Decision-making and aphasia

by

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Abstract

Background. Making one's own decisions is an important component of autonomy and expression of one's identity. After an individual has a stroke or other neurological injury, he or she may experience a disruption to their ability to speak, understand, read, and or write (aphasia). Furthermore, people with aphasia may experience a disruption to their cognitive abilities (e.g., ability to temporarily remember things, ability to pay attention, and their ability to think and reason). Disruptions to language and cognition could negatively impact an individual's ability to make decisions and/or the individual's ability to demonstrate their ability to make decisions. However, little is currently known about the true decision-making abilities of people with aphasia.

Purpose. The purpose of this study was twofold: 1) to compare performances between people with and without aphasia on decision-making tasks; and, 2) to test a theoretical framework of impaired and intact cognitive decision-making in people with and without aphasia.

Methods. The performance of people with aphasia (n = 16) and age- and education-matched controls (n = 16) was compared on three measures of decision-making; one linguistic, and two non-linguistic. While participants completed the IGT, we used an eye-tracker to concurrently collect pupil size data. Eye-tracking data provided real-time information about cognitive and emotional arousal. Participants with and without aphasia also completed a neuropsychological test battery consisting of behavioural measures of language, working memory, and executive function. The data collected in this study were used to: 1) compare performance between people with and without aphasia on different measures of decision-making using a quasi-experimental design; and, 2) explore associations between measures of cognition and measures of decision-making using an exploratory research design.

Results. People with aphasia performed worse than control participants on a linguistic test of decision-making. Language impairments largely accounted for the differential performance between people with and without aphasia. The results of this study were inconclusive regarding non-linguistic measures of decision-making. Therefore, the idea that non-linguistic decision-making is impaired in people with aphasia is neither refuted nor endorsed based on these data. Performance on linguistic and non-linguistic decision-making was predicted by performance on tasks of inhibition, attention, and problem solving. Further investigation is necessary.

Recommendations. Decision-making is an important part of daily living and life engagement, and should be addressed and supported in rehabilitation by speech-language pathologists and other healthcare professionals. Assessments of decision-making capacity should include communication supports for people with acquired communication disorders; further investigation in the area of decision-making and aphasia is needed.

Preface

This thesis is an original work by Salima Suleman. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Project Name "Decision-making and aphasia", ID Pro000057054, June 2, 2015.

In Chapter 1, we provide an introduction to aphasia and assessments of decision-making capacity in the healthcare system. We also review current advocacy movements for fair assessments of decision-making capacity for people with acquired language disorders. In Chapter 2, we lay a theoretical foundation for a research study investigating decision-making in aphasia. We discuss impairments to decision-making in related populations (e.g., individuals with primary progressive aphasia), review cognitive processes implicated in making a rational decision, and discuss known cognitive impairments associated with the presence of aphasia. We conclude Chapter 2 by reviewing measures of linguistic decision-making, non-linguistic decision-making, and cognition that will be used in the current study. Parts of Chapters 1 and 2 have been published in Suleman & Kim (2015a) and Suleman & Hopper (2016) and presented at national and international conferences (Suleman & Hopper, 2013, 2015; Suleman & Kim, 2015b)

Results from the larger research project and preliminary findings from this thesis have been published as abstracts (Suleman, Kim & Hopper, 2015; Kim & Suleman, 2015) and presented at provincial, national, and international conferences (Kim, Suleman, Dahlke, Lorenz, & Muc, 2015; Suleman, Chaouki, Kim, 2014; Suleman, Garcia, & Kim, 2016; Suleman & Hopper, 2013; Suleman & Kim, 2016)

Dedication

To the people with aphasia who choose to dance when the world tells them to sit. Thank you for this dance.

Your choices belong to you so intimately they will never leave you. They are like the changing nature of love …They will never abandon you to time; good or bad they will stay always; an antique that shows the future who you were and what you stood for.

(an excerpt from the poem *How to be a Person* by Shane Koyczan)

Acknowledgements

"Am I awake, asleep or am I dreaming? If I'm awake, promise you'll come get me" (Craig Cardiff, Virginia in the Song). Music has always had a special way of capturing the sentiment of particularly poignant moments in my life. I knew I'd have to turn to the wisdom of song to help me express the deep gratitude I feel as I remember all those who have walked beside me during the past five years.

First I'd like to thank my supervisors, Drs. Esther Kim and Tammy Hopper. Esther, one dark night you drove us through an Arizona storm from Phoenix to Tucson. Our car was small and wobbled in the wind as the rain pelted our windshield. You clutched that steering wheel and drove us confidently through the storm. Thank you for being a steady and calm force during the past few years and for sharing in my glee when I woke up to astonishingly beautiful mountains in the morning. Tammy, some of the first words I ever heard from you were "life balance is like tweezing your eyebrows; you have to be careful to not to go overboard." In the past five years, I've had moments where I let my life eyebrows get unruly and there have been times where I've plucked them down to a few vagrant hairs. Thank you for your gentle nudge to start plucking when my life was out of control and your patience during the slow process of regrowth after episodes of overzealous plucking. *"I'm feeling restless but I'm tired. Don't want to leave but I can't stay….It's time to spread our wings and go. So come, fly away! Through the clouds into the sun….When we get above the rain, they are all sunny days"* (Jeremy Fisher, Come Fly Away).

To my committee, Drs. Anthony Singhal and Esther Fujiwara, thank you for your support, thoughts, and understanding during this process. I would also like to express gratitude to all members of the Faculty of Rehabilitation Medicine and particularly the Department of

Communication Sciences and Disorders. I have been given so many opportunities and every experience has shaped me into the person and professional that I am today. I am so grateful for every student, mentor, friend, and colleague who has shared a part of themselves with me. *"I checked the weather forecast, not a cloud in the sky. My bags are all packed now and you wonder why, we're a rollercoaster. You're a rollercoaster, I swear…I'm a rollercoaster too. It was nice to meet you, to meet you"* (Michael Bernard Fitzgerald, Brand New Spaces).

"Love is louder than all this noise" (Craig Cardiff, Love is Louder). My family and friends have made love the melody of my life. To my friends - your dreams are mine and the future is ours. To my family – my tearstained squeak of a thank you will never do justice to the roar of gratitude I feel. Your unfailing trust, faith, and love is the focal point of my orbit. Love you forever.

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Glossary

Acronym	Definition
ACSLPA	Alberta College of Speech Language Pathologists and Audiologists
ANOVA	Analysis of Variance
AQ	Aphasia quotient
AX-CPT	AX-Continuous processing task
CCTI	Capacity to Consent to Treatment Instrument
DMC	Decision-making capacity
EF	Executive function
FAVRES	Functional Assessment of Verbal Reasoning and Executive Strategies
GDS	Geriatric depression screening
GDT	Game of Dice Task
IGT	Iowa Gambling Task
MCI	Mild cognitive impairment
PPA	Primary progressive aphasia
PWA	People with aphasia
RCPM	Raven's Coloured Progressive Matrices
SCA	Supported Conversation for Adults with Aphasia
SLP	Speech-language pathologist
TBI	Traumatic brain injury
TMT-A	Trail Making Test A
TMT-B	Trail Making Test B
WAB-R	Western Aphasia Battery – Revised
WCST	Wisconsin Card Sort Task
WHO	World Health Organization
WM	Working memory

Chapter 1: Aphasia and Decision-Making Capacity

Aphasia

Several definitions of aphasia have been proposed throughout the past 140 years. Although these definitions vary, most recent definitions include the following basic components: 1) aphasia results from focal brain damage to cortical and/or sub cortical brain structures in the language-dominant hemisphere (i.e., aphasia typically occurs after a cerebrovascular accident to the left middle cerebral artery); 2) aphasia manifests with multimodality deficits in comprehension and production of language (i.e., aphasia can affect a person's ability to speak, understand, read, and/or write); and, 3) aphasia represents a deficit in language functioning such that the linguistic competence of people with aphasia (PWA) exceeds their linguistic performance (Davis, 2014; McNeil & Pratt, 2001).

Different theories have been developed to explain, describe, and treat aphasia and aphasic symptoms. For example, the localization theory of aphasia addresses the relationship between brain damage and aphasic symptoms (Goodglass & Kaplan, 1972; Papathanasiou, Coppens, & Portagas, 2013). The localization theory aligns with the deficit-centric biomedical model based on linear relationships between pathology and impairment (Portney & Watkins, 2009). For example, the work of Paul Broca identified the left third frontal convolution as the "seat for articulated language" (Papathanasiou et al., 2013, p. 8). Goodglass and Kaplan (1972) compiled available localization information to develop the Boston classification system, which is internationally recognized and widely used in the diagnosis of aphasia (Davis, 2014; Papathanasiou et al., 2013). This classification system includes eight functional profiles of aphasia based on different configurations of three symptomatic features (i.e., fluency of verbal output, auditory comprehension, and repetition). Each of the symptoms is associated with lesions to a specific brain area (e.g., fluent output is associated with posterior lesions while non-fluent

output is associated with anterior lesions; Goodglass & Kaplan, 1972; Papathanasiou et al., 2013). Please see Table 1 for a complete summary of the aphasia profiles in the Boston classification system.

The cognitive theory of aphasia addresses the place of language processing within a general model of cognition. The cognitive theory was developed to provide an explanation of the disproportionate deficit in language performance relative to competence (Damasio, 2008; Davis, 2014; Hula & McNeil, 2008; McNeil, Odell, & Tseng, 1990; Papathanasiou et al., 2013). Many people consider variable linguistic performance to be a hallmark of aphasia (Hula & McNeil, 2008). As such, the performance of people with aphasia is known to be highly inconsistent, even within the same contextual environment (i.e., at different points in time, people with aphasia display varying levels of severity). Proponents of the cognitive theory of aphasia believe that high levels of performance are indicative of the individual's linguistic competence and deficits in access and allocation of cognitive resources (e.g., attention resources) can account for the fluctuations in performance that have been robustly observed in PWA (Hula & McNeil, 2008; Murray, 1999; Villard & Kiran, 2016).

With the emergence of the cognitive theory of aphasia, we have seen a growing body of literature that supports the idea that some aspects of cognition may be impaired in PWA. Specifically, PWA have been shown to have impairments in attention (e.g., allocation of limited attentional resources; Hula & McNeil, 2008; McNeil, Odell & Tseng, 1990; Murray, 1999; Murray, 2012), working memory (WM; e.g., limited memory resources and allocation of these limited resources; Laures, Shisler, & Verner, 2011; Mayer & Murray, 2012; Wright & Fergadiotis, 2011), and executive function (EF; e.g., inhibition, cognitive flexibility, planning; Martin & Allen, 2008; Purdy, 2002). The ability to make decisions is one aspect of cognition that

has important clinical implications, but has not been addressed systematically in research with PWA.

Decision-Making Capacity

Decision-making capacity (DMC) involves multiple cognitive-linguistic abilities, including understanding information relevant to a decision, manipulating that information in a deliberative process, appreciating the consequences of making or not making a decision, and communicating a choice (Appelbaum & Grisso, 1998). Although adults are generally assumed to have the ability to make decisions about their personal lives and finances (Edelstein, 2000), there are situations in which capacity for decision-making may be called into question (e.g., in the case of a medical condition that affects cognition; Church & Watts, 2011). In such cases, a capacity assessment may be conducted.

Capacity assessments are used to determine whether an individual has the requisite cognitive abilities to make a specific decision (Carling-Rowland & Wahl, 2010; Moye & Marson, 2007). In Alberta, decisions are categorized into eight domains; healthcare, place of residence, finances, choice of associates, legal matters, and participation in social, educational or employment activities (Government of Alberta, 2012). Capacity assessments are tailored to the specific domain in question. The presence or absence of DMC is assessed and determined by a professional or, ideally, by a multidisciplinary team of professionals (Moye & Marson, 2007; Newberry & Pachet, 2008). Although there is no universal capacity assessment protocol, one of the key components of capacity assessment is referred to as a *functional inquiry* (Grisso & Appelbaum, 1998; Pachet, Allan, & Erskine, 2012). A functional inquiry consists of a semi-structured clinical interview (Carling-Rowland & Wahl, 2010; Giampieri, 2012; Pachet, et al., 2012) designed to provide the assessor with insight into the individual's ability to understand,

retain, deliberate, reach a decision, communicate that decision, and initiate action based on that decision (Pachet, et al., 2012). Functional inquiries also provide professionals with insight into the individual's general cognitive status, fatigue levels, medication effects, attitudes and values, and personal history (Carling-Rowland & Wahl, 2010; Giampieri, 2012; Pachet, et al., 2012). During the functional inquiry an individual must proficiently use language to communicate beyond a basic yes or no response (Carling-Rowland, 2011; Church & Watts, 2011; Stein & Brady Wagner, 2006). As communication is a manifestation of cognition, disorders of communication may put individuals at a disadvantage during a DMC assessment (Davis & Ross, 2003). The task demands of the interview component may be linguistically challenging or even impossible for individuals affected by communication disorders (ACLSPA, 2012; Pachet et al., 2012), particularly those individuals with aphasia.

Because aphasia can occur in the absence of significant intellectual impairments, many PWA are believed to have the requisite abilities to make their own life decisions. However, a concern is that intact decision-making ability may be masked or concealed by the language deficits (Kagan, 1998). Ultimately, the presence of aphasia may result in erroneous determination of incapacity during an assessment (Carling-Rowland & Wahl, 2010; Davis & Ross, 2003; Ferguson, Duffield & Worrall, 2010).

Currently, there is a small body of literature comprising primarily case studies and discussion papers in which researchers advocate for a thorough understanding of communication disorders and an interactive, supportive capacity assessment process that can reveal DMC despite language and communication deficits (Brady & Kirschner, 1995; Brady-Wagner, 2003; Carling-Rowland & Wahl, 2010; Davis & Ross, 2003; Diener & Bischof-Rosario, 2004; Ferguson et al, 2010; Ferguson, Worrall, McPhee, Buskell, Armstrong, & Togher, 2011; Finestone & Blackmer,

2007; Mackenzie, Lincoln & Newby, 2008; Pachet et al., 2012; Stein & Brady Wagner, 2006).

Ferguson et al. (2010) used a Critical Incident Technique approach to qualitative interviewing to explore the perspectives of Australian speech-language pathologists (SLPs) related to assessments of DMC. Researchers asked nine SLPs to describe cases of PWA where DMC was questioned (Ferguson et al., 2010). SLPs described 21 cases and discussed several topics, including: different types of decisions that triggered capacity assessments, various roles SLPs can play in the capacity assessment process, roles of other professionals, and their own training and experiences as SLPs. In all cases, the SLP participants were confident that the person with aphasia was able to make decisions but viewed the assessment as important to ensure the person understood the issues and was able to communicate a decision (e.g., reliability of yes and no responses was critical; Ferguson et al., 2010). Ferguson and colleagues (2010) concluded that PWA are at risk for being excluded from full involvement in life decisions as a result of their language impairments and that professional practice guidelines and training specifically for SLPs should support practice and research in this area.

Recently, Suleman and Hopper (2016) conducted a qualitative study and found SLPs in Alberta echoed the concerns of the SLPs in the Australian study, bioethecists, physicians, neuropsychologists, occupational therapists, and social workers regarding capacity assessments of PWA (Aldous, Tolmie, Worrall, & Ferguson, 2014; Carling-Rowland & Wahl, 2010; Davis & Ross, 2003; Ferguson et al., 2010; Pachet et al., 2012; Stein & Brady Wagner, 2006; Suleman & Hopper, 2016). The SLP participants in Suleman and Hopper's (2016) study described the assessment as being language-based with inappropriate or ineffective modifications. The growing awareness of the impact of communication disorders on an individual's ability to

demonstrate capacity during assessments of DMC has spawned discussions about the best approach to help PWA demonstrate their true decision-making abilities.

Carling-Rowland and Wahl (2010) conclude their article with a powerful statement; “The notion that competent individuals may lose the right to determine where and how they will live because of a communication barrier is of grave ethical concern” (p. 185) and a strong recommendation for the current system to begin incorporating measures to reveal capacity in people with communication disorders to ensure that capacity assessments are conducted in fair manner.

At the core of the capacity assessment advocacy movement is the assumption that PWA are able to make independent decisions if they are provided with appropriate communicative supports. However, there is relatively little information about the *actual* decision-making abilities of people with aphasia (Pachet et el., 2012). Research in the area of decision-making and aphasia is limited (Golpher, Rau & Marshall, 1980; Marshall, 2002). To inform theory and practice, studies on the relationships between cognition, language, decision-making and aphasia are necessary. In the next chapter, we will present a conceptual framework for the study of decision making in PWA.

Chapter 2: Cognitive Decision-Making and People with Aphasia

The purpose of this chapter is to lay the theoretical foundation for the current research study investigating cognitive decision-making in PWA. We will begin with a brief review of what researchers have found about decision-making abilities in other clinical populations related to aphasia (i.e., aging, primary progressive aphasia, Alzheimer's disease, mild cognitive impairment, traumatic brain injury). Then we will provide an introduction to a common theory of decision-making (i.e., the dual-process theory of decision-making) and delineate the cognitive processes using a conceptual model of cognitive decision-making. Next, we will discuss the potential impact of cognitive deficits associated with aphasia on cognitive decision-making. Finally, we will explore different experimental tasks of cognition and decision-making that could be used to assess decision-making in PWA and validate the conceptual model of decision-making.

Evidence of Cognitive Processes implicated in Rational Decision-Making

The following section includes a review of the findings of studies that included investigation of the impact of cognitive impairments on decision-making in typically aging older adults, adults with primary progressive aphasia (PPA), adults with traumatic brain injury (TBI), adults with Alzheimer`s disease, and adults with mild cognitive impairment (MCI).

Aging. Researchers have associated difficulties in reasoning with deficits in attention, WM and EF in older adults. In 1994, Gilinsky and Judd examined reasoning impairment in older adults using categorical syllogisms. Categorical syllogisms consist of three statements that form an argument; two premises and a conclusion. For example, "all the artists are bee keepers; all the bee keepers are chemists; therefore, all the artists are chemists" (Johnson-Laird, 1983). The objective of the task is for the participant to discern whether the conclusion is true or false given the premises. Gilinksy and Judd (1994) used a multiple regression analysis and found WM

deficits accounted for some age-related differences in reasoning on the categorical syllogism task. They also found that when the conclusion was *believed* to be true or false, even though the conclusion was in contrast to the premises, older adults were more likely to determine the validity of the conclusion based on belief, not logic. This could indicate that older adults are less likely to inhibit beliefs when compared to younger adults. Furthermore, impairments in inhibition can negatively impact the ability to make an impartial decision (Gilinsky & Judd, 1994).

Primary progressive aphasia. In 2012, Gleichgerrcht and colleagues investigated the decision-making profile of people with PPA, a progressive language disorder that initially occurs in the absence of other cognitive and behavioural symptoms of dementia and is characterized by "gradual and isolated impairment of word usage and comprehension" (Duffy & Peterson, 1992; Gorno-Tempini et al., 2011; Mesulam, 1982, p. 425). In their study, Gleichgerrcht and colleagues used the Iowa Gambling Task (IGT) to measure decision-making in individuals with PPA (n=10), fronto-temporal dementia (n = 35), and healthy controls (n=14). The IGT is a risk-taking card game in which participants make 100 selections from four decks of cards to maximize their overall gain. It is believed that the IGT is related to real-life and rational decision-making as it involves uncertainty, reward, risk and the deliberations are conscious and controlled (Bechara, Damasio, Damasio, & Anderson, 1996; Dunn, Dalgleish, & Lawrence, 2006; Maia & McClelland, 2004). Using a one-way ANOVA analysis to compare between groups, the authors showed that people with PPA had a flat performance profile, in which they neither made advantageous decisions (like controls), nor did they demonstrate risk-appetitive behaviour (like people with fronto-temporal dementia; Gleichgerrchet, 2012). There was no association between language performance and decision-making profile. The findings from this

study suggest that some people with PPA are unable to make advantageous decisions (i.e., they do not learn from their experience in order to make advantageous selections). However, PPA and aphasia arise from different neural mechanisms so whether these results may generalize to PWA remains to be seen.

Neurological trauma & neurodegenerative diseases. In two independent studies, Dreer, DeVivo, Novack, Krzywansk and Marson (2008) and Okonkwo et al. (2008) examined cognitive predictors of decision-making in individuals with neurological damage. Both groups of investigators examined cognitive predictors of performance on a standardized assessment of decision-making called the Capacity to Consent to Treatment Instrument (CCTI; Marson, Ingram, Cody & Harrell, 1995). The CCTI is based on the four competencies used in clinical assessments of DMC (i.e., understanding the decision and options, reasoning to reach a conclusion, appreciating consequences, and communicating a choice). Dreer and colleagues (2008) made comparisons between adults with moderate to severe TBI (n=24) and controls (n=20) at baseline and at 6-month follow-up. At different points in time, correlational and multiple regression analyses showed that performance of people with TBI on measures of understanding, appreciation, and reasoning were related to performance on measures of short-term verbal memory, WM, EF, attention, and verbal processing (Dreer et al., 2008). Okonkwo and colleagues (2008) included adults with MCI (n=60), mild Alzheimer's disease (n = 31), and controls (n=56) in their study. In adults with MCI, performance on measures of understanding, appreciation, and reasoning were related to performance on measures of short-term verbal memory and EF (Okonkwo et al., 2008). In adults with mild Alzheimer's disease performance on measures of understanding, appreciation and reasoning were related to performance on measures of EF and processing speed (Okonkwo et al., 2008). To summarize, both groups of investigators

found that in populations with brain damage, performance measures of cognition such as short-term memory, WM, attention, and EF predicted performance on a clinical assessment of decision-making.

Dual-Process Theory of Decision-Making

Decision-making is often discussed within the context of dual-process theories (Evans, 2008, 2010; Evans & Stanovich, 2013; Evans & Over, 1996; Stanovich, 1999; Tverksy & Kahneman, 1973, 1983), which propose that two decision-making systems are associated with different types of decision tasks. While the two decision-making systems are referred to in a variety of ways, we will use the most neutral nomenclature and call the systems System 1 and System 2 (Evans, 2008, 2010; Stanovich, 1999). A common convention in the field of psychology is to anthropomorphize the decision-making systems. We will be following that convention here. It is important to remember however, that the systems are simply descriptions of cognitive processes and not independent of the individual making the decision (Kahneman, 2011).

System 1 is a high-capacity system and makes decisions that are fast, intuitive, implicit, and unconscious (i.e., System 1 can make many decisions quickly and simultaneously; Evans & Stanovich, 2013). For example, System 1 is implicated when one is asked to finish the phrase "rise and…" System 1 automatically chooses the word "shine" from the person's vocabulary to finish the phrase, without much cognitive effort (Kahneman, 2011). In contrast, System 2 is slow, deliberate, explicit, conscious, and has a low-capacity (i.e., System 2 can only handle a limited amount of information at a given point in time; Evans & Stanovich, 2013). System 2 is implicated in all decisions that a person consciously considers.

System 1 and System 2 have been proposed to interact in either a *parallel-competitive* or a *default-interventionist* structure (Evans, 2007, 2010; Evans & Stanovich, 2013; Kahneman, 2011; Sloman, 1996). In the *parallel-competitive* structure, both System 1 and System 2 reach a decision simultaneously and in the event of a conflict, the two systems compete with each other (Evans & Stanovich, 2013; Sloman, 1996). In the default-interventionist structure System 1 has already made a decision before System 2 even begins deliberation (Evans, 2010; Evans & Stanovich, 2013). The emotional effect of the System 1 decision (i.e., the positive or negative feelings associated with making an instinctual decision) or personal disposition towards rational thinking has the potential to bring the decision into consciousness, thus triggering System 2 to analyze the decision (Evans, 2010; Evans & Stanovich, 2013; Kahneman & Fredrick, 2002, 2005). System 2 then has two options when a decision enters consciousness; endorse the decision made by System 1, or refute the decision with a rational alternative. Both the default-interventionist and the parallel-competitive structures have been supported by empirical evidence (Evans, 2010; Sloman, 1996; Barbey & Sloman, 2007). However, many prominent theorists and researchers support the default-interventionist structure (Evans & Stanovich, 2013; Kahneman, 2011; Kahneman & Frederick, 2002). Here we will be using the default-interventionist structure to describe the interaction between System 1 and System 2.

Even though System 2 has the option to either endorse or reject the conclusion made by System 1 in the default-interventionist structure, researchers have shown that individuals have difficulty deliberating rationally to overcome their instinctual response (Evans, 2010; Evans & Stanovich, 2013; Stanovich, 1999, 2011; Wason, 1960; Wood & Bechara, 2014). For example, in the "2, 4, 6" task, participants are asked to determine the numerical rule the experimenter has in mind to create the sequence "2, 4, 6" (Wason, 1960). Most participants initially guess that the

rule is “ascending numbers with equal intervals,” when in fact it the rule is simply “ascending numbers” (Evans, 2010; Wason, 1960). Participants have difficulty overriding their System 1 intuition that the rule is related to the intervals and tend to generate triples that confirm the first rule they generated instead of rules that would disprove their original rule (i.e., a negative test such as 1, 2, 5, which would conform to the rule but provide indication that intervals are irrelevant; Evans, 2010; Wason, 1960). In other words, the rational System 2 may have difficulty overriding and ultimately rejecting the intuitive System 1 response.

Neural regions associated with System 1 and System 2. System 1 and System 2 processing utilize different neural regions (Evans & Stanovich, 2013; DeNeys, Vartanian & Goel, 2008; Lieberman, 2003, 2007). System 1 decision-making is associated with regions involved in conditioning and associative learning (i.e., amygdala, basal ganglia, ventromedial prefrontal cortex, lateral temporal cortex, dorsal anterior cingulate cortex) (Lieberman, 2003; Lieberman, 2007; Wood & Bechara, 2014). Researchers have shown that System 1 decision-making is less susceptible to decline due to aging or brain trauma than the areas associated with System 2 (Gilinsky & Judd, 1994; Osman, 2004). On the other hand, System 2 or deliberate decision-making is associated with neural regions linked with EF and explicit learning (i.e., dorsolateral prefrontal cortex, ventro-medial prefrontal cortex, orbitofrontal prefrontal cortex, lateral parietal cortex, medial parietal cortex, medial temporal lobe, anterior cingulate cortex, insula; Gleichgerrcht, Ibanez, Roca, Torralva, & Manes, 2010; Green, Nystrom, Engell, Darley, & Cohen, 2004; Lieberman, 2003, 2007; Lieberman, Jarcho, & Satpute, 2004; Wood & Bechara, 2014). The cortical areas associated with System 2 tend to be relatively more susceptible to decline and damage due to traumatic brain injury or stroke compared to System 1 (Gilinsky & Judd, 1994; Osman, 2004). There is some evidence that the neural regions associated with

System 1 and System 2 are not in competition with one another. Rather, the regions are inter-connected and regulate activation of the other system (Wood & Bechara, 2014).

The neural substrates associated with language and some of those associated with System 2 decision-making share a common blood supply from the left anterior cerebral artery and the middle cerebral artery (Damasio, 2008; Davis, 2014). Therefore, a disruption in this shared blood supply could cause diffuse brain damage resulting in aphasia and impairments in cognitive processes required for System 2 decision-making. As the purpose of this study is to examine decision-making in adults with aphasia, henceforth we will focus on cognitive processes implicated in System 2 decision-making (i.e., rational decision-making).

Cognitive Processes Associated with Decision-Making and Implications of Cognitive Deficits Associated with Aphasia

Rational decision-making is a higher level cognitive process that involves the cognitive functions of memory (specifically WM), attention, EF, and language (WHO, 2010; Evans & Stanovich, 2013). In the following section, we will discuss each of these cognitive functions in the context of decision-making, present evidence of impairments to cognitive function in PWA and discuss the potential impact of these deficits on decision-making.

Working memory and rational decision-making.

Working Memory. WM has been defined as "the ability to store representations while concurrently performing a task" (Wright & Fergadiotis, 2012, p. 258). There are many theories related to the structure of working memory (Baddeley, 2000, Baddeley & Hitch, 1974; Caplan & Waters, 1999; Daneman & Carpenter, 1980, 1983; Hasher & Zacks, 1988). However, there is some agreement among theorists that WM is comprised of systems that 1) temporarily store a finite amount of information; 2) are able to process or manipulate the finite information; 3)

control the allocation of resources. The original work of Baddeley & Hitch (1974) set forth a framework that has played an important role in historical and contemporary WM research (Wright & Shisler, 2005). In Baddeley's model, which was updated in 2000, WM is comprised of storage systems (called the *phonological loop, visuospatial sketchpad, and the episodic buffer*) and a managing system (called the *central executive system).* The storage systems are responsible for the temporary storage of verbal or visual information and are limited in capacity (Baddeley & Hitch, 1974). The items that fill the storage systems could be selected from an individual's long-term memory (i.e., the information is retrieved from stores of previously acquired knowledge) or newly acquired from the individual's environment (Murray & Clark, 2006; Wright & Fergadiotis, 2012). Memory-related cognitive processes allow the movement of information back and forth from stored memory to the conscious workspace of WM (i.e., retrieval and encoding; Baddeley & Hitch, 1974). The central executive system of WM is associated with information processing, allocating attention resources, and inhibitory control (Baddeley, 2003; Baddeley & Hitch, 1974; Hasher & Zacks, 1988; Wright & Shisler, 2005).

There is overlap in the theoretical role of the executive component of WM (central executive system, inhibitory control), attention function, and EF. Therefore, for this discussion of cognition and decision-making, we will limit WM to the role of the temporary storage and processing of conscious information. We will discuss the allocation of attention resources and inhibitory function in the upcoming sections on attention and EF.

The role of WM in rational decision-making. Information in WM storage is consciously accessible to an individual (i.e., an individual is only aware of the finite amount of information being held and processed in WM; Davis, 2014; Evans, 2008). As rational decision-making involves the conscious consideration, manipulation, and evaluation of information, rational

decision-making theoretically takes place within the temporary storage system of WM (Evans & Stanovich, 2013).

WM and aphasia. Individuals with aphasia have been shown to have deficits in WM (DeDe, Ricca, Knilans & Trubl, 2014; Friedmann & Gvion, 2003; Ivanova & Hallowell, 2012; Laures et al., 2011; Mayer & Murray, 2012; Wright & Fergadiotis, 2012; Wright & Shishler, 2005). These deficits have been demonstrated across a variety of tasks and stimuli, including simple span tasks with numbers, words, and pictures (DeDe et al., 2014; Friedmann & Gvion, 2003; Laures et al., 2011); complex span tasks that involve temporary storage and manipulation of information (DeDe et al., 2014; Ivanova & Hallowell, 2011); and, *n*-back tasks (i.e., 0-, 1-, 2-back task; Christensen & Wright, 2010; 2014; DeDe et al., 2014; Mayer & Murray, 2012). Overall, PWA have been shown to exhibit smaller WM storage capacity and difficulties manipulating information within WM (Wright & Fergadiotis, 2012; Wright & Shisler, 2005).

Attention and rational decision-making. WM relies on attention-related cognitive processes to select and maintain important information in consciousness (Bayles & Tomoeda, 2007). In order for novel information to be consciously processed in an individual's WM, the person must first attend to the piece of information using attention-related cognitive processes (Wright & Fergadiotis, 2012). Attention-related cognitive processes include processes that: maintain focus (i.e., sustained attention), focus attention on relevant information and filter out irrelevant information (i.e., selective attention), shift focus between tasks or stimuli (i.e., attention switching), and split attention among two or more tasks or stimuli simultaneously (i.e., divided attention; Murray, 2012).

Attention and aphasia. In general PWA have been found to have deficits in attention function. Researchers have shown that PWA score significantly lower than controls on measures

of sustained attention, selective attention, and attention switching (Erickson, Goldinger, & LaPointe., 1996; Glosser & Goodglass, 1990; Helm-Estabooks, 2002; Hoffman, Jefferies, Ehsan, Hopper & Ralph, 2009; Kalbe, Reinhold, Brand, Markowitsch, & Kessler 2005; Murray, 1999, 2012; Lambon Ralph, Snell, Fillingham, Conroy & Sage, 2010; Laures, 2005). Researchers have also found that PWA have difficulty orienting or directing their attention to salient items in their auditory environment even when they are provided cues directing them to orient to certain items (Murray, 1999; Peach, Rubin, & Newhoff, 1994; Petry, Crosson, Gonzalez-Rothi, Bauer, & Schauner, 1994; Robin & Rizzo, 1989). Researchers have concluded that the results from these studies indicate that PWA may have challenges focusing, maintaining, and selecting attention.

Executive function and rational decision-making. Rational decision-making does not only use cognitive processes that bring and store information in consciousness, it requires an individual to organize information, manipulate information, and perform mental simulations in order to reach a decision (Evans, 2008). EF processes allow an individual to flexibly "plan, sequence, organize, and monitor" activities and behaviour (Purdy, 2002, p.549). These EF processes can be employed to manipulate and organize information within WM (Murray & Clark, 2006). While there are many cognitive processes associated with EF (i.e., initiation, organization, planning), only two will be discussed here: inhibition and problem solving.

Inhibition and rational decision-making. Inhibition refers to the "...ability to regulate and repress automatic, routine, or extraneous processing or responding" (Murray & Clark, 2006, p. 15) and has been demonstrated to be related to decision-making abilities. In a recent study, Del Missier and colleauges (2012) found that performance on inhibition/updating tasks was related to performance on a number of decision-making tasks (e.g., making a choice between DVD players

given ratings on a multiple attributes – Applying Decision Rules) in a large cohort (N = 213) of undergraduate students.

Inhibition and aphasia. PWA may have challenges inhibiting irrelevant information from entering into their WM workspace. Impairments to inhibition in PWA has been demonstrated in studies with Stroop and Stroop-like tasks where individuals are required read words while inhibiting interfering information (i.e., naming ink colour of colour words written in different coloured ink; Biegler, Crowther & Martin, 2008; Hamilton & Martin, 2005; Martin & Allen, 2008). Difficulties in inhibition may lead to irrelevant information taking up limited WM resources (Hasher et al., 1999). The cognitive processes of inhibition can also be implicated in the interaction of intuitive and rational decision-making systems (System 1 and System 2, respectively). As mentioned earlier, it is believed that upon being presented with a decision, a person's System 1 automatically reaches a decision. System 2 may endorse or refute the decision made by System 1 (Evans, 2008). If the intuitive decision is not rationally accepted, inhibition processes are needed to suppress the initial decision in lieu of a rational alternative (Evans, 2008). If PWA are known to have difficulties in inhibition, they may have even further difficulties in suppressing System 1 decision-making.

Problem solving and rational decision-making. The EF process of problem solving refers to "...problem identification, and generation, selection, and implementation of solution" (Murray & Clark, 2006, p. 15). Mental simulations or the generation of potential solutions and evaluation of these solutions is one way an individual can consciously reach a decision (Evans, 2008). Mental simulations are highly dependent on EF processes of problem solving.

Problem-solving and aphasia. PWA have demonstrated some deficits on measures of cognitive flexibility, planning, and problem solving (Baldo, Bunge, Wilson & Dronkers, 2010;

Baldo et al., 2005; Helm-Estabrooks, 2002; Purdy, 2002). Furthermore, researchers have shown a relationship between language (i.e., comprehension and naming) and performance on complex problem solving tasks (i.e., Wisconsin Card Sort Task, WCST and/or Raven's Coloured Progressive Matrices, RCPM; Baldo et al., 2005; Baldo et al., 2010).

Deficits in problem-solving could have a negative impact on a person's ability to identify different options, weigh the different options, select the best option, and develop a plan to implement the decision. Furthermore, difficulties with planning may negatively impact the individual's ability to run through hypothetical situations and consider potential outcomes. These deficits could impact decision-making, especially if the individual is required to come up with multiple solutions independently or there are time constraints (Purdy, 2002).

Context processing and rational decision-making. Context refers to any task-relevant information that affects future behavior. Context processing is the way in which people store and use contextual information to guide their behavior (Braver et al., 2001). For example, a driver's decision to speed up or slow down when approaching a traffic intersection may be influenced by contextual information, such as the state of the pedestrian signal. A flashing hand pedestrian signal is a cue that the traffic light will turn yellow soon. A driver could use this cue and adjust his speed accordingly. Context processing has been proposed as a central cognitive function that may underlie working memory and inhibition. When making a decision a person needs to activate and maintain the goals of the decision (Braver et al., 2005). Context processing should also ensure the person is able to allocate attentional resources to information that could assist with accomplishing the goal.

Context processing and aphasia. Context processing has not been studied in PWA. However, Braver and colleagues (2005) studied context processing in older adults and found that

on an experimental task of context processing (the AX continuous processing task; AX-CPT) older adults performed in a manner consistent with an impaired context processing system. If context processing is impaired, ability to make decisions may be impaired as the person may 'forget' the decision goals or not allocate attention appropriately given the goals of the decision.

Language and rational decision-making. Language is considered the "medium" in which rational decision-making occurs (Osman, 2004, p. 989). The solutions generated as well as the risks and benefits of these solutions are encoded into language to be made explicit (Evans, 2010). In neurologically intact adults, language processing is predominantly automatic and unconscious. As such, it is does not typically take up room in an individual's WM unless the language task is particularly challenging (e.g., when a person has to explain an abstract concept).

Language and aphasia. Aphasia presents as overt impairments specific to the use of language. Most aphasiologists believe that aphasia is the result of impairments in language processing, not the result of a loss of linguistic knowledge (Davis, 2014). In PWA, everyday language tasks (e.g., comprehension, word retrieval) may not be automatically processed and therefore take up space in WM (Davis, 2014). Thus conscious language processing may take up resources needed for conscious decision-making. PWA may struggle to encode ideas into simple language, which could also disrupt the decision-making process (e.g., they may not be able to categorize certain choices as safe and others as risky; Gleichgerrcht et al, 2012). Finally, negative associations have been found between performance on problem-solving tasks and language impairment (Baldo et al., 2005).

Models of Decision Making

Intact model of cognitive decision-making. Figure 1 depicts a conceptual model of decision-making. The decision-making process begins at the top of the diagram and unfolds downwards in a sequential manner. Intuitive and automatic System 1 processing (the orange box at the top of the diagram) occurs before rational System 2 processing (the center diagram). System 2 processing can result in the rejection or endorsement of the System 1 intuitive decision (the green and orange boxes at the bottom of the diagram that indicate a *default-interventionist* system structure). Rational decision-making theoretically takes place within an individual's WM. Therefore, System 2 processing is built around WM (the green oval). The left (blue) side of the model represents the role of memory in the rational decision-making process. The memory retrieval processes bring information from memory stores into the WM workspace, while encoding processes move information from WM into long-term storage for future recall (the blue arrows that enter and exit WM). The right (yellow) side of the model represents the environment. Attention processes bring relevant information from the environment into the WM (the large yellow arrow that enters WM). Attention processes (the yellow ring that encircles WM) also maintain relevant information in WM while preventing the entry irrelevant information (the brown arrows). Inhibitory processes prevent the automatic System 1 decision from interfering with the rational decision-making process (the purple ring that encloses WM and depicted to deflect the orange arrow that descends from the System 1 orange box). The process of inhibition partially overlaps in function with selective attention processes as both processes ensure that irrelevant information does not enter into WM (the yellow and purple rings that encircle WM). Finally, language processes encode explicit problem solving without imposing on WM space (the speech bubble that encloses the puzzle pieces).

Impaired model of cognitive decision-making. Figure 2 depicts a conceptual model of impaired decision-making that incorporates all of the cognitive deficits associated with aphasia. It is important to note that this model depicts the cumulative impact of the cognitive impairments that have been associated with aphasia. PWA may or may not demonstrate deficits in all of these cognitive functions and processes. PWA may have a limited WM capacity for storage and manipulation (smaller green circle relative to circle representing WM in Figure 1). PWA may have multiple impairments in attention function (the narrowed and diverted yellow arrows entering WM and the perforated ring surrounding WM). Deficits in the ability to inhibit the decision made by System 1 may result in a higher likelihood of endorsement of the intuitive decision (the perforated purple ring, the entry of the orange arrow into WM, the orange puzzle piece in WM, and the enlarged orange endorsement outcome box). PWA may have deficits in planning and cognitive flexibility, which may make have negative consequences for conscious deliberations (the disorganized puzzle pieces in WM). Finally, conscious language processing may take up valuable WM space and impaired language processing may not facilitate the encoding of ideas during deliberations (the black speech bubble taking up space in WM and not encircling the puzzle pieces).

Purpose of the Study

The purpose of the current study was twofold: 1) to compare performances between people with and without aphasia on decision-making tasks; and, 2) to test the theoretical frameworks of impaired and intact cognitive decision-making in people with and without aphasia. In the current study, participants completed a test battery that included measures of decision-making (linguistic and non-linguistic) and cognition (WM, EF, language). In the next section we will review measures of decision-making and cognition that were used in the current study.

Measures of Decision-Making

In this section we will review three tasks of decision-making: One linguistic task and two non-linguistic tasks. For each task we will provide an overview and description of scoring.

Linguistic measure of decision-making. The Functional Assessment of Verbal Reasoning and Executive Strategies (FAVRES) has a subtest entitled *Making a Decision* (MacDonald, 2010) This subtest could be used as a measure of linguistic decision-making. The FAVRES was designed to determine the presence and extent of higher-level cognitive-communication deficits in adults with acquired brain injury. The test was validated with individuals who had sustained a traumatic brain injury as the result of a trauma (e.g., motor vehicle accidents). The FAVRES was found to have adequate sensitivity and specificity to distinguish between individuals with and without acquired brain injury (over 80%; MacDonald, 2010). The FAVRES was also found to have high concurrent validity with the higher-level scores on the Scales of Cognitive Ability for Traumatic Brain Injury (e.g., reasoning; Adamovich & Henderson, 1992). Finally, inter-rater reliability for the FAVRES is estimated with kappa coefficient above 0.8 (MacDonald, 2010).

In the *Making a Decision* task, examinees are presented with a written transcript of two older adults conversing with their son. The examinee must select a gift for the older couple from a list of eight options. Next, the examinee is interviewed and asked specific scripted questions designed to elicit insight into their decision-making process. The examinee is asked to discuss factors they considered in the decision-making process (i.e., getting the facts), compare between different options (i.e., weighing the relevant choices), consider additional factors (i.e., flexibility), generate alternative solutions (i.e., fluency), and provide pros and cons for a

selection (i.e., prediction of consequences; MacDonald 2010). The *Making a Decision* subtest yields three scores; Accuracy, Rationale, and Reasoning. The Accuracy score is an assigned rank score that allocates more points for gift selections that are better suited to the couple (i.e., maximize strengths and minimize weaknesses). The Rational score of the task is derived from examinees' written justification for their decision. The Reasoning score is a cumulative score based on the participant's responses to the structured interview. The Reasoning score provides a general measure of the examinee's ability to demonstrate justification and reasoning for their decision-making. Standard scores and percentile scores are only available for Accuracy and Rationale scores on the *Making a Decision* subtest of the FAVRES.

Non-linguistic measures of decision-making. In contrast to the highly linguistic measure of decision-making in the FAVRES, experimental measures of decision-making have minimal linguistic demands. These tasks are designed as gambling tasks and only require basic numeracy skills. When considered in the context of capacity assessments, performance on IGT or GDT could provide insight into an individual's ability to make decisions in the financial domain.

The Iowa Gambling Task (a decision-making task with ambiguity). The IGT is a neuropsychological test of decision-making (Bechara et al., 1994). The IGT is risk-taking card game in which participants select from four decks of cards to maximize their overall gain (Dunn et al., 2006, p. 242-243; Table 2):

> The task requires participants to select from one of four decks of cards that are identical in physical appearance for 100 trials. Each card choice leads to either a variable financial reward or a combination of a variable financial reward and penalty. Unknown to participants, the rewards and punishments on the decks have been fixed by the

experimenter. For each selection from decks A and B participants win $100 and from each selection from decks C and D participants win $50. Every so often variable punishment is also given. On deck A, five in ten trials generate a penalty ranging from $35 to $150. On deck B, one in ten trials incurs a penalty of $1250. On deck C, five in ten trials involve a penalty ranging from $25 to $75. Finally, on deck D, one in ten trials gives a penalty of $250. Overall, the high reward decks (A and B) give higher levels of punishment (so leading to a net loss of $250 every 10 trials), whereas the low reward decks (C and D) give lower levels of punishment (so leading to a net gain of $250 every 10 trials). Thus, successful task performance relies on sampling more from decks C and D than from decks A and B.

Scoring of the IGT. The original scoring system of the IGT involves making a comparison of number of advantageous and disadvantageous selections. The original scoring system assumes the disadvantageous nature of the disadvantageous decks are constant. However, until the losses from the disadvantageous decks exceed the gains, those decks are actually far more advantageous from the perspective of the participant. As such we will be using a modified approach to scoring the performance on the IGT that takes the participant's experience with each of the decks is taken into consideration (Maia & McClelland, 2004). In this approach, advantageous decisions were considered selections from decks that had a positive net gain at the time of selection. If at the time of selection, a deck yielded a negative net gain it was considered a disadvantageous selection. The Iowa Gambling Task (IGT) is broken into 5 blocks, each yielding a ratio score calculated by dividing number of advantageous decisions by the total number of decisions made in the block (n = 20). The IGT also yielded an overall ratio score,

calculated by dividing the total number of advantageous decisions by the total number of decisions made during the task (n = 100).

Previous research using the IGT. The IGT has been used extensively with different populations to determine decision-making abilities under ambiguous conditions (Toplak, Sorge, Benoit, West & Stanovich, 2010). The IGT has been validated with people who have had a neurological insult resulting in brain damage and has been used in studies with a wide variety of populations including: people with mental health disorders such as schizophrenia, pathological gambling, obsessive compulsive disorder, substance dependence, depression; people with traumatic brain injury; people with chronic pain; people with Attention Deficit Hyperactivity Disorder; and, people with Alzheimer's disease (Dunn et al., 2006; Toplak et al., 2010). However, to our knowledge the IGT has never been used with PWA. Therefore neither the feasibility nor the validity of using the IGT in this population has been established.

Programming of the IGT for the current study. The IGT was programmed using Experiment Builder software created by SR Research (2016). Before each trial, the participant fixed their gaze on a dot located in the center of the screen as an 'eye-gaze drift correction'. After the drift correct was completed, participants were shown a screen with four decks of cards (i.e., the "deliberation" screen). Participants were free to look around the screen for as long as they desired. When the participant was ready to make a selection, he/she fixated on the deck they would like to select for 2000ms. When a fixation of 2000ms was detected on a single deck, the deck was selected, and the screen changed to the "gain/loss" screen. On this screen the participant was shown the amount of money they won, the amount of money they lost, their total net amount before the trial, and their updated total net amount. Participants pressed a key to

indicate they had completed reading the "gain/loss" screen and were returned to the drift correct screen.

The Game of Dice Task (a decision-making task without ambiguity). The GDT is another risk-taking, gambling task. However, the GDT was developed to mimic real life decision-making where the probabilities of risk and reward are known explicitly (Brand et al., 2005). For example, when people make a decision to drive over the speed limit they know that the monetary punishment (i.e., the speeding ticket) they may receive will be proportional to the speed they are going (Brand et al., 2005). People also know to slow down when they see a police officer, thus reducing the probability of getting a speeding ticket.

In the GDT, participants begin with $1000. The goal is to maximize their overall gain. A single die is rolled 18 times and participants bet on the number that will be rolled. Bets are associated with a single number of a combination of numbers (two, three, or four numbers). The amount of the bets is fixed based on the probability of a choice. Participants are presented with a visual representation of their decisions and the probability of winning is represented in the diagram. For example, if a participant bets on the number 5 (probability of winning is 1:6), they will either gain $1000 if the number 5 is rolled or they will lose $1000 if the number 5 is not rolled. If a person bets on the numbers 2, 3, 4, 5 (probability of winning is 2:3) s/he will gain $100 if any of those numbers are rolled, but will lose $100 if the numbers 1 or 6 are rolled (Brand et al., 2005). Participants make 18 choices and are provided an updated total after each roll of the die (Brand et al., 2005). Table 3 summarizes the GDT task.

Scoring of the GDT. Decisions are classified as either advantageous (i.e., not risky) or disadvantageous (i.e., risky). If the probability of winning is equal or greater than 50% (i.e., 1:2 or 2:3 for bets of 3 or 4 numbers) then the decision is considered advantageous. If the probability

of winning is less than 50% (i.e., 1:6 or 1:3 for bets of 1 or 2 numbers) then the decision is considered disadvantageous (Brand et al., 2005). The Game of Dice Task (GDT) yielded a net score by subtracting number of disadvantageous decisions from the number of advantageous decisions.

Previous research using the GDT. The GDT has been used in a variety of different populations including: adolescents (Donati, Panno, Chiesi & Primi, 2014); people with cancer (Chen et al., 2014); people with multiple sclerosis (Farez, Crivelli, Leiguarda, & Correale, 2014); people with bulimia nervosa and binge-eating disorder (Wu et al., 2013); and people with schizophrenia (Fond et al., 2013) to ascertain decision-making abilities under risky conditions. A computerized version of the GDT was provided by Brand and colleagues and used in the current study. The task screen showed the following information: 1) a short video showing a dice being rolled using a cup; 2) a gain/loss amount that was updated after each selection; 3) a total gain/loss screen; 4) a visual depiction of gains and losses using a bar graph; 5) a visual representation of possible combinations and gain loss amounts (similar to what is presented in Table 3); 6) participant demographic information; and, 7) trial or selection number (out of 18). Participants identified their bet selection by touching a single or combination of dice using a touch screen interface. The task was not timed and participants were allowed to freely deliberate before making a selection.

Measures of Cognition

To assess cognitive functions linked to decision making, a battery of tests was used in the current study. These tests and the constructs they measure are described in the section that follows.

Language. The Western Aphasia Battery Revised (WAB-R) was designed to determine the "presence, severity and type of aphasia" (Kertesz, 2007, p. 1). The Aphasia Quotient (AQ) will be used as the measure of language performance as it is a measure of aphasia severity regardless of aphasia type or etiology (i.e., very severe, severe, moderate, mild). The AQ ranges from 0-100, with higher scores meaning less impairment. The WAB-R also yields sub-scores related to spontaneous speech, auditory comprehension, repetition, and naming/word finding.

Working memory. The forward and backward picture span tasks are measures of non-verbal working memory (DeDe et al., 2014). The use of forward and backward span captures both the storage and manipulation components of working memory (DeDe et al., 2014).

Executive function.

Inhibition. The spatial Stroop task was designed to be a non-verbal task of inhibition (Hamilton & Martin, 2005). In this task, participants are presented with an arrow pointing either to the right or the left. The arrow can be presented in the center, on the right, or on the left of the screen. The participant must ignore the location of the arrow on the screen and press the right button when the arrow is pointing to the right, and the left button when the arrow is pointing to the left. The task is divided into three trial types: 1) neutral – where the arrow appears in the center of the screen; 2) congruent – where the location and direction of the arrow are the same (i.e., a right pointing arrow on the right side of the screen); 3) incongruent – where the location and direction of the arrow are not the same (i.e., a left pointing arrow on the right side of the screen). During incongruent trials, the participant must ignore the location-related information in order to respond correctly to arrow direction. The spatial Stroop yield multiple scores including the ratio of incorrect responses on all three trial types, the mean reaction time on all three trial

types, a measure of interference (i.e., the difference in reaction time between incongruent and neutral trials), and a measure of facilitation (i.e., the difference in reaction time between congruent and neutral trials; Allen, Martin, & Martin, 2012; Hamilton & Martin, 2005).

The spatial Stroop task was programmed using the Experiment Builder software developed by SR Research (2016). Right and left arrows appeared on the right, left or center of a 9.25 x 1.75 inch box in the center of the screen. Participants advanced between trials by pressing the either the right or left arrow button on a standard QWERTY keyboard. Participants completed two sets of 120 trials containing equal numbers of congruent, incongruent, and neutral trials.

Complex tasks. *The Trail Making Test* A and B (TMT-A, TMT-B) require the individual to integrate multiple executive function processes (i.e., planning, sequencing, inhibition, planning, cognitive flexibility); working memory storage and manipulation; and sustained attention processes (Fridriksson, Nettles, Davis, Morrow, Montgomery, 2006; Reitan, 1992). Performance on the TMT-A and TMT-B is measured by the time it takes a participant to complete the trace. The TMT-A and TMT-B are available on an iPad application created by Neuroscience Research Australia (2015; NeuRA Trail making test)

Raven's Coloured Progressive Matrices (RCPM) has been used in PWA as a measure of problem-solving (Baldo et al., 2005, 2010). In this task the participant is shown a matrix and must select the 'missing' piece from six options (Kertesz, 2007; Raven & Court, 1998). The RCPM yields a total score that includes the potential for a bonus point if the task is completed in under five minutes. The RCPM is a part of the WAB-R test battery (Kertesz, 2007)

The *Wisconsin Card Sort Task* (WCST) is a test of complex executive function and involved processes of cognitive flexibility and categorization. In the WCST, the participant must sort card to determine unstated changing rules of sorting. The WCST yields a number of scores including number of categories completed, total number of errors, number of perseveration errors, number of non-perseveration errors and the trials required to complete the first category. (Allen, Martin & Martin, 2012; Heaton, Ceune, Talley, Kay & Curtiss, 1993; Purdy, 2002). A computerized version of the WCST is available from Psychology Experiment Building Language and was used in the current study (Mueller, 2012; Mueller & Piper, 2014)

The *AX-Continuous Processing Task* (AX-CPT) is a test of context processing. The AX-CPT involves the presentation of a sequence of single letters. The letters alternate between cue stimuli (A, B) and probe stimuli (X, Y). Participants are asked to press a target button when they see an X probe preceded by an A cue (AX trials). For all other cue-probe sequences (AY, BX, BY), the participants press a different non-target button (Braver et al., 2001, 2005). In the AX-CPT the cue stimulus provides contextual information and individuals may employ either a proactive or a reactive strategy to process the cue stimulus. Processing strategies are differentiated by error patterns on non-target trials. Proactive processors (i.e., not impaired) tend to make errors on AY trials, indicating that they processed the cue stimulus and made errors anticipating a potential target response. When the probe Y is presented, the participant must inhibit expectation of a target response and press the non-target button. Reactive processors (i.e., a less efficient method of processing) tend to make more errors on BX trials, indicating that the cue is processed after the probe is presented. In other words, the participant is responding to the presentation of the probe X and not utilizing cue information to anticipate whether the trial could be a target or not (Braver et al., 2005; Chatham, Frank, & Munakata, 2009). The AX-CPT yields

ratios of error and reaction time scores for each of the trial types (i.e., AX, AY, BX, BY). Scores on AX trials were also interpreted as an indicator of sustained attention while scores on the AY trials were also considered indicative of an individual's inhibitory processes.

In the current study, the AX-CPT was programmed using the Experiment Builder software developed by SR Research (2016). In this version, participants were presented with a sequence of shapes and instructed to press the right arrow button on a standard QWERTY keyboard when presented with the circle (i.e., cue A) followed by the star (i.e., probe X, AX-trials). After any other trial type (i.e., AY, BX, BY), participants were instructed to press the left arrow button. Cue B was represented by the following shapes: triangle, square, diamond, pentagon, and parallelogram. Probe Y was represented by the following shapes: moon, cross, arrow, "X", and heart. Trial types were randomized and participants completed 70 AX trials, 10 AY trials, 10 BX trials, and 10 BY trials. Participants completed both a long and short versions of the AX-CPT. Cue and probe stimuli were presented for 500ms in the center of the screen. In the short version the delay between the cue offset and the probe onset was 1000ms with a 5000ms inter-trial delay. In the long version the delay between the cue offset and the probe onset was 5000ms with a 1000ms inter-trial delay (Braver et al., 2005)

Pupillometry

When researchers use behavioural tests of cognitive and decision-making they use overt behaviours of the participants to measure cognitive performance and reaction time (i.e., pointing, pressing a button, etc). Another dimension of cognition is the amount of effort required to complete the task (Chapman & Hallowell, 2015). Since the 1960's, researchers have been

reporting a positive relationship between pupil size and cognitive load (i.e., as load increases, pupil size increases; Hess & Polt 1960, 1964; Kahneman & Beatty, 1966).

Pupillary responses to cognitive tasks is considered a valid measure of cognitive or mental effort (Kahneman, 1973). Pupil dilation proportional to processing load has been observed within many different types of tasks including: mental arithmetic tasks (i.e., multiplication, division; Ahern & Beatty, 1981; Bradshaw, 1968; Hess & Polt, 1964); short term memory tasks (i.e., digit and word span tasks; Kahneman & Beatty, 1966); language processing tasks (i.e., classification of letters into upper and lower case; classification of letters as vowels and consonants, semantic judgements, sentence processing; (Ahern, 1978; Ahern & Beatty, 1981; Beatty & Wagoner, 1978; Wright & Kahneman, 1971); perceptual tasks (i.e., detection of visual and auditory signals; Hakerem & Sutton, 1966); tasks of inhibition (i.e., Stroop task; Laeng, Orbo, Holmlund & Miozzo, 2010); and attention tasks (i.e., selective and sustained attention; Beatty, 1982a, 1982b; Parasuraman, 1979; Parasuraman & Davies, 1977). Tasks that are more complex are associated with larger pupil dilations than tasks that are simpler (e.g., difficult multiplication is associated with greater pupil dilation than recall of one to seven digits; Beatty, 1982a). Thus, pupil dilation is effectively able to capture varying processing load between qualitatively different tasks. Pupillometry has also been used to establish differences in processing load between groups of participants (e.g., high and low intelligence; mono-lingual and bi-lingual children; Ahern & Beatty, 1979; Beatty, 1982a; Kuipers & Thierry, 2013; Sebastian-Galles, 2013).

Pupillary responses to cognitive task demands have a short onset latency (i.e., 100-120 milliseconds after the onset of processing) and rapidly disappear once processing is complete (Beatty, 1982a). Pupils dilate between 0.1 and 0.5mm in response to changes in cognitive

loading between tasks and between groups of participants. The muscles of the iris that control pupil size are controlled by the sympathetic and parasympathetic branches of the autonomic nervous system (Lowenfeld & Lowenstein, 1993). Cognition-related changes in pupil size are thought to be related to changes in activation of the neurons in the locus coerulus which are linked to the norepinephrine system (Alnæs et al., 2014; Laeng, Sirois, & Gredback, 2012; Murphy, O'Connell, O'Sullivan, Robertson, & Balsters, 2014; Rajkowski, Majczynski, Clayton & Aston-Jones, 2004; Samuels & Szabadi, 2008). When norepinephrine is released, it inhibits pupil constriction, which subsequently results in dilation. The degree of inhibition of constriction has been linked to task demands (i.e., the more difficult a task, the more norepinephrine is released by the locus coerulus, resulting in a greater inhibition of constriction and greater dilation; Chapman & Hallowell, 2015).

Pupil size can also be affected by other variables (Beatty, 1982). The tonic or baseline size of a person's pupil can be influenced by reflexive responses to the environmental and personal factors. Therefore it is important to control for environmental factors (i.e, light levels) and track emotional arousal (i.e., use change in pupil size measures during individual trials, collect multiple baseline measures). Henceforth we will interpret the phasic changes in pupil size as *cognitive arousal* and tonic changes in pupil size as *emotional arousal.*

Pupillometry and PWA Chapman and Hallowell (2015) successfully piloted the use of pupillometry in PWA using a linguistic processing task. In their study, Chapman and Hallowell (2015) used a passive single-word processing task and compared changes in pupil size between PWA and controls. They found that pupil dilation increased with words that were more semantically complex for both the controls and PWA. However, the researchers did not find a between-groups effect for the pupillometric responses (i.e., no difference in pupil dilation

between people with and without aphasia; Chapman & Hallowell, 2015). The researchers concluded that people with and without aphasia exerted similar amounts of cognitive effort to process the simple linguistic task. Chapman and Hallowell (2015) suggested their findings may be due to the fact that the task required very little processing and did not tax the cognitive system of controls or PWA. To our knowledge, there is currently no published research reporting the use of pupillometry in conjunction with a cognitive task in PWA. We conducted a pilot study using a WM picture span task in conjunction with pupillometry to test feasibility of pupillometry with a basic cognitive task (Kim, Suleman, Dahlke, Lorenz, & Muc, 2015; Suleman, Garcia, & Kim, 2016; Suleman & Kim, 2016). We found that pupillometry was sensitive to changes in task demands during a test of WM in PWA (Kim et al., 2015; Suleman et al., 2016, Suleman & Kim, 2016).

Pupillometry and the IGT. To our knowledge, only one study has combined pupillometry with performance on the IGT (Lavin, San Martin, & Jubal, 2014). In this study researchers were interested in pupillary responses to uncertainty of negative feedback (i.e., dilation in anticipation of loss amount) and surprise (i.e., dilation after loss amount is presented; Lavin et al., 2014). The results of this study provided evidence that uncertainty and surprise play a role in learning and pupil dilation can serve as a marker for these variables (Lavin et al., 2014). However, the researchers did not evaluate pupil dilation during deliberation (i.e., before a card was selected). Therefore, the relationship between cognitive arousal and the task demands associated with selecting a card (i.e., making a choice) is still unknown. A feasibility study to determine whether or not pupillometry could be used in conjunction with the deliberation phase of the IGT was carried out with two individuals with mild aphasia (Suleman, Chaouki, & Kim, 2014; Suleman & Kim, 2015b; Suleman, Kim & Hopper, 2015). We found that the use of

pupillometry provided insight into cognitive and emotional arousal during deliberations in PWA (Suleman et al., 2014; Suleman & Kim 2015b. Suleman, Kim, & Hopper, 2015).

Conclusions

Adults with and without aphasia make many different decisions every day. Any decision that an individual is consciously aware of involves the rational decision-making system. Due to associated cognitive deficits, PWA may struggle with day-to-day decision-making. However, decision-making abilities of PWA remain to be systematically investigated in a controlled research study. Further, the proposed theoretical model of intact and impaired decision-making must be systematically validated or refuted through a variety of qualitative, quantitative, and mixed-methods research studies.

Chapter 3: Methods

In this study, participants completed three measures of decision-making; one linguistic, and two non-linguistic (the *Making a Decision* subtest of the FAVRES, the IGT, and the GDT, respectively). While participants completed the IGT, researchers used an eye-tracker to concurrently collect pupil size data. Eye-tracking data provided real-time information about cognitive and emotional arousal. Participants with and without aphasia also completed a neuropsychological test battery consisting of behavioural measures of language, WM, and EF. The data collected in this study were used to: 1) compare performance between people with and without aphasia on different measures of decision-making using a quasi-experimental design; and, 2) explore associations between measures of cognition and measures of decision-making using an exploratory research design.

Research Questions

Linguistic Decision-making.

Question 1: Do people with and without aphasia differ in performance on linguistic measures of decision-making?

Hypothesis. We expected people with aphasia to perform worse than people without aphasia on linguistic measures.

Question 2. What are the cognitive predictors of linguistic decision-making?

Hypothesis. We expected performance on the FAVRES to be predicted by performance on the WAB, WM span tasks, and at least some of the measures of EF (i.e., the TMT-A and TMT-B).

Non-Linguistic Decision-Making.

Question 3. Do people with and without aphasia differ in performance on non-linguistic measures of decision-making?

Hypothesis. We expected people without aphasia to demonstrate improved performance on the IGT and GDT as the tasks progressed (i.e., make more advantageous decisions as they gain experience). We expected that as control participants gain experience with the decks on the IGT, their cognitive arousal would decrease (i.e., we expected to observe a reduction in change in pupil size over time). We did not expect PWA and controls to significantly differ on measures of non-linguistic decision-making.

In our pilot analysis (Suleman & Kim, 2015a, 2015b) we found that PWA can perform disparately on the IGT (i.e., one participant made increasingly advantageous decisions while the other made increasingly disadvantageous decisions). Both participants showed a decrease in cognitive arousal throughout the task when we controlled for tonic pupil changes (i.e., using block-specific baselines). Preliminary findings suggested that cognitive arousal would decrease for PWA as the task progresses.

Question 4. What are the cognitive predictors of non-linguistic decision-making?

Hypothesis. To date, researchers have not been able to consistently find significant associations between performance on the IGT and measures of cognition (Toplak et al., 2010). Therefore, we did not expect to find an association between the IGT and cognitive measures. However, in this study we used a modified scoring that incorporated participant experience with the decks and thought that the modified scoring may reveal some associations between cognition and the IGT. We explored the relationship between cognitive arousal and the IGT and expected to find some significant patterns over the duration of the task. We expected performance on the

GDT to be associated with performance on the WCST and possibly other measure of complex EF (i.e., RCPM, AX-CPT).

Participants

Demographic information. Participants were 32 individuals (17 male, 15 female) divided into two groups; people with aphasia (PWA; $n = 16$) and age/education-matched controls ($n = 16$). All participants were 18 years or older and spoke English as their primary language. All participants were screened and found to have adequate hearing and vision to complete the tasks (with adaptive devices if necessary). Independent samples t-tests were used to determine there was no significant difference between PWA and controls on age, $t\ (30) = 0.120$, $p = 0.905$, and total years of education, $t\ (30) = -1.175$, $p = 0.249$. All participants completed the Geriatric Depression Screening (GDS) and the two groups were significantly different on this measure, $t\ (16.114) = 2.394$, $p = 0.029$, with PWA having higher scores on the GDS. Three PWA were at risk of depression (i.e., had a score higher than 5 on the GDS). Table 4 contains means and standard deviations for people with and without aphasia on demographic measures.

Participants with aphasia had to have experienced aphasic symptoms consistent with mild to moderate aphasia as a result of a stroke in the left hemisphere of the brain for at least 6 months prior to participating in the study so as to ensure neurological stability. Scores on the WAB-R were used to characterize the aphasia profiles of participants with aphasia (Table 5).

Procedures

Recruitment. PWA were recruited through the client/participant network that is a part of the Aphasia Research Laboratory, Corbett Clinic in the Faculty of Rehabilitation Medicine, and Alberta Aphasia Camp (i.e., individuals with aphasia who are known and willing participants in

research projects). Age and education matched adults with no history of brain injury were recruited through public advertisement and open-ended calls for participants through organizations catering to the older adults (e.g., the Edmonton Life-Long Learners Association).

Screening. A registered SLP administered a basic vision, hearing, and depression screening including the Rosenbaum pocket vision screening, minimal-pairs discrimination hearing test (adapted from the Psycholinguistic Assessments of Language Processing in Aphasia; Kay, Coltheart, & Lesser, 1992) and the GDS (short form; Yesavage et al., 1983). Pupil reflex was assessed by shining a penlight from the outside corner of each eye to the center of the eye while the participant looked directly forward. If the participants' pupil quickly constricted in response to the light stimulus, the person was considered to have a normal pupillary reflex.

Testing. Participants attended 2-6 sessions to complete a decision-making test battery and a cognitive test battery. The decision-making test battery included the *Making a Decision* subtest of the FAVRES, the IGT, and the GDT (Table 6). The FAVRES was selected for this study because the reasoning interview is akin to a domain-general capacity assessment interview. The IGT was selected for this study because of it has been used robustly in a variety of populations has appropriate predictive capacity of difficulties in real life decision-making, especially when the probability of winning and losing is unknown (Dunn et al., 2006). The GDT was selected because it is a simple task for participants to understand and could be completed in under 10 minutes. The GDT also provides information about an individual's risk-taking behavior when the probability of winning and losing is known. Both the IGT and GDT provide some insight into an individual's ability to make financial decisions as management of monetary risk is considered part of the financial domain. The cognitive test battery included measures of language, WM, and EF (Table7). Cognitive measures were selected if they had: 1) been

previously been used in a study of decision-making and/or with PWA; and, 2) adequate reported reliability and validity (i.e., greater than 70%; Table 8). In this study, a direct measure of attention was not used, as testing burden for participants was an issue. Also, researchers have found performance on measures of attention is related to performance on other cognitive measures (e.g., Stroop task, TMT-B, WCST, and backward digit span; Robertson, Ward, Ridgeway, & Nimmo-Smith, 1996).

Tests formats include paper-and-pencil based tasks, computerized tasks, and computerized tasks completed while the EyeLink 1000+ eye-tracker (SR Research, 2014) collected eye movement and pupil size data. We used the desk-mounted system and participants used a chin rest to ensure pupil and head stability. The size of the left pupil was measured at a rate of 1000 Hz using an arbitrary unit of pupil size generated by the EyeLink 1000+ system (SR Research, 2014). The sampling rate was reduced (i.e., downsampled) to 250Hz during analysis. Participants were seated approximately 50 centimeters from the camera and positioned according to guidelines provided by SR Research (2014). Light levels in the room were measured using the iPad application, Lux Meter Pro (AM Power Software). Light levels were measured during the task and did not fluctuate as a result of changing images on the screen.

Compensation. Participants were compensated $50 for their time and participation in the study.

Data Analysis

Comparing performances of people with and without aphasia on linguistic and non-linguistic decision-making tasks. Data were analyzed using mixed Analyses of Variance (ANOVAs) to determine main and interaction effects between people with and without aphasia on linguistic and non-linguistic measures of decision-making.

Exploring associations between measures of decision-making and cognition. For each of the three decision-making measures, we conducted a multiple regression analysis using scores from cognitive measures as predictors or components in the model.

Chapter 4: Results

Comparing performance on measures of decision-making between participants with and without aphasia on linguistic and non-linguistic measures of decision-making (Research questions 1 and 3)

Research question 1: Do people with and without aphasia differ in performance on linguistic measures of decision making? The linguistic measure of decision-making (*Making a Decision* subtest on the FAVRES) yielded two subscores; Accuracy and Reasoning. This analysis was conducted using a 2x2 Mixed ANOVA with one within-groups factor, linguistic decision-making (2 levels: Accuracy, Reasoning) and one between-groups factor, group (2 levels: PWA, controls). The dependent variables for this analysis were the ratio scores for each level of the within-groups measure. The main effects for linguistic decision-making, F (2, 60) = 39.394, $p < 0.0001$, and group, F (1, 30) = 49.818, $p < 0.0001$ were both statistically significant. There was also a statistically significant interaction between group and linguistic decision-making, F (2, 60) = 9.647, $p < 0.0001$ (Table 9 and Figure 3).

Post hoc non-parametric correlation analyses were used to further explore the significant main effect for linguistic decision-making for each group. There was no significant relationship between Accuracy and Reasoning scores for neither PWA, $r_x = 0.236$, p (2-tailed) = 0.378, nor controls, $r_x = 0.236$, p (2-tailed) = 0.37. Performance on Accuracy and Reasoning measures were independent for both PWA and controls.

Post hoc independent t-test analyses were used to further explore the significant main effect for group and the interaction effect. This analysis found a greater mean difference between PWA and controls on the Reasoning score, t (30) = -6.708, $p < 0.0001$, than on the Accuracy

score, t (19.164) = -2.239, p = 0.037. For this analysis, a Bonferroni correction was applied and significance was determined at $p < 0.025$. Therefore, PWA performed significantly worse than controls on both the accuracy and reasoning measures of linguistic decision-making; however, their performance was markedly worse on the reasoning measure.

Secondary analysis of PWA - severity. Non-parametric correlation analyses were conducted between WAB-R AQ as a measure of aphasia severity and ratio scores on linguistic measures of decision-making for PWA. A not significant positive correlation was found between the WAB-R AQ and the Accuracy score, $r_x = 0.059$, p (2-tailed) = 0.828. A significant positive correlation was found between the WAB-R AQ and the Reasoning score, $r_x = 0.763$, p (2-tailed) = 0.001. Aphasia severity was related to participants' ability to discuss their decision-making process.

Secondary analysis of PWA - fluency. PWA were subdivided into two fluency groups based on aphasia type as determined by score distribution on the WAB-R. Individuals with Broca's aphasia were considered non-fluent, while individuals with Anomia or Wernicke's aphasia were considered fluent. This analysis was conducted using a 2x2 Mixed ANOVA with one between-groups factor, fluency group (2 levels: fluent, non-fluent), and one within-groups factor, linguistic decision-making (2 levels: Accuracy, Reasoning). The dependent variables for this analysis were the ratio scores for each level of the within-groups measure (Table 10, Figure 4).

The main effect for linguistic decision-making, F (1, 14) = 0.952, p = 0.001 was statistically significant. There was no significant main effect for fluency group, F (1, 14) = 2.926, p = 0.109 and no significant interaction between linguistic decision-making and aphasia fluency,

F (1, 14) = 0.003, p = 0.954. People with fluent and non-fluent aphasia did not differ in performance on the Accuracy and Reasoning linguistic decision-making scores.

Research question 3: Do people with and without aphasia differ in performance on non-linguistic measures of decision-making? The Game of Dice Task (GDT) yielded a net score by subtracting number of disadvantageous decisions (defined as selections with less than a 50% probability of winning) from the number of advantageous decisions (defined as selections with a 50% or higher probability of winning). The Iowa Gambling Task (IGT) was broken into 5 blocks, each yielding a ratio score calculated by dividing number of advantageous decision by total number of decisions made in the block (n = 20). The IGT also yielded an overall ratio score, calculated by dividing the total number of advantageous decisions by the total number of decisions made during the task (n = 100).

This analysis was conducted using a 2x2 Mixed ANOVA with one between-groups factor, group (2 levels: PWA, controls), and one within-groups factor, non-linguistic decision-making (2 levels: IGT, GDT). The dependent variables for this analysis were the net and overall scores for the GDT and IGT, respectively. The main effect for non-linguistic decision making, F (1, 30) = 16.003, p <0.001 was significant. The main effect for group, F (1, 30) = 1.524, p = 0.227, and the interaction between group and non-linguistic decision-making, F (1, 30) = 1.546, p = 0.233, was not significant. PWA and controls did not perform differently on the IGT or the GDT (Table 11, Figures 5-6).

A post-hoc non-parametric correlation was used to further explore the main effect of non-linguistic decision-making. The correlation was used because the IGT and GDT used different types of scores (i.e., the IGT used a ratio score and the GDT used a net score). There was no

significant correlation between IGT and GDT scores for PWA, $r_s = 0.432$, p (2-tailed) = 0.095, or control participants, $r_s = 0.277$, p (2-tailed) = 0.299.

Comparison of people with aphasia and control performance across five blocks of the IGT. This analysis was conducted using a 2x5 Mixed ANOVA with one between-groups factor, group (2 levels: PWA, controls), and one within-groups factor, IGT block (5 levels: blocks 1-5). The dependent variable for this analysis was the ratio of advantageous decisions made during each block. The main effect for IGT block was significant, F (1.635, 49.063) = 34.038, $p <$ 0.0001. Both the main effect for group, F (1, 30) = 0.805, p = 0.377, and the interaction effect between group and IGT block, F (1.635, 49.063) = 0.336, p = 0.673 were not significant. There were no significant differences in performance pattern between people with and without aphasia (Table 12, Figure 7).

Pupillometry and IGT. While participants were completing the IGT, an eye-tracking system collected measures of pupil dilation as an index of cognitive arousal. In this analysis only pupil size measures collected during the Deliberation period were used. The deliberation period was defined as the time from the onset of the "deliberation screen" (i.e., the presentation of the 4 decks of cards) to 200ms after the final fixation was detected, to account for the latency of pupillary responses. Change in pupil size was calculated by subtracting the minimum pupil size for each trial from each measure of pupil size during the deliberation period. Average change in pupil size per trial and block during the deliberation phase was used as the dependent variable in the following analyses. The deliberation phase was defined as the time from presentation of four decks of cards to the beginning of the final fixation indicating a decision had been made.

Trial-based analysis of change in pupil size (cognitive arousal). Three Pearson correlation analyses were used to examine associations between trial and average change in pupil size per trial during deliberation. Before these analyses were carried out, extreme outliers (defined as scores greater than three standard deviations from the mean) were removed from the data. Thirty-nine, or 1%, of all trials were identified as extreme outliers.

The overall correlation between change in pupil size and trial number included both PWA and control participants and was not significant, $r = -0.033$, p (2-tailed) = 0.064. The sample was stratified and correlation analyses were performed independently for PWA ($r = -0.075$, p (2-tailed) = 0.003) and controls ($r = -0.011$, p (2-tailed) = 0.666). As the task progressed, PWA exhibited less cognitive arousal during trials, whereas the cognitive arousal of control participants remained relatively stable (Table 13).

Block-based analysis of change in pupil size (cognitive arousal). This analysis was conducted using a 2x5 Mixed ANOVA with one between-groups factor, group (2 levels: PWA, controls), and one within-groups factor, IGT block (5 levels: blocks 1-5). The dependent variables for this analysis were the average change in pupil size during deliberation per block. Both the main effect for IGT block, F (3.362, 100.846) = 0.454, $p = 0.737$) and the main effect for group, F (1, 30) = 0.080, $p = 0.779$, were not significant. There was no significant interaction effect between group and IGT block, F (3.362, 100.846) = 1.844, $p = 0.137$. There was no discernable change in pupil size as the blocks increased, nor did the two groups differ significantly in pupil size. Therefore, this analysis shows that across blocks, cognitive arousal remained generally stable and the PWA and controls exerted similar amounts of arousal during all blocks (Table 14, Figure 8).

Trial-based analysis of minimum pupil size (Emotional arousal). Tonic or gradual overall changes in pupil size are indicative of changes in levels of arousal. For example, increasing minimum pupil size could indicate increasing frustration while decreasing minimum pupil size would indicate disengagement from the task (Laeng et al., 2012). Three Pearson correlation analyses were used to look for associations between trial and absolute minimum value for pupil size per trial during deliberation. The overall correlation between change in pupil size and trial number included both PWA and control participants and was not significant, r = -0.023, p (2-tailed) = 0.192. The sample was stratified and correlation analyses were performed for PWA only (r = -0.017, p (2-tailed) = 0.499) and controls only (r = -0.029, p (2-tailed) = 0.248). These results indicate that neither PWA nor controls were experiencing overall increasing or decreasing arousal (i.e., the groups were neither getting frustrated nor disengaging from the task; Table 15).

Participant subjective ranking of four decks during the IGT. After each block, participants were asked to rank the decks of cards from best (1) to worst (4) for winning money. In our study, Decks A & C were considered generally disadvantageous and Decks B & D were considered generally advantageous. This subjective information is based on explicit reports of participant perceptions of the decks. All participants were shown a diagram of the four decks and asked to point to the decks from best to worst. This was done to minimize the language demands for PWA. Please note, not all participants provided a response after every block. When a participant identified two decks were equal, the higher rank was assigned to both decks (e.g., if the participant stated both decks B and D could be ranked as 2 or 3, both decks were assigned a rank of 2). These data show that after block 2, control participants were clearly identifying the 'advantageous' decks as being better than 'disadvantageous' decks. PWA did not make a clear distinction between the different decks throughout the task (Table 16, Figures 9-10).

Secondary Analysis of PWA – severity. Non-parametric correlation analyses between WAB-R AQ and scores on non-linguistic measures of decision-making (i.e., overall scores for the GDT and IGT) were conducted for PWA. Only a significant positive correlation was found between WAB-R AQ and GDT scores, $r_x = 0.548$, p (2-tailed) = 0.028. Therefore, aphasia severity was related to the ability to make decisions in conditions where the probability of risk and reward were made explicit, as more severe aphasia was related to lower performance on the GDT (Table 17).

Secondary Analysis of PWA – fluency. People with aphasia were subdivided into two fluency groups based on aphasia type as determined by score distribution on the WAB-R. Individuals with Broca's aphasia were considered non-fluent, while individuals with Anomia or Wernicke's aphasia were considered fluent. This analysis was conducted using a 2x2 Mixed ANOVA with one between-groups factor, fluency group (2 levels: fluent, non-fluent), and one within-groups factor, non-linguistic decision-making (2 levels: IGT, GDT). The dependent variables for this analysis were the net and overall scores for the GDT and IGT, respectively.

There was a significant main effect for fluency group, F (1, 14) = 4.619, p = 0.05 and a significant interaction between fluency group and non-linguistic decision-making, F (1, 14) = 4.654, p = 0.049. There was no significant main effect for non-linguistic decision-making, F (1, 14) = 4.038, p = 0.064. Post-hoc independent t-tests were used and a Bonferroni correction was applied, such that significance was determined at $p < 0.025$. There were no significant differences between people with fluent aphasia and people with non-fluent aphasia on the GDT, t (14) = 2.153, p = 0.049, or the IGT, t(14) = 0.536, p = 0.537 (Table 18, Figures 11-12).

Exploring associations between measures of decision-making and measures of cognition (Research questions 2 and 4: What are the cognitive predictors of linguistic decision-making; what are the cognitive predictors of non-linguistic decision-making?)

Outcome variables. Four interval-level, unbounded, continuous outcome variables were used in this analysis. Outcome variables included two linguistic measures of decision-making (i.e., Accuracy and Reasoning ratio scores on the FAVRES) and two non-linguistic measures of decision-making (i.e., GDT net score, IGT overall ratio score). For each of the outcome variables, three multiple regression models were built; 1) an overall model that included all participants, 2) a model for PWA, 3) a model for control participants.

Predictor variables. People with and without aphasia completed a series of tasks designed to measure different aspects of cognition. Forty-five scores of cognition and three demographic factors were identified as interval-level, continuous predictor variables. A correlation analysis of all predictors was conducted to identify variables that were highly correlated with one another ($r > 0.8$). This was done to reduce possible violation of the assumption of multicollinearity. If two or more variables were highly correlated, a single score was selected to represent the correlated group. As a result 19 predictor variables were excluded from the analysis. The viability of each of the 29 uncorrelated predictor variables (26 cognitive, 3 demographic) was tested for each outcome variable using univariate regression analyses. If a predictor variable was significant (determined at $p < 0.15$), it was included in the multiple regression analysis as a potential predictor variable for that outcome variable.

Independent t-test analyses were conducted to determine whether people with aphasia and controls differed in performance on the 26 cognitive predictor variables. A full summary of

means and standard deviations for all cognitive measures can be found in Table 19. As this analysis was exploratory, between-groups significance was determined at $p < 0.05$ and marked with an asterisk.

Multiple regression model development. Backward stepwise multiple regressions were used to complete this exploratory analysis (Field, 2009). All significant variables identified by a priori univariate analyses were included in the initial multiple regression model. Predictor variables were considered significant in the multiple regression model at $p < 0.05$. For each analysis assumptions of normality, multicollinearity, homoscedasticity, and independence of errors were tested. Because of the small sample size and the exploratory nature of this study, these assumptions were occasionally violated, but did not halt the analysis process. Furthermore, potential extreme cases were identified for each analysis and tested using a sensitivity test. No cases were excluded from the analysis as these cases were not considered clinical or population outliers, even though they were outliers for this sample. Table 20 contains a complete summary of the significant predictors for each of the regression models. Please refer to Table 21 for a summary of assumption violations and the number of extreme cases identified. Please see Appendices A – L for full summaries of the stepwise regression models.

Accuracy multiple regression models.

Accuracy overall model for all participants. Six potential predictors were identified for this analysis. The final model included two significant predictors: Stroop errors on incongruent trials and Stroop interference, F (2, 26) = 7.804, p = 0.002, R^2= 0.375, $R^2_{adjusted}$ = 0.327.

Accuracy model for PWA. Two potential predictors were identified for this analysis. The final model for this analysis was not significant, F (1, 11) = 3.233, p = 0.100, R^2= 0.227, $R^2_{adjusted}$ = 0.157.

Accuracy model for controls. Two potential predictors were identified for this analysis. The final model had one significant predictor, the number of errors on the AX-CPT long on BX trials, F (1, 14) = 10.938, p = 0.005, R^2= 0.439, $R^2_{adjusted}$ = 0.398**.**

Reasoning multiple regression models.

Reasoning overall model for all participants. Thirteen potential predictors were identified for this analysis. The final model included five significant predictors: Score on the Geriatric Depression Scale, errors on Stroop incongruent trials, errors on AX-CPT short AX trials, errors on AX-CPT BX trials, and TMT-B time, F (5, 22) = 12.127, p < 0.001, R^2= 0.734, $R^2_{adjusted}$ = 0.673.

Reasoning model for PWA. Nine potential predictors were identified for this analysis. The final model included three significant predictors: WAB aphasia quotient, errors on AX-CPT short AX trials, errors on AX-CPT AY trials, F (3, 12) = 13.338, p < 0.0001, R^2= 0.769, $R^2_{adjusted}$ = 0.712.

Reasoning model for controls. Only one potential predictor was identified for this analysis, time to complete TMT-B. Therefore a linear regression analysis was used for this analysis, F (1, 14) = 7.741, p = 0.015, R^2= 0.356, $R^2_{adjusted}$ = 0.310.

IGT multiple regression models.

IGT Overall model for all participants. Six potential predictors were identified for this analysis. The final model included three significant predictors: Stroop errors on incongruent trials, WCST trials to complete the first category, and time to complete the RCPM, F (3, 24) = 4.601, p = 0.011, R^2= 0.365, $R^2_{adjusted}$ = 0.286.

IGT model for PWA. Three potential predictors were identified for this analysis. The final model had one significant predictor, AX-CPT long AX reaction time, F (1,14) = 4.703 , p = 0.048, R^2= 0.251, $R^2_{adjusted}$ = 0.198.

Iowa Gambling Task model for controls. Four potential predictors were identified for this analysis. The final model had one significant predictor, the number of trials to complete the first category on the WCST, F (1,14) = 4.858, p = 0.045, R^2= 0.258, $R^2_{adjusted}$ = 0.205**.**

GDT multiple regression models.

GDT overall model for all participants. Fifteen potential predictors were identified for this analysis. The final model included four significant predictors: age, Stroop errors on incongruent trials, WCST trials to complete the first category, and total score on the RCPM, F (4, 24) = 13.044, p < 0.001, R^2= 0.685, $R^2_{adjusted}$ = 0.632.

GDT model for PWA. Ten potential predictors were identified for this analysis The final model included four significant predictors: age, Stroop errors on incongruent trials, AX-CPT short errors on BX trials, WCST total errors, and WCST trials to complete the first category, F (5, 7) = 161.69, p < 0.001, R^2= 0.991, $R^2_{adjusted}$ = 0.985.

GDT model for controls. Two potential predictors were identified for this analysis The final model included both these predictors: age and WCST trials to complete the first category $F(2,13) = 7.252$, $p = 0.008$, $R^2 = 0.527$, $R^2_{adjusted} = 0.455$.

Power Analysis

Additional analyses were carried out to determine the statistical power of the findings of this study using the power analysis software, PASS (2014). Between group power analyses were carried out using means and standard deviations on linguistic and non-linguistic decision-making tasks. When a significant between group difference was found in this study (i.e., on linguistic measures of decision-making), group sample sizes of $n = 16$ ($N = 32$) achieved acceptable power to reject the null hypothesis that the two groups are similar. For accuracy scores, power was estimated at 56.6% and for reasoning scores power was estimated at 100%. This indicates that, especially for reasoning, the findings were unlikely to be the result of a beta error (i.e., false negative). When between groups differences were not significant (i.e., on non-linguistic measures of decision-making), the power analysis indicated a comparatively low estimate of statistical power (34% for GDT, 7% for IGT). In other words, for non-linguistic measures of decision-making, if a significant between group differences had been found, it would likely be the result of an alpha error (i.e., false positive).

The exploratory analyses of this study involved multiple regression analyses. All attempts were made to ensure that minimum number of variables were inputted into the models to increase power. However 29 predictor variables were identified for this study. To detect an *R*-squared value of 0.38 (the minimum R-squared value found in the analysis), a sample size of $N =$

32 has 8% power. Therefore, the exploration of relationships between cognitive measures and decision-making measures is underpowered in this study and should be interpreted accordingly.

Chapter 5: Discussion

In this study, people with and without aphasia completed a neuropsychological test battery that included measures of decision-making, language, WM, and EF. This discussion is divided into six subsections: 1) Linguistic decision-making; 2) Non-linguistic decision-making with ambiguity; 3) Non-linguistic decision-making without ambiguity; and 4) Implications for theoretical understanding of cognitive decision-making; 5) Limitations & future directions; and, 6) Implications for clinical practice and advocacy movements.

Linguistic Decision-Making

In this study, PWA and controls completed the *Making a Decision* subtest of the FAVRES (MacDonald, 2005), which yielded Accuracy and Reasoning scores. In general, the findings suggest that linguistic decision-making may be negatively impacted in PWA.

Accuracy. Accuracy can be interpreted as an indicator of an individual's ability to make the best decision based on the information provided. PWA performed significantly worse than controls on the measure of Accuracy. It is possible that PWA did not comprehend or process all the information that was presented to them, which limited their ability to make a good choice. Theoretically, this task relied heavily on the participant's ability to comprehend oral and written language (i.e., receptive language via listening to the recording and/or reading the typed transcript), which can be negatively affected in PWA. However, neither the measure of receptive language nor any other measures of cognitive abilities were found to be significant predictors of Accuracy performance for PWA.

The lack of a predictive relationship between receptive language, other cognitive measures as and the Accuracy score may be a result of small sample size and the nature of the

tasks used in this study. The stratified regression only used data from PWA (n = 16) and was underpowered, especially given each model began with 29 predictor variables. Therefore, there is a high probability of a beta error resulting in a false negative finding. A larger sample size and a more focused set of predictor variables may have yielded a positive regression result for the Accuracy score. In particular, a more robust measure of receptive language could make a significant contribution to the regression model for Accuracy in PWA. The receptive language measure used in this study was the raw Auditory Verbal Comprehension score from the WAB-R (Kertesz, 1982). This measure included accuracy on yes/no questions, auditory word recognition, and sequential commands, all of which were single sentences. Therefore, the complexity of language comprehension necessary for the FAVRES may not be reflected in the assessment of auditory comprehension captured by the WAB-R.

For example, PWA0022 demonstrated a relative strength in auditory comprehension on the WAB-R (Auditory Verbal Comprehension score of 8.5/10) but failed to make a good selection on the FAVRES. This participant selected to purchase stocks for the older couple, even though the father character made an explicit statement against the purchase of stocks. This statement is made later in the transcript (after 1 minute and 45 seconds). PWA0022 stated that "mom and dad want money" as a justification for his decision. PWA0022's conclusion that the characters desire money was not a natural conclusion given the dialogue between the characters (i.e., the characters indicated having recently gone on vacation and have hired some kids to help with their gardening, which suggested they are not in financial need). In this case, it is plausible that the participant was unable to comprehend the long and more complex narrative of the script despite being able to comprehend single sentences as assessed by the WAB-R.

The selection of stocks by PWA00022 may also be related to the cognitive functions of attention (i.e., selective and sustained attention to listen and/or read the full transcript) or inhibition. The potential effect of inhibition on Accuracy is further illustrated in the example of PWA0005. Like PWA0022, PWA0005 also selected stocks as a gift for the characters. PWA0005 had a lower Auditory Verbal Comprehension score (6.8/10) than PWA00022, which suggested she could have had more difficulty understanding the script. There was also a large interference effect on her performance during the spatial Stroop task (i.e., her reaction time was negatively affected for incongruent trials; PWA0005 interference = 257ms compared to the PWA mean interference of 103.5 ms, *SD* = 70.4). 'Stocks' is the second option on the list of gift ideas, and PWA0005's written notes suggested that it was the first option she understood and processed. PWA0005 also indicated that she understood that the father character believed stocks were a form of gambling and he disapproved of gambling. However, PWA0005 still selected stocks as her final choice. PWA0005 indicated that she had a better understanding of the characters than PWA0022, yet these two participants made the same, less than ideal, selection. PWA0005 may have had difficulty refuting her initial selection with her rational decision-making system (i.e., PWA0005's deficits in inhibition may have negatively impacted her performance).

Unlike PWA0022, PWA0005, and other PWA, control participants did not exhibit much difficulty selecting an appropriate gift for the characters. The only control participant to select a gift that was considered less appropriate was C00030. C00030 decided to purchase gardening equipment, even though the characters described no longer partaking in gardening activities due to arthritis. C00030 had an Accuracy score of 0.6, which was the lowest score obtained among control participants. He justified his decision by saying "it would be good for their health." Like

PWA0005, C00030 indicated an awareness of contraindications for his selection (i.e., the parents have arthritis). However, unlike PWA0005, C00030 was able to tell the researcher that he was drawing upon his own beliefs and values to make a decision that he thought would benefit the characters.

C00030's decision to ignore contraindications and select a gift based on his personal opinions could also be a manifestation of a deficit in inhibition. We observed a higher than average interference effect on the Stroop task for C00030, but his interference effect was still within one standard deviation of the mean for control participants (i.e., C00030 interference = 71.3 ms, mean interference effect for control participants = 47.8, *SD* = 43.0).

When all participants were considered together, a measure of inhibition (Stroop) did emerge as a significant predictor of performance on the Accuracy score on the FAVRES. Inhibitory processes can theoretically aid decision-making in two ways: 1) by filtering out irrelevant information in a manner that is theoretically akin to selective attention (e.g., extraneous details in the script, options that were not appropriate); and 2) by suppressing the intuitive System 1 to make a decision that would be most appropriate to the context (i.e., a rational, System 2 decision; Suleman & Kim 2015). The relationship between inhibition and rational decision making has been confirmed by other researchers. For instance, Del Missier and colleagues (2012) presented undergraduate students with 10 multifactorial descriptions of DVD players and were asked to select one DVD player that best met a specific need (e.g., weighing cost and benefit). The researchers found that performance on inhibition tasks was related to performance on this decision-making task. Del Missier and colleagues (2012, p. 345) stated that the role of inhibition could "be attributed either to the functional support of inhibition to goal-directed processing…or to active updating of working memory contents during rule application."

In this statement, Del Missier and colleagues highlighted the overlap in function between inhibition, selective attention and the central executive component of WM. In another study, Gilinsky and Judd (1994) found that deficits in inhibition were associated with older adults' tendency to rely on belief and not logic (i.e., System 1 not System 2 decision-making). The findings from Del Missier and colleagues (2012), Gilinsky and Judd (1994), and the current study, support the conclusion that inhibitory processes support the selection of an appropriate option in a given context.

Reasoning. The Reasoning score can be considered a measure of an individual's ability to understand information, deliberate using considered manipulations of information, and appreciate differential consequences. The interview that informed the Reasoning score is akin to a domain-general capacity assessment interview. PWA had significantly lower Reasoning scores when compared to controls. The difference in performance between PWA and controls on the Reasoning score was expected, given the high expressive language demands of this portion of the task (i.e., the participant had to verbally respond to structured interview questions about their decision-making process). As expected, overall language ability (measured by the WAB-R AQ) emerged as a significant predictor in the multiple regression model for Reasoning for PWA only. Additionally, more severe aphasia (lower WAB-R AQ scores) was found to be associated with lower Reasoning scores. Overt expression of reasoning is an integral component of assessments of decision-making capacity in healthcare settings (Bremault-Phillips, Parmar, Friesen, Rogers, & Pike, 2016; Pachet et al., 2012). The finding that language deficits can negatively impact a person with aphasia's ability to perform on a linguistic measure of decision-making underscores the importance of supporting language and communication during assessments of decision-making for PWA (Carling-Rowland & Wahl, 2010; Suleman & Hopper, 2016).

A closer examination of Reasoning scores revealed that there were cases of individuals with mild aphasia receiving similar scores to individuals with severe aphasia as a result of scoring criteria on the FAVRES. In these cases, participants' verbal and nonverbal behaviours during the test provided insight into their decision-making ability. For example, PWA0006 with WAB-R AQ of 83 and PWA00023 with a WAB-R AQ of 41.3 had the same overall Reasoning score. In response to the statement, "tell me 5 important things you have learned about the couple who are to receive the gift" PWA0006 did not answer the question and spoke in general phrases that were not specific enough to demonstrate decision-making capacity; "I don't know them. Nice guy. He's nice. She's nice." When asked the same question, PWA00023 walked to a map of the world hanging on the wall and pointed to the country of Mexico, which communicated his decision to send the characters to a sunny vacation spot, but did not answer the question. PWA0006 indicated he was having difficulty with inferencing about people he did not personally know, while PWA00023 either did not understand the question or could not answer the question. Despite qualitatively different responses, both participants received zero points on that test item.

The multiple regression model for Reasoning in PWA identified three significant cognitive predictors in addition to the language predictor. Specifically, measures of inhibition (Stroop, AX-CPT AY errors) and sustained attention (AX-CPT AX Errors) were found to also predict performance on the Reasoning score for PWA. As discussed in the section above about Accuracy scores, the role of inhibition in decision-making can act to filter out extraneous information or suppress System 1 responses (Del Missier et al., 2012; Judd & Gillinsky, 1994; Suleman & Kim, 2015). Sustained attention processes would be important to ensure the participant maintained focus for the duration of the recording (2 minutes) and the subsequent

structure interview (10 minutes). Sustained attention has been theoretically linked to rational decision-making (Suleman & Kim, 2015).

The integration of sustained attention and inhibition during the decision-making task may be illustrated by one component of the structured interview. In this component, participants were given one minute and asked to list as many stores as possible that sell cameras. To complete the task, the participant had to think generatively (to create a list of unique stores), attend to the task for a full minute, remember the stores they already listed (so as not to be repetitive), filter out extraneous stimuli, and inhibit incorrect responses. During this component, PWA00023 listed two stores and then started indicating locations of the stores ("East"). PWA00023's switch to discuss store locations could indicate deficits in inhibition (i.e., he may not have been able to inhibit incorrect responses) or sustained attention (i.e., he may not have been able to maintain his focus on stores for the full minute).

When PWA and controls were considered together, a number of predictors for performance on the reasoning task emerged including scores on the depression scale and measures of inhibition (Stroop), sustained attention (AX-CPT AX Errors), and cognitive flexibility (TMT-B), and context-processing (AX-CPT BX Errors). Answering questions during a structured interview to demonstrate Reasoning ability is an integrated cognitive task that draws upon multiple cognitive systems.

The questions asked during the Reasoning interview required that participants alternate between reporting concrete information presented in the transcript and making inferences. The relationship between performance on the TMT-B and linguistic measure of decision-making has been reported by other researchers. In their study with individuals who had a TBI, Dreer and

colleagues (2008) found performance on the TMT-B to be a significant univariate predictor of an individual's ability to understand information on the Capacity to Consent to Treatment Instrument (CCTI, a measure designed to mimic assessments of DMC; Marson et al., 2005). Okonokwo and colleagues (2008) also found performance on trail making tasks (TMT-A and a newly developed Trails 3 task) to significantly predict performance on the CCTI for individuals with mild Alzheimer's disease. As performance on Trail Making tasks seem to be related to performance on linguistic decision-making tasks across groups of people with different neurological disorders (aphasia, TBI, mild Alzheimer's disease), cognitive flexibility and attention switching may play a foundational role in rational decision making and verbal reasoning.

Finally, overall performance on Reasoning scores for PWA and controls was also predicted by errors on the BX trials of the AX-CPT. Errors on BX trials would indicate an individual was reactively processing some information. Braver (2012) stated that proactive and reactive processing serve different purposes in daily living (e.g., proactive processing is necessary for anticipated goal directed tasks while reactive processing is necessary for goal reactivation). Proactive processing would have theoretically augmented performance during the *Making a Decision* subtest of the FAVRES. Before the recording begins, the participant was told the goal of the task (i.e., to select a gift for the parents). A participant who used a proactive processing strategy would have actively listened for information to assist their decision-making process (i.e., listened for factors in the transcript that would influence the selection the participant made). A participant who adopted a reactive strategy would have passively listened to the transcript and then made a decision by reflecting back on the transcript. Therefore a participant who used a reactive strategy might miss information or not be as 'tuned in' to the

nuances of the transcript. To respond appropriately to the structured interview and to achieve a high Reasoning score, a participant had to explicitly report the factors they considered to make their decisions. A reactive processing strategy would not support performance on the structured interview. At this time, discussions of context processing are highly theoretical (Braver, 2012). The impact of proactive and reactive processing strategies in daily living, particularly related to decision-making, is a potential avenue for future investigation.

Linguistic decision-making summary. Listening to a 2-minute narrative of information and making a decision can be considered similar to the way in which healthcare decisions are presented to patients (e.g., a physician presents information about treatment options verbally and the patient must select an option). The structured interview that informed the Reasoning score is akin to a functional capacity assessment that is not specific to a single decision-making domain (Bremault-Phillips et al., 2016; Pachet et al., 2012). In this study, PWA performed worse than controls on the Accuracy and Reasoning sections from the *Making a Decision* subtest of the FAVRES. As expected, the performance of PWA on the Reasoning score is highly confounded by linguistic abilities. Therefore, asking PWA to verbally discuss their decision-making process is an ineffective way to determine whether or not that individual is able to deliberate and make rational decisions. After the interview it was difficult to determine whether the person's decision-making performance was the result of language impairments, decision-making impairments, or a combination of both. Holistic individual assessments are necessary to develop a thorough understanding of an individual's decision-making abilities. Performance on a non-linguistic task of decision-making may aid in differentiating between language and decision-making impairments in PWA.

Non-linguistic decision-making with ambiguity (the IGT)

In this study, PWA and controls completed a computerized version of the IGT while an eye-tracking system collected online measures of pupil size as a proxy for cognitive arousal. In this study, the IGT yielded three scores: 1) performance – ratio of advantageous decisions to total number of decisions made; 2) change in pupil size as a measure of cognitive arousal; and, 3) participant perceptions (qualitative information). Performance was determined using a modified scoring system where selections were coded as advantageous or disadvantageous given the participant's experience and net gains from each deck at the time of the selection. Change in pupil size, or phasic change, was considered a proxy for cognitive arousal, and minimum pupil size was used as an indicator of tonic changes in emotional arousal (i.e., frustration or disengagement).

The IGT is considered an ambiguous decision-making task where the participant does not explicitly know timing and amount of win and loss amounts (i.e., the reward and punishment schedule is not transparent). The IGT was originally proposed to be a task of implicit, non-declarative learning. However, there is a growing body of evidence that the task is actually related to explicit decision-making (Dunn et al., 2006; Maia & McClelland, 2004). In this study, we gathered participant perceptions of the decks to gain insight into the explicit information participants were using to inform their decisions (Maia & McClelland, 2004). The IGT was segmented into five blocks and after each block participants were asked to: 1) describe what they know about the decks of cards; and 2) rank the decks from best (1) to worst (4), based on the ability to make the most money.

Performance measures from the IGT showed that participants with and without aphasia made similar decisions throughout the task. Both groups showed a significant decline in performance as the task progressed. The decline in performance from blocks 1 to 3 is particularly

pronounced in this study and may be a result of the scoring approach used. In block 1, almost any selection from any deck is advantageous from a participant's perspective (i.e., no deck had a negative net gain in block 1), and almost all participants performed at ceiling during block 1. Therefore, the discussion will be focused on the performance of participants in the final three blocks of the IGT (i.e., blocks 3-5).

In this study, participants with and without aphasia made advantageous selections with similar frequency to disadvantageous selections in the final three blocks of the IGT. In a comparable study, Gleichgerrcht and colleagues found that people with PPA demonstrated a similar pattern that the researchers described as a "flat performance" (Gleichgerrcht, et al., 2012, p. 49). Gleichgerrcht and colleagues state that the flat performance indicated that participants were unable to "adopt an advantageous strategy" (p. 45). The observation of a flat performance in control participants was an atypical and unexpected finding. Gleichgerrcht and colleagues (2012) used a control group that was highly comparable to the control group in this study (i.e., adults with a mean age of 60 without neurological disorders). Gleichgerrcht and colleagues (2012) found that in blocks 3-5, control participants differentiated from people with PPA and made advantageous decisions with increasing frequency.

Despite their flat performance, control participants stated explicit awareness of the advantageous nature of decks B and D by the end of block 2 and maintained that perception for the duration of the task (Figure 10). Essentially, control participants continued to make selections from decks that they knew were disadvantageous. Also, at least half of control participants indicated a desire to figure out the exact timing of the losses (e.g., "maybe I shouldn't hit the same deck more than twice"; "the 4th time takes away money"; "Get 7-ish from this one [deck]"; "Penalties are huge but timing is unknown"). The exploration of the decks to uncover the exact

timing may have been motivated the control participants' desire to provide complex responses to the qualitative questions that were asked at the end of each block.

Additionally, control participants' phasic and tonic pupil sizes remained stable throughout the task. Therefore, control participants continued to exhibit similar levels of arousal to make their selections and were neither getting frustrated, excited nor disengaging from the task. Control participants may have continued to engage similar levels of cognitive resources throughout the task and allocated their resources to discerning more complex patterns instead of 'releasing' their cognitive resources after they had figured out the basic pattern of the IGT. Finally, performance on the IGT was predicted by performance on a complex problem solving task (WCST) for control participants. During the WCST, participants had to discern between shifting and changing patterns. The predictive value of performance of the WCST on the IGT for control participants aligns with the theory that control participants were trying to uncover patterns in the decks during the IGT.

In this study, PWA also exhibited a flat performance, however, qualitative and pupillometric measures suggest that PWA were unable to "adopt an advantageous strategy," like people with PPA (Gleichgerrcht et al., 2012, p. 45). PWA did not demonstrate a clear, explicit understanding of the advantageous nature of decks B and D or the disadvantageous nature of decks A and C. Their rankings of the decks were inconsistent and the statements made the PWA indicated they had not figured out a concrete pattern in the decks; "…losing no matter where you were"; "you have to keep switching or you're going to lose. It's not that clean"; "They really take your money and run." However, informal observations of PWA completing the task indicated that they understood the premise of the task because they expressed surprise and frustration whenever they lost money (e.g. PWA00020 cursed loudly when she lost $1250).

Thus, despite understanding the goal of the task, the participants were unable to discern a pattern in the decks. These findings are in direct contrast to control participants who quickly understood the basic pattern of the decks and were exploring further to uncover complexities.

PWA were further differentiated from controls by pupillometric findings. Like control participants, tonic pupil size remained stable for PWA, indicating that PWA were not growing frustrated, getting excited, or emotionally disengaging from the task. Unlike control participants, phasic pupil size decreased over trials for PWA, which indicated a reduction in cognitive arousal. It may be that some PWA were unable to figure out the IGT and were cognitively fatigued by the task. Also, performance on the IGT was predicted by performance on a measure of sustained attention, which is linked to maintaining levels of cognitive arousal. Physical, chronic, and pathological fatigue is a common complaint poststroke, although the effects of fatigue on cognitive function are unclear (de Groot, Phillips, Eskes, 2003; Staub & Bogousslavsky, 2001) and fatigue was not measured in this study. It is possible that cognitive fatigue may have negatively affected the ability of PWA to determine and use an advantageous strategy, although this is an issue for future investigations

Gleichgerrcht and colleagues (2012) offer two explanations for the flat profile they observed in people with PPA, and these explanations may also be applicable to the PWA in the current study: 1) language may indirectly affect performance on the IGT (i.e., the individual may struggle to assign categorical labels of *safe* or *risky* to the decks due to language impairment); and 2) there may be an shared mechanism that underlies both decision-making and language abilities (e.g., a mechanism that allows access to mental representations, such as the semantic construct of ‘advantageous’).

In summary, the results from the IGT are inconclusive. The findings neither support nor refute the contention that non-linguistic decision-making is intact in PWA.

Non-linguistic decision-making without ambiguity (the GDT)

In this study, participants completed the GDT, a risk-taking game where the probability of winning and win/loss amounts are fixed and known to participants. Participants were given a net score that was calculated by subtracting the number of selections where the probability of winning was 50% of lower (disadvantageous) from the number of selections where the probability of winning was over 50% (advantageous). Overall, there was no significant difference in performance between PWA and controls. However, there were some indicators that PWA might have had more difficulty with the task than controls.

The average performance of PWA was lower than controls and there was more variability in performance for PWA (Table 11). Second, increased aphasia severity was associated with a lower performance on the GDT, indicating that people with more severe aphasia did not fully understand the task. However, observations of individuals with the most severe aphasia indicated they were aware of the expectations. For example, PWA00026 who had a WAB AQ of 58 told the researcher that she was making a conscious decision to "go big or go home" and made selections that she knew were ultimately causing her to lose money. PWA00026's decision to rely on her personal desire to "go big or go home" did not align with the explicit task goal of maximizing gains and minimizing losses. Perhaps PWA0026's behaviour during the GDT was not indicative of a lack of comprehension of the task, but rather indicated challenges in inhibition. As discussed earlier, deficits in inhibition can explain an individual's reliance on

System 1 responses, and it may be that PWA00026 was unable to refute her System 1 response for a more rational System 2 response that aligned with the task goals.

In this study, performance on the GDT for all participants was predicted by inhibition (Stroop), the individual's ability to problem solve (WCST), and age. In previous studies, researchers had not found a relationship between inhibition and performance on the GDT (Brand et al., 2005; Chen et al., 2014). However, the relationship between performance on the WCST and the GDT was reported in a study of individuals with Korsakoff syndrome (i.e., a population with a high likelihood of frontal lobe dysfunction; Brand et al., 2005). Furthermore, for individuals with Korsakoff syndrome, age was associated with more risky decisions (Brand et al., 2005). Typical cognitive aging is related to decline in some cognitive functions (e.g., memory, inhibition, processing speed; Harada, Love, & Triebel, 2013) Age as a predictor of performance on the GDT could indicate that general age-related cognitive decline was associated with difficulty making non-ambiguous decisions. The findings from the current and previous studies confirm that performance on this measure of decision-making is related to performance on measures of inhibition and problem solving.

Implications for Theoretical Understanding of Cognitive Decision-Making

In Chapter 2, a theoretical model of cognitive decision-making was introduced (Figure 1). This model proposed that the cognitive functions of memory, attention, executive function, and language and all related cognitive processes (e.g., memory retrieval/encoding, sustained attention, inhibition) could be implicated in the rational decision-making process. The theoretical model of decision-making was designed to be context-independent and provides an overarching framework for cognitive decision-making. Three distinct measures of decision-making were used

in this study and each measure had unique task demands; therefore performance on each task was predicted by performance on different combinations of cognitive tasks. The findings from this study provide evidence that cognitive decision-making is related to inhibition, attention, and problem solving.

The theoretical model is centered on the conscious WM workspace. PWA and controls performed significantly differently on the picture WM span task, but scores on the WM task were not found to be predictors of any measures of decision-making used in this study. (Table 19; DeDe et al., 2014). However, the lack of association between WM and decision-making may be a result of the measures used in this study. Murray, Salis, Martin, and Drale (2016) conducted a systematic review of tests of short term and working memory used in studies with PWA. These researchers found over 20 possible tests of short term memory and working memory and recommended that a combination of tests be used to assess WM capacity in PWA, particularly because a gold standard test of WM does not yet exist for individuals with language disorders (Murray et al., 2016). Future research be focused on investigating the relationship between different decision-making (e.g., CCTI, Marson et al., 1995) and WM tasks using a variety standardized measures of WM (e.g., WMS-IV Symbol Span).

One of the major findings of this study was that performance on inhibition tasks (i.e., the Stroop task, and AY trials of the AX-CPT) were prominent predictors of all the measures of decision-making. Inhibition can play two important roles in decision-making; 1) preventing irrelevant information from entering the deliberation workspace (a similar function to selective attention); and 2) preventing the automatic System 1 decision from unduly influencing the rational System 2 deliberations. For example, in the linguistic decision-making task, the participants had to disregard extraneous information provided in the transcript that did not

contribute to the decision-making process and suppress their own desires to select a gift that was appropriate for the characters. The findings of this study clearly provide a link between inhibition and decision-making; thus strategies to support any form of decision-making should strive to reduce the cognitive load on inhibitory processes. For example, individuals with decision-making challenges can be taught to make a pros and cons list to improve salience of important factors to consider and reduce the need to inhibit irrelevant factors.

Study Limitations and Future Directions

The linguistic measure of decision-making had adequate face, criterion, and concurrent validity as well as inter-rater reliability. However, the absence of a normative sample and standard scores for the Reasoning subscore of the FAVRES make the results difficult to interpret in comparison to other individuals with aphasia. Future inquiries should use different measures of linguistic decision-making including tests that formally assess constructs of legal decision-making capacity (e.g., the CCTI; Marson et al., 1995). Future studies could also draw upon literature in the field of marketing and psychology to use functional daily decision-making tasks to examine differences between PWA and controls (e.g., studies that use online shopping paradigms; Childers, Carr, Peck, & Carson, 2001; Javadi, Dolatabadi, Nourbakhsh, Poursaeedi, & Asadollahi, 2012).

This study used two non-linguistic tasks set in gambling paradigms to investigate management of known and unknown risk by PWA. The use of pupillometry and informal questioning about rationale for decisions, in conjunction with the IGT, may have affected participants' performance. Future research could include the use of a more standardized version of the IGT (i.e., without asking qualitative questions or eye-tracking) so findings can be

compared with existing research involving various groups of participants. Using standard or traditional approaches to scoring would make between-study comparisons are easier to interpret.

Pupillometry is a valuable tool to understand mechanisms of arousal and fatigue in PWA. Future studies can explore the utility of this tool when paired with different cognitive and linguistic tasks (e.g., Stroop, WM span, auditory comprehension). In this study pupillometry was used to explore cognitive arousal while individuals made decisions during the IGT. However, decision-making may have taken place before pupil sizes were recorded on some trials for some participants. Control participants, in particular, were sometimes observed looking to the location of their next selection before the trial had even started. Anticipatory eye movements indicated that some control participants had completed the deliberation process before pupil sizes were being recorded. Therefore, we recommend that future investigations use simple tasks to further validate pupillometry.

Future studies could also characterize aphasia types based on neuropathology instead of a beahvioural assessment (i.e., performance on a test of language abilities). Size and location of lesion, and other characteristics of aphasia could be used to develop a predictive model of performance on decision-making measures to aid clinicians in identifying clients who are more at risk than others for disruptions to their decision-making process.

Decision-making is also a subjective experience. The current study focused on objective aspects of decision making and did not explore the perceptions and experiences of PWA. As decision-making has objective and subjective components, we strongly recommend that future inquiries use mixed and qualitative methodologies to develop a holistic understanding of the decision-making phenomena (Suleman & Hopper, 2014).

Implications for Clinical Practice and Advocacy Movements

The findings from this study further underscore the need for an individualized approach to capacity assessment and are aligned with current advocacy movements for fair assessments of decision-making capacity for individuals with communication disorders (Carling-Rowland & Wahl, 2010). Judgements of decision-making capacity must be made on the demonstrated decision-making abilities of an individual at a specific point in time and health care professionals should strive to minimize the negative confounding effects of a language deficit on performance (ACSLPA, 2012; Aldous, et al., 2014; Carling-Rowland & Wahl, 2010; Pachet et al., 2012; Suleman & Hopper, 2015). As such, when the decision-making abilities of an individual with aphasia are questioned, we strongly suggest the capacity assessment process include communication supports to reveal underlying capacity in PWA.

As decision-making is integral to the way one expresses identity and participates in life activities, it is important that it be considered as a possible avenue for rehabilitation. Decision-making ability and engagement can be revealed and enhanced using the techniques included in Supported Conversation for Adults with Aphasia (SCA; Kagan, 1998, 2000; Kagan, Black, Duchan, Simmons-Mackie, & Square, 2001). Researchers have shown that when conversation partners use the SCA techniques of using spoken and written key words, drawing, and pointing to pictographs, the general competency of PWA is revealed (Kagan et al., 2001). The techniques of SCA also support cognitive deficits associated with aphasia. For example, these strategies may facilitate selective attention and inhibitory processes by drawing attention to salient information. Additionally, when a conversation partner provides a written and graphic representation of the conversation they are also reducing demands on working memory and

auditory comprehension for the person with aphasia. Therefore, the use of SCA techniques can support cognitive decision-making and reveal competency in PWA.

Figures

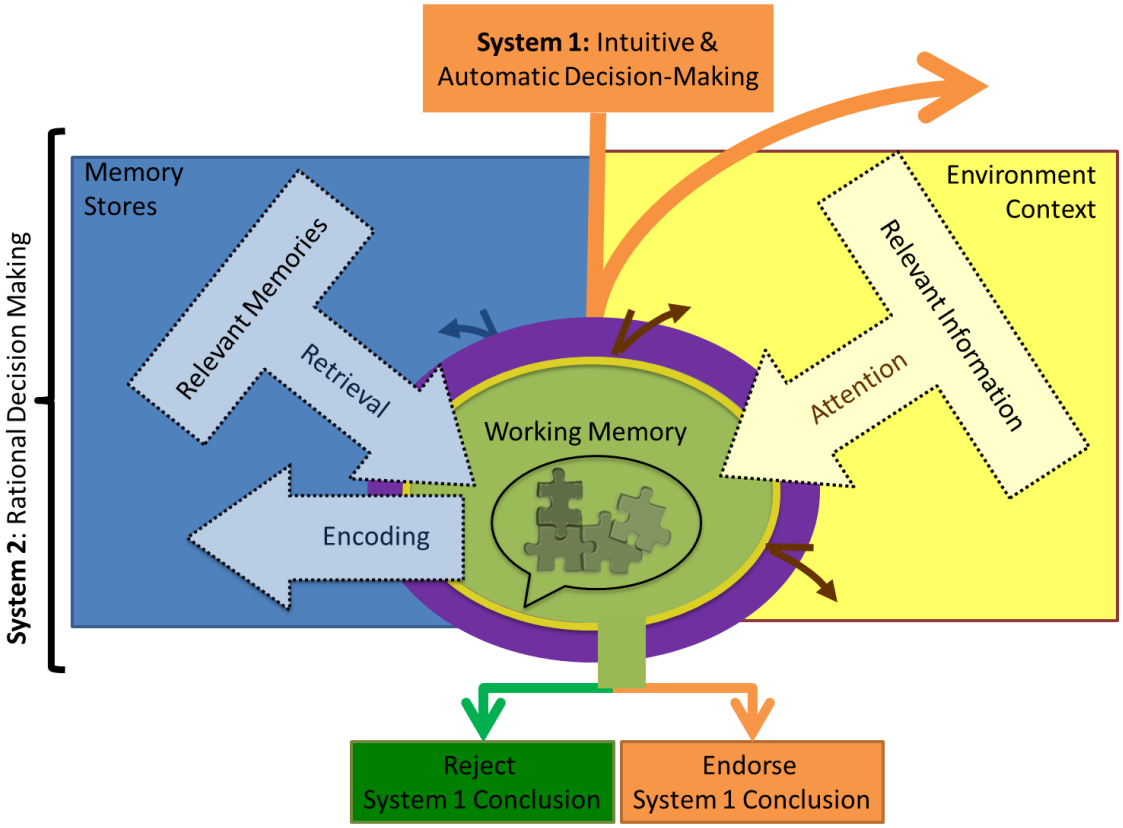


Figure 1. Model of intact decision-making

Note: The yellow ring that encircles working memory depicts attention processes that maintain relevant information in working memory. Irrelevant information is depicted by brown arrows. The purple ring that encloses working memory illustrates inhibitory processes. Language is represented by the speech bubble. Problem solving is depicted by puzzle pieces.

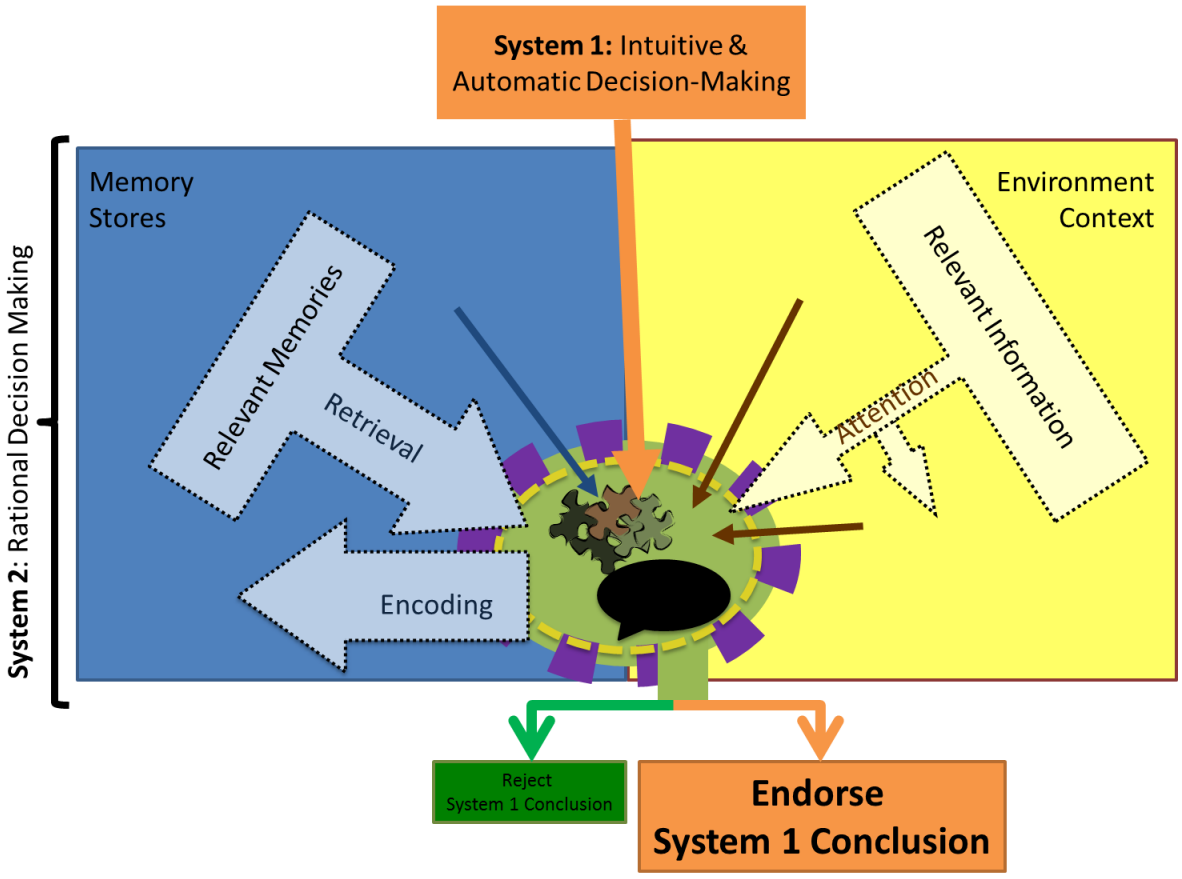


Figure 2. Model of impaired decision-making

Note: The perforated yellow ring that encircles working memory depicts a deficit in attention processing. Irrelevant information is depicted by brown arrows. The perforated purple ring around working memory depicts impaired inhibitory processes. Impaired language is represented by the black speech bubble. Impaired problem solving is depicted by disorganized puzzle pieces.

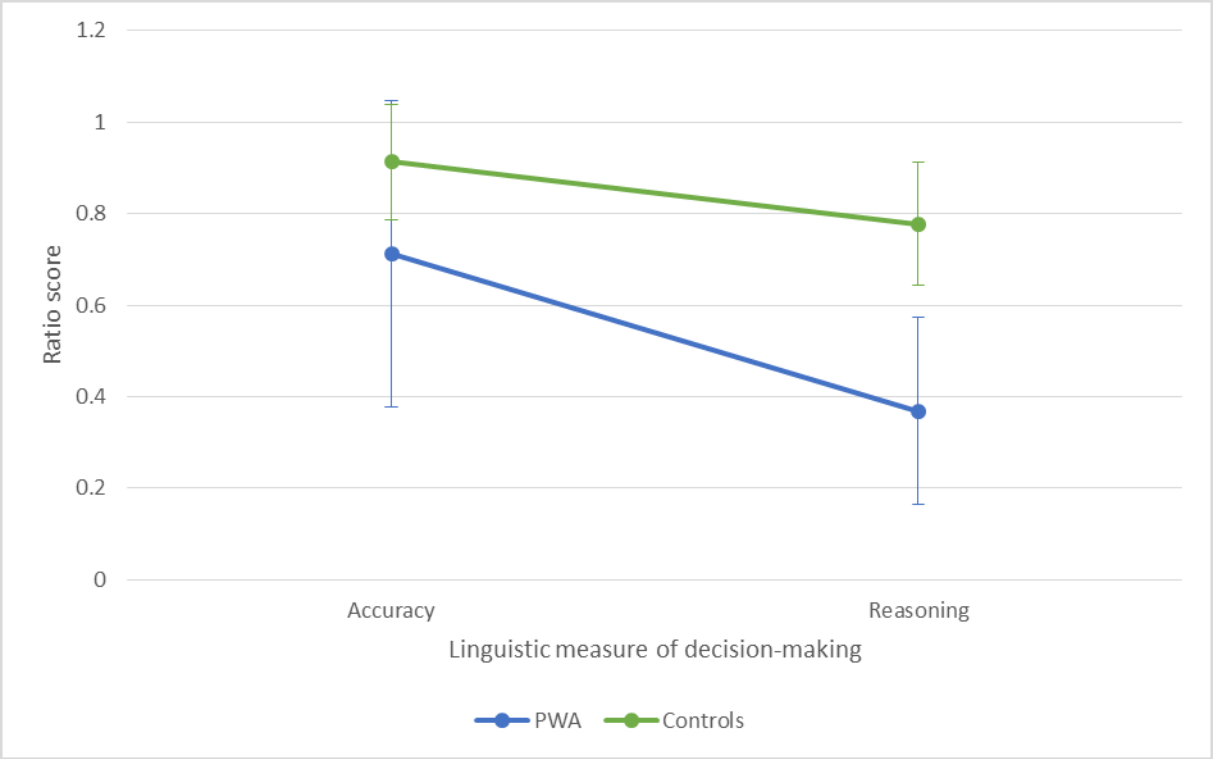


Figure 3. Means and standard deviations of linguistic measures of decision-making for people with aphasia and controls.

Notes: Error bars are drawn at +/- 1 standard deviation; Ratio score derived from the Functional Assessment of Verbal Reasoning and Executive Strategies *Making a Decision* subtest.

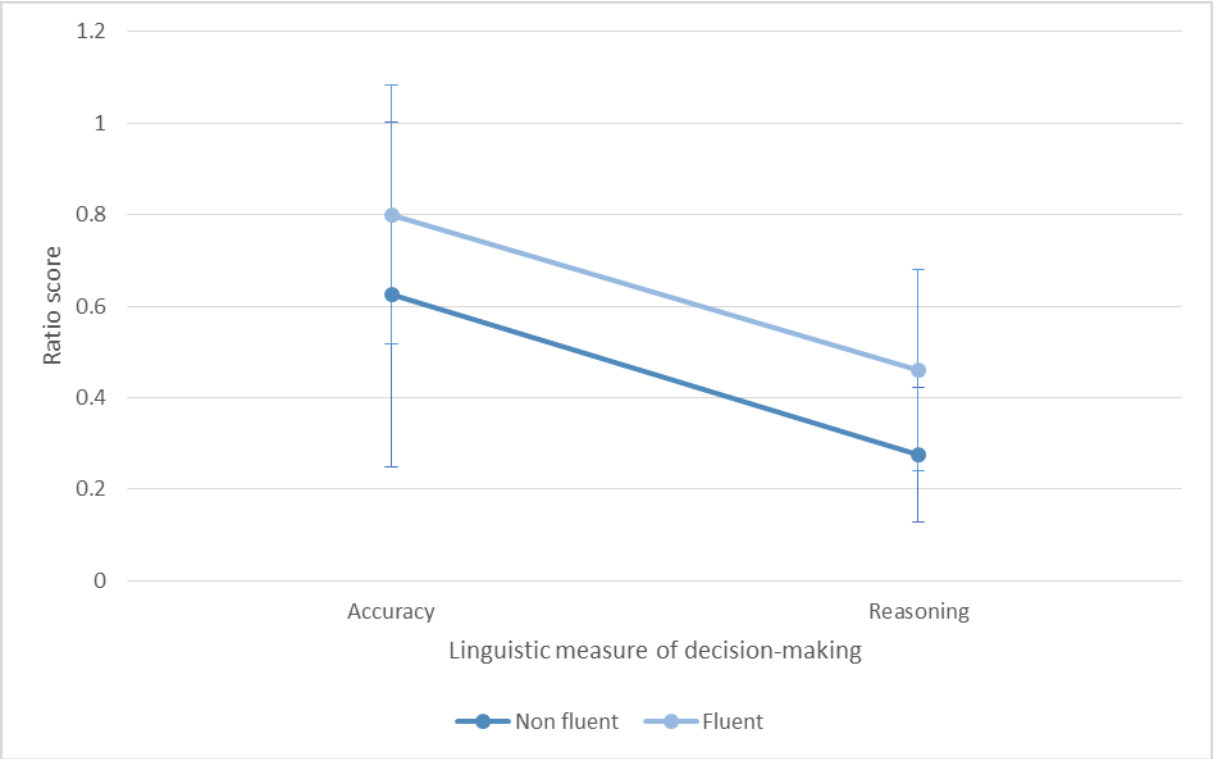


Figure 4. Means and standard deviations of linguistic measures of decision-making for people with fluent and non-fluent aphasia.

Notes: Error bars are drawn at +/- 1 standard deviation. Ratio score derived from the Functional Assessment of Verbal Reasoning and Executive Strategies *Making a Decision* subtest.

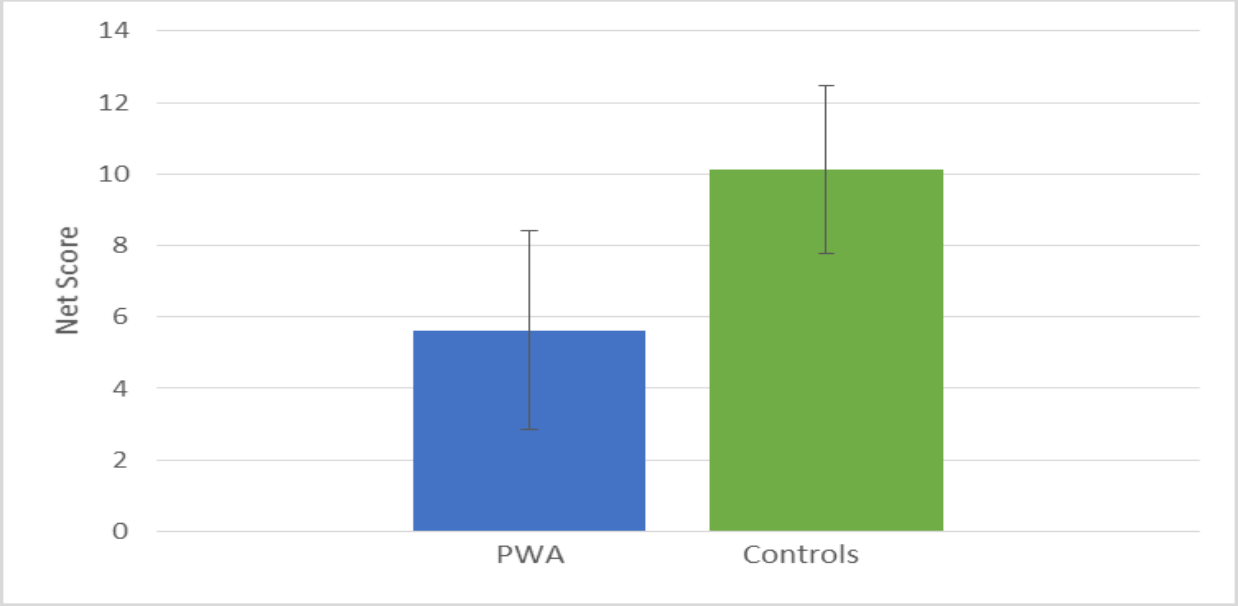


Figure 5 – Game of dice mean net score and standard error for people with aphasia and controls

Note: PWA, people with aphasia, blue; Error bars are shown at +/- 1 standard error of measurement

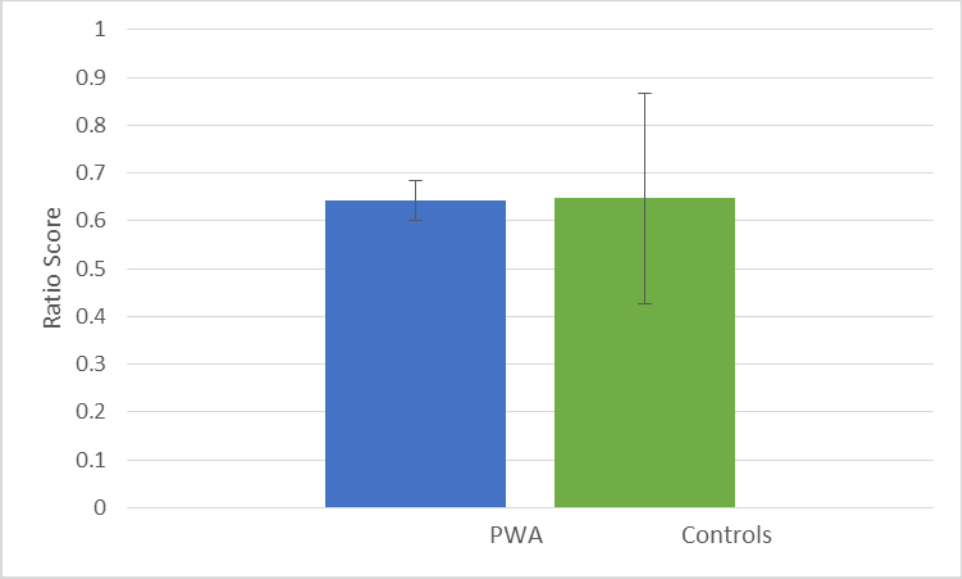


Figure 6 – Iowa Gambling Task mean ratio score and standard error for people with aphasia and controls

Note: PWA, people with aphasia, blue; Error bars are shown at +/- 1 standard error of measurement

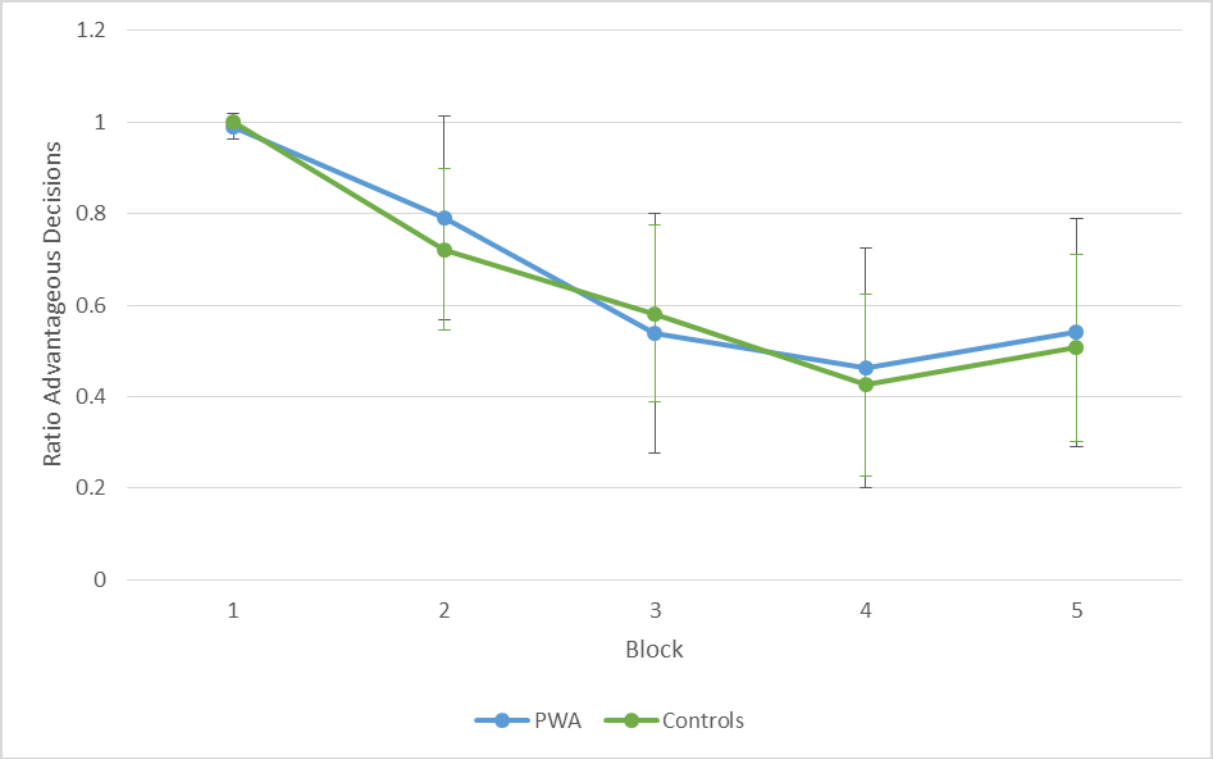


Figure 7. Means and standard deviations of performance over five blocks of the Iowa Gambling Task for people with aphasia and controls

Notes: Error bars are drawn at +/- 1 standard deviation. Ratio scores were used the IGT and Net scores were used for the GDT; IGT, Iowa Gambling Task; GDT, Game of Dice Task.

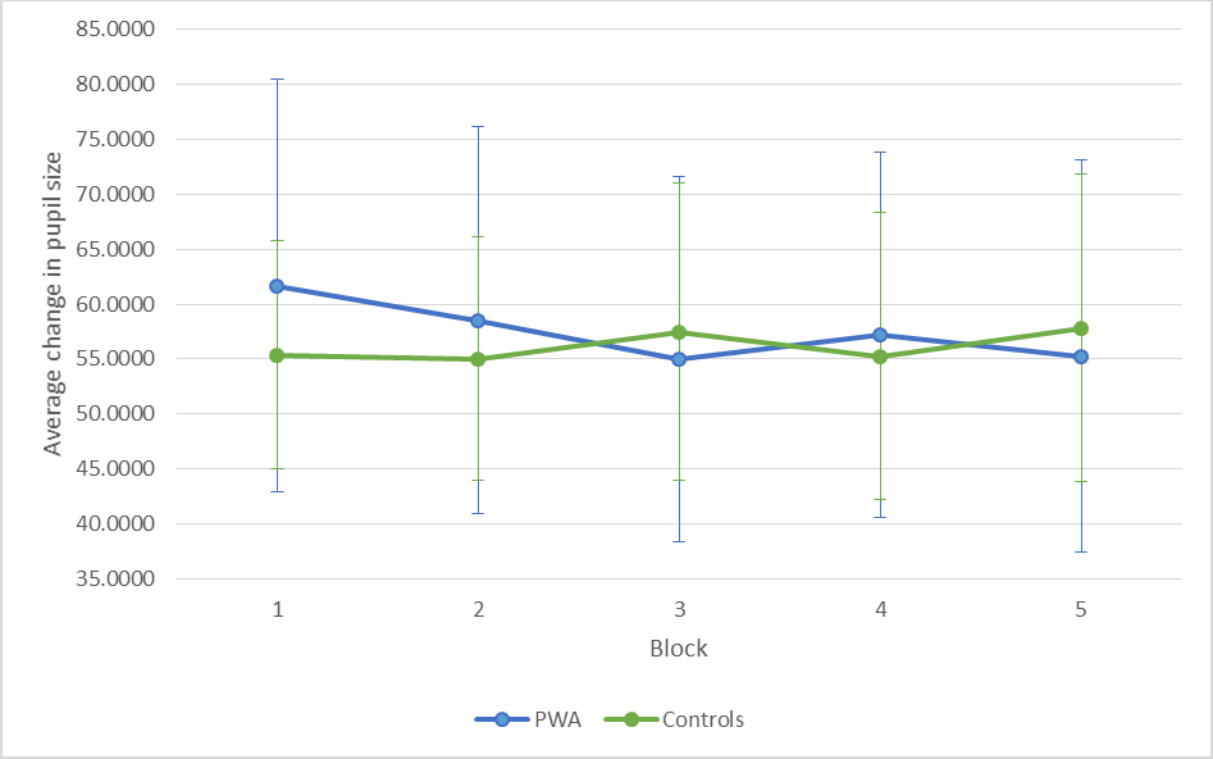


Figure 8. Means and standard deviations of average change in pupil size over five blocks of the Iowa Gambling Task for people with aphasia and controls

Notes: Error bars are drawn at +/- 1 standard deviation; Pupil size was measured using an arbitrary unit generated by the EyeLink 1000+ eye tracking system (SR Research, 2014); Change in pupil size was calculated by subtracting minimum pupil size in a given trial from all measures of pupil size within the given trial. These calculated change in pupil size values were averaged per trial; IGT, Iowa Gambling Task.

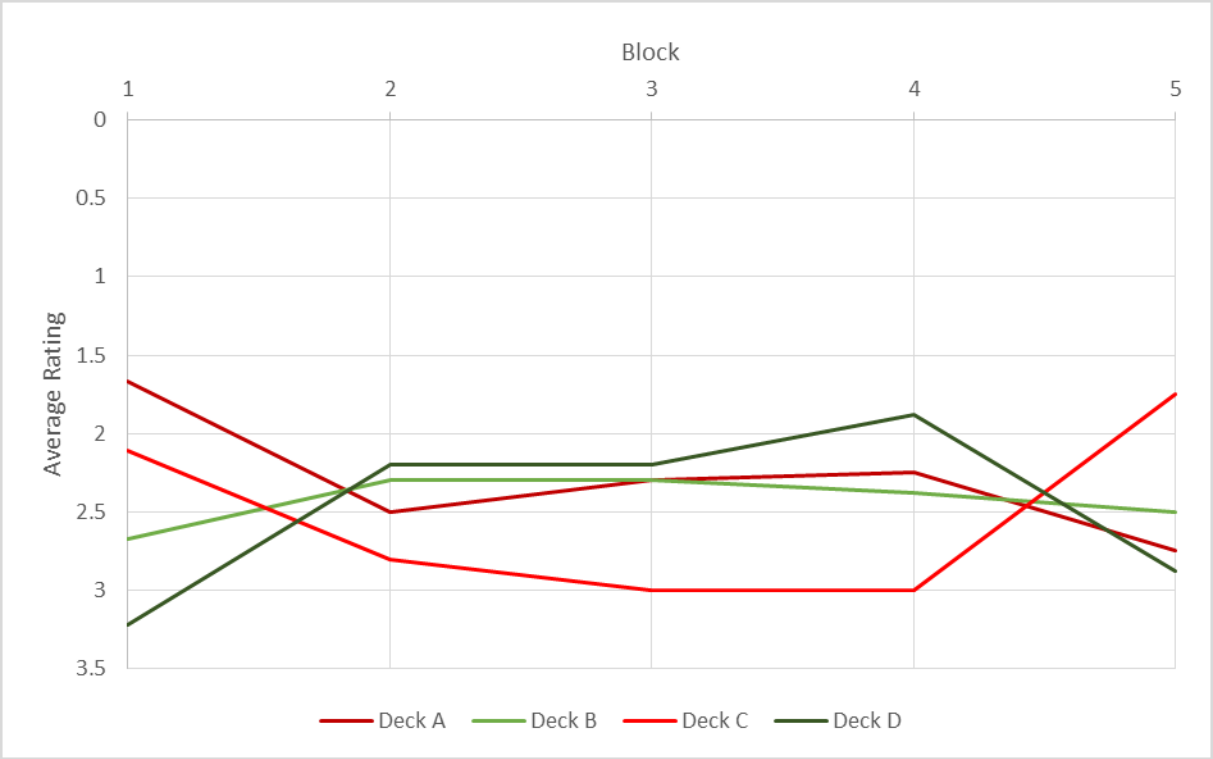


Figure 9. PWA mean subjective ranking of 4 decks over five blocks of IGT.

Notes: Decks considered advantageous are coloured green (B and D) and decks considered disadvantageous are coloured red (A and C); IGT, Iowa Gambling Task.

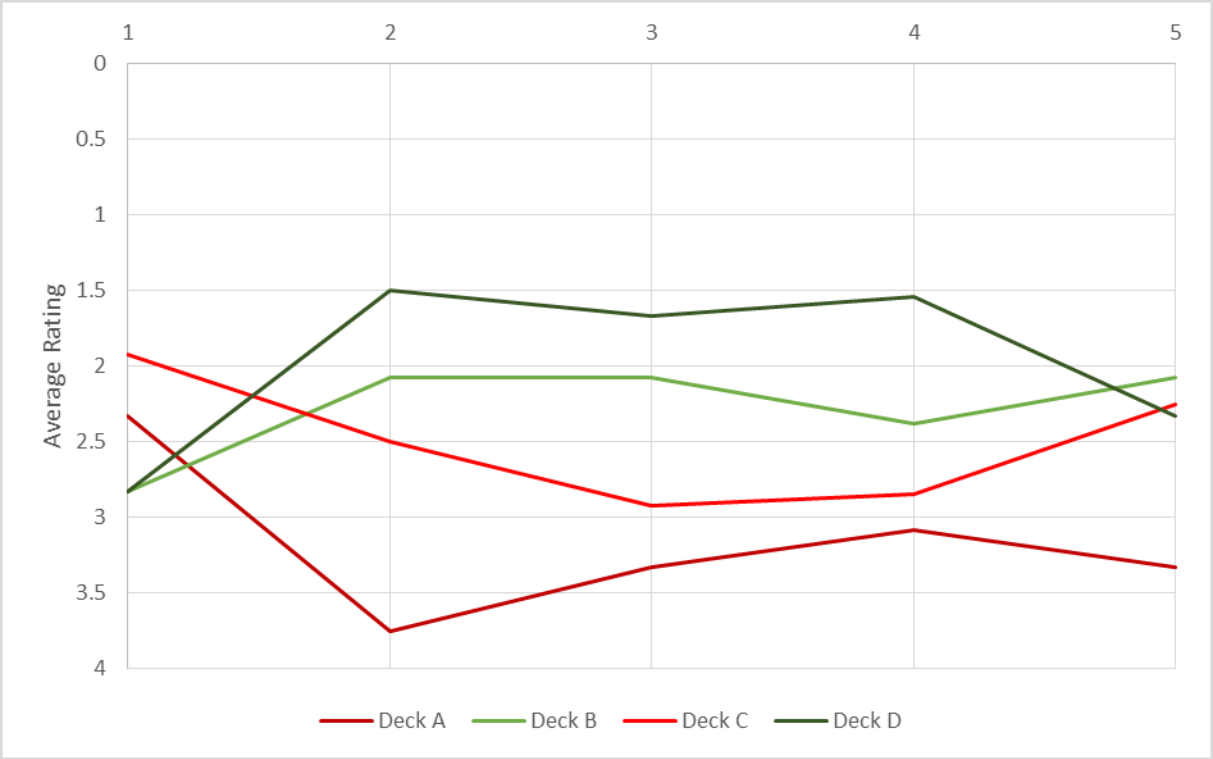


Figure 10. Controls mean subjective ranking of 4 decks over five blocks of IGT.

Notes: Decks considered advantageous are coloured green (B and D) and decks considered disadvantageous are coloured red (A and C); IGT, Iowa Gambling Task.

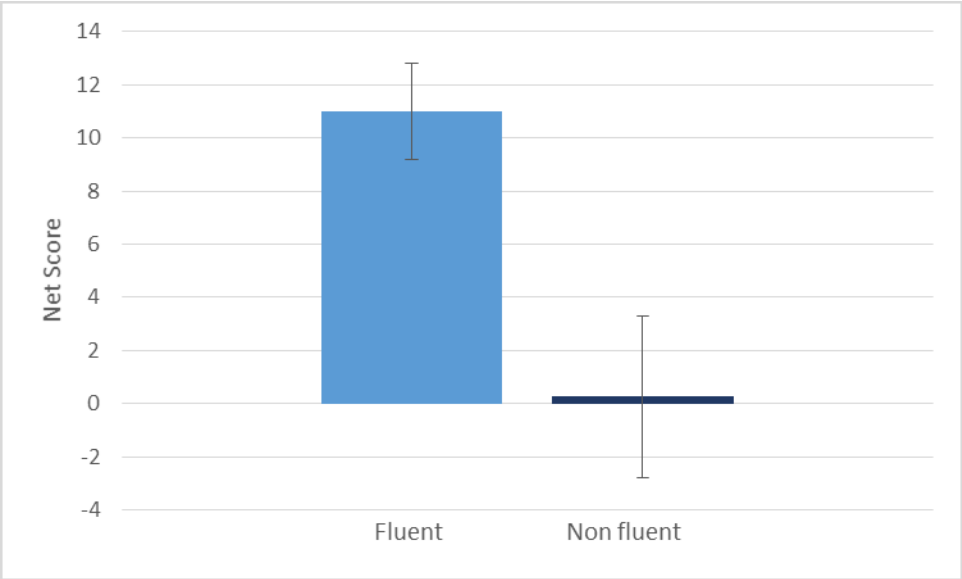


Figure 11 – Game of dice mean net score and standard error for people with fluent and non-fluent aphasia

Note: Fluent aphasia, light blue; Non-fluent aphasia, dark blue; Error bars are shown at +/- 1 standard error of measurement

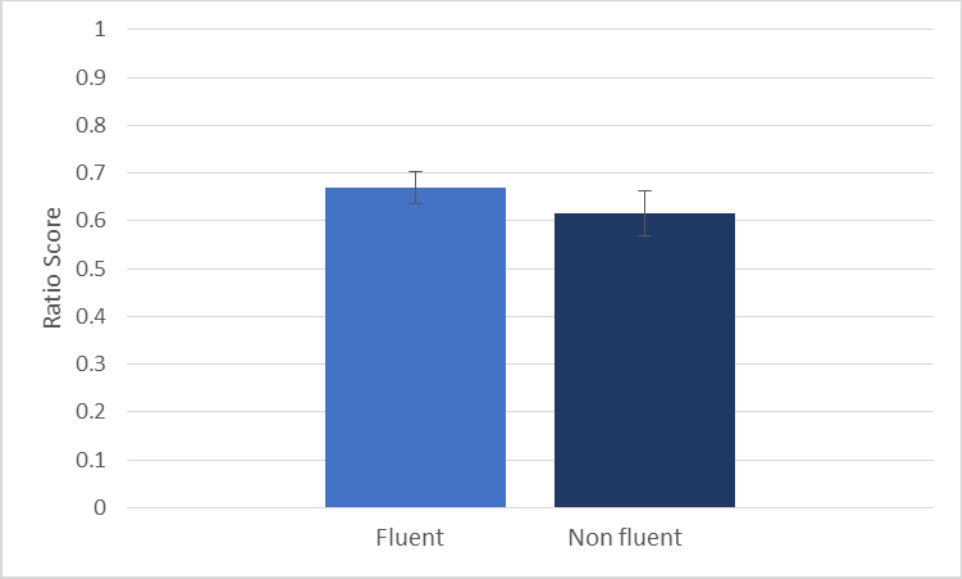


Figure 12 – Iowa Gambling Task mean ratio score and standard error for people with fluent and non-fluent aphasia

Note: Fluent aphasia, light blue; Non-fluent aphasia, dark blue; Error bars are shown at +/- 1 standard error of measurement

Tables

Table 1. Summary of Boston Classification of Aphasia

Symptomatic Feature	Fluency		Auditory Comprehension		Repetition	
	Fluent	Non Fluent	Spared	Impaired	Spared	Impaired
Anomic	●		●		●	
Conduction	●		●			●
Transcortical Sensory	●			●	●	
Wernicke's	●			●		●
Transcortical Motor		●	●		●	
Broca's		●	●			●
Mixed Transcortical		●		●	●	
Global		●		●		●

Note: Information based on Goodglass & Kaplan (1972)

Table 2. Summary of gains/losses associated with card decks in the Iowa Gambling Task

Card	Deck A (+$100)	Deck B (+$100)	Deck C (+$50)	Deck D (+$50)
1				
2				
3	-150		-50	
4				
5	-300		-50	
6				
7	-200		-50	
8				
9	-250	-1250	-50	
10	-350		-50	-250
11				
12	-350		-25	
13			-75	

14	**-250**	**-1250**		
15	**-200**			
16				
17	**-300**		**-25**	
18	**-150**		**-75**	
19				
20			**-50**	**-250**
21		**-1250**		
22	**-300**			
23				
24	**-350**		**-50**	
25			**-25**	
26	**-200**		**-50**	
27	**-250**			
28	**-150**			
29			**-75**	**-250**

30			**-50**	
31	**-350**			
32	**-200**	**-1250**		
33	**-250**			
34			**-25**	
35			**-25**	**-250**
36				
37	**-150**			
38	**-300**		**-75**	
39			**-50**	
40			**-75**	

Note: Information in this table from Bechara et al., 1994. The reward amount per deck remains constant (i.e., cards from decks A and B always yield a gain of $100/card and cards from decks C and D always yield a gain of $50/card.

Table 3. Summary of the Game of Dice Task

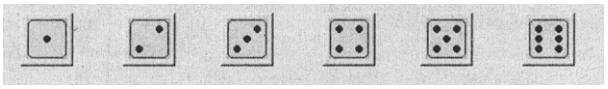
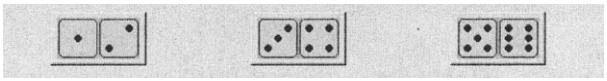
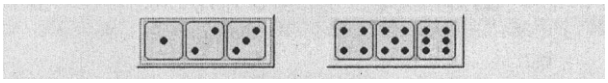
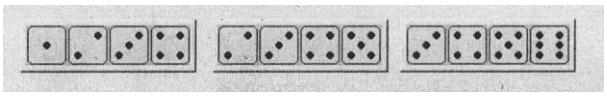
Possible Combination of Numbers	**Gain/Loss**	**Probability of Winning**	**Advantageous**	**Disadvantageous**
	$1000	1:6		X
	$500	1:3		X
	$200	1:2	X	
	$100	2:3	X	
Note: Information in this table from Brand et al., 2005, p. 270				

Table 4. Demographic information

	People with Aphasia			**Controls**		
	n	Mean	Std. Dev	*n*	Mean	Std. Dev
Age	16	60.688	8.761	16	60.313	8.860
Education (total years)	16	14.125	2.941	16	15.188	2.105
Geriatric Depression Score	16	2.867	3.204	16	0.813	0.911

Table 5. Aphasia profiles for people with aphasia

			n	Mean	Std. Dev
Months post stroke			16	93.125	87.000
WAB Aphasia Quotient	Overall		16	76.338 (Range: 41.3 – 97.4)	18.885
	Fluency	Fluent	8	88.600	11.674
		Non-fluent	8	64.075	16.860
	Aphasia Type	Anomic	7	92.443	4.601
		Broca's	8	64.075	16.860
		Wernicke's	1	61.7	-

Note: Aphasia classifications based on scores from the Western Aphasia Battery-Revised (Kertesz, 2007)

Table 6. Summary of decision-making measures

	Instrument	Construct	Score
Linguistic	Functional Assessment of verbal Reasoning & Executive Strategies	Accuracy	Ratio score (Score/Highest score by a participant)
		Reasoning	Ratio Score (Score/Highest score by a participant)
Non Linguistic	Game of Dice Task	Performance	Net score
	Iowa Gambling Task	Performance (modified scoring; Maia & McClelland, 2004))	Ratio per block (Advantageous/20)
			Ratio overall (Advantageous/100)
		Pupillometry	Average change in pupil size per trial (cognitive effort, phasic)
			Minimum pupil size per trial (emotional arousal, tonic)
		Perceptions	Subjective rankings of decks after each block

Table 7. Summary of cognitive measures

Cognitive Function		Instrument	Score
Language		Western Aphasia Battery	Aphasia Quotient (Severity)
			Spontaneous Speech
			Auditory Comprehension
			Repetition
			Naming and Word Finding
Working Memory		Forward Picture Span	Ratio (correct/100)
		Backward Picture Span	Ratio (correct/100)
Executive Function	Inhibition	Spatial Stroop	Ratio (incorrect/total) + Reaction time • Neutral trials • Congruent trials • Incongruent trials Interference • Incongruent-Neutral Facilitation • Congruent - Neutral
	Sequencing/Planning	Trail Making Test A	Time to complete trace (s)
		Trail Making Test B	Time to complete trace (s)
	Cognitive Flexibility	Wisconsin Card Sort Task	Number of categories completed
	Categorization		Total correct
			Total errors
			Non-perseveration errors
			Perseveration errors
			Trials to complete 1st category
	Non-Verbal reasoning	Raven's Coloured Progressive Matrices	Total Score
			Time to complete (s)
	Context Processing Sustained attention Inhibition	AX-CPT	AX-CPT Short Errors + Reaction Time • AX, AY, BX, & BY trials
			AX-CPT Long Errors + Reaction Time • AX, AY, BX, & BY trials

Table 8. Detailed summary of cognitive measures

	Cognitive Measure	Purpose	Description Subtests	Time (min)	Reliability	Validity	Used with PWA?
Language	Western Aphasia Battery – Revised[1]	• Diagnose aphasia • Determine severity • Classify Aphasia type	• Spontaneous speech • Auditory-verbal comprehension • Repetition • Naming/word-finding	30 - 45	Inter-rater ($r = 0.99$, $p \leq 0.01$, n = *10*)[1] Intra-rater ($r = 0.99$, $p < 0.03$, n=10)[1] Test-retest ($r = 0.97$, $p \leq 0.01$, n = 35)	Criterion[1] Concurrent ($r = 0.96$ with the Neurosensory Center Comprehensive Examination for Aphasia, $p \leq 0.01$, n = 15) [1]	Yes
Working Memory	Forward Picture Span Task[2]	Short term storage in WM	• Span of pictures presented sequentially • Participant identifies pictures in the order they were presented • Up to span 6 • Paper & Computerized	30-45	Test-retest - acceptable ($r = 0.88$, *p not provided,* n=10)[2] Split-half - acceptable (*r* = 0.85, *p not provided,* n = 47)[2]	Construct - acceptable (*r* = 0.83 with *gold standard* from Waters & Caplan, 2003, *p not provided,* n = 47)[2]	Yes[2]

	Cognitive Measure	Purpose	Description Subtests	Time (min)	Reliability	Validity	Used with PWA?
	Backward Picture Span Task[2]	Transformation or Manipulation	• Span of pictures presented sequentially • Participant identifies pictures in the reverse order • Up to span 6 • Paper only		Test-retest (r = 0.90, p not provided, n=10)[2] Split-half (r = 0.79, p not provided, n=47)[2]	Construct - acceptable *(*r = 0.75 with *gold standard* from Waters & Caplan, 2003, p not provided*,* n = 47)[2]	Yes[2]
	Spatial Non-Verbal Stroop[3]	Inhibition	• Push left or right-arrow based on the direction of an arrow stimuli • Arrow stimuli can appear on the left side, right side, or center of the screen. Location can be congruent. Incongruent or neutral with direction of the arrow stimuli Participant is to disregard location of arrow on the screen and match their button press to the direction the arrow is pointing		Split half (r =0.98, p not provided, n = 84) [4]	Convergent with Verbal Stroop (r = 0.27, p < 0.01*,* n =100)[4]	Yes[3,5]

	Cognitive Measure	Purpose	Description Subtests	Time (min)	Reliability	Validity	Used with PWA?
	Trail Making Test A	• Sequencing • Planning • Inhibition	Connect the numbers in serial order		Reliability between TMT-A & TMT-B (r = 0.73)[6]	Concurrent with visuoperceptual abilities[6]	Yes[7]
	Trail Making Test B	• Sequencing • Planning • Cognitive Flexibility • Shifting	Connect alternating numbers and letters in serial order			Face validity Concurrent validity with working memory & task switching[6]	Yes[7]
	Raven's Coloured Progressive Matrices[8]	• Non-verbal reasoning / General intelligence	• Select the 'missing' piece from a matrix from six options	5-10	Available in manual[8]	Available in manual[8]	Yes[1]
	AX Continuous Performance Test[9]	• Inhibition • Updating • Context processing	• Push Button if a probe "X" follows a cue "A" (AX sequence) • Do not push a button for AY, BX sequences		Not available	Construct (BX errors long delay with TMTB r = 0.41, with category verbal fluency r = 0.44, with Paired associates r = *0.38*, with delayed logical memory r = 0.63, $p<0.05$, n = 33)[10]	No

	Cognitive Measure	Purpose	Description Subtests	Time (min)	Reliability	Validity	Used with PWA?
	Wisconsin Card Sort Task[11]	• Categorization • Cognitive Flexibility	• Set of cards with different colours, shapes, and number of items • Determine the rule used by the researcher to select 4 cards through trial-and-error		Available in manual[12]	Available in manual[12]	Yes[8, 13]

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Table 9. Linguistic measures of decision-making: Means and standard deviations of ratio scores for people with aphasia and controls on the FAVRES *Making a Decision* subtest

	People with Aphasia			**Controls**		
	n	Mean	Standard Deviation	*N*	Mean	Standard Deviation
Accuracy	*16*	0.7125	0.33441	*16*	0.9125	0.12583
Reasoning	*16*	0.3675	0.20460	*16*	0.7775	0.13384

Note: FAVRES, Functional Assessment of Verbal Reasoning and Executive Strategies (MacDonald, 2010).

Table 10. Linguistic measures of decision-making: Means and standard deviations of ratio scores for people with aphasia and controls on the FAVRES *Making a Decision* subtest

	Fluent			**Non-Fluent**		
	n	Mean	Standard Deviation	*n*	Mean	Standard Deviation
Accuracy	8	0.8	0.28284	8	0.6250	0.37702
Reasoning	8	0.46	0.22013	8	0.2750	0.14726

Note: FAVRES, Functional Assessment of Verbal Reasoning and Executive Strategies (MacDonald, 2010).

Table 11. Non-linguistic measuerse of decision-making: Means and standard deviations of ratio and net scores for people with aphasia and controls

	People with Aphasia			**Controls**		
	n	Mean	Standard Deviation	*n*	Mean	Standard Deviation
GDT Net Score	16	5.625	11.1288	16	10.125	9.3372
IGT Ratio Score	16	0.6425	0.16205	16	0.6475	0.8820

Note: IGT, Iowa Gambling Task; GDT, Game of Dice Task.

Table 12. Iowa Gambling Task - Means and standard deviations of ratio scores for people with aphasia and controls overall and across blocks

	People with Aphasia			**Controls**		
	n	Mean	Standard Deviation	*n*	Mean	Standard Deviation
Block 1	16	0.9906	0.02720	16	1.0000	0.00000
Block 2	16	0.7906	0.22228	16	0.7219	0.17792
Block 3	16	0.5375	0.26173	16	0.5813	0.19397
Block 4	16	0.4625	0.26173	16	0.4250	0.20000
Block 5	16	0.5406	0.24981	16	0.5063	0.20565
Overall	16	0.6425	0.16205	16	0.6475	0.8820

Table 13. Iowa Gambling Task – Overall means and standard deviations of average change in pupil size for people with aphasia and controls

	People with Aphasia			**Controls**			**Overall**		
	n	Mean	Standard Deviation	*n*	Mean	Standard Deviation	*n*	Mean	Standard Deviation
Overall Change in pupil size	16	57.357	28.873	16	55.588	27.524	32	56.475	28.218

Note: Pupil size was measured using an arbitrary unit generated by the EyeLink 1000+ eye tracking system (SR Research, 2014); Change in pupil size was calculated by subtracting minimum pupil size in a given trial from all measures of pupil size within the given trial. These calculated change in pupil size values were averaged per trial; IGT, Iowa Gambling Task.

Table 14. Iowa Gambling Task - Means and standard deviations of average change in pupil size across blocks for people with aphasia and controls

	People with Aphasia			**Controls**		
	n	Mean	Standard Deviation	*n*	Mean	Standard Deviation
Block 1	16	61.6725	18.79836	16	55.3723	10.39017
Block 2	16	55.3723	10.39017	16	58.5224	15.27970
Block 3	16	58.5224	15.27970	16	58.5278	17.60136
Block 4	16	58.5278	17.60136	16	55.0115	11.09160
Block 5	16	55.0115	11.09160	16	56.7697	14.58168

Note: Pupil size was measured using an arbitrary unit generated by the EyeLink 1000+ eye tracking system (SR Research, 2014); Change in pupil size was calculated by subtracting minimum pupil size in a given trial from all measures of pupil size within the given trial. These calculated change in pupil size values were averaged per trial and per block; IGT, Iowa Gambling Task.

Table 15. Iowa Gambling Task – Overall means and standard deviations of absolute minimum pupil size during deliberation for people with aphasia and controls

	People with Aphasia			**Controls**			**Overall**		
	n	Mean	Standard Deviation	*n*	Mean	Standard Deviation	*n*	Mean	Standard Deviation
Overall Change in pupil size	1593	630.67	160.323	16	599.58	158.421	3190	615.11	160.105

Note: Pupil size was measured using an arbitrary unit generated by the EyeLink 1000+ eye tracking system (SR Research, 2014); Change in pupil size was calculated by subtracting minimum pupil size in a given trial from all measures of pupil size within the given trial. These calculated change in pupil size values were averaged over the entire task.

Table 16. Iowa Gambling Task - Means and medians for participant subjective rankings of decks after each block.

		People with Aphasia			Controls		
		n	Mean Rating	Median Rating	*n*	Mean Rating	Median Rating
Block 1	Deck A	10	1.67	2	13	2.33	2
	Deck B	9	2.67	3	12	2.83	3
	Deck C	10	2.11	2	13	1.92	1
	Deck D	10	3.22	4	12	2.83	3
Block 2	Deck A	10	2.5	2.5	14	3.75	4
	Deck B	11	2.3	2.5	12	2.08	2
	Deck C	11	2.8	3.5	13	2.5	2.5
	Deck D	11	2.2	2	13	1.5	1
Block 3	Deck A	10	2.3	2	12	3.33	3
	Deck B	11	2.3	2.5	13	2.08	2
	Deck C	10	3	3	13	2.92	3.5
	Deck D	11	2.2	2	13	1.67	1.5
Block 4	Deck A	9	2.25	2	14	3.08	3
	Deck B	8	2.38	3	13	2.38	2
	Deck C	10	3	3.5	14	2.85	3
	Deck D	10	1.88	1.5	13	1.54	1
Block 5	Deck A	8	2.75	2.5	12	3.33	4
	Deck B	9	2.5	2	12	2.08	2
	Deck C	9	1.75	1.5	12	2.25	2
	Deck D	8	2.88	3	13	2.33	2

Notes: Decks A & C were considered generally disadvantageous. Decks B & D were considered generally advantageous (and highlighted green).

Table 17. Secondary analysis of aphasia severity – Non-linguistic decision-making performance means and standard deviations of ratio and net scores for people with mild and moderate-severe aphasia

	Mild			**Moderate-Severe**		
	n	Mean	Standard Deviation	*n*	Mean	Standard Deviation
GDT Net Score	9	10.444	10.4297	7	-0.571	9.2170
IGT Overall Ratio	9	0.6533	0.13500	7	0.6286	0.20236

Note: IGT, Iowa Gambling Task; GDT, Game of Dice Task.

Table 18. Secondary analysis of aphasia fluency – Non-linguistic decision-making performance means and standard deviations of ratio and net scores for people with f aphasia

	Fluent			**Non Fluent**		
	n	Mean	Standard Deviation	*n*	Mean	Standard Deviation
GDT Net Score	8	11.000	7.2506	8	0.250	12.1155
IGT Overall Ratio	8	0.6688	0.13601	8	0.6163	0.19026

Note: IGT, Iowa Gambling Task; GDT, Game of Dice Task.

Table 19. Cognitive Measures – Performance means and standard deviations for people with aphasia and controls

			People with Aphasia			Controls		
			n	Mean	Std. Dev	*n*	Mean	Std. Dev
Language	Western Aphasia Battery	Aphasia Quotient[+]*	16	76.34	18.89	16*	98.44*	0.96*
		Spontaneous speech	16	15.13	4.77	-	-	-
		Auditory comprehension[+]	16	9.28	2.76	16*	9.50*	0.52*
		Repetition	16	6.89	2.49	-	-	-
		Naming & word finding	16	7.46	1.91	-	-	-
Working Memory	Picture Span	Forward ratio correct	16	0.52	0.19	16	0.87	0.06
		Backward ratio correct*	16	0.56	0.14	16	0.83	0.11
Executive Function	Stroop	Ratio incorrect (congruent trials)	16	0.05	0.11	16	0.01	0.01
		Ratio incorrect (neutral trials)	16	0.11	0.19	16	0.01	0.01
		Ratio incorrect (incongruent trials)	16	0.1125	0.19	16	0.03	0.03
		Mean reaction time (congruent trials)	16	848.50	282.86	16	618.15	102.40
		Mean reaction time (neutral trials)	16	841.88	249.68	16	630.47	89.98
		Mean reaction time (incongruent trials)*	16	945.37	286.75	16	678.27	95.36

		Interference*	16	103.49	70.412	16	47.80	43.06
		Facilitation	16	-6.61	79.91	16	12.322	56.48
	Trail Making Test	TMT-A time to complete (s)	15	55.11	22.06	16	25.31	4.90
		TMT-B time to complete (s)*	13	183.70	84.33	16	66.50	24.24
	RCPM	Total score*	16	30.75	4.52	16	33.44	2.45
		Time to complete (s)*	12	491.17	211.33	16	245.13	71.65
	AX-Continuous Processing Task	Ratio short AX errors	16	0.03	0.06	16	0.00	0.00
		Ratio short AY errors	16	0.06	0.12	16	0.03	0.10
		Ratio short BX errors	16	0.15	0.31	16	0.00	0.00
		Ratio short BY errors	16	0.05	0.12	16	0.00	0.00
		Ratio long AX errors	16	0.01	0.02	16	0.01	0.01
		Ratio long AY errors	16	0.11	0.26	16	0.08	0.12
		Ratio long BX errors	16	0.18	0.33	16	0.06	0.25
		Ratio long BY errors	16	0.11	0.25	16	0.01	0.05
		Short AX reaction Time (ms)	16	719.34	215.16	16	692.06	260.64
		Short AY reaction time (ms)	16	885.89	239.32	16	682.11	207.77
		Short BX reaction time (ms)	16	682.11	207.77	16	729.08	324.29
		Short BY reaction	16	759.65	264.31	16	709.21	346.50

		time (ms)						
		Long AX reaction time (ms)	16	628.76	129.54	16	609.31	182.79
		Long AY reaction time (ms)	16	799.25	162.87	16	795.14	179.95
		Long BX reaction time (ms)	16	627.02	181.55	16	600.05	238.98
		Long BY reaction time (ms)	16	627.66	151.08	16	599.74	201.90
	Wisconsin Card Sort Task	Number of categories completed	16	1.69	1.45	16	3.81	1.05
		Total correct	16	33.56	12.38	16	49.44	8.55
		Total errors*	16	30.44	12.38	16	14.56	8.55
		Non-perseveration errors	16	19.69	16.23	16	5.94	3.43
		Perseverative errors	16	10.94	8.86	16	8.56	5.97
		Trials to complete 1st category*	16	28.63	23.60	16	12.88	3.69

Notes:

- Forward span is an average between paper-based and computerized versions of the forward picture span task
- Shaded cells indicate variables included as predictor variables in regression analyses
- *indicates variables with significant between group differences; significance determined at $p < 0.05$
- + indicates imputed data based on norms found in Kertesz (2007)

Table 20. Summary of significant predictor variables across all regression models

	Overall	People with Aphasia	Controls
Accuracy	Stroop errors Stroop interference	-	AX-CPT Long BX errors
Reasoning	Depression Scale Stroop errors AX-CPT short AX errors AX-CPT short BX errors TMT-B	WAB-R AQ AX-CPT short AX errors AX-CPT short AY errors	TMT-B
IGT	WCST Trials to complete 1st category Stroop Errors RCPM Time to complete		WCST Trials to complete 1st category

	AX-CPT Long AX Reaction Time		
GDT	Age	Age	Age
	Stroop errors	Stroop errors	
	WCST trials to complete 1st category	WCST trials to complete 1st category	WCST trials to complete 1st category
	RCPM total score	WCST total errors	
		AX-CPT Short BX Errors	

Note: IGT, Iowa Gambling Task; GDT, Game of Dice Task; AX-CPT, AX-Continuous Processing Task; WCST, Wisconsin Card Sort Task; RCPM, Raven's Coloured Progressive Matrices; WAB-R AQ, Western Aphasia Battery-Revised Aphasia Quotient.

Table 21. Summary of error violations in regression models

Analysis	Normality	Multicollinearity	Homoscedasticity	Independence of Errors	Number of Extreme Cases Identified
Accuracy Overall	Violated	Ok	Violated	Ok	2
Accuracy PWA only	-	-	-	-	-
Accuracy controls only	Violated	Ok	Violated	Ok	0
Reasoning Overall	Violated	Ok	Ok	Ok	0
Reasoning PWA only	Violated	Ok	Ok	Ok	0
Reasoning controls only	Violated	Ok	Ok	Ok	0
IGT Overall	Ok	Ok	Ok	Ok	1
IGT PWA only	Violated	Violated	Ok	Ok	1
IGT Controls Only	Violated	Violated	Ok	Ok	1
GDT Overall	Violated	Ok	Violated	Ok	2
GDT PWA only	Violated	Ok	Ok	Ok	0
GDT Controls Only	Violated	Ok	Ok	Ok	0

Note: IGT, Iowa Gambling Task; GDT, Game of Dice Task

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Appendix A

Accuracy multiple regression model for all participants

	Beta	Standard Error Beta	Standardized Beta (β)
Model 1			
F (6,22) = 4.020, p = 0.007, R^2= 0.523, $R^2_{adjusted}$ = 0.393			
Constant	0.108	0.724	
WAB aphasia quotient	0.005	0.006	0.261
Education	0.024	0.017	0.226
Stroop errors (incongruent trials)	-1.312	0.446	-0.506*
Stroop interference	-0.002	0.001	-0.378
WCST total errors	-0.006	0.005	-0.274
TMT-B	0.002	0.001	0.566
Model 2			
F (5, 23) = 4.806, p = 0.004, R^2= 0.511, $R^2_{adjusted}$ = 0.405			
Constant	0.603	0.282	
Education	0.026	0.017	0.253
Stroop errors (incongruent trials)	-1.261	0.437	-0.487*
Stroop interference	-0.002	0.001	-0.467*
WCST total errors	-0.007	0.005	-0.332
TMT-B	0.001	0.001	0.438
Model 3			
F (4, 24) = 5.062, p = 0.004, R^2= 0.458, $R^2_{adjusted}$ = 0.367			

Constant	1.031	0.085	
Stroop errors (incongruent trials)	-1.279	0.450	-0.494*
Stroop interference	-0.002	0.001	-0.436*
WCST total errors	-0.009	0.005	-0.390
TMT-B	0.001	0.001	0.371
Model 4			
F (3, 25) = 5.900, p = 0.003, R^2= 0.414, $R^2_{adjusted}$ = 0.344			
Constant	1.039	0.087	
Stroop errors (incongruent trials)	-1.016	0.415	-0.392*
Stroop interference	-0.001	0.001	-0.289*
WCST total errors	-0.005	0.004	-0.214
Model 5			
F (2, 26) = 7.804, p = 0.002, R^2= 0.375, $R^2_{adjusted}$ = 0.327			
Constant	0.964	0.065	
Stroop errors (incongruent trials)	-1.133	0.411	-0.437*
Stroop interference	-0.001	0.001	-0.347*

Notes: * indicates $p \leq 0.05$

Appendix B

Accuracy multiple regression model for PWA

	Beta	Standard Error Beta	Standardized Beta (β)
Model 1			
F (2, 10) = 1.499, p = 0.270, R^2= 0.231, $R^2_{adjusted}$ = 0.077			
Constant	-0.150	0.573	
Education	0.056	0.033	0.497
TMT-B	0.000	0.001	0.062
Model 2			
F (1, 11) = 3.233, p = 0.100, R^2= 0.227, $R^2_{adjusted}$ = 0.157			
Constant	-0.071	0.417	
Education	0.053	0.030	0.477

Appendix C

Accuracy multiple regression model for controls

	Beta	Standard Error Beta	Standardized Beta (β)
Model 1			
F (2, 13) = 7.174, p = 0.008, R^2= 0.525, $R^2_{adjusted}$ = 0.452			
Constant	0.760	0.115	
AX-CPT long errors on BX trials	-0.290	0.100	-0.575*
AX-CPT long AY reaction time	0.000	0.000	0.306
Model 2			
F (1, 14) = 10.938, p = 0.005, R^2= 0.439, $R^2_{adjusted}$ = 0.398			
Constant	0.933	0.025	
AX-CPT long errors on BX trials	-0.333	0.101	-0.662

Notes: * indicates $p \leq 0.05$

Appendix D

Reasoning regression model for all participants

	Beta	Standard Error Beta	Standardized Beta (β)
Model 1			
F (13, 12) = 3.994, p = 0.011, R^2= 0.812, $R^2_{adjusted}$ = 0.609			
Constant	0.594	0.745	
Education	-0.003	0.019	-0.026
Depression Scale	-0.052	0.025	-0.382
WAB aphasia quotient	0.003	0.006	0.185
WM Backward span	0.033	0.360	0.022
Stroop errors (incongruent trials only)	0.601	0.538	0.279
Stroop interference	-0.001	0.001	-0.177
AX-CPT short errors on AX trials	-9.564	7.408	-0.557
AX-CPT short errors on AY trials	-0.469	0.447	-0.181
AX-CPT short errors on BX trials	0.750	0.583	0.544
WCST total errors	-0.004	0.005	-0.173
TMT-B	-0.001	0.001	-0.528
RCPM total	0.002	0.015	0.025
RCPM time	0.000	0.000	0.191
Model 2			
F (12, 13) = 4.684, p = 0.005, R^2= 0.812, $R^2_{adjusted}$ = 0.639			

Constant	0.609	0.699	
Education	-0.003	0.018	-0.029
Depression Scale	-0.052	0.024	-0.382
WAB aphasia quotient	0.003	0.005	0.190
Stroop errors (incongruent trials only)	0.617	0.488	0.287
Stroop interference	-0.001	0.001	-0.172
AX-CPT short errors on AX trials	-9.931	5.992	-0.578
AX-CPT short errors on AY trials	-0.458	0.412	-0.176
AX-CPT short errors on BX trials	0.774	0.500	0.561
WCST total errors	-0.004	0.004	-0.175
TMT-B	-0.001	0.001	-0.530
RCPM total	0.002	0.014	0.030
RCPM time	0.000	0.000	0.178
Model 3			
F (11, 14) = 5.489, p = 0.002, R^2= 0.812, $R^2_{adjusted}$ = 0.664			
Constant	0.671	0.558	
Education	-0.002	0.017	-0.024
Depression Scale	-0.051	0.023	-0.376*
WAB aphasia quotient	0.003	0.005	0.193
Stroop errors (incongruent trials only)	0.601	0.460	0.279
Stroop interference	-0.001	0.001	-0.170
AX-CPT short errors on AX trials	-9.613	5.444	-0.560
AX-CPT short errors on AY trials	-0.461	0.397	-0.178
AX-CPT short errors on BX trials	0.737	0.428	0.535

WCST total errors	-0.004	0.004	-0.181
TMT-B	-0.002	0.001	-0.544
RCPM time	0.000	0.000	0.188
Model 4			
F (10, 15) = 6.458, p = 0.01, R^2= 0.812, $R^2_{adjusted}$ = 0.686			
Constant	0.654	0.527	
Depression Scale	-0.050	0.019	-0.363*
WAB aphasia quotient	0.003	0.005	0.180
Stroop errors (incongruent trials only)	0.598	0.444	0.278
Stroop interference	-0.001	0.001	-0.172
AX-CPT short errors on AX trials	-9.352	4.957	-0.545
AX-CPT short errors on AY trials	-0.479	0.365	-0.184
AX-CPT short errors on BX trials	0.717	0.389	0.520
WCST total errors	-0.004	0.004	-0.178
TMT-B	-0.002	0.001	-0.550
RCPM time	0.000	0.000	0.187
Model 5			
F (9, 16) = 7.450, p < 0.001, R^2= 0.807, $R^2_{adjusted}$ = 0.699			
Constant	0.953	0.074	
Depression Scale	-0.050	0.018	-0.366*
Stroop errors (incongruent trials only)	0.716	0.385	0.333
Stroop interference	-0.001	0.001	-0.227
AX-CPT short errors on AX trials	-10.166	4.650	-0.592
AX-CPT short errors on AY trials	-0.489	0.357	-0.188

AX-CPT short errors on BX trials	0.777	0.367	0.564
WCST total errors	-0.004	0.004	-0.216
TMT-B	-0.002	0.001	-0.693
RCPM time	0.000	0.000	0.227
Model 6			
F (8, 17) = 8.263, $p < 0.001$, $R^2 = 0.795$, $R^2_{adjusted} = 0.699$			
Constant	0.995	0.061	
Depression Scale	-0.045	0.018	-0.333
Stroop errors (incongruent trials only)	0.593	0.365	0.276*
Stroop interference	-0.001	0.001	-0.237
AX-CPT short errors on AX trials	-11.607	4.418	-0.676*
AX-CPT short errors on AY trials	-0.307	0.306	-0.118
AX-CPT short errors on BX trials	0.837	0.362	0.607*
WCST total errors	-0.005	0.004	-0.242
TMT-B	-0.001	0.001	-0.462
Model 7			
F (7, 18) = 9.295, $p < 0.001$, $R^2 = 0.783$, $R^2_{adjusted} = 0.699$			
Constant	0.981	0.059	
Depression Scale	-0.046	0.018	-0.338
Stroop errors (incongruent trials only)	0.646	0.361	0.301
Stroop interference	-0.001	0.001	-0.222
AX-CPT short errors on AX trials	-12.921	4.220	-0.753*
AX-CPT short errors on BX trials	0.917	0.353	0.665*
WCST total errors	-0.004	0.004	-0.211

TMT-B	-0.001	0.001	-0.494
Model 8			
F (6, 19) = 10.368, $p < 0.001$, $R^2 = 0.766$, $R^2_{adjusted} = 0.692$			
Constant	0.948	0.053	
Depression Scale	-0.041	0.017	-0.301*
Stroop errors (incongruent trials only)	0.713	0.361	0.332
Stroop interference	-0.001	0.001	-0.197
AX-CPT short errors on AX trials	-13.118	4.265	-0.764*
AX-CPT short errors on BX trials	1.022	0.346	0.741*
TMT-B	-0.002	0.001	-0.714*
Model 9			
F (6, 21) = 10.446, $p < 0.001$, $R^2 = 0.749$, $R^2_{adjusted} = 0.677$			
Constant	0.951	0.053	
Depression Scale	-0.047	0.015	-0.380*
Stroop errors (incongruent trials only)	0.691	0.362	0.316
Stroop interference	-0.001	0.001	-0.167
AX-CPT short errors on AX trials	-13.368	4.274	-0.765*
AX-CPT short errors on BX trials	1.031	0.343	0.733*
TMT-B	-0.002	0.001	-0.693*
Model 10			
F (5, 22) = 12.127, $p < 0.001$, $R^2 = 0.734$, $R^2_{adjusted} = 0.673$			
Constant	0.935	0.052	
Depression Scale	-0.042	0.014	-0.337*
Stroop errors (incongruent trials only)	0.745	0.361	0.342*

AX-CPT short errors on AX trials	-13.312	4.301	-0.762*
AX-CPT short errors on BX trials	1.012	0.345	0.720*
TMT-B	-0.002	0.000	-0.810*

Notes: * indicates $p \leq 0.05$

Appendix E

Reasoning multiple regression model for PWA

	Beta	Standard Error Beta	Standardized Beta (β)
Model 1			
F (9,6) = 6.307, p = 0.018, R^2= 0.812, $R^2_{adjusted}$ = 0.609			
Constant	0.375	0.483	
WAB Quotient	0.005	0.003	0.483
WM backward span	-0.733	0.367	-0.513
AX-CPT short errors on AX trials	-2.823	1.310	-0.782
AX-CPT short errors on AY trials	-0.719	0.242	-0.423*
AX-CPT long reaction time on AY trials	0.000	0.000	0.287
AX-CPT long reaction time on BX trials	0.000	0.000	0.128
WCST total errors	-0.003	0.005	-0.173
WCST trials to complete first category	0.000	0.002	-0.008
RCPM total	-0.005	0.018	-0.120
Model 2			
F (8, 7) = 8.275, p = 0.006, R^2= 0.812, $R^2_{adjusted}$ = 0.609			
Constant	0.380	0.427	
WAB Quotient	0.005	0.003	0.485
WM backward span	-0.734	0.338	-0.514
AX-CPT short errors on AX trials	-2.848	1.030	-0.788*

AX-CPT short errors on AY trials	-0.720	0.223	-0.424*
AX-CPT long reaction time on AY trials	0.000	0.000	0.290
AX-CPT long reaction time on BX trials	0.000	0.000	0.132
WCST total errors	-0.003	0.004	-0.176
RCPM total	-0.006	0.014	-0.128
Model 3			
F (7,8)= 10.512, p = 0.002, R^2= 0.812, $R^2_{adjusted}$ = 0.609			
Constant	0.301	0.363	
WAB Quotient	0.004	0.002	0.394*
WM backward span	-0.683	0.299	-0.478
AX-CPT short errors on AX trials	-2.551	0.712	-0.706*
AX-CPT short errors on AY trials	-0.687	0.199	-0.404*
AX-CPT long reaction time on AY trials	0.000	0.000	0.282
AX-CPT long reaction time on BX trials	0.000	0.000	0.081
WCST total errors	-0.004	0.004	-0.213
Model 4			
F (6,9) = 13.359, p < 0.0001, R^2= 0.812, $R^2_{adjusted}$ = 0.609			
Constant	0.391	0.299	
WAB Quotient	0.004	0.002	0.408*
WM backward span	-0.679	0.286	-0.475*
AX-CPT short errors on AX trials	-2.434	0.641	-0.674*
AX-CPT short errors on AY trials	-0.702	0.188	-0.413*
AX-CPT long reaction time on AY trials	0.000	0.000	0.264
WCST total errors	-0.005	0.003	-0.274

Model 5			
F (5, 10) = 13.474, $p < 0.0001$, $R^2 = 0.812$, $R^2_{adjusted} = 0.609$			
Constant	-0.004	0.178	
WAB Quotient	0.006	0.001	0.516*
WM backward span	-0.502	0.283	-0.351
AX-CPT short errors on AX trials	-2.344	0.685	-0.649*
AX-CPT short errors on AY trials	-0.722	0.201	-0.425*
AX-CPT long reaction time on AY trials	0.000	0.000	0.331*
Model 6			
F (4, 11) = 13.428, $p < 0.0001$, $R^2 = 0.812$, $R^2_{adjusted} = 0.609$			
Constant	-0.214	0.146	
WAB Quotient	0.005	0.002	0.456*
AX-CPT short errors on AX trials	-1.422	0.489	-0.394*
AX-CPT short errors on AY trials	-0.659	0.216	-0.388*
AX-CPT long reaction time on AY trials	0.000	0.000	0.282
Model 7			
F (3, 12) = 13.338, $p < 0.0001$, $R^2 = 0.769$, $R^2_{adjusted} = 0.712$			
Constant	-0.038	0.129	
WAB Quotient	0.006	0.002	0.585*
AX-CPT short errors on AX trials	-1.169	0.527	-0.324*
AX-CPT short errors on AY trials	-0.750	0.236	-0.441*

Notes: * indicates $p \leq 0.05$

Appendix F

Reasoning multiple regression model for controls

	Beta	Standard Error Beta	Standardized Beta (β)
Constant	0.997	0.084	
TMT-B	-0.003	0.001	-0.597*

Notes: * indicates $p \leq 0.05$

Appendix G

IGT multiple regression model for all participants

	Beta	Standard Error Beta	Standardized Beta (β)
Model 1			
F (6,21) = 2.970, p = 0.029, R^2= 0.459, $R^2_{adjusted}$ = 0.304			
Constant	0.593	0.227	
Education	0.011	0.012	0.196
Stroop errors (incongruent trials)	-0.321	0.239	-0.254
AX-CPT long AX reaction time	0.000	0.000	-0.395
AX-CPT long BY reaction time	0.000	0.000	0.187
WCST trials to complete first category	-0.002	0.002	-0.280
RCPM - time	0.000	0.000	0.334
Model 2			
F (5,22) = 3.497, p = 0.018, R^2= 0.443, $R^2_{adjusted}$ = 0.316			
Constant	0.669	0.204	
Education	0.008	0.011	0.147
Stroop errors (incongruent trials)	-0.372	0.228	-0.295
AX-CPT long AX reaction time	0.000	0.000	-0.280
WCST trials to complete first category	-0.002	0.002	-0.283
RCPM - time	0.000	0.000	0.293
Model 3			

F (4, 23) = 4.342 , p = 0.009, R^2= 0.430, $R^2_{adjusted}$ = 0.331			
Constant	0.792	0.105	
Stroop errors (incongruent trials)	-0.426	0.212	-0.338
AX-CPT long AX reaction time	0.000	0.000	-0.272
WCST trials to complete first category	-0.003	0.001	-0.378*
RCPM - time	0.000	0.000	0.317
Model 4			
F (3, 24) = 4.601 , p = 0.011, R^2= 0.365, $R^2_{adjusted}$ = 0.286			
Constant	0.643	0.052	
Stroop errors (incongruent trials)	-0.528	0.209	-0.418*
WCST trials to complete first category	-0.003	0.001	-0.414*
RCPM - time	0.000	0.000	0.378*

Note: * indicates $p \leq 0.05$

Appendix H

IGT multiple regression model for PWA

	Beta	Standard Error Beta	Standardized Beta (β)
Model 1			
F (3,12) = 2.943, p = 0.076, R^2= 0.424, $R^2_{adjusted}$ = 0.280			
Constant	0.633	0.280	
Education	0.018	0.012	0.328
AX-CPT long AX reaction time	0.000	0.000	-0.309
Stroop facilitation	0.001	0.001	0.261
Model 2			
F (2,13) = 3.893, p = 0.047, R^2= 0.375, $R^2_{adjusted}$ = 0.278			
Constant	0.709	0.270	
Education	0.020	0.012	0.357
AX-CPT long AX reaction time	-0.001	0.000	-0.437
Model 3			
F (1,14) = 4.703 , p = 0.048, R^2= 0.251, $R^2_{adjusted}$ = 0.198			
Constant	1.037	0.185	
AX-CPT long AX reaction time	-0.001	0.000	-0.501*

Note: * indicates $p \leq 0.05$

Appendix I

IGT multiple regression model for controls

	Beta	Standard Error Beta	Standardized Beta (β)
Model 1			
F (4,11) = 3.068, p = 0.063, R^2= 0.527, $R^2_{adjusted}$ = 0.355			
Constant	0.286	0.439	
Stroop facilitation	-0.001	0.000	-0.425
WCST trials to complete first category	-0.011	0.006	-0.441
RCPM total	0.014	0.011	0.384
AX-CPT long AX reaction time	0.000	0.000	0.148
Model 2			
F (3,12) = 4.317, p = 0.028, R^2= 0.519, $R^2_{adjusted}$ = 0.399			
Constant	0.428	0.288	
Stroop facilitation	-0.001	0.000	-0.396
WCST trials to complete first category	-0.010	0.005	-0.404
RCPM total	0.011	0.008	0.292
Model 3			
F (2,13) = 5.201 , p = 0.022, R^2= 0.444, $R^2_{adjusted}$ = 0.359			
Constant	0.810	0.066	
Stroop facilitation	-0.001	0.000	-0.432
WCST trials to complete first category	-0.012	0.005	-0.501*

Model 3			
F (1,14) = 4.858, p = 0.045, R^2= 0.258, $R^2_{adjusted}$ = 0.205			
Constant	0.804	0.074	
WCST trials to complete first category	-0.012	0.006	-0.508*

Note: * indicates $p \leq 0.05$

Appendix J

GDT multiple regression model for all participants

	Beta	Standard Error Beta	Standardized Beta (β)
Model 1			
F (15,13) = 3.192, p = 0.021, R^2= 0.786, $R^2_{adjusted}$ = 0.540			
Constant	-32.537	33.987	
Age	-0.450	0.244	-0.365
Education	0.592	0.632	0.148
WAB Quotient	0.057	0.279	0.081
Working memory backward span	17.332	14.926	0.267
Stroop errors (incongruent trials)	-70.873	25.633	-0.711*
Stroop interference	-0.009	0.039	-0.057
Stroop facilitation	0.025	0.037	0.143
AX-CPT short errors AX trials	209.327	236.944	0.275
AX-CPT short errors BX trials	-20.774	16.072	-0.471
AX-CPT long errors BX trials	7.214	7.290	0.186
AX-CPT short AY reaction time	-0.003	0.007	-0.081
WCST total errors	0.173	0.235	0.202
WCST trials to complete first category	-0.281	0.157	-0.458
TMT-B	0.074	0.055	0.577
RCPM total	1.262	0.776	0.377

Model 2			
F (14,14) = 3.668, p = 0.010, R^2= 0.786, $R^2_{adjusted}$ = 0.572			
Constant	-28.580	27.020	
Age	-0.438	0.229	-0.355
Education	0.621	0.595	0.155
Working memory backward span	17.144	14.379	0.264
Stroop errors (incongruent trials)	-69.230	23.503	-0.695*
Stroop interference	-0.013	0.032	-0.082
Stroop facilitation	0.024	0.036	0.140
AX-CPT short errors AX trials	191.838	213.406	0.252
AX-CPT short errors BX trials	-19.385	14.071	-0.439
AX-CPT long errors BX trials	7.069	7.003	0.183
AX-CPT short AY reaction time	-0.003	0.006	-0.067
WCST total errors	0.163	0.223	0.191
WCST trials to complete first category	-0.286	0.150	-0.466
TMT-B	0.068	0.043	0.528
RCPM total	1.292	0.735	0.386
Model 3			
F (13,15) = 4.168, p = 0.005, R^2= 0.783, $R^2_{adjusted}$ = 0.595			
Constant	-27.894	26.212	
Age	-0.481	0.198	-0.390*
Education	0.575	0.568	0.144
Working memory backward span	15.676	13.539	0.241
Stroop errors (incongruent trials)	-65.384	20.964	-0.656*

Stroop facilitation	0.025	0.035	0.143
AX-CPT short errors AX trials	165.588	197.953	0.218
AX-CPT short errors BX trials	-17.150	12.618	-0.389
AX-CPT long errors BX trials	6.886	6.793	0.178
AX-CPT short AY reaction time	-0.002	0.006	-0.060
WCST total errors	0.165	0.216	0.192
WCST trials to complete first category	-0.293	0.145	-0.477
TMT-B	0.059	0.037	0.459
RCPM total	1.394	0.673	0.417*
Model 4			
F (12,16) = 4.745, p = 0.005, R^2= 0.781, $R^2_{adjusted}$ = 0.616			
Constant	-30.660	24.709	
Age	-0.471	0.191	-0.382*
Education	0.566	0.553	0.141
Working memory backward span	15.335	13.162	0.236
Stroop errors (incongruent trials)	-64.689	20.354	-0.649*
Stroop facilitation	0.021	0.032	0.120
AX-CPT short errors AX trials	167.318	192.749	0.220
AX-CPT short errors BX trials	-16.401	12.166	-0.372
AX-CPT long errors BX trials	6.627	6.589	0.171
WCST total errors	0.168	0.211	0.197
WCST trials to complete first category	-0.290	0.141	-0.472
TMT-B	0.054	0.033	0.417
RCPM total	1.423	0.652	0.425

Model 5			
F (11,17) = 5.322, p = 0.002, R^2= 0.775, $R^2_{adjusted}$ = 0.629			
Constant	-29.838	24.248	
Age	-0.514	0.176	-0.417*
Education	0.614	0.538	0.153
Working memory backward span	15.083	12.928	0.232
Stroop errors (incongruent trials)	-68.407	19.179	-0.686*
AX-CPT short errors AX trials	190.546	186.061	0.250
AX-CPT short errors BX trials	-14.009	11.385	-0.318
AX-CPT long errors BX trials	6.297	6.455	0.163
WCST total errors	0.195	0.203	0.227
WCST trials to complete first category	-0.317	0.132	-0.516*
TMT-B	0.045	0.030	0.347
RCPM total	1.492	0.632	0.446*
Model 6			
F (10, 18) = 5.787, p = 0.0021 R^2= 0.763, $R^2_{adjusted}$ = 0.631			
Constant	-20.188	22.019	
Age	-0.554	0.171	-0.450*
Education	0.622	0.537	0.155
Working memory backward span	13.747	12.825	0.211
Stroop errors (incongruent trials)	-62.589	18.157	-0.628*
AX-CPT short errors AX trials	142.534	178.828	0.187
AX-CPT short errors BX trials	-13.592	11.352	-0.308
AX-CPT long errors BX trials	7.075	6.390	0.183

WCST trials to complete first category	-0.239	0.103	-0.388*
TMT-B	0.052	0.029	0.407
RCPM total	1.340	0.610	0.400*
Model 7			
F (9, 19) = 6.484, p = 0.001, R^2= 0.754, $R^2_{adjusted}$ = 0.638			
Constant	-19.078	21.763	
Age	-0.574	0.167	-0.465*
Education	0.591	0.530	0.148
Working memory backward span	10.816	12.168	0.166
Stroop errors (incongruent trials)	-55.974	15.994	-0.562*
AX-CPT short errors BX trials	-7.295	8.073	-0.165
AX-CPT long errors BX trials	7.314	6.321	0.189
WCST trials to complete first category	-0.261	0.098	-0.425*
TMT-B	0.053	0.028	0.410
RCPM total	1.433	0.593	0.428*
Model 8			
F (8, 20) = 7.272, p = 0.001, R^2= 0.744, $R^2_{adjusted}$ = 0.642			
Constant	-10.510	19.410	
Age	-0.544	0.163	-0.441*
Education	0.538	0.524	0.134
Stroop errors (incongruent trials)	-55.148	15.883	-0.553*
AX-CPT short errors BX trials	-7.732	8.015	-0.175
AX-CPT long errors BX trials	6.769	6.258	0.175
WCST trials to complete first category	-0.292	0.092	-0.475*

TMT-B	0.040	0.025	0.313
RCPM total	1.446	0.590	0.432*
Model 9			
F (7, 21) = 8.205, $p < 0.001$, $R^2 = 0.732$, $R^2_{adjusted} = 0.642$			
Constant	-13.184	19.179	
Age	-0.570	0.161	-0.462*
Education	0.598	0.520	0.149
Stroop errors (incongruent trials)	-49.285	14.650	-0.495*
AX-CPT long errors BX trials	3.585	5.308	0.093
WCST trials to complete first category	-0.304	0.091	-0.494*
TMT-B	0.034	0.024	0.265
RCPM total	1.560	0.577	0.466*
Model 10			
F (6, 22) = 9.737, $p < 0.001$, $R^2 = 0.726$, $R^2_{adjusted} = 0.652$			
Constant	-10.777	18.611	
Age	-0.530	0.148	-0.430
Education	0.587	0.513	0.147
Stroop errors (incongruent trials)	-48.097	14.363	-0.483
WCST trials to complete first category	-0.290	0.087	-0.471
TMT-B	0.033	0.023	0.257
RCPM total	1.424	0.534	0.425
Model 11			
F (5, 23) = 11.271, $p < 0.001$, $R^2 = 0.710$, $R^2_{adjusted} = 0.647$			
Constant	-4.479	17.898	

Age	-0.541	0.149	-0.439*
Stroop errors (incongruent trials)	-50.615	14.289	-0.508*
WCST trials to complete first category	-0.323	0.082	-0.526*
TMT-B	0.033	0.023	0.258
RCPM total	1.536	0.528	0.459*
Model 12			
F (4, 24) = 13.044, $p < 0.001$, $R^2 = 0.685$, $R^2_{adjusted} = 0.632$			
Constant	10.362	14.800	
Age	-0.518	0.151	-0.420*
Stroop errors (incongruent trials)	-41.274	12.933	-0.414*
WCST trials to complete first category	-0.267	0.073	-0.434*
RCPM total	1.110	0.443	0.332*

Note: * indicates $p \leq 0.05$

Appendix K

GDT multiple regression model for PWA

	Beta	Standard Error Beta	Standardized Beta (β)
Model 1			
F (10, 2) = 70.057, p = 0.014, R^2= 0.997, $R^2_{adjusted}$ = 0.983			
Constant	20.103	13.056	
Age	-0.326	0.131	-0.235
Education	0.238	0.203	0.061
Stroop errors (incongruent trials)	-45.299	6.644	-0.583*
Stroop facilitation	0.024	0.039	0.135
AX-CPT short BX errors	-17.746	7.148	-0.501
AX-CPT long BX errors	8.518	7.717	0.216
WCST total errors	-0.206	0.189	-0.214
WCST trials to complete first category	-0.158	0.060	-0.304
TMT-B	0.008	0.015	0.059
RCPM total	0.518	0.305	0.160
Model 2			
F (9, 3) = 101.511, p = 0.001, R^2= 0.997, $R^2_{adjusted}$ = 0.987			
Constant	24.952	8.396	
Age	-0.321	0.114	-0.232
Education	0.218	0.175	0.056

Stroop errors (incongruent trials)	-46.337	5.574	-0.597*
Stroop facilitation	0.011	0.026	0.059
AX-CPT short BX errors	-16.197	5.746	-0.457
AX-CPT long BX errors	8.020	6.709	0.204
WCST total errors	-0.243	0.155	-0.252
WCST trials to complete first category	-0.156	0.053	-0.300
RCPM total	0.435	0.232	0.134
Model 3			
F (8, 4) = 144.560, $p < 0.001$, $R^2 = 0.997$, $R^2_{adjusted} = 0.990$			
Constant	25.164	7.446	
Age	-0.290	0.073	-0.209*
Education	0.195	0.147	0.050
Stroop errors (incongruent trials)	-47.270	4.498	-0.609*
AX-CPT short BX errors	-14.513	3.469	-0.409*
AX-CPT long BX errors	6.347	4.655	0.161
WCST total errors	-0.295	0.076	-0.306*
WCST trials to complete first category	-0.146	0.041	-0.281*
RCPM total	0.414	0.201	0.128
Model 4			
F (7, 5) = 143.113, $p < 0.001$, $R^2 = 0.995$, $R^2_{adjusted} = 0.988$			
Constant	29.408	7.221	
Age	-0.264	0.076	-0.191*
Stroop errors (incongruent trials)	-48.364	4.748	-0.623*
AX-CPT short BX errors	-15.243	3.678	-0.430*

AX-CPT long BX errors	6.013	4.991	0.153
WCST total errors	-0.321	0.079	-0.333*
WCST trials to complete first category	-0.144	0.044	-0.276*
RCPM total	0.345	0.208	0.106
Model 5			
F (6, 6) = 155.052, $p < 0.001$, $R^2 = 0.994$, $R^2_{adjusted} = 0.987$			
Constant	26.504	7.058	
Age	-0.199	0.055	-0.144*
Stroop errors (incongruent trials)	-44.805	3.854	-0.577*
AX-CPT short BX errors	-11.378	1.865	-0.321*
WCST total errors	-0.328	0.082	-0.340*
WCST trials to complete first category	-0.129	0.044	-0.247*
RCPM total	0.304	0.213	0.094
Model 6			
F (5, 7) = 161.69, $p < 0.001$, $R^2 = 0.991$, $R^2_{adjusted} = 0.985$			
Constant	35.581	3.283	
Age	-0.165	0.053	-0.119*
Stroop errors (incongruent trials)	-45.020	4.127	-0.580*
AX-CPT short BX errors	-13.308	1.377	-0.375*
WCST total errors	-0.408	0.063	-0.423*
WCST trials to complete first category	-0.088	0.035	-0.168*

Notes: * indicates $p \leq 0.05$

Appendix L

GDT multiple regression model for controls

	Beta	Standard Error Beta	Standardized Beta (β)
Model 1			
F (2,13) = 7.252, p = 0.008, R^2= 0.527, $R^2_{adjusted}$ = 0.455			
Constant	58.766	14.185	
Age	-0.482	0.202	-0.457*
WCST Trials to complete first category	-1.520	0.484	-0.600*

Notes: * indicates $p \leq 0.05$