of suppression is often explored within the framework of relative activation and decay of targets, related neighbors, or perseverative errors – worthy of study but outside the scope of the present document.

for positive priming or facilitation effects separate from negative priming effects. Also, negative priming tasks using lexical decision are reported to evoke episodic retrieval rather than reactive inhibition (Kane, May, Hasher, Rahhal & Stolzfus, 1997; May, Kane & Hasher, 1995). Cognitive mechanisms of memory and retrieval were not explored in this study. For these reasons, Bartols-Tobin and Hinckley's findings did not provide comprehensive evidence about interference control and reactive inhibition in aphasia central to the present study.

2.D. RESEARCH QUESTIONS AND HYPOTHESES

Previous research suggests PWA have diminished working memory and selective attention, which impairs language processes. While interference is almost certainly a challenge for PWA, impairments in inhibition have been hypothesized but not studied systematically. To further understand the role and potential limits in selective attention during spoken word production, the present study seeks to explore the presence and magnitude of reactive inhibition within the context of interference. Specifically, this study is the first step in examining inhibition separate from excitation to better understand how it is involved in word retrieval. The following research questions were explored (see Appendix B for research questions with stimuli examples; also see Table 2 for research questions, variables, analyses and hypotheses, at the end of Methods):

Research Question 1: Evoke interference and facilitation effects.

As a control condition, is there a significant difference between Stroop incongruent, congruent and neutral trials, in word naming latency and accuracy, for PWA and Controls? Comparisons of incongruent and neutral conditions yield interference effects, and comparisons of congruent and neutral conditions yield facilitation effects.

Hypothesis: PWA will show significantly greater interference effects compared to controls due to diminished attention, but not significantly different facilitation effects.

Research Question 2: Test reactive inhibition via inhibitory rebound.

Is inhibitory rebound significantly different, in word naming latency and accuracy, for PWA compared to Controls?

2a) Is inhibitory rebound significantly different in PWA compared to Controls when tested with repeated interference/incongruent probes? This negative priming task requires a significant degree of attention. It tests whether participants have inhibited the prime distractor by reactivating it using a weakly represented probe target (i.e. another incongruent trial, where the prime distractor/word becomes probe target/font color), and comparing this response to the novel interference/incongruent condition (RQ1).

2b) Is inhibitory rebound significantly different in PWA compared to Controls when tested using facilitation/congruent probes? This negative priming task requires less attention than the previous task. It tests whether participants have supplied attention to inhibit the prime distractor by reactivating it using a strongly represented probe target (i.e. where prime distractor/word becomes congruent probe/font color and word), and comparing this response to repeated interference (2a).

2c) Is inhibitory rebound significantly different in PWA compared to Controls when tested using facilitation/congruent probes contrasted with novel facilitation/congruent condition? This question looks for the presence of inhibitory rebound by comparing two conditions that require the least attention of all tasks. It compares whether participants have supplied attention to inhibit the prime distractor by reactivating it with a strongly represented congruent probe (2b) relative to a novel facilitation/congruent trial (RQ 1).

Hypothesis: PWA will not show inhibitory rebound at the same magnitude as controls, as determined by response latency and accuracy, and regardless of task demands. In other words, if attention is not available to suppress the prime distractor, then that item may be more readily available for the subsequent probe selection. The resulting probe response may be faster for PWA than controls, or PWA may show a positive priming effect. Conversely, if attention is misallocated and suppression of the prime distractor is greater for PWA than for Controls, the resulting probe response may be slower for PWA than Controls. PWA may show a greater negative priming effect than Controls.

CHAPTER 3

Methods

3.A. PARTICIPANTS

Of the 22 people with aphasia (PWA) and 22 age- and education-matched Controls recruited for this study, 19 PWA (10 female, 9 male) and 20 Controls (13 female, 7 male) met all study criteria. The average age of PWA was 56.3 years (SD 13.3) and of Controls was 57.5 years (SD 9.02). The average years of education for PWA was 16.4 (SD 3.37), and for Controls was 16.0 (SD 1.85) (for participant demographic data, please see Appendix C1&2).

After IRB approval, PWA were recruited from the UW Aphasia Registry, UW Speech & Hearing Clinic, and via flyers distributed to area clinicians and support groups. Control participants were recruited from the UW Communications Studies Participant Pool, the UW Speech and Hearing Clinic, area support groups, and via word of mouth. Eligible PWA had a diagnosis of aphasia using the clinical criteria described by McNeil and Pratt (2001): a language-dominant hemisphere lesion resulting in acquired, multi-modal language processing deficits. These impairments were described by the Boston Naming Test (BNT; Kaplan, Goodglass & Weintraub, 1983; mean 38.84, SD 15.96), Western Aphasia Battery (WAB; Kertesz, 1982; mean 81.91, SD 11.89), the Standardized Assessment of Phonology in Aphasia (SAPA; Kendall, Del Toro, Nadeau, Johnson, Rosenbek & Velozo, 2010; mean 112.32, SD 17.66), and confirmed by clinical neurology and brain imaging reports, and in the absence of degenerative neurological disease, dementia, schizophrenia, schizoaffective disorder, or bi-polar disorder. Furthermore, PWA were at least six-months post onset (mean 65.16 months; SD 56.73 months) left hemisphere stroke with no prior neurologic event per participant or caregiver report, and were excluded with moderately-severe to profound dysarthria or apraxia of speech. Presence and severity of dysarthria and apraxia of speech was determined by an experienced speech-language pathologist's observation of a speech sample including connected speech, and repetition of single and multisyllabic real words (Duffy, 2005). Discriminatory diagnostic descriptors of apraxia of speech were based on Wambaugh et al (2006). All participant diagnostic and screening information can be found in Appendix D1&2.

Participants in either group were (premorbidly) right-handed, native speakers of English, with vision better than 20/40 (corrected if necessary), and excluded with a history of psychiatric disturbance, schizophrenia or schizoaffective disorder, bi-polar disorder, learning disability, developmental language delay, attention deficit disorder, a currently uncontrolled mood disorder or substance abuse, diffuse brain injury or disease, hemianopia, or color blindness.

3.B. SCREENING AND DESCRIPTIVE MEASURES

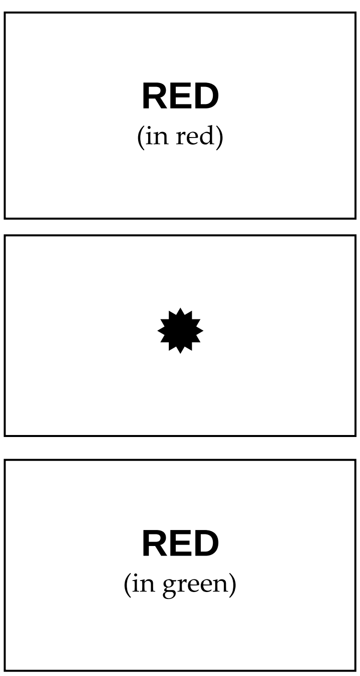
Participants with aphasia were screened using the aforementioned criteria by both self-report and medical record review. Vision and colorblindness screenings were also completed during the screening portion of the study session (Snellen Vision Screen and Ishihara Colorblindness Test, respectively). All participants completed forward and backward digit spans (Wechsler Adult Intelligence Scale, 3rd Ed.; Wechsler; 1997), Trail Making tests (Reitan, 1958), the Attention Questionnaire (from APT-II; Sohlberg, Johnson, Paule, Raskin, and Mateer, 2001), and the regular reading, neutral and incongruent subtests of the Computerized Revised Token Test-Reading (McNeil, Pratt, Szuminsky, Sung, Fossett, Kim & Fassbinder, 2008; McNeil

	Trail Making (sec)		Digit Span		Attn.	CRTT-R					
PWA	A	B	Forward	Backward	Quest.	Read score	Read eff	Neu score	Neu eff	Inc score	Inc eff
mean	47.42	159.13	5.68	3.11	22.42	13.76	4.63	13.82	5.14	13.52	3.65
sd	25.14	107.17	2.94	1.85	9.57	0.71	2.13	0.75	2.41	1.11	2.76
Controls											
mean	23.80	49.88	11.20	7.60	11.55	14.49	8.81	14.52	9.09	14.41	8.48
sd	5.57	12.27	1.94	1.79	6.32	0.25	1.32	0.27	1.27	0.70	1.29

TABLE 1. Screening data (means and standard deviations) for both groups on screening measures: Trail Making A and B (in seconds), WAIS-III Digit Span Forward and Backward scores, Attention Questionnaire scores, and accuracy and efficiency scores for Regular Reading, Neutral and Incongruent subtests of CRTT-R.

& Prescott, 1978). (Mean and standard deviations for each group on screening measures is provided in Table 1; individual participant screening data detail is provided in Appendix D1&2.) Participants who performed at 80% accuracy or better on a Stroop stimuli screen were permitted into the study (see Appendix E).

Of the original 22 participants recruited for each group, two Control participants were excluded from final analysis as they reported using a strategy during the experiment. Two PWA did not complete the study protocol as they did not pass the Stroop stimuli screening, and one PWA was eliminated as his WAB, BNT, and SAPA scores were within normal limits.



3.C. STIMULI

Five colors and color-words (red, blue, green, pink, white) were presented in 54-point Arial font centered on a gray background on a computer monitor. These five colors and color-words were used in three basic stimuli types: congruent, neutral and incongruent (Figure 6). As in similar studies, the congruent condition presented color-words with matching font color (e.g.

FIGURE 6. Basic stimuli, top to bottom: congruent, neutral, incongruent.

"RED" in red font), the neutral condition presented colored splotches (✹ measured approximately 2 inches in diameter), and the incongruent condition presented color-words with a mismatched font color (e.g. "RED" in green font). For the Negative Priming stimuli, the incongruent trials served as primes for two probe stimuli types. Incongruent prime trials were followed by either: a) repeated interference/incongruent probe, where the prime trial distractor becomes the incongruent probe trial target, e.g. prime is "RED" in green font; probe is "BLUE" in red font, or b) facilitation/congruent probe, where the prime trial distractor becomes a congruent probe, e.g. prime is "RED" in green font; probe is "RED" in red font (Figure 7). (See Appendix A for color examples of these stimuli.)

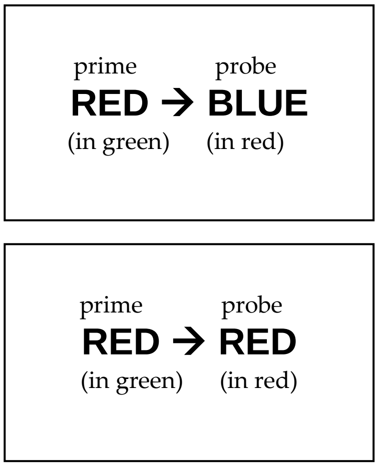


FIGURE 7. Negative priming stimuli, top: repeated interference/ incongruent probe (prime distractor becomes probe target); bottom: facilitation/ congruent probe (prime distractor becomes congruent probe).

The experiment was comprised of 340 total trials: 40 congruent trials, 40 neutral trials, 80 incongruent trials, 80 probe trials (40 repeated interference/incongruent probes, 40 facilitation/congruent probes), and 100 neutral fillers (number of tokens based on Hogge et al, 2008; Vitkovitch et al, 2002; Wiener et al, 2004). Each incongruent trial served as a prime for one of the two probe trials. An unrelated neutral filler trial followed each of the 80 probe trials to control for episodic retrieval or lingering suppression effects. Twenty neutral filler trials followed half of the congruent trials to help conceal the prime-probe-neutral pattern. All trials were presented in 10 sets of 34 trials each. Each of the 10 sets was presented in random order; the 34-trials within each set were presented in pseudorandom order: aside from prime-probe trial pairs, no stimulus was repeated in the immediate subsequent trial to allow dissipation of any priming effects (Hasher et al, 1991; May et al, 1995). The color stimuli were also balanced; each color was represented nearly equally.

3.D. EQUIPMENT

The experiment was conducted using E-Prime 2.0 software (Psychology Software Tools, Schneider, Eschman & Zuccolotto, 2002), on a Dell Precision 870 computer, and displayed using a Dell A5501 19" monitor with 20 msec response time and maximum resolution of 1280x1024. Participants wore an Audio-Technica ATM 75 head microphone attached a Psychology Software Tools Serial Response Box (model #200A). Participants also wore Audio-Technica QuietPoint ATH-ANC7 headphones (not plugged in) to dampen environmental sounds.

3.E. PROCEDURES

Participants sat about 20 inches from the monitor. Experimental instructions were presented on the computer screen as well as read aloud by the examiner: "Look at the (fixation crosses). You will see words and symbols. Name the font color out loud, as quickly and accurately as you can." The examiner also instructed participants to a) look at the whole word/symbol, not just a part of it, and refrain from b) making any vocalization prior to response, c) making self-corrections or d) squinting, blurring vision or using any other strategies during the experiment. The examiner also reinforced the instruction of balancing accuracy and speed of response. Prior to the testing session, participants completed one to three 34-item practice set(s), in which stimuli types were randomly presented without embedded prime-probe trial pairs, to acquaint them with the task and trial types, verify they understand the experimental instructions, and bring performance to a personal maximum.

Within the experiment itself, the participant saw 250 msec of blank screen followed by 250 msec of 3 fixation crosses (which appeared in the location and width of color words), then the trial stimulus. The stimulus remained on the screen until 1000 msec after the onset of vocalization/response. Then, this screen/stimulus progression would repeat for each of the 34 trials in each set (see Appendix F for a screen-by-screen depiction of the experiment). After each 34-trial set, the participant had a brief (<1 minute) break before the start of the next set. The entire experiment was divided into two 5-set/170-trial sessions with <10-minute break between sessions. Breaks included, the experimental session lasted 30-45 minutes, and was audio recorded for intra- and inter-rater reliability purposes.

Following the experimental session, most (see Limitations section) participants were asked a general question about their experience of the experiment to capture if they noticed a relationship between prime-probe trial sets or used any strategies during the experiment. One control participant noted the prime-probe relationship; one participant mentioned using a strategy in responding to the stimuli. Both participants were subsequently excluded from analysis.

3.F. DATA PROCESSING AND DESIGN

Accuracy data were recorded by the examiner using pen/paper score sheets. A correct response was coded as incorrect if it was preceded by vocal hesitation, false start, or included a phonemic paraphasia. Other incorrect responses included semantic substitutions, omissions, or offline, responses shorter than 250 msec or outside 3 standard deviations from each participant's mean response time for that condition (Wiener et al, 2004). Responses that needed to be repeated due to low microphone level, or were incomplete due to high microphone level (trials skipped ahead too quickly) were also omitted. Probe trials that followed an incorrect or omitted prime trial were not included in response latency analyses, but were included in accuracy analyses. (See Appendix K for accuracy and error coding details.)

For each research question, between-condition differences in response latency and accuracy were determined for each participant first. Then, these individual participant differences between conditions were compared between groups. Therefore, for Research Question 1, interference effects were determined for each participant by subtracting neutral from incongruent trials; for facilitation effects, congruent from neutral trials. For Research Question 2, between-condition differences were determined by subtracting a) novel interference/incongruent trials from repeated interference/incongruent probes, b) facilitation/congruent probes from repeated interference/incongruent probes, and c) novel facilitation/congruent trials from facilitation/congruent probes.

After data were initially analyzed using an omnibus two-group by five-condition repeated measures ANOVA, each research question was addressed separately using ten planned comparisons (five response latency, five accuracy), with a corrected significance level of .005. Response latency data (correct responses only) were analyzed using one-way, repeated measures ANOVAs. Accuracy data were analyzed using nonparametric, two-independent sample/Mann-Whitney tests. Descriptive, within-group analyses involved paired samples t-tests for response latency, and nonparametric, two-related samples/Wilcoxon tests for accuracy.

RESEARCH QUESTIONS	IND. VARIABLES	ANALYSES	HYPOTHESES[10]
1. Evoke interference and facilitation effects.			
RQ: As a control condition, is there a significant difference between Stroop incongruent, congruent and neutral trials, in word naming latency and accuracy, for PWA and Controls?	Incongruent vs. Neutral; Congruent vs. Neutral	Repeated measures 2x2 ANOVA: group by condition (Inc, Neu; Con, Neu) interaction; nonparametric tests for accuracy	PWA will show significantly greater interference effects compared to controls due to diminished attention, but not significantly different facilitation effects.
2. Test reactive inhibition via inhibitory rebound… RQ: Is inhibitory rebound significantly different in word naming latency and accuracy for PWA compared to Controls?			
2a. …with repeated interference/incongruent probe. RQ: Is inhibitory rebound significantly different in PWA compared to Controls when tested with repeated interference/incongruent probes?	Incongruent condition vs. repeated interference/ incongruent probes	Repeated measures 2x2 ANOVA: group by condition (Inc, IncProbe) interaction; nonparametric tests for accuracy	PWA appear to have diminished attention. Therefore, they will not show inhibitory rebound at the same magnitude as Controls, as determined by response latency and accuracy, and regardless of task demands. In other words, if attention is limited or misallocated, inhibitory rebound may be larger, smaller, or non-existent for PWA.
2b. …with facilitation/congruent probe. RQ: Is inhibitory rebound significantly different in PWA compared to Controls when tested using facilitation/congruent probes?	Repeated interference/ incongruent probe vs. facilitation/ congruent probe	Repeated measures 2x2 ANOVA: group by condition (IncProbe, ConProbe) interaction; nonparametric tests for accuracy	
2c. …by comparing facilitation/ congruent probe to novel facilitation/congruent condition. RQ: Is there a significant difference between facilitation/congruent probes and the novel facilitation/congruent condition for PWA and Controls?	Facilitation/ congruent probe vs. novel facilitation/ congruent condition	Repeated measures 2x2 ANOVA: Group by condition (ConProbe, Con) interaction; nonparametric tests for accuracy	

TABLE 2. Research questions, variables, analyses and hypotheses.

[10] Hypotheses based on model of Houghton and Tipper (1994), and results of Hamilton and Martin (2005) and McNeil et al (2010).

CHAPTER 4
Results

Response latencies for each condition, and the interactions of condition and group, were initially analyzed using a five-condition by two-group repeated measures ANOVA. Participants with aphasia (PWA) showed more variability in response latencies compared to Controls, therefore raw response latencies were logarithmically transformed to meet the homogeneity of variance assumption. The omnibus analysis showed a statistically significant main effect of Condition, $F(1.752, .699) = 103.609$, $p<.05$, and a statistically significant interaction of Condition by Group, $F(1.752, .115) = 17.095$, $p<.05$.[11]

PWA	Con	Neu	Inc	IncPro	ConPro
mean	3.049	3.076	3.235	3.243	3.088
sd	0.121	0.118	0.174	0.191	0.134
Controls					
mean	2.853	2.829	2.919	2.925	2.862
sd	0.076	0.061	0.068	0.071	0.074

TABLE 3. Response latency (log transformed) for each group and condition: means and standard deviations.

PWA	Con	Neu	Inc	IncPro	ConPro
mean	0.971	0.939	0.894	0.873	0.958
sd	0.037	0.073	0.102	0.094	0.039
Controls					
mean	0.998	0.993	0.972	0.980	0.999
sd	0.008	0.014	0.039	0.028	0.006

TABLE 4. Accuracy proportions for each group and condition: means and standard deviations.

Each research question was addressed separately. Response latency data (correct responses only) were analyzed using one-way, repeated measures ANOVAs (see Table 3 and Figure 8 for group response latency data/means and standard deviations; Appendix G1&2 for participant response latency data). Accuracy data were analyzed using nonparametric,

[11] It had been suggested that an analysis using ratio scores of each condition comparison would account for general processing differences between Controls and PWA. A ratio analysis yielded similar results to those described here, therefore these particular ratio results are not further described in this document.

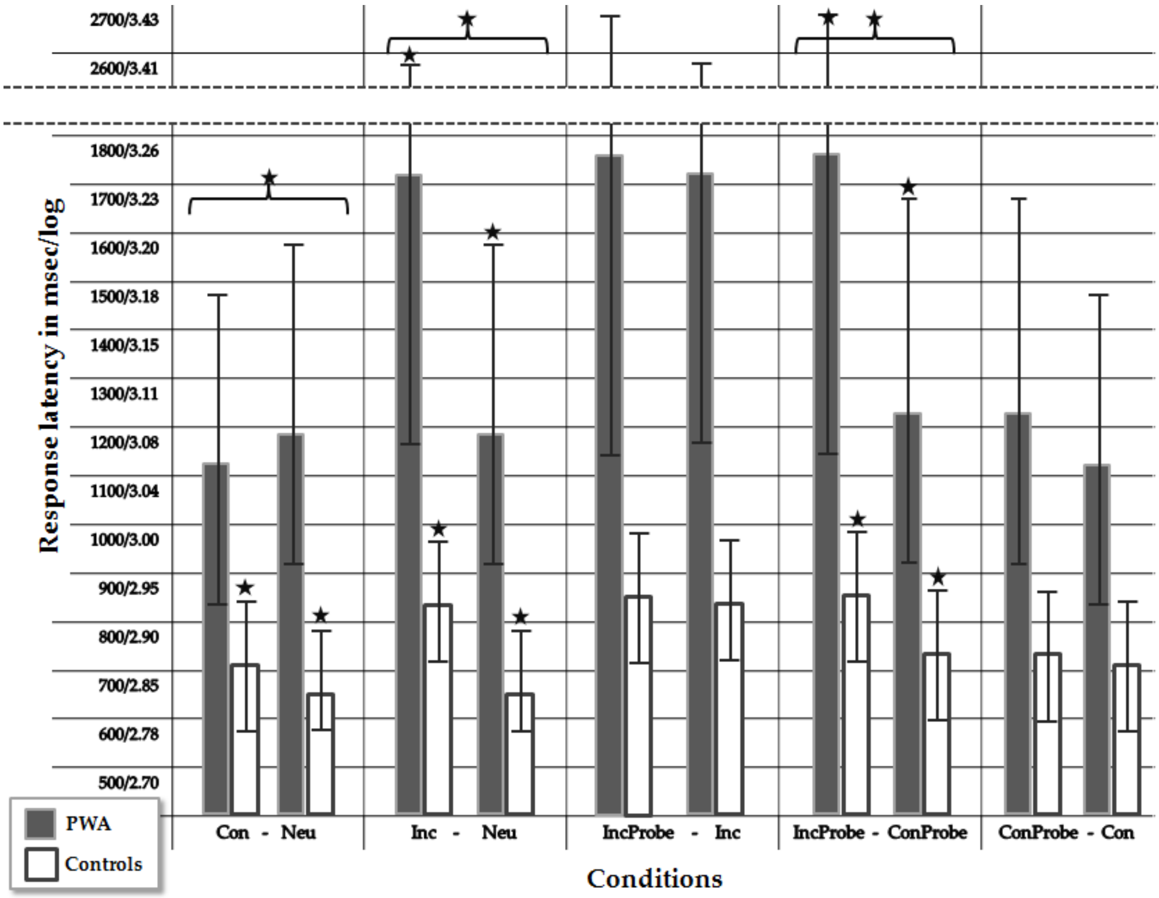


FIGURE 8. Response latency in msec/log for both groups on all condition comparisons. Significance (p<.005) indicated a) between groups with bracket and star, and b) within groups with star over both conditions. See Figures 9-13 for each condition comparison.

* sig p<.005	RQ1		RQ2		
	Facilitation Neu – Con	Interference Inc – Neu	a) Rep Interference IncProbe – Inc	b) Facilitation probe IncProbe – ConProbe	c) comparing ConProbe – Con
RESPONSE LATENCY Between groups	p<.005*	p<.005*	p=.786	p<.005*	p=.034
PWA	p=.017	p<.005*	p=.400	p<.005*	p=.006
Control	p<.005*	p<.005*	p=.132	p<.005*	p=.038
ACCURACY Between groups	p=.026	p=.133	p=.069	p=.010	p=.045
PWA	p=.015	p=.024	p=.040	p<.005*	p=.047
Controls	p=.102	p=.007	p=.437	p=.026	p=1.00

TABLE 5. Research questions with between- and within-group p-values for all five research question condition comparisons. Significance level $p < .005$.

two-independent sample/Mann-Whitney tests (see Table 4 for group accuracy data/means and standard deviations; Appendix H1&2 for participant accuracy data). Research questions were addressed via these ten planned comparisons (five response latency, five accuracy), with a corrected significance level of .005 (two-tailed). Descriptive, within-group analyses involved paired samples t-tests for response latency, and nonparametric, two-related samples/Wilcoxon tests for accuracy. Reliability analyses of 30 percent of each participant's accuracy scores resulted in 98.70% intra-rater reliability and 98.92% inter-rater reliability. (See Table 5 for statistical results/p-values of all research questions/condition comparisons; see Appendix I1&2 for individual participant data on condition comparisons; see Appendix J for scatterplots of condition comparisons.)

4.A. RESEARCH QUESTION 1 – Evoke interference and facilitation effects

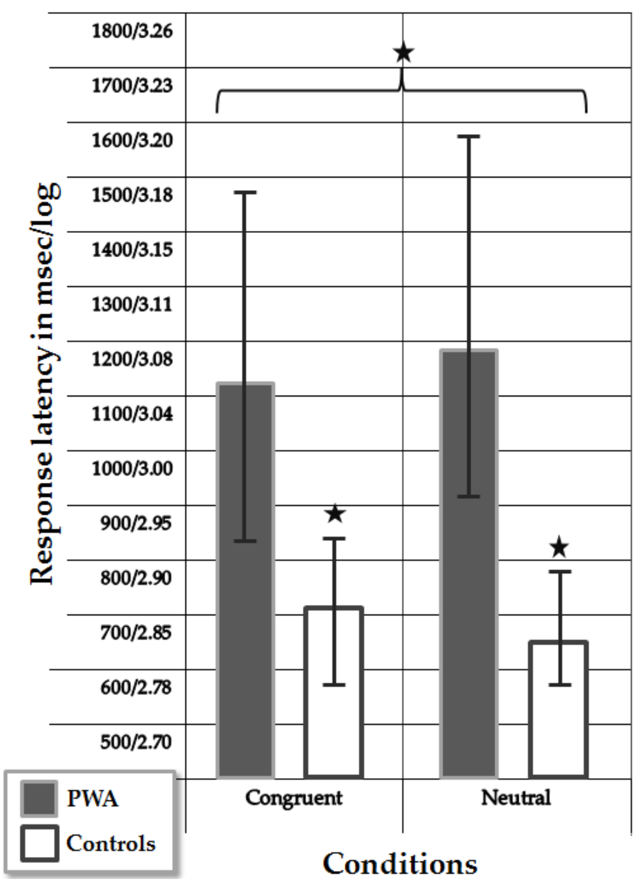


FIGURE 9. Comparison of congruent and neutral conditions to obtain facilitation effects. Significance (p<.005) indicated a) between groups with bracket and star, and b) within groups with star over both conditions.

4.A.1a. Response latency

There were statistically significant group-by-condition interactions for both planned comparisons that address this question. First, to address **facilitation effects**, there were significant differences in response latency between neutral and congruent conditions when comparing PWA (*M*=.027, *SD*=.044) and Controls (*M*=-.024, *SD*=.027); *t*(29.833)=4.303, *p*<.005. Within-group analyses showed PWA performed more slowly in the neutral condition (*M*=3.076, *SD*=.118) compared to the congruent condition (*M*=3.049, *SD*=.121); *t*(18)=2.605, *p*=.017. Controls showed the opposite trend: they performed faster in the neutral condition (*M*=2.830, *SD*=.061), compared to the congruent condition (*M*=2.853, *SD*=.076); *t*(19)=3.928, *p*<.005. Therefore, PWA did not show a significant difference between these two conditions; Controls showed a reverse facilitation effects (Figure 9).

Second, to address **interference effects**, statistically significant group-by-condition interactions were present when examining differences in response latency between neutral and incongruent conditions when comparing PWA (*M*=.159, *SD*=.086) and Controls (*M*=.090, *SD*=.030); *t*(22.105)=3.298, *p*<.005. Both groups demonstrated an interference effect, i.e. incongruent condition response latency was significantly slower than neutral condition response latency. The within-group differences between these conditions were statistically significant for both groups. PWA performed faster in the neutral condition (*M*=3.076, *SD*=.118) than the incongruent condition (*M*=3.235, *SD*=.174); *t*(18)=8.066,

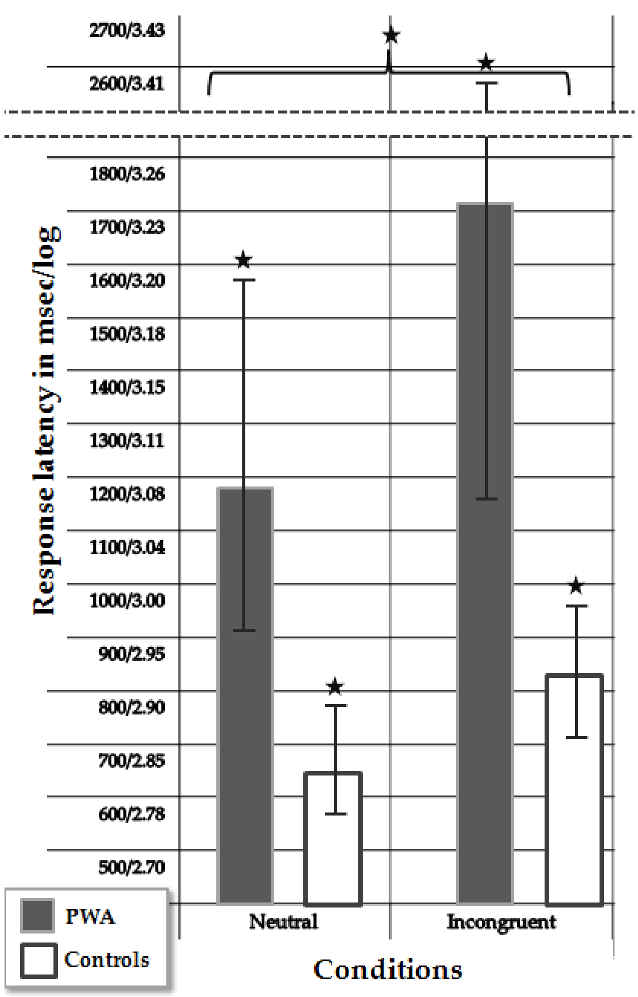


FIGURE 10. Comparison of neutral and incongruent conditions to obtain interference effects. Significance (p<.005) indicated a) between groups with bracket and star, and b) within groups with star over both conditions.

p<.005. Controls also performed faster in the neutral condition (M=2.830, SD=.061) than the incongruent condition (M=2.920, SD=.068); $t(19)$=13.610, p<.005. While both groups demonstrated a significant interference effect, this effect was more variable and proportionally greater for PWA. Specifically, after log transformation, PWA were 5.2% slower on the incongruent compared to neutral condition while Controls were 3.2% slower on the incongruent compared to neutral condition (Figure 10).

<u>4.A.1b. Accuracy</u>

There was no statistically significant group-by-condition interaction in accuracy when comparing the difference between neutral and congruent conditions in PWA compared to Controls, $U(37)$=119.500, Z=2.230, p=.026. Within-group analyses showed performance was more accurate for PWA in the congruent condition (M=97.1%, SD=3.7%) compared to the neutral condition (M=93.9%, SD=7.3%); Z=2.441, p=.015. The within-group difference between neutral (99.3%) and congruent (99.8%) conditions was not significant for Controls (see Table 4 for all group accuracy results).

There was no significant difference in group-by-condition interaction in accuracy when examining the difference between neutral and incongruent conditions in PWA compared to Controls, $U(38)$=137, Z=1.504, p=.133. Within-group analyses showed PWA performed more accurately in the neutral condition (M=93.9%, SD=7.3%) compared with the incongruent condition (M=89.4%; SD=10.2%); Z=2.257, p=.024. Similarly, Controls performed more accurately in the neutral condition (M=99.3%, SD=1.4%) compared with the incongruent condition (M=97.2%, SD=3.9%); Z=2.719, p=.007. Overall, both groups performed less accurately in the incongruent compared with neutral condition, but there were not significant differences between groups on these condition comparisons.

4.B. RESEARCH QUESTION 2 – Test reactive inhibition via inhibitory rebound

4.B.1. RQ2a Repeated interference/incongruent probe vs. novel interference

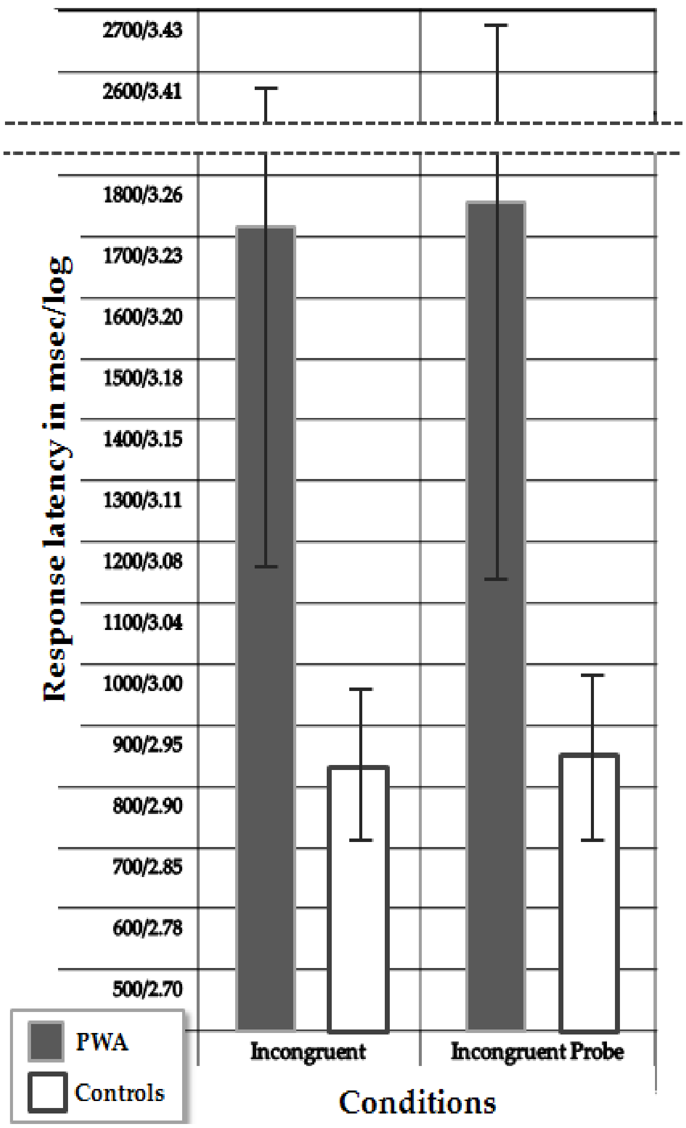


FIGURE 11. Comparison of incongruent and repeated interference/incongruent probe conditions to obtain interference effects. This condition comparison was not significant between or within groups.

<u>**4.B.1a. Response latency**</u>

There are no statistically significant differences in responses latency between novel incongruent condition and repeated interference/incongruent probe conditions when comparing PWA (*M*=.008, *SD*=.040) and Controls (*M*=.005, *SD*=.015); *t*(22.615)=.272, *p*=.786. There were no significant within-group differences on this condition comparison. In other words, neither group showed evidence of inhibitory rebound when tested by repeated interference/incongruent probe (Figure 11). However, a post hoc analysis provided some additional information about these results, detailed in Discussion.

4.B.1b. Accuracy

There was no significant group-by-condition interaction in accuracy measures when comparing the difference between novel incongruent and repeated interference/incongruent probe condition in PWA compared to Controls, *U*(37)=125.5, *Z*=1.817, *p*=.069. Within-group analyses showed a difference between these conditions for PWA, where performance was more accurate in the novel incongruent condition (*M*=89.4%, *SD*=10.2%) compared to the repeated interference/incongruent probe condition (*M*=87.3%, *SD*=9.4%); *Z*=2.053, *p*=.040. The within-group difference between novel incongruent (97.2%) and repeated interference/incongruent probe (98.0%) conditions was not significant for Controls.

4.B.2. RQ2b Repeated interference/incongruent probe vs. facilitation/congruent probe

4.B.2a. Response latency

There was a significant difference in response latency between repeated interference/incongruent probe condition and facilitation/congruent probe when comparing PWA (*M*=.155, *SD* .086) and Controls (*M*=.062, *SD*=.037); *t*(24.271)=4.339, *p*<.005. Within-

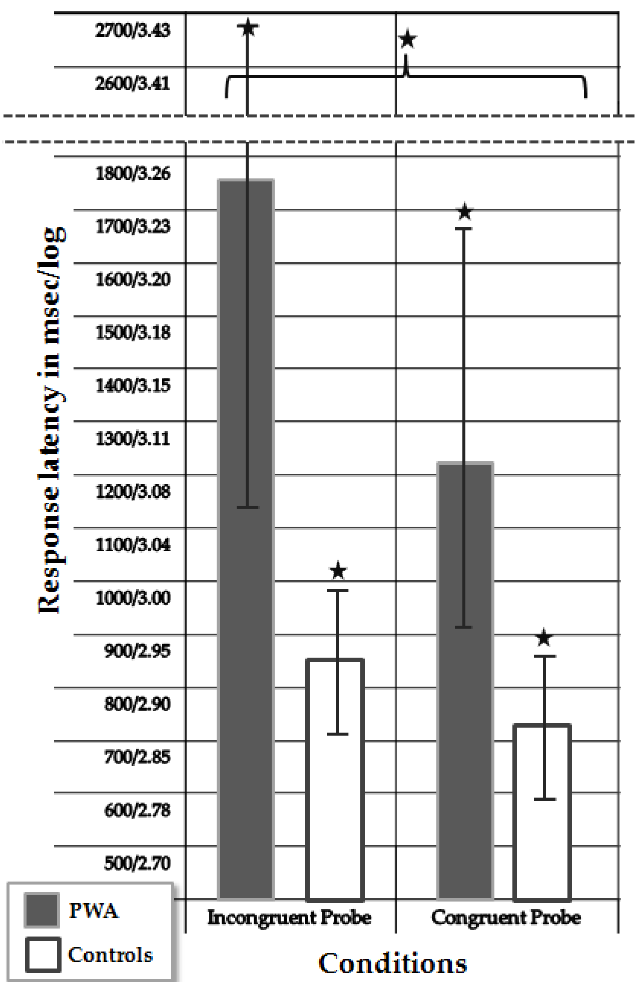


FIGURE 12. Comparison of incongruent probe and congruent probe conditions. Significance (p<.005) indicated a) between groups with bracket and star, and b) within groups with star over both conditions.

group analyses showed PWA performed significantly more slowly on repeated interference/incongruent probe (*M*=3.242; *SD*=.191) than on facilitation/congruent probe (*M*=3.088, *SD*=.134); *t*(18)=7.890, *p*<.005. Likewise, Controls also performed significantly more slowly on repeated interference/incongruent probe (*M*=2.925, *SD*=.071) than on facilitation/congruent probe (*M*=2.862, *SD*=.074); *t*(19)=7.538, *p*<.005. Both groups performed significantly slower on the repeated interference condition compared to the facilitation probe, and this difference between conditions was greater for PWA (Figure 12).

4.B.2b. Accuracy

There was no significant group-by-condition interaction in accuracy when examining the difference between repeated interference/incongruent probe and facilitation/congruent probe conditions in PWA compared to Controls, *U*(37)=100.5, *Z*=2.560, *p*=.010. Within-group analyses showed PWA performed significantly more accurately on facilitation/congruent probe (*M*=95.8%, *SD*=3.9%) compared with repeated interference/incongruent probe (*M*=87.3%, *SD*=9.4%); *Z*=3.481, *p*<.005. Similarly, Controls performed more accurately on facilitation/congruent probe (*M*=99.9%, *SD*=.6%) compared to repeated interference/incongruent probe (*M*=98.0%, *SD*=2.8%); *Z*=2.222, *p*=.026. In other words, while both groups performed more accurately on the facilitation probe compared with the repeated interference condition, this difference in accuracy scores was not significant between groups.

4.B.3. RQ2c Facilitation/congruent probe vs. novel facilitation/congruent

4.B.3a. Response latency

There was no significant difference in response latency between facilitation/congruent probe condition and novel congruent conditions when comparing PWA

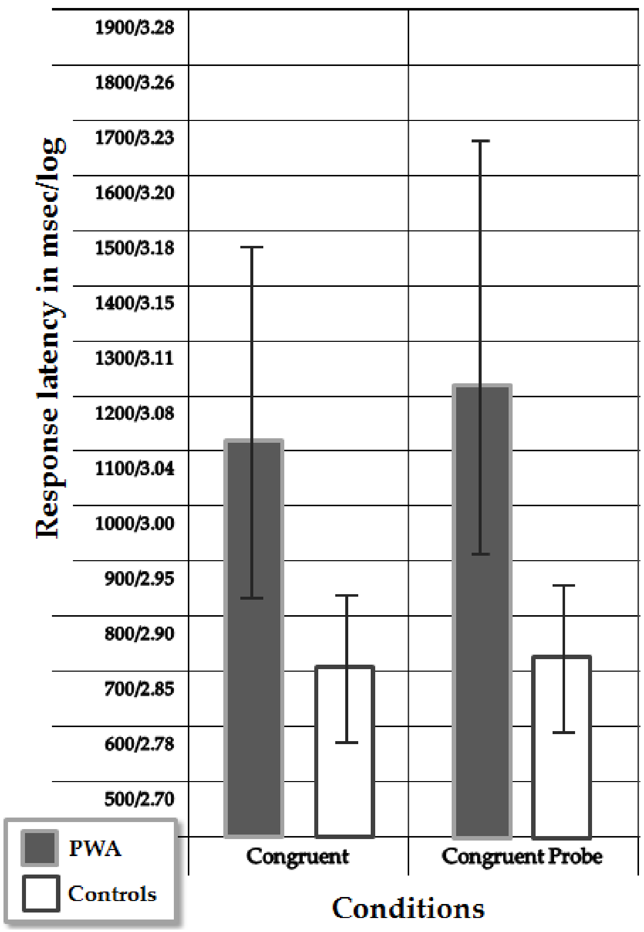


FIGURE 13. Comparison of the congruent condition and congruent probes. This condition comparison was not significant between or within groups.

(*M*=.039, *SD*=.054) and Controls (*M*=.009, *SD*=.018); *t*(21.639)=2.268, *p*=.034. Within group analyses showed PWA performed more slowly on facilitation/congruent probe (*M*=3.088, *SD*=.134) compared to novel congruent (*M*=3.049, *SD*=.121); *t*(18)=3.067, *p*=.007. Likewise, Controls also performed more slowly on facilitation/congruent probe (*M*=2.862, *SD*=.074) compared to novel congruent (*M*=2.853, *SD*=.076); *t*(19)=2.217, *p*=.038. While both groups were slower on facilitation/congruent probe than novel congruent, this difference was greater for PWA, though not statistically significant (Figure 13).

4.B.3b. Accuracy

There was no significant group-by-condition interaction in accuracy when examining the difference between facilitation/congruent probe and novel congruent conditions in PWA compared to Controls, *U*(37)=125.5, *Z*=2.004, *p*=.045. Within group analyses showed PWA performed more accurately in the novel congruent condition (*M*=97.1, *SD*=3.7%) compared with the facilitation/congruent probe condition (*M*=95.8%, *SD*=3.9); *Z*=1.983, *p*=.047. Controls performed nearly identically in accuracy on these conditions (novel congruent 99.8%, congruent probe 99.9%).

CHAPTER 5

Discussion

"It is necessary to know not only the result the patient obtained, but how he obtained it. It is necessary to know not only the tasks the patient failed, but why he could not perform them." – Hildred Schuell (1967)

The results of the present study provide some insights into inhibitory processes in aphasia, both during and immediately following interference. The following discussion will address the results of each research question separately. First, the results will be explained in relation to the model on which this study is based (Houghton & Tipper, 1994; or H&T94), and then in relation to other models and research evidence. An integrated discussion of the results will appear in General Discussion. (Refer to Table 6 for clarification of experimental condition terminology.)

5.A. RQ 1 – EVOKE INTERFERENCE AND FACILITATION EFFECTS

Incongruent condition – also called "interference/incongruent prime, condition or trials," or "novel incongruent condition"
Congruent condition – also called "facilitation/congruent condition or trials," or "novel facilitation/congruent condition"
Neutral condition – also called "color-splotch condition"
Repeated interference/incongruent probe – also called "incongruent probe"
Facilitation/congruent probe – also called "congruent probe"

TABLE 6. Experimental condition terminology.

Houghton and Tipper (1994) discussed our ability to perceive multiple items in the environment, suppress activation related to the unwanted items and boost activation and response execution related to the target items. This initial stage of the model speaks to interference and facilitation, the domain of Research Question 1.

5.A.1. Interference effects

In the present study, PWA and Controls performed similarly when interference was present: both groups responded significantly more slowly to the novel incongruent condition compared with the novel neutral condition. However, PWA showed more variable and proportionately slower response latency during the novel interference condition compared to Controls. PWA's apparent greater difficulty with interference has also been reported by Hamilton and Martin (2005), Lim et al (2012), McNeil et al (2010), and Wiener et al (2004). Markedly significant interference effects were also observed in PWA's efficiency scores of the CRTT-R (See Table 1 in Methods or Appendix D1&2). The groups, however, did not show significant differences in accuracy.

Using specific components of H&T94's model, there are a variety of reasons that may explain this marked slowing for PWA. (See Background and Significance for definitions and Figures 3-5 for graphic representations of model components.) First, neurological damage could have disrupted the network nodes that comprise the object field, i.e. the object's activated representation based on perceptual inputs. The object field networks are built of numerous property fields, i.e. individual features of an object, with on-channel/excitatory and off-channel/inhibitory function. On-channel/excitatory and off-channel/inhibitory activation occurs with perceptual input, and their corresponding activation levels are adjusted through feedback loops as a target is matched or mismatched. Each channel functions independently (Houghton et al, 1996), and hypothetically, these channels may be damaged independently. Therefore, damage to neural networks could result in poor excitation and/or inhibition at the level of the property units/features and therefore at the broader level of the object field/representation. If these components are impaired, PWA's resulting responses may have been slowed and/or inaccurate when distractions were present. This interpretation of the interference results may be further developed when considered alongside PWA's facilitation results.

In the experiment, PWA as a group demonstrated no significant differences between the the neutral and congruent conditions. Individually, 13 of 19 PWA performed more quickly when the word matched the font color in the congruent condition compared to the neutral condition; 4 of 19 PWA were slower in the congruent compared to the neutral condition; and 2 of 19 PWA had response times that were roughly equivalent in these conditions. Therefore, the on-channels' function within the object field responded to the match of the color and word with an excitatory "boost" to activation for most PWA, while the color and word matched provided no greater or slightly less excitatory activation for other PWA. However, the proportionally slower interference effects for PWA compared to Controls could indicate impaired off-channel function. According to H&T94, a task may demand greater off-channel function when, for example, suppressing dominant word reading in favor of weaker color naming. Therefore, while it seems unlikely that the on- and off-channels would be differently impaired, they may function differently if there are limitations in available resources necessary for optimal channel function. In other words, if the overall level of activation resource is diminished, then we may see more impairment in off-channel function, which requires greater resources/activation, than in on-channel function, which requires fewer resources/activation.

Neurological damage could have also disrupted the target fields, or the internally generated representation of the target as dictated by the goal-state. If the target field is absent, inaccurate or otherwise not maintained, then it may not inform the match/mismatch field to initiate target motor schemas. In other words, if the mechanisms that initiate the responses and actions associated with the goal-state are not wholly intact, then schema execution may either not occur or may be delayed. An examination of both groups' results related to facilitation may shed more light on this interpretation.

5.A.2. Facilitation effects

Control participants did not demonstrate facilitation effects – they were faster to respond to the color splotch condition (neutral) than to the conditions where the word and color matched (congruent). How might H&T94 explain this result? We assume Controls have intact property units and object fields. Their on- and off-channel function should be optimal. So why didn't Controls "take advantage" of the word and font color match, which should boost on-channel/excitation activation and speed response in the congruent condition? The instructions in the experiment – "name the color; don't read the word aloud" – informed the goal-state, and therefore the target and match/mismatch fields as described in H&T94. Additionally, each participant's goal-state (and subsequently these model components) was also informed by the context of the task. This experiment was comprised of 23% congruent, 41% neutral and 36% incongruent total trials (i.e. paired and unpaired; both analyzed and filler trials) presented in pseudo-random order. Congruent trials, therefore, were the fewest of the basic trial types: they comprised just over half of the number of the neutral trials, and 13% fewer than the incongruent trials. Therefore, of the three basic trial types, the congruent trials were the least likely to be habituated by the participants. This may account for Controls lack of facilitation effect – these participants were simply expecting interference more than facilitation. In fact, a number of

Controls reported, "…when the color and the word matched, I double checked my response..." or "…when I saw the splotch, it was a relief because I didn't have to worry about the word…"

Conversely, PWA as a group showed no significant difference between the neutral and congruent condtions – and in fact most PWA were faster to respond in the congruent condition than in the neutral condition. While Control participants appeared to adapt their response strategy to accommodate the task context, only 4 of 19 PWA demonstrated a similar pattern in response latency. Instead, most PWA demonstrated facilitation to some degree even though the neutral condition was more frequent than the congruent condition. Hogge et al (2008) used a similar proportion of congruent, neutral and incongruent trial types as in the present study and reported similar results – i.e. "reverse facilitation effects" – for not one but all participant groups (younger adults, older adults, probable Alzheimer's disease adults).

As described by Cohen et al (1990), even processing considered more automatic, such as what is required for the congruent condition, may become slower depending on the surrounding context. The individual's "weighting" of stimulus types is altered within the early stages of the task. This phenomenon has been described in a number of ways in subsequent reports. Some have described these contextual factors as "mental set," or how the individual may differently apply suppression to the task given the context (Catena et al, 2002; Marí-Beffa, Fuentes et al, 2000). Kane & Engle (2003) reported the proportion of trial type can influence participants' ability to maintain the goal-state and resolve the conflict presented by interference. Specifically, with a proportionately lower number of congruent trials the "response-competition mechanism" is more fully engaged to respond to a greater number of incongruent trials. This phenomenon is also called "proportion congruent effect" by others (Torres-Quesada, Fúnes, &

Lupiáñez, 2013), which describes how the proportion of congruent and incongruent trial types yield adaptations in cognitive control. Therefore, the relatively fewer number of congruent trials compared to neutral and incongruent trials may have changed Control participants' response strategy, but appears to have not had the same influence on PWA's response strategy.

These results reflect the findings of Tseng et al (1993). While Tseng and colleagues used a different type of experimental task, PWA appeared to be unable to use either explicit or implicit probability information in their task performance, unlike their neurologically healthy counterparts. Tseng and colleagues attributed this performance difference to PWA's inability to appropriately allocate attention in evaluating the demands of the task. In another study, Lim et al (2012) concluded PWA were unable to use contextual information within an experimental task. Specifically, PWA demonstrated no significant differences in error rates when comparing two conditions with proportionately different number of incongruent trials: one 19% incongruent and the other 73% incongruent. The authors concluded that these results indicated impaired goal maintenance, a component of executive attention and working memory capacity.

5.A.3. Results and working memory capacity in aphasia

The results of the present study align with other previous research of working memory impairment in people with aphasia (including Caspari et al, 1998; Hula & McNeil, 2008; Lim et al, 2012; McNeil et al, 2010; Sung et al, 2009; Wright et al, 2007; Wright & Fergadiotis, 2012; Wright & Shisler, 2005). PWA appear to have diminished working memory capacity, as initially measured in the present study using backward digit span, and significantly diminished vigilance, as measured by Trail Making tests. With diminished working memory capacity, one might expect deficits in conflict resolution (as measured by response latency) and goal maintenance (as measured by accuracy), the mechanisms involved in interference control (Kane & Engle, 2003). The present study appears to underscore these previous results related to conflict resolution: PWA show marked slowing in their responses when interference is present. However, PWA and Controls did not differ significantly in accuracy on any of the condition comparisons (incongruent, neutral, congruent). This result is contrary to McNeil et al (2010) and Lim et al (2012), both of which reported significantly greater error rates for PWA compared to Controls. Interestingly, the present results suggest that while PWA were unable to integrate task contextual factors into their response strategies, they appear able to maintain the goal to some extent, though the present task differs from those reported by McNeil, Lim, and colleagues.

Diminished goal maintenance and cognitive flexibility may also be explored from the overarching perspective of impairment of executive function (Alexander, 2006; Fridriksson, Nettles, Davis, Morro and Montgomery, 2006; Helm-Estabrooks, 2002). However, and regardless of how they are categorized, additional work is necessary to provide more valid measures of these cognitive functions and their relationship to one another, especially in relation to aphasia (Donovan, Kendall, Heaton, Kwon, Velozo, and Duncan, 2008).

5.A.4. Final note about facilitation results

One might consider the present study's facilitation results another way: PWA have anomia, or difficulty retrieving the correct lexical item from purely perceptual input, presented in this study in the neutral condition. Conversely, when Controls are faced with a neutral trial, they have no trouble retrieving the word directly from the perceptual input. In and of itself, one might assume the neutral condition would naturally be more difficult for PWA, regardless of contextual factors, and therefore expect the reported neutral vs. congruent condition results. Since the present study did not include a regular reading condition, we cannot speak to the nature of the neutral condition responses relative to regular reading within this experimental framework. However, the participants' CRTT-R scores (see Table 1 in Methods or Appendix D1&2) indicate that there were no significant between-group differences when comparing the neutral and regular reading conditions in efficiency (calculated using sentence reading response latency data) and accuracy. These scores indicate that the neutral condition may be relatively good baseline measure for both participant groups, i.e. even participants with anomia.

5.A.5. Summary of Research Question 1

Given the proportionally greater interference effects and the insignificant group facilitation results shown by PWA, these participants have potentially demonstrated a) impaired off-channel/inhibitory function, possibly due to b) limits to the available resources (attention) necessary for off-channel/inhibitory function, and/or c) limited working memory capacity, as demonstrated not only by greater interference effects, but also an inability to integrate contextual information into their responses.

5.B. RQ2 – TESTING REACTIVE INHIBITION VIA INHIBITORY REBOUND

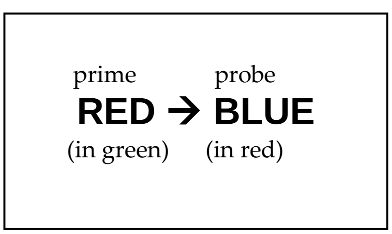


FIGURE 14. RQ2a stimuli. Repeated interference/ incongruent probe (prime distractor becomes probe target), compared against novel incongruent.

5.B.1. RQ2a Repeated interference/incongruent probe vs novel incongruent condition

Reactive inhibition is reported to be evidence of a mechanism of selection (H&T94; Houghton et al, 1996; Tipper et al, 1991). The most traditional test of reactive inhibition is a negative priming paradigm in which two incongruent trials are presented as prime-probe trial sets: the prime distractor (e.g. color-word) becomes the probe target (e.g. font color)(Figure 14). Hypothetically, a response to a target that has just served as a distractor should be delayed. This delay indicates that the prime distractor has been suppressed and entered a state of inhibitory rebound (H&T94), and is therefore temporarily unavailable for selection. This effect has been studied numerous ways, and with varying results. (Because most of these studies reportedly test the "negative priming effect," I will use this terminology below to describe the presence of inhibitory rebound, a la H&T94.)

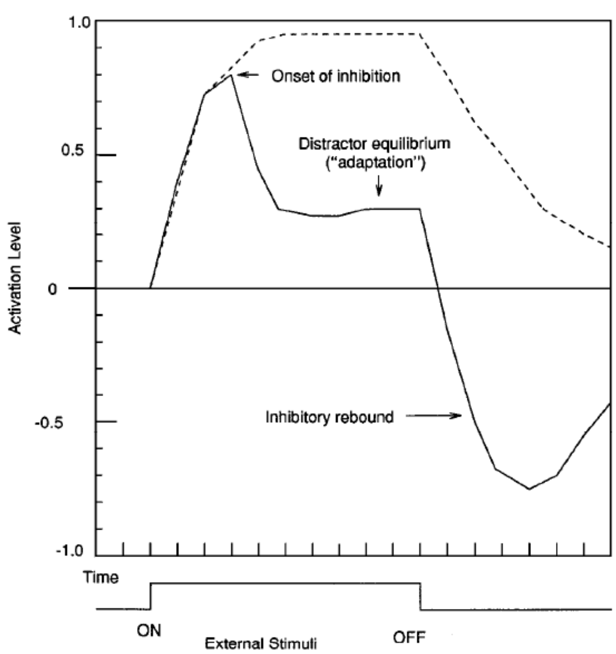


FIGURE 15. Houghton & Tipper (1994) prime stimuli activation and subsequent inhibitory rebound, from Houghton et al (1996, pg 130).

As described previously, H&T94 hypothesized that activated on- and off-channels reach distractor equilibrium while, for example, an incongruent prime is visible (see Figure 15). At the offset of the incongruent prime, the greater magnitude off-channel/ inhibition overcomes the weaker on-channel/excitation,[12] forcing the representation for the distractor (e.g. the color-word) below threshold temporarily.

[12] Reminder: the word representation is so well-established that it requires greater off-channel/inhibitory activation to suppress it, relative to on-channel/excitatory activation required for color-naming.

A short time later (within seconds or less), if the inhibited distractor is re-presented as the probe target, the response will be slowed.

In the present study, between- and within-group analyses revealed neither Controls nor PWA demonstrated significant inhibitory rebound via negative priming. Additionally, there were no significant between-group differences on accuracy scores. While PWA responded significantly slower than Controls on both the novel incongruent condition and the repeated interference/incongruent probes, group results show the incongruent probes were only slightly slower than the novel incongruent condition for both participant groups. This result was not statistically significant either within groups or between groups. In other words, when examining these results alone there appears to be little carryover effect of the prime distractor onto the probe target within the context of these experimental conditions.

However, further post-hoc analyses of within-group response latency data revealed an interesting finding: both groups can be split between participants who demonstrated significant negative priming effects and participants who demonstrated significant positive priming effects on the repeated interference/incongruent probe compared to the novel incongruent condition.[13] Nine PWA demonstrated significant within-group negative priming effects (p=.001); eleven Controls demonstrated significant within-group negative priming effects (p=.002). Ten PWA demonstrated significant within-group positive priming effects (p=.013); eight Controls also demonstrated significant within-group positive priming effects (p=.001). One Control demonstrated nearly equal response latencies in the conditions under consideration.

[13] This post hoc analysis was conducted by taking the difference between the novel incongruent condition and the repeated interference/incongruent probe for each participant. Then participants who were slower in the repeated interference/incongruent probe condition were compared (t-test) on these conditions; the same comparison was made for participants who were slower in the novel incongruent condition.

Interpreting these findings using H&T94's model, it appears about half of the participants in each group may have supplied the prime distractor with enough off-channel/inhibitory activation to push the representation into a state of inhibitory rebound, making subsequent selection during the probe trial slower. However, it appears the other half of participants in each group did not demonstrate sufficient off-channel/inhibitory activation to warrant evidence of inhibitory rebound. Furthermore and surprisingly, the prime distractor may have had so little off-channel/inhibitory activation that a degree of excitation carried over into the probe trial response, making this response faster than the novel interference/incongruent prime trial. These positive priming effects could therefore be called repeated interference facilitation.

5.B.1a. Previous reports of repeated interference facilitation

Neither H&T94 nor Houghton and colleagues (1996) speak specifically to facilitatory effects following interference. Many studies of the negative priming effect explored either the presence, magnitude or absence of the effect, and do not address positive priming (Andrés et al, 2008**;** Engle et al, 1995; Filoteo et al, 2002; Gamboz el al, 2002; Hogge et al, 2008; Mayas et al, 2011; Stuss et al, 1999; Titz et al, 2008; Vitkovitch et al, 2002; Verhaeghen & DeMeersman, 1998b). Other reports of facilitation during negative priming give accounts of stimuli that have been degraded (Kane, May & Hasher, 1997), or an absence of interference in the probe trial (Catena et al, 2002; explored in-depth in discussion of RQ2b), or when the prime consists of a "low level perceptual task" (i.e. letter search in target word; Marí-Beffa et al, 2000). None of these issues are consistent with the stimuli or methodology involved the current condition comparison. However, both Metzler and Parkin (2000) and McDonald and colleagues (2005) reported some participants with left frontal lesions demonstrated positive priming effects on a negative priming task. While these results may help explain the findings for one group in the present study, they do not account for the positive priming/repeated interference facilitation observed in neurologically healthy Control participants.

5.B.1b. Variable evidence of reactive inhibition

Puzzling and inconclusive findings related to negative priming/reactive inhibition are not uncommon. Houghton and colleagues (1996) conceded that because negative priming effects are unreliable from one study to the next, the effects may vary given the experimental methods and context (also Fox, 1995; Gamboz, Russo & Fox, 2002). First, instructions to participants about speed and accuracy of response could influence the resulting negative priming effect. For example, if accuracy is encouraged over speed, then a negative priming effect may be greater. If speed is encouraged over accuracy, then positive priming may result (Fox, 1995). In the present study, participants were told to balance speed and accuracy.

Second, difficult prime trial selection may result in a more consistent negative priming effect. H&T94 reported that when the degree of interrelationship between the stimuli is high there is greater interference; related object fields share property nodes, and therefore influence each other's relative activation. The present experiment used five stimuli within the color category, yielding a high degree of semantic relationship between stimuli. However, all participants received practice prior to the experiment, habituating them to the stimuli and the task, potentially making the task easier. The relative difficulty level in the present study is also reflected in the accuracy results: participants' accuracy scores were 87.3% for PWA and 98.0% for Controls for the more difficult incongruent condition. However, other studies have used similar closed-set Stroop stimuli and found consistent negative priming effects (Andrés et al, 2008; Hogge et al, 2008; Titz et al, 2008).

Third, while there are a number of variables that yield inconclusive negative priming results, such as stimuli presentation duration, interstimulus interval and probe stimuli type, these variables were well-considered and controlled within this study. However, Fox (1995) outlined another reason individuals may vary in their demonstration of a negative priming effect: cognitive slowing or advanced age. Indeed, the present study included many participants who fit either one or both of these criteria. However, studies that have examined cognitive slowing, aging and negative priming have reached varied conclusions.

5.B.1c. Aging and reactive inhibition via negative priming

A number of studies of inhibition via negative priming have reported the effect does not vary with age (Andrés et al, 2008; Gamboz et al, 2002; Hogge et al, 2008; Titz et al, 2008), while others have reported that negative priming effects dissipate – though not reverse – with age (Hasher et al, 1991; Kane et al, 1994; Mayas, Fuentes, Ballesteros, 2011; Stolzfus et al, 1993; some of which based on the early work of Hasher & Zacks, 1988). Notably, all of these studies showed a consistent and significant difference between age groups in the interference effect: older participants (generally 60 and up) showed a more pronounced interference effect than younger participants (generally 18-30).

The post-hoc analyses that revealed the negative and positive priming results for each group were further investigated with regards to participant age. Age differences were not statistically significant for PWA ($p=.61$): PWA who demonstrated a negative priming effect had a mean age of 56.0 (SD 13.0); PWA who demonstrated a positive priming effect had a mean age of 56.6 (SD 14.0). However, age differences were nearly statistically significant for Control participants (p=.05): Controls who demonstrated a negative priming effect had a mean age of 55.3 (SD 9.1); for Controls with a positive priming effect, the mean age was 62.5 (SD 5.3). Though this analysis is conjectural and beyond the goals of the research questions, it alludes to a possible difference between groups. However, these findings are better addressed with tightly controlled analyses outside the scope of the present study.

5.B.1d. Summary

In summary, the results of these analyses reveal that PWA and Controls performed similarly when there is repeated interference, though there are some perplexing and highly variable within-group results currently unexplained. Regardless of group, some participants demonstrated inhibitory rebound while other participants demonstrated repeated interference facilitation. See General Discussion for further and more integrated interpretations of these and other results.

5.B.2. RQ2b Repeated interference/incongruent probe vs. facilitation/congruent probe

prime		probe
RED	→	**RED**
(in green)		(in red)

FIGURE 16. RQ2b stimuli. Facilitation/congruent probe (prime distractor becomes congruent probe), compared against incongruent probe.

In RQ2a, we looked at inhibitory rebound using a repeated interference/incongruent probe, one in which the prime distractor became the probe target in two back-to-back incongruent trials, a traditional “negative priming” approach. The current research question was created to examine inhibitory rebound as well, but from a different angle. This time, we tested reactive inhibition with a strongly represented probe, where the prime distractor becomes a congruent probe (Figure 16).[14]

Results show that the two groups performed significantly differently in this condition comparison. Both PWA and Controls showed a marked difference between the probe types: responses to the facilitation/congruent probes were significantly faster than responses to the repeated interference/incongruent probes. However, the difference between these conditions was much greater for PWA compared to Controls, yielding a statistically significant between-group difference. (It is important to note that the individual variability within each group observed in the previous question was not observed within this condition comparison.) Additionally, PWA showed a significant within-group difference in accuracy scores when comparing these conditions: incongruent probes during repeated interference were the least accurate of any condition, and significantly less accurate than facilitation/congruent probe responses. These accuracy results are in line with the comparison of these conditions: PWA's diminished accuracy in the repeated interference condition highlights the challenge that interference presents during word finding relative to facilitation/congruent probes.

Based on H&T94, a facilitation/congruent probe should yield a faster response compared to a repeated interference/incongruent probe, though not as fast as the novel facilitation/congruent condition. Using the model components to explore these responses, let's

[14] Several negative priming studies are divided on the efficacy of a congruent probe, i.e. a probe without interference, to test reactive inhibition (Fox, 1995; Tipper, 2001; Tipper & Cranston, 1985; Yee, 1991). Some report congruent probes do not allow participants to maintain a "selection state" necessary to see the presence of inhibition. To test this hypothesis, Groh-Bordin & Frings (2009) examined the negative priming effect using a congruent probe, and their results supported the hypothesis in part: if participants anticipate a congruent probe, they will not maintain a selection state and inhibition will not be evident. However, participants in the present study could not anticipate congruent probes as they occurred equally with intermixed incongruent probes. Therefore, the use of congruent probes appears a valid way to test inhibitory rebound, but only if participants cannot anticipate these types of probes.

examine the on- and off-channel function of the object field. If the prime distractor has entered a state of inhibitory rebound due to a greater magnitude of off-channel/inhibitory activation, it is temporarily unavailable for retrieval. However, retrieval speed may be altered given the characteristics of the probe stimulus. An incongruent probe is comprised of some on-channel/excitation and some off-channel/inhibitory activation, yielding a diminished excitatory activation necessary to bring the representation to response threshold. On the other hand, a congruent probe is comprised of only on-channel/excitatory activation, yielding a greater amount of overall excitatory activation to bring the representation to response threshold. So while in both cases, there is inhibitory rebound to overcome, the congruent probe has more net excitation for a faster response. H&T94 described the use of this type of probe as "rapid and effective, though there is still some lag…" (pg 96).

While we would expect to see significant differences between these condition comparisons, it is difficult to interpret the between-group differences with regards to the model, its underlying mechanisms, and their potential impairment. That is to say, if we take into consideration the previously discussed results, wherein a) PWA as a group showedno significant facilitation or reverse facilitation effects, while Controls showed significant reverse facilitation effects, b) PWA showed a markedly greater interference effect, and c) both groups showed similar but widely variable results related to the presence of inhibitory rebound or repeated interference facilitation, then the results that address this question are muddy at best. On one hand, since individuals within both the PWA and Control groups are demonstrating significant response variability related to subsequent suppression of the prime distractor, the difference in response due to probe type may not be observable with regards to reactive inhibition. On the other hand, the results for this comparison may also be influenced by the interference (and for many, facilitation) inherent within the probe trials. Put differently, the between-group difference could be due to a combination of slower interference effects and, for many, the presence of facilitation in PWA responses.

5.B.2a. Summary

In summary, these results must be interpreted with some hindsight perspective. This research question proposed a comparison of repeated interference/incongruent probes with facilitation/congruent probes. Since both interference effects and either facilitation or reverse facilitation effects are likely at play in this comparison, we cannot differentiate how much of each may be contributing to the overall result. This question would have been better explored by comparing each probe type to a neutral probe. For example, if the present study had included a neutral probe that had just served as the prime distractor (e.g. prime=RED in green; probe=red splotch), interference effects could have been separated from facilitation or reverse facilitation effects, yielding a clearer picture of the mechanisms underlying response differences.

5.B.3. RQ2c – Facilitation/congruent probe vs. novel facilitation/congruent condition

Like the previous questions, this question examines the presence of inhibitory rebound with a final comparison: facilitation/congruent probes compared to the novel facilitation/congruent condition. The results of this condition comparison were not statistically significant, but were nearly so, and interesting. Both PWA and Controls showed a trend toward a significant difference between the novel facilitation/congruent condition and the facilitation/congruent probes within groups: the congruent probes were slower than the novel congruent condition for both groups. There was also a nearly significant difference between groups: PWA were significantly slower with the congruent probe compared to Controls. (Of note, the individual variability within each group observed in RQ2a was not apparent in this condition comparison.)

These non-significant results fit within H&T94 model. As described in the last section (RQ2b – see page 72), H&T94 reported that a congruent probe following an incongruent prime will demonstrate just slight slowing compared to a novel congruent trial. Specifically, when the incongruent prime distractor has entered into inhibitory rebound, a congruent probe provides exclusively on-channel/excitatory activation to the object field. As such, this strongly activated representation is able to retrieve the inhibited representation for selection. Only a slight delay would be expected when compared to a novel congruent trial.

On the other hand, there are a couple potential explanations for the trend toward a more significant slowing of the congruent probe compared to the novel congruent condition for PWA. First, if using the H&T94 model exclusively, it appears as if there may be possible carryover effects from the prime trial to the probe trial response. In other words, there is a suggestion of inhibitory rebound impeding the retrieval of the former distractor-current congruent probe. However, if we consider the results to RQ2a, the lack of significant between-group results coupled with the similar and broad individual variability within groups motivates other interpretations of these near-significant findings.

Second, these results may suggest the influence of trial type and order on responses. If the participant had trouble switching from the interference presented in the prime trial to the facilitation presented in the congruent probe trial, we may see a difference when comparing the congruent probe to a novel congruent trial. A way to consider this is through the lens of "conflict monitoring" or "conflict adaptation" (Botvinick, Braver, Barch, Carter & Cohen, 2001; Torres-Quesada et al, 2013; respectively), wherein the participant begins to monitor for conflict/interference once it has occurred. Therefore, if the prime trial is incongruent, the participant becomes unconsciously "ready" for another incongruent trial. In the present study, Controls showed a slight slowing effect of the facilitation/congruent probes compared to the novel facilitation/congruent condition. PWA showed a more pronounced slowing of the congruent probes compared to the novel congruent condition. We may interpret these results as PWA had more difficulty adapting to a congruent probe when preceded by an incongruent prime. PWA may therefore have diminished ability to adapt to changes in the task.

5.B.3a. Summary

In summary, it is difficult to say more about these interpretations since the results are not statistically significant. As such, both PWA and Controls appear to fit within H&T94-motivated predictions – a slight slowing of the congruent probe compared to the novel congruent condition is expected. However, the near-significant between group differences inspire additional questions about PWA's ability to adapt to changing conflict resolution requirements, and may warrant further study.

5.B.4. Summary of Research Question 2

Overall group results indicate that both participant groups showed statistically similar absence of inhibitory rebound. However, when looking closer, both groups included individuals who demonstrated significant inhibitory rebound as well as individuals who demonstrated significant repeated interference facilitation. In other words, the groups were quite similar in their variability given the context of repeated interference. However, we cannot disregard the potential influence of age, the influence of experimental methods, and the possible inability of PWA to adapt to moment-by-moment changes in contextual factors. Given these results alone, we may interpret these findings to mean that PWA and their neurologically healthy counterparts are similarly able to participate in lexical retrieval of the item in the moment considering the influence of a previous distraction, an indicator of automatic inhibition, addressed below.

5.C. GENERAL DISCUSSION

While the discussion above gives us some interpretations of the results independently, additional interpretations exist when integrating the results. First, as mentioned previously, while one might predict a positive correlation between interference and inhibition – i.e. the greater the interference stimulus (successfully suppressed), the more pronounced the inhibitory rebound – the relationship between the two is complicated and not well-understood, as the present study's results emphasize. It is this complex relationship that led Houghton and colleagues (1996) to conclude that inhibition alone cannot be responsible for selective attention. In the present study, we see proportionally greater interference effects for PWA, and similarly variable evidence of reactive inhibition in PWA and Controls. The distinction between the two constructs warrants further discussion.

Specifically, the response lag we observed during novel interference/incongruent condition (i.e. interference control) is considered the result of a deliberate effort to suppress a distraction; the response lag related to repeated interference/incongruent probes (reactive inhibition) is considered the automatic, unintended suppression of a previously activated semantic representation (Andrés et al, 2008). Using Cohen and colleagues' (1990) view of automatic and controlled processes, interference control requires greater attentional resources than the automatic inhibition seen in reactive inhibition/inhibitory rebound (see also Engle et al, 1995). The results of the present study are in line with the variable attentional demands of interference control and reactive inhibition. While PWA showed great difficulty with attention-demanding interference control, as a group they appear quite similar to healthy Controls in the less attention-demanding reactive inhibition.

Some lesion data supports the present findings, though in a general way. Conway and Fthenaki (2003) report patients with both frontal and temporal brain lesions had more difficulty with the more attention-demanding "intentional" inhibition (even more pronounced in frontal lesion patients) than with less attention-demanding automatic inhibition. Their hypotheses are also in line with findings by Jonides and Nee (2006) and Nelson et al (2009), who reported the processes involved in interference control, i.e. executive inhibition, are reportedly located in the left inferior frontal gyrus. It is important to note that McDonald et al (2005) and Metzler and Parkin (2000) reported patients with inferior frontal gyrus lesions may not exhibit automatic/reactive inhibition when tested using negative priming tasks, though Conway and Fthenaki (2003) provided the same interpretation for patients with left temporal lesions. Taken together, these studies described inhibition-related impairments in regions that are highly connected and often implicated in aphasia. However, the striking similarity of the two participant groups in the present study when examining responses to the repeated interference condition does not motivate study of negative priming and lesion site. Instead it underscores the influence of individual variability when attempting to capture the presence and magnitude of reactive inhibition – variability that may be unaffected by the impairments of aphasia.

The between- and within-group differences in interference and facilitation effects (or lack thereof) suggest diminished executive inhibition and therefore attentional resources for PWA, as reported in previous studies (Hula & McNeil, 2008; McNeil et al, 1991; Murray, 2012, among others). As the variable component of working memory, diminished attention also points to limited working memory capacity in aphasia (Wright & Fergadiotis, 2012). In the present study, diminished working memory capacity is evidenced by PWA's a) apparent inability to integrate contextual information into their responses, b) potentially diminished adaptability to the presence and absence of interference moment-by-moment, along with c) impaired performance on span tasks. These interpretations are also supported by work outside of aphasiology. As described previously, Grandjean and Collette (2011) examined inhibitory function and its correlation with individual working memory capacity. Building upon the work of Kane, Engle and colleagues (2001; 2003), Grandjean and Collette found participants with low working memory span, like PWA in the present study, had diminished inhibitory ability compared to individuals with higher working memory span, especially observed in tasks with increased attentional demands. The authors interpreted this difference between participant groups as limitations in attentional resources for working memory/conflict resolution tasks, a conclusion that fits the PWA in the present study as well.

5.D. STUDY LIMITATIONS

A number of factors limit the interpretation of these results, especially related to missing data on 1) regular reading ability, 2) undifferentiated excitation and inhibition on probe trials, 3) younger participant performance, and 4) consistent participant reports of experimental experience. First, the present study did not include a condition to capture response latency and accuracy during reading aloud. While participants' CRTT-R scores (both overall accuracy and efficiency) indicate no significant differences between groups when comparing regular reading and neutral conditions (see Table 1 in Methods or Appendix D1&2), including a regular reading condition as an additional baseline measure would have given us information about how PWA's orthographic to lexical retrieval abilities differ from semantic to lexical retrieval abilities. Additionally, in a study reported by McNeil et al (2010), post hoc analysis revealed participants with faster regular reading times demonstrated greater interference effects compared with participants with slower regular reading times. This finding further motivates a regular reading condition in future studies of interference and inhibition.

Second, the present study included a direct comparison of interference and facilitation probe trials (RQ2b). This type of comparison averages interference and facilitation effects, making it impossible to understand the presence and magnitude of each. A neutral probe condition, where a prime distractor becomes a probe color-splotch, would have been useful addition. The comparison of a neutral probe to a repeated interference probe would have yielded better information about interference effects; comparing a neutral probe to a congruent probe would have yielded better information about presence, absence or reverse facilitation effects. These probe-specific interference and facilitation effects could have also helped further distinguish evidence of inhibitory rebound.

Third, the present study did not include data on younger (ages 18-30) participants to further account for potential age differences in reactive inhibition. By including younger participants, more information would have been available about the presence, absence or reversal of negative priming given this particular experiment and its methods.

Last, many but not all participants were asked about their experience of the experiment following its administration. This general (and intentionally vague) question helped to identify two Control participants who used a strategy during the experiment (e.g. one was able to predict probe stimuli), thus eliminating them from the analysis. There may have been other participants who used a strategy, but were not asked about this.

5.E. FUTURE DIRECTIONS

In addition to addressing the missing elements described above, there are many potential directions to pursue, some that could augment the present study and others that may build upon it to further this line of research. Ultimately, all of these possible directions build toward the same goal – understanding the degree and influences of impaired selective attention in language processes in aphasia.

While the conditions in the present study did not result in consistent evidence of inhibitory rebound, this phenomenon must be explored a few additional ways before concluding impairments in reactive inhibition is or is not a factor for PWA. First, using a repeated interference condition in which the probe is wholly novel would provide information on performance related to interference control vs. carryover suppression from prime to probe trial (as tested in the present study). Second, exploring if site of lesion (as in Wiener et al, 2004) has any bearing on interference control may indeed prove illuminating (though evidence presented in this study does not support this direction), especially given the work by Jonides, Nelson and colleagues (1998; 2006; 2009) that implicated specific regions (i.e. LIFG) involved in interference control and aphasic impairment. Third, while H&T94 reported positive priming stems from a different but related attentional mechanism, it would be valuable to include a priming condition using the same stimuli and timing parameters of the present study. The resulting data could provide additional information about the nature of excitation in aphasia, thus furthering our understanding of its relationship to reactive inhibition and interference control, especially given the surprising repeated interference facilitation demonstrated by many participants. Fourth, an examination of the present study's error types (see Appendix K) may provide some compelling additional information about inhibitory and excitatory mechanism function in aphasia, especially in relation to contextual factors of condition and stimuli type. Fifth, an exploration of "conflict adaptation" (Torres-Quesada et al, 2013) may result in further clarification of the influence of selective attention and its impairment in language processes in aphasia. Last, efforts have already begun to examine the presence of inhibitory rebound in a silent sentence reading task involving repeated interference of incongruent color words (CRTT-R; McNeil et al, 2010).

Since the present study tested participants using a closed semantic category, it would be interesting to explore interference and inhibition across semantic categories. A cross-category study of interference was undertaken by Lim et al (2012), and building upon this study with some conditions that address inhibition may yield useful information, potentially using the components of H&T94 model that focus on the semantic-relation effects of a distractor.

All of the potential directions listed above relate to interference control and reactive inhibition in the reading and visual modalities. While we would not anticipate a significant difference between aphasic impairments in different modalities, it would be useful to examine interference control and reactive inhibition with aurally presented stimuli. When considering distractions and language processes, especially in clinical environments, we often think of auditory distractions, such as noisy environments or surrounding conversations. Buchner and Mayr (2004; also Mayr & Buchner, 2006) and others have studied auditory negative priming, including use of auditory Stroop stimuli. An auditory examination of interference and inhibition would add depth to this line of research.

Lastly, participants in the present study provided self-reported information on levels of attention and focus using The Attention Questionnaire (Sohlberg et al, 2001). A regression analysis of these self-report scores compared to performance in the present study might yield some useful information about PWA awareness of their abilities and how these abilities influence everyday communication in the midst of distraction.

CHAPTER 6

Conclusion

"In normal conditions the process of choice does not evoke difficulty. The high selectivity of higher nervous processes provides all the necessary conditions for adequate word finding and, as a rule, strong (or significant) traces or connections are evoked readily whereas weak (or insignificant) traces or connections are easily blocked. … All these conditions are severely affected in pathological states of the brain."

– Alexander Luria (1973)

People with aphasia appear to have difficulty with simultaneously presented distracting stimuli and integrating contextual information into language processes. Both of these hypothesized impairments may relate to diminished or misallocated executive attentional resources necessary for both of these working memory processes. However, PWA and Controls have similarly variable demonstrations of automatic/reactive inhibition of previously activated distractions, which suggests that this type of inhibition is not a factor in the word finding impairments in aphasia.

This study highlights the importance of understanding the impact of distraction and the mechanisms of selective attention in people with aphasia within clinical environments as well as in everyday life. Specifically, how do we adequately measure an individual's ability in interference control and integrating contextual factors into language processes? A few measures exist, though they are not sensitive enough to fully understand these types of impairments and the extent to which they influence the presenting language impairments of aphasia. Furthermore, many practicing clinicians are not aware of these factors in assessment and treatment, and few consider these potential impairments in clinical activities. The work ahead is essential: build upon our understanding of the role selective attention plays in language impairments in aphasia, create more sensitive measures of attention and executive function in aphasia, and build toward more effective treatments of aphasia.

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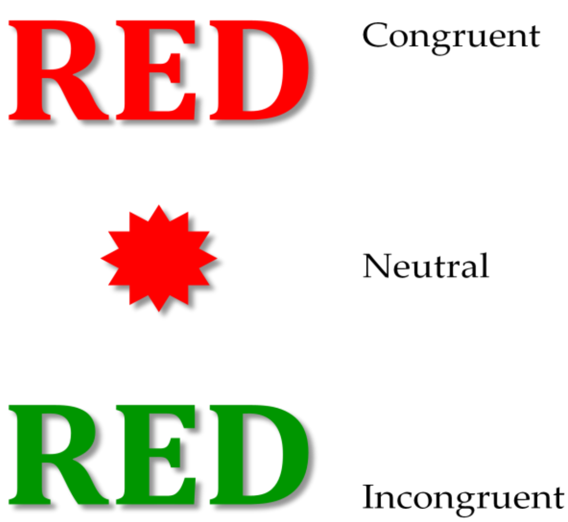
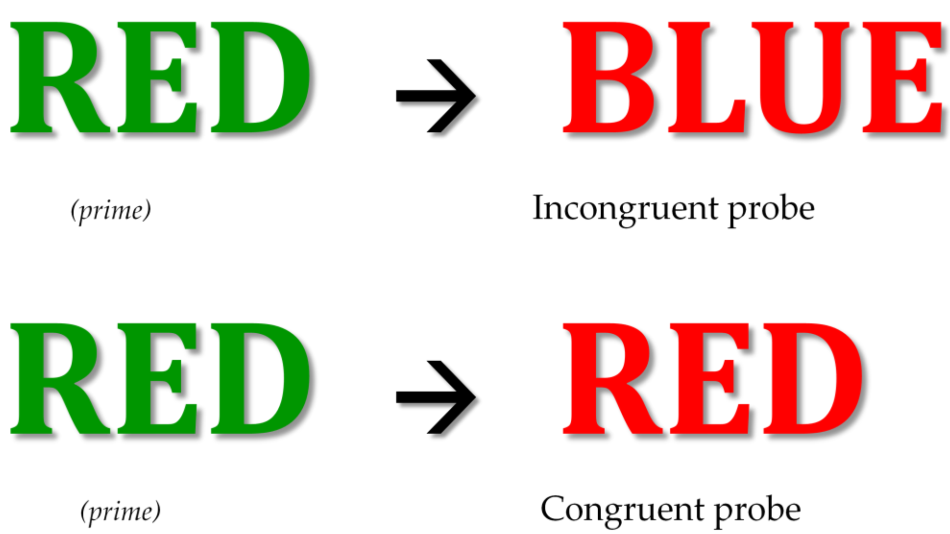
Appendix A
Stimuli examples

Examples of Stroop color-word stimuli:

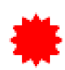


Examples of Stroop color-word stimuli used in negative priming/repeated interference prime-probe trial pairs:



Appendix B

Research questions with stimuli examples

	Con	Inc (prime)	Neu	Inc probe	Con probe
RQ 1 Interference (Inc-Neu) & Facilitation (Neu-Con)	RED	RED			
RQ 2a Repeated interference/ incongruent probes vs. novel incongruent condtion (prime trials)		RED		BLUE	
RQ 2b Repeated interference/ incongruent probes vs. Facilitation/ congruent probe				BLUE	RED
RQ 2c Facilitation/congruent probes vs. novel facilitation/ congruent condition	RED				RED

Appendix C.1.

PWA demographic information

participant	age	gender	yrs ed	mpo	presence of AOS	presence of dysarthria	lesion data per neurologic report
101	67	M	15	23	mild	none	left sylvian fissure region and basal ganglia
102	50	M	20	8	none	moderate	left internal capsule extending into the thalamus, posterior basal ganglia
103	70	M	25	32	mild	none	left basal ganglia, adjacent insular cortext, left corona radiata
104	48	F	16	17	none	none	left middle and inf temporal gyri; superior temporal gyrus, posterior insula
105	52	M	16	43	mild	none	(participant reported left hemisphere lesion; no neuro report available)
106	65	M	23	53	none	none	left posterior frontal, left parietal and posterior temporal lobe
107	68	F	14	180	none	none	left cortical infarct
108	34	M	12	15	mild	none	left medial anterior cingulate gyrus, superior frontal cortex
111	58	M	16	47	mild-mod	none	left basal ganglia, posterior frontal lobe, temporal lobe, parietal cortex
112	67	F	16	169	none	none	left temporal lobe cortex, insular cortex and the temporal or opercular cortex
113	74	M	18	108	none	none	(participant reported left hemisphere lesions; no neuro report available)
114	34	F	15	50	none	none	left MCA territory
115	62	F	16	101	none	none	left temporal frontal parietal
116	51	F	13	24	moderate	none	left rostral sup temporal, incl sup temp gyrus, insula, frontal, parietal lobe
117	69	M	17	126	moderate	mild-mod	left frontal
118	48	F	12	40	none	none	left basal ganglia and external capsule
120	61	F	16	24	moderate	mild	extensive frontal involvement, temporal lobe, superior temporal gyrus, insula
121	62	F	18	159	mild-mod	none	left putamen, globus pall, caudate head; insular cortex, frontal int capsule
122	30	F	14	19	moderate	none	ant left temporal lobe, extensive frontal operculum, some parietal lobe; small at margin of gyrus-right frontal operculum, high right parietal region
mean	**56.3**		**16.4**	**65.2**			
sd	**13.1**		**3.4**	**56.7**			

Appendix C.2.
Control participant demographic information

participant	age	gender	yrs ed
201	41	F	16
202	45	F	16
203	45	F	15
204	52	F	19
205	53	F	14
206	59	F	12
207	69	M	16
208	66	M	13
209	48	M	16
211	60	F	16
212	63	M	19
213	66	F	18
214	66	F	18
215	61	F	14
216	43	F	16
217	56	M	18
218	60	M	16
219	67	F	16
220	67	F	15
222	62	M	16
mean	**57.5**		**16.0**
sd	**9.02**		**1.85**

Appendix D.1.

PWA diagnostic and screening data

	Trail Making (sec)		Digit Span			CRTT-R									
PWA	A	B	Forward	Backward	Attn. Quest.	Read score	Read Eff	Neu Score	Neu Eff	Inc Score	Inc Eff	WAB AQ	BNT	SAPA	Raven's
101	49	135	9	6	28	13.88	2.30	13.81	0.33	13.65	-1.45	86.2	30	129	32
102	59.1	367	2	2	19	12.40	1.96	13.50	2.98	13.50	2.98	58.7	8	88	32
103	45	135	7	4	21	14.24	5.22	14.41	5.51	14.18	4.54	90	57	123	34
104	24	105	6	4	39	13.73	6.95	13.95	7.57	13.80	6.71	90	48	131	35
105	23	90	4	2	13	14.16	7.89	14.17	7.20	14.21	6.51	89.6	51	107	33
106	78	178	6	3	19	13.08	4.43	11.83	4.84	10.08	1.46	78.9	7	98	31
107	25	97	4	4	22	14.49	5.46	13.69	5.85	13.74	2.17	86.9	42	107	--
108	80	135	11	4	28	13.75	4.17	13.66	5.75	13.69	5.75	92.2	58	141	36
111	47.6	150	7	1	14	14.32	4.84	14.13	5.54	14.24	3.72	83.6	42	113	32
112	25	90	7	4	24	14.19	5.09	14.70	5.84	14.63	5.29	99	55	127	33
113	115	365	2	0	27							63.6	35	96	24
114	21.5	47.5	2	0	4	13.68	6.19	13.83	7.88	13.97	7.37	80.4	40	85	35
115	46.8	--	2	2	19	13.65	4.51	13.52	4.05	12.97	2.15	65.5	24	93	12
116	78	403	5	2	24	11.88	0.39	12.60	1.05	12.77	-0.81	73.3	46	113	29
117	37.7	104.2	9	2	44	13.74	1.95	13.44	3.74	12.19	1.95	82.5	57	119	33
118	36.4	122.5	9	7	29							91.9	30	132	33
120	37.7	186	7	4	26	14.00	6.08	14.25	7.61	13.58	5.02	95	54	126	33
121	49.1	95.1	8	5	8	14.47	3.28	14.60	2.72	13.67	1.13	86.8	35	123	34
122	23	59	1	3	18	14.22	7.96	14.89	8.88	14.99	7.62	62.2	19	83	33
mean	**47.42**	**159.13**	**5.68**	**3.11**	**22.42**	**13.76**	**4.63**	**13.82**	**5.14**	**13.52**	**3.65**	**81.91**	**38.84**	**112.32**	**31.33**
sd	**25.14**	**107.17**	**2.94**	**1.85**	**9.57**	**0.71**	**2.13**	**0.75**	**2.41**	**1.11**	**2.76**	**11.89**	**15.96**	**17.66**	**5.50**

Appendix D.2.

Control participant screening data

Controls	Trail Making (sec)		Digit Span		The Attn.	CRTT-R					
	A	B	Forward	Backward	Quest.	Read score	Read Eff	Neu Score	Neu Eff	Inc Score	Inc Eff
201	15.6	32.1	14	11	10	14.81	10.62	14.86	10.89	14.76	9.98
202	29.7	52.3	9	6	9	14.65	8.11	14.65	8.11	14.78	8.35
203	24.1	44	14	10	2	14.70	9.30	14.73	9.66	14.93	9.67
204	20.2	48.2	12	9	14	14.43	9.73	14.48	10.06	14.70	9.80
205	26	75	8	5	15	14.61	7.42	14.61	7.42	14.60	7.74
206	18.6	41.1	10	7	16	14.49	8.33	14.57	9.43	14.64	8.58
207	20.8	34.8	10	6	3	14.47	7.50	14.73	8.06	12.43	7.26
208	32	60	10	8	19	14.13	5.35	13.92	6.05	14.02	5.24
209	22	44.3	14	8	4	14.55	9.22	14.44	9.44	14.35	8.15
211	24.6	56.5	12	5	21	13.78	9.44	14.34	9.60	14.64	9.37
212	25	37	9	8	13	14.35	9.78	14.63	10.10	14.70	9.39
213	34.5	57	12	8	11	14.46	9.97	14.80	10.24	14.76	10.07
214	17.8	48.2	12	10	17	14.61	10.17	14.59	10.56	14.89	9.66
215	32.8	70.2	13	6	18	14.12	7.34	13.87	7.40	14.18	6.76
216	17.5	45.6	12	10	15	14.67	10.15	14.19	9.52	14.47	9.42
217	18.5	39.7	8	7	2	14.82	9.80	14.57	10.06	14.87	8.99
218	28.7	61.4	13	8	11	14.57	8.57	14.45	8.56	14.73	7.65
219	26.4	66	12	5	17	14.37	7.30	14.52	7.53	14.48	6.76
220	22.8	49.7	10	8	14	14.66	9.25	14.70	9.50	14.82	8.76
222	18.3	34.4	10	7	0	14.51	8.79	14.75	9.60	12.52	7.92
mean	**23.80**	**49.88**	**11.20**	**7.60**	**11.55**	**14.49**	**8.81**	**14.52**	**9.09**	**14.41**	**8.48**
sd	**5.57**	**12.27**	**1.94**	**1.79**	**6.32**	**0.25**	**1.32**	**0.27**	**1.27**	**0.70**	**1.29**

Appendix E

Stroop stimuli screen

Score sheet

Participant ID____________ Date of Testing______________ Examiner____________

For each of the 3 steps below, present the 5 cards one at a time (you may demonstrate with a card for each step if necessary). With each card, ask the participant to name aloud the INK/FONT COLOR of the ✹ symbol or color word presented on a card. Mark incorrect responses below. Then shuffle the cards and re-present the same 5 cards <u>in a different order</u>.

<u>STEP I – SYMBOLS:</u> "Name the color of the symbol out loud." (If necessary, show one card to demonstrate.) Shuffle and repeat. Enter a ✓ below for incorrect responses.

	BLUE	RED	GREEN	PINK	WHITE
1st presentation					
2nd presentation					

incorrect ______ % correct _______

<u>STEP 2 – WORDS/CONGRUENT:</u> "Name the **ink color** of the word out loud." (If necessary, show one card to demonstrate.) Shuffle and repeat. Enter a ✓ below for incorrect responses.

	BLUE	RED	GREEN	PINK	WHITE
1st presentation					
2nd presentation					

incorrect ______ % correct _______

<u>STEP 3 – WORDS/INCONGRUENT:</u> "Name the **ink color** of the word out loud." (If necessary, show one card to demonstrate.) Shuffle and repeat. Enter a ✓ below for incorrect responses.

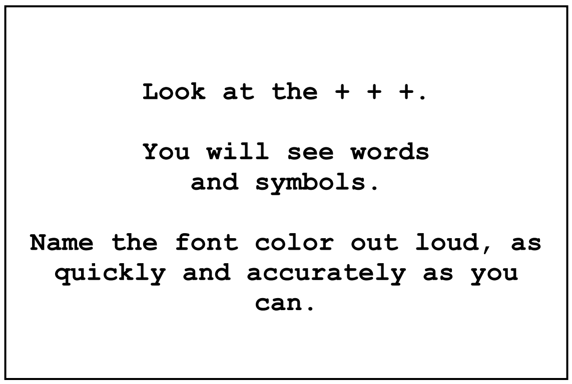
	BLUE in red	RED in white	GREEN in pink	PINK in blue	WHITE in green
1st presentation					
2nd presentation					

incorrect ______ % correct _______

PASS – at least 80% correct on all 3 steps? No_____ Yes_____

Appendix F

Screen-by-screen depiction of the experiment

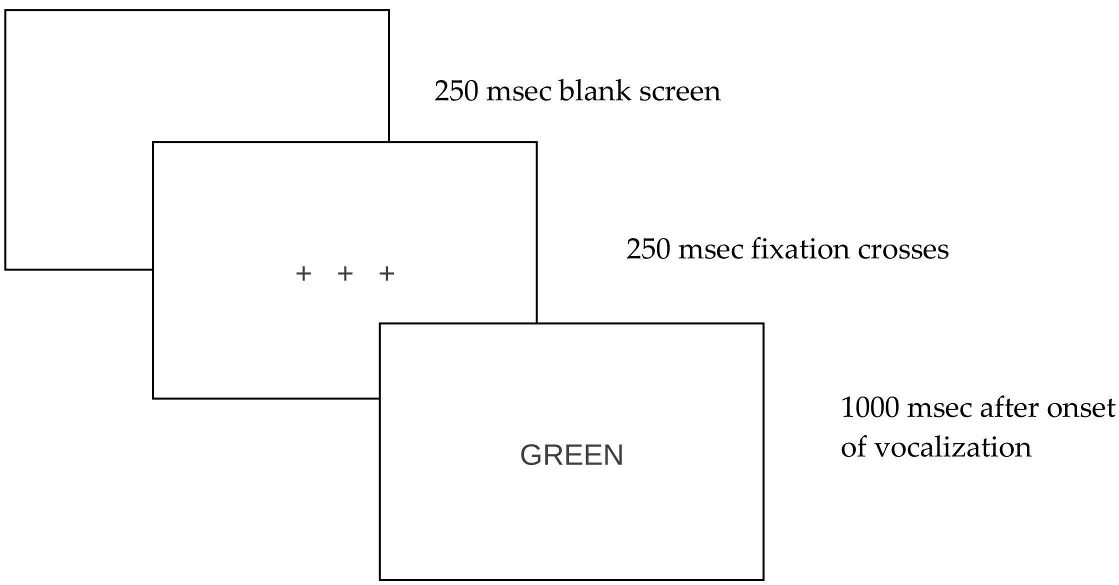


These instructions were presented and read aloud to the participant before the beginning of the practice sets and the experiment. The examiner also reinforced that the participant should:

a) balance accuracy and speed

b) respond without vocal hesitation or self-correction

c) use no strategies (e.g. blurring vision, seeing only part of stimulus)



These screens were repeated for every trial. Prime-probe trial pairs involved a repetition of these three screens.

Appendix G.1.

PWA response latencies/log scores

PWA	Con		Neu		Inc		IncProbe		ConProbe	
	msec	log	raw	log	raw	log	raw	log	raw	log
101	1803	3.256	1648	3.217	2843	3.454	2449	3.389	1661	3.220
102	1106	3.044	1186	3.074	1426	3.154	1400	3.146	1058	3.024
103	1193	3.077	1138	3.056	1910	3.281	2074	3.317	1237	3.092
104	858	2.933	992	2.996	1305	3.116	1336	3.126	938	2.972
105	901	2.955	814	2.910	1091	3.038	1120	3.049	871	2.940
106	873	2.941	956	2.981	1578	3.198	1476	3.169	987	2.994
107	922	2.965	956	2.980	1347	3.130	1340	3.127	1003	3.001
108	1095	3.039	1073	3.031	1336	3.126	1285	3.109	1120	3.049
111	1018	3.008	1112	3.046	1633	3.213	1730	3.238	1101	3.042
112	959	2.982	961	2.983	1146	3.059	1123	3.051	983	2.993
113	808	2.907	1033	3.014	1798	3.255	1966	3.294	1031	3.013
114	1825	3.261	2059	3.314	3173	3.501	3765	3.576	2360	3.373
115	888	2.949	871	2.940	1132	3.054	1130	3.053	878	2.943
116	1305	3.116	1460	3.164	1845	3.266	2054	3.313	1316	3.119
117	2201	3.343	2241	3.350	5586	3.747	6588	3.819	2634	3.421
118	1275	3.105	1297	3.113	1510	3.179	1729	3.238	1451	3.162
120	1014	3.006	1212	3.083	1876	3.273	1786	3.252	1578	3.198
121	1096	3.040	1157	3.063	1851	3.268	1610	3.207	1132	3.054
122	1025	3.011	1337	3.126	1417	3.151	1381	3.140	1140	3.057
mean	**1167**	**3.049**	**1237**	**3.076**	**1884**	**3.235**	**1965**	**3.243**	**1288**	**3.088**
sd	**379**	**0.121**	**382**	**0.118**	**1046**	**0.174**	**1278**	**0.191**	**482**	**0.134**

Note: Each raw msec data point was first log transformed before eliminating outlying data points; msec shown here were calculated from mean log scores for each participant/each condition after outlier elimination.

Appendix G.2.

Control participant response latencies/log scores

	Con		Neu		Inc		IncProbe		ConProbe	
CONTROL	msec	log	msec	log	msec	log	msec	log	msec	log
201	721	2.858	694	2.841	824	2.916	824	2.916	711	2.852
202	679	2.832	665	2.823	757	2.879	778	2.891	671	2.827
203	839	2.924	775	2.890	964	2.984	1025	3.011	806	2.906
204	708	2.850	646	2.810	742	2.871	738	2.868	751	2.876
205	997	2.999	888	2.949	1241	3.094	1261	3.101	1029	3.012
206	757	2.879	756	2.879	909	2.959	880	2.945	789	2.897
207	934	2.970	765	2.884	905	2.957	959	2.982	940	2.973
208	854	2.931	785	2.895	1040	3.017	1013	3.006	827	2.917
209	675	2.829	665	2.823	839	2.924	926	2.967	728	2.862
211	744	2.872	694	2.841	783	2.894	790	2.898	734	2.866
212	530	2.724	583	2.766	769	2.886	753	2.877	560	2.748
213	505	2.703	507	2.705	618	2.791	626	2.796	490	2.690
214	714	2.854	645	2.810	920	2.964	899	2.954	712	2.853
215	827	2.918	793	2.899	874	2.941	897	2.953	852	2.931
216	577	2.761	514	2.711	658	2.818	662	2.821	630	2.799
217	742	2.870	662	2.821	854	2.932	885	2.947	821	2.915
218	697	2.844	644	2.809	801	2.904	794	2.900	694	2.841
219	676	2.830	671	2.827	815	2.911	808	2.908	681	2.833
220	579	2.762	583	2.765	707	2.850	691	2.839	602	2.780
222	713	2.853	680	2.833	794	2.900	823	2.915	729	2.863
mean	**723**	**2.853**	**681**	**2.829**	**841**	**2.919**	**852**	**2.925**	**738**	**2.862**
sd	**125**	**0.076**	**95**	**0.061**	**138**	**0.068**	**145**	**0.071**	**125**	**0.074**

Note: Each raw msec datapoint was first log transformed before eliminating outlying data points; msec shown here were calculated from mean log scores for each participant/each condition after outlier elimination.

Appendix H.1.
PWA accuracy percentages

PWA	Con	Neu	Inc	IncProbe	ConProbe
101	0.975	0.900	0.875	0.829	0.897
102	0.850	0.725	0.638	0.707	0.923
103	1.000	0.975	0.900	0.878	0.974
104	0.975	0.975	0.963	0.976	1.000
105	1.000	1.000	0.988	1.000	1.000
106	0.975	1.000	0.788	0.756	0.923
107	0.950	1.000	0.988	0.927	0.974
108	1.000	0.975	0.913	0.854	1.000
111	0.950	0.850	0.738	0.756	0.923
112	0.950	0.925	0.975	0.878	0.974
113	1.000	0.950	0.688	0.659	0.974
114	0.950	0.950	0.958	0.902	0.923
115	1.000	1.000	0.963	0.976	1.000
116	0.975	0.950	0.925	0.951	0.949
117	0.925	0.825	0.913	0.854	0.923
118	1.000	0.975	0.925	0.902	1.000
120	1.000	1.000	0.963	1.000	1.000
121	1.000	1.000	0.975	0.902	0.974
122	0.975	0.875	0.925	0.878	0.872
mean	**0.971**	**0.939**	**0.894**	**0.873**	**0.958**
sd	**0.037**	**0.073**	**0.102**	**0.094**	**0.039**

Appendix H.2.

Control participant accuracy percentages

CONTROLS	Con	Neu	Inc	IncProbe	ConProbe
201	1.000	1.000	0.975	1.000	1.000
202	1.000	1.000	0.988	0.976	1.000
203	1.000	0.975	0.950	0.976	1.000
204	1.000	1.000	1.000	1.000	1.000
205	1.000	0.950	0.950	0.951	1.000
206	1.000	1.000	1.000	1.000	1.000
207	1.000	1.000	1.000	1.000	1.000
208	1.000	1.000	0.988	1.000	1.000
209	1.000	1.000	1.000	0.976	1.000
211	0.975	0.975	0.975	0.927	1.000
212	1.000	1.000	0.825	1.000	0.974
213	1.000	1.000	0.963	1.000	1.000
214	1.000	1.000	0.963	1.000	1.000
215	0.975	0.975	1.000	1.000	1.000
216	1.000	1.000	1.000	0.976	1.000
217	1.000	0.975	0.950	0.951	1.000
218	1.000	1.000	0.975	0.902	1.000
219	1.000	1.000	0.988	1.000	1.000
220	1.000	1.000	0.963	1.000	1.000
222	1.000	1.000	0.988	0.976	1.000
mean	**0.998**	**0.993**	**0.972**	**0.980**	**0.999**
sd	**0.008**	**0.014**	**0.039**	**0.028**	**0.006**

Appendix I.1.

PWA response latencies (log)/condition comparisons

PWA	Neu-Con	Inc-Neu	IncProbe-Inc	IncProbe-ConProbe	ConProbe-Con
101	-0.039	0.237	-0.065	0.168	-0.036
102	0.030	0.080	-0.008	0.122	-0.019
103	-0.020	0.225	0.036	0.224	0.016
104	0.063	0.119	0.010	0.154	0.039
105	-0.044	0.128	0.011	0.109	-0.015
106	0.039	0.217	-0.029	0.175	0.053
107	0.016	0.149	-0.002	0.126	0.037
108	-0.009	0.095	-0.017	0.060	0.010
111	0.038	0.167	0.025	0.196	0.034
112	0.001	0.077	-0.009	0.058	0.011
113	0.107	0.241	0.039	0.280	0.106
114	0.052	0.188	0.074	0.203	0.112
115	-0.008	0.114	-0.001	0.110	-0.005
116	0.049	0.102	0.047	0.193	0.004
117	0.008	0.397	0.072	0.398	0.078
118	0.008	0.066	0.059	0.076	0.056
120	0.077	0.190	-0.021	0.054	0.192
121	0.023	0.204	-0.061	0.153	0.014
122	0.115	0.025	-0.011	0.083	0.046
mean	**0.027**	**0.159**	**0.008**	**0.155**	**0.039**
sd	**0.044**	**0.086**	**0.040**	**0.086**	**0.054**

Appendix I.2.

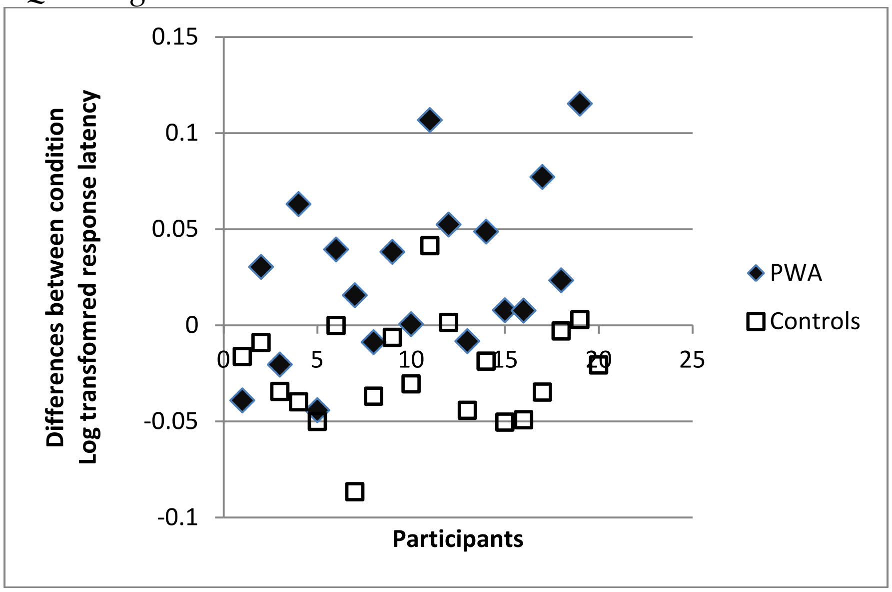
Control participant response latencies (log)/condition comparison

CONTROLS	Neu-Con	Inc-Neu	IncProbe-Inc	IncProbe-ConProbe	ConProbe-Con
201	-0.016	0.074	0.000	0.064	-0.006
202	-0.009	0.056	0.012	0.064	-0.005
203	-0.034	0.095	0.027	0.104	-0.018
204	-0.040	0.060	-0.002	-0.008	0.026
205	-0.050	0.145	0.007	0.088	0.014
206	0.000	0.080	-0.014	0.047	0.018
207	-0.087	0.073	0.025	0.009	0.003
208	-0.037	0.122	-0.011	0.088	-0.014
209	-0.006	0.101	0.043	0.105	0.033
211	-0.030	0.052	0.004	0.032	-0.006
212	0.041	0.120	-0.009	0.129	0.024
213	0.001	0.086	0.005	0.106	-0.013
214	-0.044	0.154	-0.010	0.101	-0.001
215	-0.019	0.042	0.011	0.022	0.013
216	-0.050	0.107	0.002	0.022	0.038
217	-0.049	0.110	0.016	0.032	0.044
218	-0.035	0.095	-0.004	0.058	-0.002
219	-0.003	0.084	-0.003	0.074	0.004
220	0.003	0.084	-0.010	0.060	0.017
222	-0.021	0.067	0.015	0.052	0.009
mean	**-0.024**	**0.091**	**0.005**	**0.063**	**0.009**
sd	**0.027**	**0.030**	**0.015**	**0.037**	**0.018**

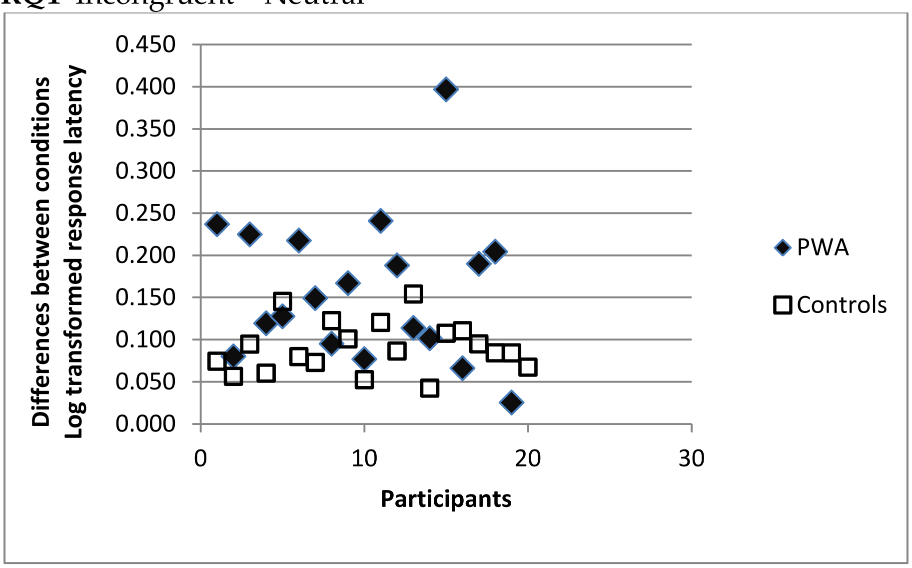
Appendix J

Scatterplots of condition comparisons

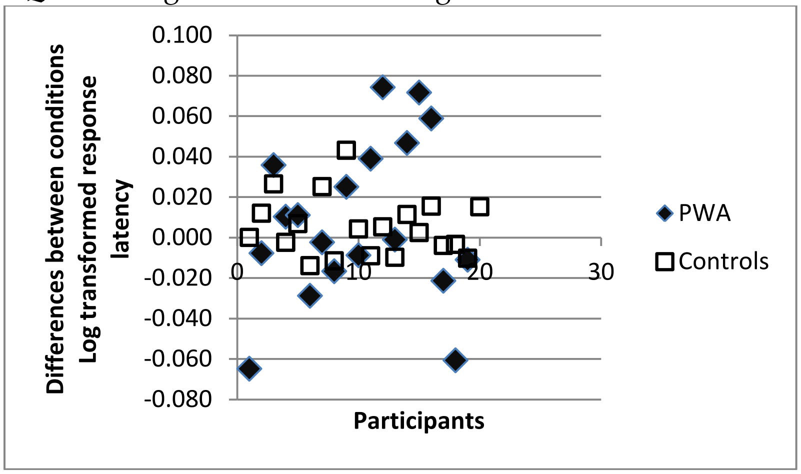
RQ1 Congruent – Neutral



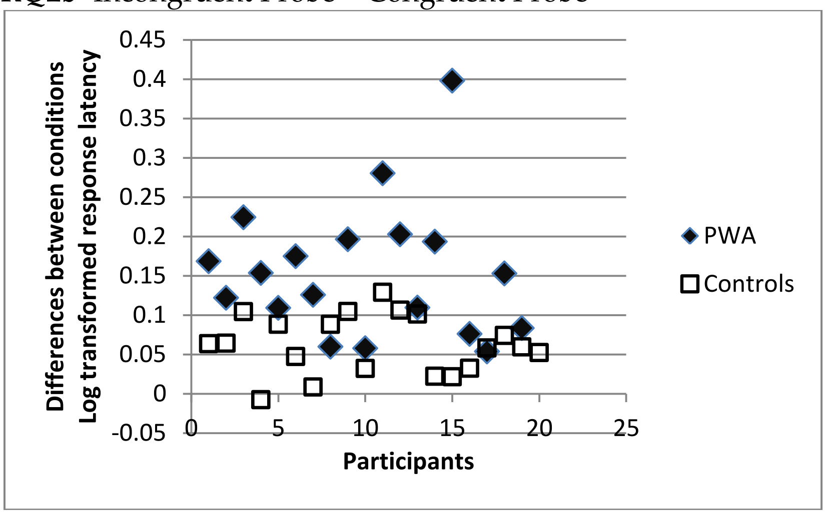
RQ1 Incongruent – Neutral



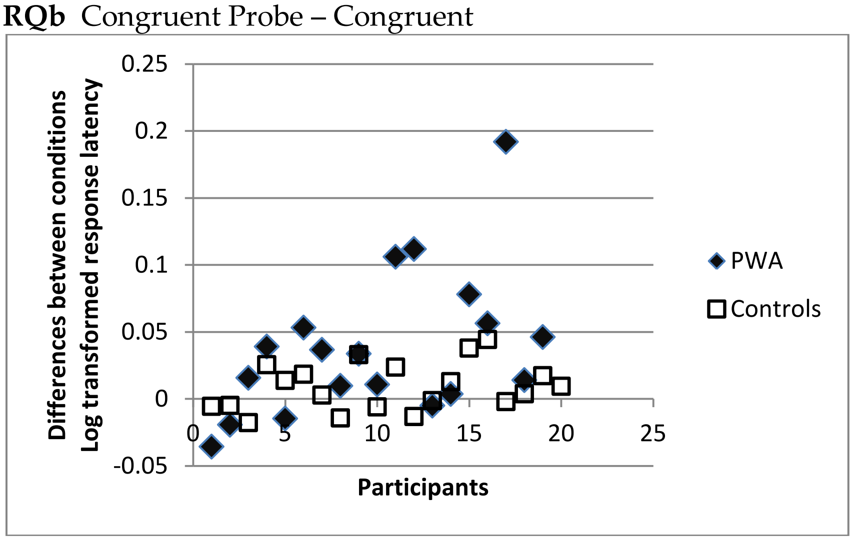
RQ2a Incongruent Probe – Incongruent



RQ2b Incongruent Probe – Congruent Probe



RQb Congruent Probe – Congruent



Appendix K

Error type data summary

Percentages of error type per condition for each group:

	PWA					Control				
	Con	Neu	Inc	IncProbe	ConProbe	Con	Neu	Inc	IncProbe	ConProbe
wrong or omit	36.0%	59.2%	59.7%	43.2%	15.7%	0.0%	28.6%	66.0%	18.6%	0.0%
hesitation	0.0%	6.1%	12.9%	7.1%	0.9%	0.0%	0.0%	6.4%	9.3%	0.0%
false start	8.0%	6.1%	6.5%	2.4%	1.9%	0.0%	0.0%	14.9%	2.3%	0.0%
did not advance	32.0%	14.3%	4.8%	4.1%	1.9%	33.3%	57.1%	4.3%	7.0%	0.0%
advance too quick	8.0%	10.2%	11.3%	8.9%	6.5%	0.0%	0.0%	0.0%	0.0%	0.0%
<250msec	4.0%	2.0%	0.5%	0.0%	1.9%	0.0%	0.0%	4.3%	0.0%	5.0%
prev prime incorrect	0.0%	0.0%	0.0%	34.3%	70.4%	0.0%	0.0%	0.0%	55.8%	85.0%
outside 3sd	12.0%	2.0%	4.3%	0.0%	0.9%	66.7%	14.3%	4.3%	7.0%	10.0%

Number of each error type for each condition and group:

	PWA						Control					
PWA	Con	Neu	Inc	IncProbe	ConProbe	TOTAL	Con	Neu	Inc	IncProbe	ConProbe	TOTAL
wrong or omit	9	29	111	73	17	**239**	0	2	31	8	0	**41**
hesitation	0	3	24	12	1	**40**	0	0	3	4	0	**7**
false start	2	3	12	4	2	**23**	0	0	7	1	0	**8**
did not advance	8	7	9	7	2	**33**	2	4	2	3	0	**11**
advance too quick	2	5	21	15	7	**50**	0	0	0	0	0	**0**
<250msec	1	1	1	0	2	**5**	0	0	2	0	1	**3**
prev prime incorrect	0	0	0	58	76	**134**	0	0	0	24	17	**41**
outside 3sd	3	1	8	0	1	**13**	4	1	2	3	2	**12**
TOTAL	**25**	**49**	**186**	**169**	**108**	**537**	**6**	**7**	**47**	**43**	**20**	**123**