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Chapter 1

Review of Literature

Executive functioning is an elusive and multifaceted term that involves multiple aspects of higher order cognitive functioning and has become increasingly popular in the field of neuropsychology (Chan, Shum, Touloupoulou, & Chen, 2008; Jurado & Rosselli, 2007; Suchy, 2009). It is a term that has been used to describe the regulation of the more basic cognitive processes (Jodzio & Biechowska, 2010). In other words, it is the command center that allows a person to make a plan, initiate behavior, inhibit behavior, and think flexibly to switch behavior. Although definitions vary, there is a general agreement within the field that executive functioning describes complex cognitive functions that are requisite for many of our instrumental activities of daily living, such as driving and managing finances (Chan et al., 2008; Royall et al., 2002).

Impairment in the above mentioned cognitive processes is referred to as executive dysfunction, which can occur for a variety of reasons. The most common cause of acquired executive dysfunction is due to a cerebrovascular accident (CVA; aka stroke) with approximately 50% of first-time stroke patients experiencing executive problems at varying levels of severity (Jodzio & Biechowska, 2010; Zinn, Bosworth, Hoenig, & Swartzwelder, 2007). Executive dysfunction initially was thought to result from damage to the frontal lobes (Suchy, 2007), and severe frontal lesions have been associated with impaired performance on executive functioning measures including abstract reasoning or verbal fluency (Alvarez & Emory, 2006). However, there have been instances in which
individuals with traumatic brain injury have damage to other areas of the brain and have shown impaired performance on measures of executive functioning (Miller & Cummings, 2007). In this case, executive dysfunction in individuals with non-frontal brain injuries is explained by damage to circuitry between the frontal lobes and other cortical and subcortical areas. Even though executive dysfunction can occur as a result of injury outside the frontal lobes, the frontal lobes and frontal system circuitry have been implicated in many executive functions (Miller & Cummings).

Moreover, the location of the stroke within the frontal lobes (i.e., right versus left side) can affect clinical presentation. For example, left frontal lesions have been associated with higher incidence rates of perseveration on tasks, which is the inability to shift from a previous task and adapt to a new one, while right frontal lesions have been associated with poor monitoring of behavior (Milner & Petrides, 1984). In addition, the left frontal lobe has been associated with the initiation of internal cues such as self-generated plans and strategies, whereas the right frontal lobe has been associated with incorporating external environmental cues on problem solving tasks (Goldberg, Podell, and Lovell, 1994; Milner & Petrides, 1984). In addition to executive dysfunction, damage to frontal lobes and frontal circuitry has been associated with poor functional outcomes (Benge, Caroselli, & Temple, 2007; Ownsworth & Shum, 2008; Royall et al., 2002). It is argued that poor functional outcomes in these stroke patients are likely due to the involvement of the executive functioning systems in many instrumental activities of daily living that affect independence such as driving, managing finances, and returning to work (Chan et al., 2008; Jodzio & Bicchowska, 2010; Royall et al., 2002). Because of
the real world implications, it is important to assess executive functioning in high risk patient populations such as stroke survivors.

One of the most common assessment measures of executive functioning is the Wisconsin Card Sorting Test (WCST; Heaton, 1981). The WCST is a card-sorting task which requires the examinee to sort cards into one of three particular categories with minimal direction and feedback from the examiner. This test requires flexibility on the part of the participant to switch their response pattern as the demands of the task change (Warrington, 2000). Lesion studies on the WCST indicate that the measure is sensitive to executive dysfunction in a wide range of populations, particularly patients with frontal lobe damage (Jodzio & Biechowska, 2010; Stuss et al., 2000). In regard to laterality, imaging studies have demonstrated involvement of both the right and left dorsolateral prefrontal cortex on the WCST, with contradictory findings regarding preferential activation (Berman et al., 1995; Marenco, Coppola, Daniel, Zigun, & Weinberger, 1993). Positive Emissions Topography (PET) findings have demonstrated preferential activation in both the left dorsolateral region (Berman et al., 1995) and the right dorsolateral region (Marenco et al., 1993). Lesion studies have also yielded mixed results regarding laterality on the WCST, suggesting that the measure’s effectiveness is limited in distinguishing left versus right frontal lobe damage. Several lesion studies have demonstrated that patients with left frontal lesions perform worse and commit more perseverative errors than patients with right frontal lesions (Drewe, 1974; Jodzio & Biechowska, 2010; Milner 1964; Taylor, 1979). In contrast, other lesion studies have demonstrated the measure’s sensitivity to right frontal lesions (Robinson, Heaton, Lehman, & Stilson, 1980; Stuss et al., 2000). Moreover, the WCST has some clinical
limitations when used with stroke patients. More specifically, the WCST involves only three categories with five switches and high functioning participants often obtain a ceiling score because a high proportion of individuals achieve all six categories (Warrington, 2000). Furthermore, the WCST takes approximately 45 minutes to administer, which can be a poor fit for a bedside evaluation of stroke patients in an acute rehabilitation setting.

Similar to the WCST with respect to requiring strategy generation, monitoring feedback, and set-shifting to new rules, a relatively new measure, the Brixton Spatial Anticipation Test (BSAT; Burgess & Shallice, 1997) may have greater clinical utility. A benefit of the BSAT is that the test involves nine rules to follow compared to three on the WCST, and is thus more sensitive. Several studies have examined the validity of the BSAT on several clinical samples, including patients diagnosed with Attention Deficit Hyperactivity Disorder (Shallice et al., 2002), eating disorders (Tchanturia et al., 2004), Korsakoff’s Syndrome, psychiatric disorders, and stroke (Van den Berg et al., 2009). Burgess and Shallice found that patients with frontal lesions were significantly impaired on the BSAT and differed from non-frontal lesion patients in regard to error type in that they were more likely to commit random errors. Also, the BSAT is portable with brief administration of approximately 15 minutes and immediate scoring, allowing for convenient use for bedside assessments in rehabilitation settings with stroke patients.

A limited number of studies have examined the BSAT’s efficacy in discriminating between damage to the right versus left frontal lobes, but the results have been mixed, which may be due to methodological differences. Van den Berg et al. (2009) did not differentiate between stroke patients with right versus left frontal lesions. Instead
they compared stroke patients with lesions in the right hemisphere versus the left hemisphere. Van den Berg et al. (2009) did not find a laterality effect, which is likely a result of their gross classifications considering substantial research demonstrating frontal lobe involvement in executive functioning tasks (Berman et al., 1995; Burgess & Shallice, 1996; Marenco et al., 1993; Royall et al., 2002). Burgess and Shallice (1996) explored laterality differences with primarily tumor patients. Their lesion classifications were more specific than Van den Berg et al. (2009), as they differentiated anterior lesions from posterior lesions. They did not find a lateralization effect within the anterior group or within the posterior group; however, these findings could again be influenced by the limited specificity of lesion classification and nature of the lesion, namely tumor. The clinical presentation of patients with tumors can involve a more diffuse impairment (Lezak et al., 2004). The tumor occupies space within the brain and its presence can lead to displacement of other surrounding brain structures and lead to midline shift. Thus, the mass effect of the tumor can damage the surrounding tissue of the tumor and also damage tissue further away from the tumor site due to displacement and resulting in more diffuse impairment.

Reverberi, Lavaroni, Gigli, Skrap, and Shallice (2005) classified lesions more specifically than the aforementioned authors by examining anterior lesions localized to the left dorsolateral prefrontal cortex, right dorsolateral prefrontal cortex, inferior medial region, and superior medial region. They found that patients with left dorsolateral lesions performed significantly worse than patients with right dorsolateral lesions, inferior medial lesions, and superior medial lesions, characterized by greater number of total errors. These findings are consistent with other studies demonstrating the involvement of
the dorsolateral prefrontal cortex on executive measures. The lesion sample used by Reverberi et al. (2005) was of mixed etiology, including tumor, stroke, and traumatic brain injury, and it is unclear whether a specific type of lesion created the significant effect.

To this author's knowledge, no studies have examined both the relationship between lesion location and performance on the BSAT in a sample of only stroke patients and the relationship between performance on the BSAT in stroke patients and functional outcomes. More specifically, this study examines performance on the BSAT with stroke patients, using classifications fitting for the stroke population, by comparing left versus right anterior lesions. This anterior classification includes lesions to the frontal lobes and to the subcortical structures involved in the frontal subcortical circuitry, implicated in executive functioning. This study will also assess the relationship between BSAT performance and functional outcomes. Before hypotheses are presented, a literature review will encompass executive function and dysfunction; the role of the frontal lobes and frontal subcortical circuits in executive functioning; lateralization of frontal lobe functioning in general and in relation to executive functioning; executive dysfunction due to cerebrovascular accidents; assessment of executive function; and the Brixton Spatial Anticipation Test and its ability to differentiate between right versus left lesions and its relationship to functional status.

**Executive Functioning**

Executive functioning is an elusive and multi-faceted term that involves many aspects of higher order cognitive functioning (Jurado & Rosselli, 2007; Royall et al., 2002; Suchy, 2009). In their review of the literature, Jurado and Rosselli (2007)
identified over 30 concepts or components of executive functions; some of the components mentioned include volition, planning, purposive action, effective performance, working memory, supervisory attentional system, cognitive flexibility, concept formation, cue-directed behavior, task analysis, strategy control, strategy monitoring, goal setting, initiation, inhibition, problem-solving, abstract thinking, creativity, reflection, reasoning, updating, shifting, and efficiency of lexical access (i.e., verbal fluency). Given the many proposed components of executive functioning, the question arises as to whether there is a single ability that underlies these components or whether these parts comprise related but distinct factors of executive functioning.

The unity theory describes executive functioning as a single underlying ability which comprises all of the various components of executive functioning (Jurado & Rosselli, 2007). In regard to the theory of unity, several hypotheses have been presented in the literature to describe the underlying mechanism of the executive system. It has been proposed that the underlying mechanism is behavioral inhibition and working memory (Pennington, Bennetoo, McAleer, & Roberts, 1996), reasoning and perceptual speed (Salthouse, 2005), and intelligence (Duncan, Emslie, Williams, Johnson, & Freer, 1996). Although some authors have made attempts to designate one underlying mechanism of executive functions, there is also empirical support for the non-unity theory, suggesting that they are separate entities. The non-unity theory proposes that while each executive function is related to each other, nonetheless they are distinct processes.

The non-unity theory is supported by studies in which patients with frontal lobe injuries demonstrate variability in their performance on executive functioning measures
EXECUTIVE FUNCTIONING IN STROKE

(Godefroy, Cabaret, Petit-Chenal, Pruvo, & Rousseaux, 1999). Similarly, correlations among executive tasks are generally low, which also provides support for the non-unity theory (Lehto, 1996; Miyake, Friedman, Emerson, Witzki, & Howerton, 2000; Salthouse, Atkinson, & Berish, 2003). More recently, there has been a movement towards conceptualizing executive functioning as containing both unitary and non-unitary components, in which executive functions are distinguishable, but share common features (Fisk & Sharp, 2004; Miyake et al., 2000).

Although exact definitions of executive functioning vary and the debate regarding unity versus non-unity theories continues, a general consensus within the field of neuropsychology exists that executive systems are responsible for complex cognitive functions that allow individuals to engage in instrumental activities of daily living (Chan et al., 2008; Royall et al., 2002). In short, executive function is vital to goal-oriented behavior and involves planning (abstract reasoning), generating possible solutions to problems, selecting behaviors in novel situations given the context and goals, capacity for storing and manipulating information during problem solving (i.e., working memory), initiating and stopping a behavior, cognitive persistence and flexibility including switching tactics as needed, and self-monitoring (Friedman et al., 2008; Jurado & Rosselli, 2007; Lezak et al., 2004; Miyake et al., 2000; Zinn et al., 2007).

Executive dysfunction. When the executive system of the brain is disrupted, the ability to regulate complex brain functions is compromised (Lezak et al., 2004); this disruption is referred to as executive dysfunction (Levine, Turner, & Stuss, 2008). While there are a variety of symptoms of executive dysfunction, three common executive symptoms have been noted. First, individuals with executive dysfunction often
demonstrate difficulties in generating plans and strategies needed to solve a given problem (Jodzio & Biechowska, 2010; Levine et al., 2008). Second, they may also demonstrate poor monitoring of their behavior (Levine et al., 2008; Milner & Petrides, 1984). In other words, they have difficulty both monitoring whether their actions are successful or unsuccessful and incorporating this feedback from their environment into their decision-making process (Jodzio & Biechowska, 2010). The final feature of executive dysfunction is inflexible thinking. This difficulty can present as perseveration or being “stuck in set”, such as repeatedly attempting to fit a square peg into a round hole, without success (Lezak et al., 2004). Individuals who demonstrate this “stuck in set” phenomena, have trouble generating new alternatives to their failed attempts.

Impairment in these executive functions has a neuroanatomical basis.

**Role of the frontal lobes and fronto-subcortical circuits.** Historically, executive dysfunction was referred to as the “frontal lobe syndrome” because of its common occurrence in patients with frontal lobe damage (Jodzio & Biechowska, 2010). Research on executive functioning has demonstrated the involvement of the frontal lobes (Levine et al., 2008; Stuss & Levine, 2002: Suchy, 2009). More specifically, executive functions such as set shifting and sequencing are most often associated with the dorsolateral prefrontal cortex (DLPFC), motivation and error detection are implicated in the anterior cingulate cortex (ACC), and social behavior and personality are most often associated with the orbitofrontal cortex (Cummings & Mega, 2003; Rankin, 2007). Research done on patients with lesions of the dorsolateral prefrontal cortex consistently demonstrates the involvement of the DLPFC in executive functioning components,
particularly attention, working memory, initiation, cognitive flexibility, planning, and organization (Koziol & Budding, 2009; Lichter & Cummings, 2001; Suchy, 2009).

Although executive functioning is often associated with the frontal lobes, damage to other areas of the brain can also result in executive dysfunction including the posterior associative cortices and subcortical structures such as the basal ganglia and thalamus (Collette & van der Linden, 2002; Jurado & Rosselli, 2007; Parkin, 1998; Royall et al., 2002). This dysfunction can be explained in part because the prefrontal cortex also has important connections that allow communication with the parietal, temporal, occipital cortices and subcortical structures including the basal ganglia and thalamus (Collette & van der Linden, 2002; Koziol & Budding, 2009; Lezak et al., 2004). These prefrontal circuits are pointed out to emphasize that although the frontal lobes are highly involved in executive functioning, disruption elsewhere in the brain that damages these connections can also result in executive functioning deficits.

**Five frontal subcortical circuits.** There are five main cortical-subcortical circuits connecting the frontal cortex with the basal ganglia (Alexander, DeLong, & Strick, 1986; Chow & Cummings, 2007; Cummings, 1998; Koziol & Budding, 2009; Lichter & Cummings, 2001). All of the frontal-subcortical circuits involve parallel loops that project from the frontal lobes to the striatum (caudate and putamen), to the globus pallidus and substantia nigra, to the thalamus, and back to the frontal lobes (Cummings, 1998; Koziol & Budding, 2009). The five frontal-subcortical circuits are differentiated by where in the frontal lobes they originate. More specifically, the five circuits connect the following frontal areas to the subcortical structures: the frontal motor cortex, the
frontal eye fields, the orbitofrontal cortex, the dorsolateral prefrontal cortex, and the medial frontal cortex (Cummings, 1998).

The first fronto-subcortical circuit, the motor circuit, begins in the motor, premotor, supplementary motor, and somatosensory cortices (Chow & Cummings, 2007). Signals travel through the putamen, to the globus pallidus and substantia nigra, to the thalamus, and then relayed back to the supplementary motor cortex (Koziol & Budding, 2009). A disruption in the motor circuits to the basal ganglia can result in a disturbance of voluntary control of movement (Cummings & Miller, 2007). The second circuit is the oculomotor circuit, which originates in the frontal and supplementary eye fields, travels through the putamen, to the globus pallidus and substantia nigra, to the thalamus, and loops back to the eye fields (Chow & Cummings, 2007). A disturbance of the oculomotor circuit can disrupt the ability to control visual fixations and control visual search (Koziol & Budding, 2009).

The remaining three circuits originate in the prefrontal cortex and when disrupted, can result in behavioral syndromes (Cummings, 1998). Specifically, if the circuit is disrupted, then the functioning of the region of origin is compromised. These circuits are the orbitofrontal circuit (OFC), the medial frontal circuit (MFC), and the dorsolateral prefrontal circuit (DLPFC). The OFC originates in the orbitofrontal cortex, travels through the ventro-medial caudate, to the globus pallidus and substantia nigra, to the thalamus, and back to the orbitofrontal cortex. Disruptions in the OFC often result in a similar presentation to individuals with damage to the orbitofrontal cortex such as personality changes, social inappropriateness, disinhibition, impulsiveness, irritability, and emotional lability (Chow & Cummings, 2007; Koziol & Budding, 2009). The MFC,
also referred to as the anterior cingulate circuit, originates in the anterior cingulate, travels through the nucleus accumbens, to the globus pallidus and substantia nigra, to the thalamus and back to the anterior cingulate area (Cummings, 1998). Damage to this circuit can result in apathy and patients may demonstrate diminished spontaneous speech, brief verbalizations, and poor motivation (Koziol & Budding, 2009). The MFC has also been implicated in monitoring behavior and self-correcting errors (Jurado & Rosselli, 2007). Lastly, the DLPFC begins in the dorsolateral prefrontal cortex, travels through the head of the caudate, to the globus pallidus and substantia nigra, to the thalamus and back to the dorsolateral prefrontal cortex (Cummings, 1998). Disruptions to this circuit can result in executive dysfunction that impairs strategy generation, self-monitoring, and cognitive flexibility (Chow and Cummings, 2007; Koziol & Budding, 2009). It has also been implicated in planning, goal selection, and working memory (Jurado & Rosselli, 2007).

The five frontal-subcortical circuits discussed are the main sources of circuitry from the frontal lobes to the basal ganglia. However, more recent research has found evidence that the basal ganglia also sends and receives information through circuitry connecting to other cortical areas than was originally proposed (Middleton & Strick, 2002). Revised conceptualizations of the cortical-subcortical circuits have added the inferotemporal loop and the posterior parietal loop, resulting in seven basal ganglia circuits (Koziol & Budding, 2009). The two additional circuits will not be discussed, as they do not directly involve the frontal lobe circuitry to the basal ganglia.
**Laterality of frontal lobe functions and related to executive functions.** Within the frontal lobes, laterality differences have been demonstrated in regard to a variety of cognitive functions (Geschwind & Iacoboni, 2007). For example, language functions have widely been localized to the left frontal lobe for individuals who are left-hemisphere dominant, which is the majority of the population (Benson, 1986; Geschwind, 1970). In contrast, the right frontal lobes are highly specialized in visuospatial abilities and other nonverbal functions (Geschwind & Iacoboni, 2007). Consistent with this differentiation, laterality differences have been demonstrated with regard to working memory, in which patients with left frontal lesions perform worse on verbally-based working memory tasks and patients with right frontal lesions perform worse on visuospatially-based tasks (Milner, 1995). The left hemisphere specialization in language and the right hemisphere specialization in visuospatial functioning are generally accepted differentiations in the field of neuropsychology.

There is growing support for a similar differentiation, as well as other lateralized characteristics of the executive functions (Geschwind & Iacoboni, 2007; Kolb & Whishaw, 2009). Historically, the left and right frontal lobes have been viewed as having equal involvement in the executive functions (Jurado & Rosselli, 2007). In fact, both the left and right regions of the dorsolateral cortex, as well as the superior and inferior medial frontal areas have all demonstrated involvement on executive tasks. Nonetheless, different regions (left vs. right) of the frontal lobes have been implicated in particular executive functions through imaging and lesion studies, even though the available research is limited.
Executive functioning in stroke

Functional neuroimaging studies have been used to explore the location of brain activation during executive tasks. Specifically, functions of the right prefrontal cortex and the left prefrontal cortex have been associated with different components of executive functioning (Lezak et al., 2004). The left prefrontal cortex has been associated with verbal processing and verbal fluency on both PET and fMRI studies (Frith, Friston, Liddle, & Frackowiak, 1991; Pihlajamaki et al., 2000). Activation of both the right and left dorsolateral regions have been demonstrated on tasks of cognitive flexibility, whereas the right prefrontal cortex has demonstrated involvement in monitoring behavior (Jurado & Rosselli, 2007). Goldberg, Podell, and Lovell (1994) explored laterality effects that occur in novel situations. When faced with a decision on a cognitive-selection task, the individual's left prefrontal cortex was primarily involved when they relied on internal cues in the decision-making process. Reliance on internal cues occurred when there was a sense of familiarity to the task and when past experience dictated their decision. In contrast, the individual's right prefrontal cortex was primarily involved when faced with a novel situation, and thus had to rely on external cues from the environment in their decision-making process. More specifically, the authors suggest that the left prefrontal system is responsible for incorporating internal contingencies, past experiences, and context into behavior, while the right prefrontal cortex is responsible for incorporating external environmental contingencies into the cognitive selection process and behavior.

In addition to functional imaging studies, there are studies exploring laterality effects in patients with frontal lobe lesions. For example, Milner and Petrides (1984) examined patients with unilateral and bilateral frontal lobe lesions and found that patients with left frontal excisions had higher incidences of perseveration on a card-sorting task.
Furthermore, the left prefrontal cortex was found to be important in the initiation of self-generated plans and strategies, whereas the right prefrontal cortex was more important for monitoring externally associated events (1984). This internal vs. external lateralization of the prefrontal cortex has been replicated in other subsequent studies. In addition to the above findings, lateralization effects also emerged when Burgess, Veitch, Costello, and Shallice (2000) explored performance on a multi-tasking procedure involving retrospective memory, prospective memory, and planning for patients with left and right anterior and posterior lesions. Patients with left anterior lesions demonstrated impairment in remembering the task contingencies and had more failures in set shifting. However, patients with lesions in the right dorsolateral prefrontal cortex performed worse on the planning components of the task (2000).

Overall, the above studies examined the laterality of the frontal lobes in regard to their role in the executive system. Although the laterality research of the frontal lobes is limited, some themes emerge among the findings that have been presented thus far. Specifically, it appears that the left frontal cortex is important for the utilization of internal information, such as self-generated plans, initiation, set-switching and the use of internal memory cues (Burgess et al., 2000; Goldberg et al., 1994; Milner & Petrides, 1984). In contrast, it appears that the right frontal cortex is important for the utilization of external information, such as planning, monitoring the environment and the use of external feedback and cues. Although specific regions of the frontal lobes have been implicated in particular executive functions, it is important to note that efficient executive functioning also relies on other areas of the brain. Given the connectivity of the frontal lobes with the subcortical and posterior regions, proper functioning of the frontal lobes
rely on the proper functioning of the other systems involved in the frontal circuits (Jurado & Rosselli, 2007). Thus, even though we can implicate certain regions as being heavily involved in specific executive functions, those regions do not operate in isolation from the other areas of the brain.

**Executive Dysfunction in the Stroke Population**

**How stroke lesions affect the brain.** Disruption of the executive system can occur after brain injury from multiple different pathologies, including stroke, traumatic brain injury, and tumor (Levine et al., 2008). Different insults have different clinical presentations. For example, traumatic brain injury can result in diffuse axonal injury from impact, swelling, and involve both coup and contrecoup injuries (Lezak et al., 2004; Stuss & Gow, 1992). Tumors can also have diffuse impact, due to the space-occupying mass resulting in displacement of surrounding structures or midline shift (Kolb & Whishaw, 2009; Lezak et al., 2004). In contrast, a stroke has the potential to be more focal in comparison to other types of brain injuries because damage generally occurs within a specific vascular pathway (Levine et al., 2008).

The term stroke refers to a cerebrovascular accident (CVA) within the brain, which involves damage to the vasculature system in which there is a decrease or loss of blood flow to a particular region of the brain and subsequent tissue death (Kolb & Whishaw, 2009). There are several mechanisms that can produce a stroke, including transient ischemic attacks (TIA), thrombotic or embolic infarcts, and hemorrhages (Zillmer, Spiers, & Culbertson, 2008). A TIA occurs when there is a temporary disruption of blood flow within a particular brain region, resulting in insufficient oxygen supply to that area. When there is insufficient blood supply to brain tissue, the tissue
does not function optimally (Zillmer et al.). In the case of TIA, this disruption of blood flow is temporary and as circulation to the tissue resumes, the functioning of the tissue generally recovers. Infarctions occur when there is inadequate blood supply to a region of the brain due to a blockage within the vascular circulation, resulting in a loss of oxygen to the brain tissue and ultimately tissue death (Zillmer et al.). This permanent ischemia can result from two types of blockages, or occlusions. This first type of occlusion is a thrombosis, which is the most common cause of stroke and generally occurs when fat deposits accumulate along the blood vessel walls. This reduces the size of the cerebral artery, resulting in a blood clot and blocked blood flow (Zillmer et al.). The second type of occlusion is an embolism, in which a blood clot, or piece of plaque from the heart, enters the body’s blood circulation and travels to the brain. The blood clot then lodges within a blood vessel in the brain, obstructing the blood flow and resulting in permanent ischemia (Zillmer et al.). Lastly, strokes can also occur from a hemorrhage within the brain. A hemorrhage occurs when a blood vessel ruptures and blood leaks into the cerebral tissue. A hemorrhage can occur from a defective artery within the brain and flood the surrounding brain tissue with blood, which is known as an intracerebral hemorrhage. In contrast, a subarachnoid hemorrhage occurs when the ruptured blood vessel is located on the surface of the brain and blood leaks into the subarachnoid cavity that surrounds the brain (Zillmer et al.).

Given the vasculature of the brain, stroke lesions often occur within a specific vascular pathway and result in focal damage to that particular brain tissue (Lezak et al., 2004). Strokes can also result in diffuse damage if there is a disruption of blood flow to a large portion of the brain (2004). However, when they occur in a single region of the
brain, the impairment is more likely to be focal and isolated to that region in comparison to other types of injuries such as tumors or traumatic brain injuries, allowing localized examinations of lesion effects on brain functions. (Zillmer et al., 2008). High levels of executive dysfunction have been observed in patients suffering a stroke in the regions supplied by the middle cerebral artery and those supplied by the anterior cerebral arteries, understandably given that these arteries supply blood to the frontal lobes and frontal circuitry involving the subcortical structures (Vataja et al., 2003; Zinn et al., 2007).

**Subcortical strokes.** Research has indicated that lesions to several subcortical structures can impact executive functioning (Wilde, 2010). Subcortical strokes can also disrupt the executive system due to their role within the aforementioned frontal lobe circuitry implicated in executive functioning, particularly the dorsolateral prefrontal circuit (Chow and Cummings, 2007; Koziol & Budding, 2009). Impaired executive functioning, memory and attention have all been demonstrated with lesions in particular regions of the thalamus (Van der Werf et al., 2003; Van der Werf, Witter, Uylings, & Jolles, 2000). Furthermore, disrupted executive functioning has also been associated with vascular lesions to the white matter tracts, or circuitry, of the prefrontal-subcortical loops involved in executive control (Reed et al., 2004; Tullberg et al., 2004). In addition to the role of the thalamus and white matter tracts, damage to the basal ganglia can cause significant deficits. Lesions of the basal ganglia have been associated with a wide range of cognitive dysfunction, including executive functioning (Hochstenbach, van Spaendonck, Cools, Horstink, & Mulder. 1998; Su, Chen, Kwan, Lin, Guo, 2007). Specifically, in a sample of 30 patients with hemorrhagic basal ganglia strokes, executive functioning performance was significantly worse than controls (Su et al., 2007). On the
WCST, these stroke patients demonstrated higher perseverative errors, lower conceptual level responses, number of categories completed, and total correct responses (2007). Overall, there is evidence that strokes occurring in subcortical structures can result in executive dysfunction. However, research regarding about the impact of subcortical strokes on executive functioning is lacking and is an area in need of further exploration (Wilde, 2010).

Assessment of Executive Function

Importance. The evaluation of executive functioning is important because of its relationship to functional outcomes, especially among stroke patients. The executive functioning systems are involved in many instrumental activities of daily living that affect independence such as driving, managing finances, and returning to work (Royall et al., 2002). Stroke is the most common cause for executive dysfunction, with 50% of first-time stroke patients experiencing executive problems at varying levels of severity (Jodzio & Biechowska, 2010; Zinn et al., 2007). The presence of executive functioning deficits on testing has been correlated with poorer functional outcomes and increased supervision needs (Benge et al., 2007). Furthermore, poor performance on executive functioning measures of planning, self-monitoring, and self-regulation have been associated with lower post-stroke occupational productivity (Ownsworth & Shum, 2008). Because of the instrumental role that executive functioning plays in daily functioning, its assessment is vital, particularly in high-risk patient populations such as stroke survivors.

While executive functions are purportedly integral to the successful completion of basic and instrumental activities of daily living, the assessment of executive functions is challenging for several reasons. As discussed earlier, there is a lack of consensus
regarding the exact nature of executive functioning and which constructs are subsumed under it. Second, given the range and complexity of executive functioning and that neuropsychological tests generally assess more than one of these cognitive features, it is often difficult to isolate a particular aspect of executive functioning (Marcotte & Grant, 2010). Third, in light of the structure of the neuropsychological tests and the testing environment, there is a question of whether executive functioning measures demonstrate sufficient ecological validity to predict everyday functioning. It has been argued that the testing environment is structured and controlled, making it difficult for executive problems to manifest (Lezak, 1982) and thus there is an emphasis placed on using less structured measures (Cripe, 1996). There are also other factors that impact the relationship between neuropsychological performance and everyday functioning including the limited specificity of neuropsychological tests, multiple cognitive determinants of real-world functioning, limited sampling of behavior, environmental factors, experience, and motivation (Marcotte, Scott, Kamat, & Heaton, 2010). There has been a recent interest in developing ecologically valid test instruments that are performance-based and designed to mirror real-world activities and everyday functioning (2010). Although these instruments demonstrate promising ecological validity, performance on these tests does not always perfectly translate into the examinee’s ability to effectively manage problems in everyday life because of the increased demands in the real world (2010). The fourth and final reason that assessing executive functions is difficult is that there can be an over-reliance on quantitative scores and underutilization of qualitative data when making interpretations based on test scores alone (Cripe, 1996). Consequently, the recommended approach to assessing executive functions is through a
comprehensive lens involving both quantitative and qualitative measures (1996). In light of the aforementioned constraints, two methods for assessing executive functions currently exist, namely, self-and informant- based report measures and neuropsychological tests.

**Self-and informant- based report measures.** Behavioral ratings of executive functioning can be useful during assessments and allow the patient and an informant to describe the level of functioning in everyday life. This is valuable because it provides qualitative data regarding the patient's real-world executive functioning above and beyond the data yielded by measures administered in structured testing settings and thus increases ecological validity (Strauss, Sherman, & Spreen, 2006). There are also limitations to behavior rating scales of executive functions which are similar to self-report measures in general, including response bias and variations in response styles. Additionally, discrepancies between self- and informant-report can occur if there is a lack of awareness on the part of the patient or on the part of the informant. Self- and informant report measures of executive dysfunction include the Frontal Systems Behavior Scale (Grace & Malloy, 2001), the Dysexecutive Questionnaire (Wilson, Alderman, Burgess, Emslie, & Evans, 1996), the Behavior Rating Inventory of Executive Function – Adult Version (Roth, Isquith, & Gioia, 2005) and the Barkley Deficits in Executive Functioning Scale (Barkley, 2011). Although self-and informant- report measures have become recognized more as assessment tools for executive functioning, neuropsychological testing is the more traditional and widely used measure of executive functions.
Neuropsychological measures of executive functioning. In general, executive functioning measures attempt to assess any combination of the following functions: initiation, planning and organization, inhibition, cognitive shifting, working memory, flexibility, generating and implementing strategies, and using feedback to correct errors (Strauss et al., 2006). Because definitions of executive functioning vary, not all neuropsychological tests measure the same executive functions. Some tests measure one of these functions, whereas other tests measure several executive functions and thus vary in their underlying constructs. There are several neuropsychological executive functioning measures that have been developed. These tests include the Tower of London, (Shallice, 1982), the Trail Making Test (Reitan & Wolfson, 1992), the Tower of Hanoi, (Miyake, Emerson, & Friedman, 2000), Category Test (Halstead & White, 1950), Verbal Concept Attainment Test (Rosen, 1962), Controlled Oral Word Association Test (Benton & Hamsher, 1976), Thurstone Word Fluency Test (Thurstone, 1938), Design Fluency Test (Jones-Gotman & Milner, 1977), Austin Maze Test (Milner, 1965), Tinker Toy Test (Lezak, 1993), Rey Complex Figure (Meyers & Meyers, 1995), Stroop Test (Regard, 1981), and the Wisconsin Card Sorting Test (WCST; Heaton, 1981).

Wisconsin Card Sorting Test. The Wisconsin Card Sorting Test is one of the most commonly used executive measures in neuropsychological test batteries and has received the most attention and research for assessing brain injuries and associated executive dysfunction (Royall et al., 2002). Furthermore, the WCST has been researched with the stroke population specifically and involves similar executive components as the BSAT. Therefore, studies using the WCST have laid the groundwork for other measures of executive functioning, particularly the BSAT, and their findings provide a basis for the
hypotheses of this study, which are presented later. For these reasons, a brief description and synopsis of the available research on stroke performance on the WCST will be presented.

The WCST is a card-sorting task that involves generating abstract concepts, shifting and maintaining set, and utilizing feedback (Strauss et al., 2006). The task involves matching cards with limited direction and feedback from the examiner (Heaton, 1981). Specifically, the examinee is given a stack of 64 cards and instructed to match each card to one of the four stimulus cards. The four choices, as well as the cards to sort contain a visual stimuli that vary by color (red, green, yellow, and blue), by form (triangle, star, cross, and circle) and by quantity (one, two, three, and four). The examinee is not given direction for how to match the cards; although, there are three possible choices for how to sort the cards: by color, form, or quantity. Rather, the examinee is given feedback after each selection as to whether their choice was correct or incorrect according to the current sorting rule. The sorting rule changes after the examinee achieves 10 consecutive correct responses, requiring the examinee to “change set” and begin sorting by a different rule. The WCST involves strategic planning, organized searching of the correct response, the ability to shift cognitive set by using feedback from the environment, goal-directed behavior, and disinhibition and modulating of impulsive responding (Strauss et al., 2006). It provides several outcome measures to interpret including number of categories achieved, number of perseverative errors, number of nonperseverative errors, and failures to maintain set.

Reliability and validity. Studies have demonstrated adequate psychometrics for the WCST including interrater reliability (Axelrod, Goldman, & Woodard, 1992) and
construct validity with other executive measures requiring a "shifting" ability (Miyake et al., 2000). The WCST has demonstrated ecological validity in predicting the management of instrumental activities of daily living (Heinrichs, 1990), vocational outcome (Nybo & Koskiniemi, 1999) and functional status at hospital discharge with stroke patients (Greve, Bianchini, Hartley, & Adams, 1999). Studies have found strong support for the sensitivity of the WCST in detecting executive dysfunction with a variety of populations including patients with schizophrenia (Shad, Tamminga, Cullum, Haas, & Keshavan, 2006) and patients with frontal lobe damage (Demakis, 2003; Stuss et al., 2000).

Sensitivity to frontal and subcortical structures. Numerous imaging and lesion studies have examined the frontal lobe involvement of the WCST. There are consistent findings from both imaging and lesion studies that the prefrontal cortex plays a major role in WCST performance, and more specifically the dorsolateral prefrontal cortex (Berman et al., 1995; Marenco et al., 1993; Nagahama et al., 1996; Stuss et al., 2000). Positive Emissions Tomography studies have demonstrated activation of the dorsolateral prefrontal cortex during the WCST task and suggest a major role of working memory on the card-sorting task (Berman et al., 1995; Nagahama et al., 1996). In regard to specificity, lesion studies using the WCST have yielded mixed results regarding anatomical correlates. Patients with lesions to the frontal lobes, subcortical structures, and frontal-striatal circuitry have all been associated with impaired performance on the WCST in comparison to patients with posterior lesions and healthy controls (Jodzio & Biechowska, 2010). Other studies have found that some patients with extensive frontal damage performed normally on the WCST and that the accuracy rate of classifying
patients into frontal and nonfrontal lesion groups based on WCST scores alone was only 62% (Anderson, Damasio, Jones, & Tranel, 1992). While the WCST may demonstrate some sensitivity to the frontal lobes, impaired test performance on the measure is not specific to frontal dysfunction (Cripa, 1996).

**Predicting lateralization.** In regard to laterality, results from functional imaging and lesion studies with the WCST are mixed. Imaging studies have demonstrated involvement of both the right and left dorsolateral prefrontal cortex on the measure (Berman et al., 1995; Marenco et al., 1993). Positive Emissions Topography (PET) studies of healthy participants have indicated simultaneous activation in both left and right dorsolateral prefrontal lobes during the WCST. However, there are contradictory findings regarding preferential activation of these regions while performing the task. The findings of Berman et al. (1995) indicate preferential activation in the left dosolateral prefrontal cortex, while the findings of Marenco et al. (1993) indicate preferential activation of the right dorsolateral prefrontal cortex. Lesion studies have also yielded mixed results regarding laterality. Some studies have found that patients with left frontal lesions perform worse, achieve significantly less categories and commit more perseverative errors on the WCST than patients with right frontal lesions (Drewe, 1974; Goldstein, Obrutz, John, Ledakis, & Armstrong, 2004; Jodzio & Biechowska, 2010; Milner 1964; Taylor, 1979). In contrast, patients with diffuse right frontal lesions have been found to perform worse than those with left diffuse frontal lesions (Robinson et al., 1980). More specifically, patients with right dorsolateral lesions have also been found to demonstrate more severe impairment, with a lower number of categories achieved and a higher ratio of perseverative responses (Stuss et al., 2000). In the above mentioned
studies, laterality effects were found in patients with frontal lesions only, and these differences were not demonstrated in patients with posterior lesions. Although the results mentioned have been mixed, these imaging studies and lesion studies suggest that there is evidence of some differentiation between the role of the left frontal lobe and the role of the right frontal lobe in the executive functioning system, and the exact nature requires further research.

**Limitations of the WCST.** Although the WCST is the most researched executive-based measure in regard to laterality effects, the WCST has some limitations. The WCST generally has a narrow range of scores and does not typically yield a normal distribution of scores because of a ceiling effect within normative samples (Suchy, 2009). The WCST has limited specificity in predicting lesion laterality and the studies to date have yielded mixed results regarding the anatomical correlates of the measure (Jodzio & Biechowska, 2010). The WCST also has potential limitations to its clinical application (Royall et al., 2002). More specifically, the WCST involves only 3 categories with five switches and takes approximately 45 minutes to administer, which can be a poor fit for bedside assessment of stroke patients in an acute rehabilitation setting. Additionally, the WCST can be experienced as stressful for frail and easily overwhelmed patients in contrast to other executive measures that are generally well-tolerated by patients (Strauss et al., 2006).

**The Brixton Spatial Anticipation Test**

Compared with the WCST, the Brixton Spatial Anticipation Test (BSAT; Burgess & Shallice, 1997) is a relatively new and under-researched measure of executive function. Similar to the WCST, it is a rule attainment task and involves the executive
functions of strategy generation, monitoring feedback from the environment, and set-shifting. It involves a stimulus book containing 56 pages with identical 2x5 display of ten circles, of which one is a blue-filled circle. The circle that is filled-in blue changes throughout the task according to the given rule sequence. The examinee is instructed to predict which of the ten circles the blue circle will appear on the subsequent page. The task requires the examinee to learn and apply the current rule in order to predict correctly. For example, if on the first page the #1 circle is blue, on the next page the #2 circle is blue, and on the next page the #3 circle is blue, then the current rule is N+1. The blue circle is moving forward by increments of one. Thus, the correct response is to predict that the #4 circle will be blue on the next page. The rules change without warning throughout the task, which requires the examinee to detect the change and switch to the new rule. The BSAT yields an outcome measure that is calculated by the number of wrong predictions that the examinee makes (Burgess & Shallice, 1997). This is referred to as the total number of errors. The examinee’s predictions for the pages in which the rule has changed are not scored. For example, if the pages are following the N+1 rule as described above, the examinee’s prediction for the page in which the rule has changed is not scored and thus not factored into their total error score. A high total number of errors on the BSAT is reflective of poor performance on the measure. The mean total number of errors from normative data was used to calculate standard scores for the measure. However, the standard scores presented in the BSAT manual are not specific to age groups and subsequent studies have demonstrated age effects on the measure (Bielak, Mansueti, Strauss, & Dixon, 2006), consistent with other tests of executive functioning. In the research to date on the BSAT, studies have generally looked solely at the total
number of errors score as their outcome measure and not converted the raw scores into scaled scores, nor will the current study.

In comparison to the WCST, the BSAT is a relatively less stressful measure and is considered easy to give and well tolerated by patients (Strauss et al., 2006). It can be more accommodating to the rehabilitative setting in that it is a portable book and does not require a test surface (Chan et al., 2008). It requires approximately 15 minutes to administer and less than a minute to hand-score, allowing convenient use for bedside assessments in rehabilitation settings with stroke patients. Furthermore, the nature of the test allows for modified use with nonverbal patients and patients with limited mobility, which are both common within the stroke population (Zillmer et al., 2008).

**Normative Data and Reliability.** The BSAT was normed on a sample of 121 healthy individuals, aged 18 to 80 (Burgess & Shallice, 1997). Subsequent studies have published updated norms using different and larger samples. Bielak et al. (2006) explored the use of the BSAT test with 457 older adults aged 53-90. The authors developed normative data for older age groups, which suggest an overall decline in performance on the BSAT with normal aging, consistent with current theories regarding age-related decline in executive functioning. Split-half reliability has been found to be marginal ($r = .62, p < .001$), likely due to the differing rules among the halves and test-retest reliability was demonstrated as adequate ($r = .71, p < .001$; Burgess & Shallice, 1997).

**Construct validity.** Variable analyses suggest that the BSAT test is significantly correlated with other existing measures of executive functioning (de Frias, Dixon, & Strauss, 2006; Doninger et al., 2008; Wood & Liossi, 2007). During factor loading
analyses, the total error score on the BSAT tends to load on the same factor as the
number of WCST categories, and Trail Making Test B T-score (de Frias et al., 2006;
Doninger et al., 2008). Performance on the BSAT generally correlates more strongly
with executive measures than with tests that measure other domains, such as language,
visuospatial, and motor screening (Doninger et al., 2008). Furthermore, BSAT
performance is associated with other measures of set-shifting, visual analytic reasoning,
and initiation/perseveration, even after controlling for general ability (de Frias et al.,
2006; Doninger et al., 2008). More specifically, after controlling for Wechsler
Abbreviate Scale of Intelligence (WASI) Full Scale IQ, Doninger et al. (2008) found that
the BSAT correlated significantly with the Dementia Rating Scale (DRS) Initiation
subtest (Pearson’s $r = .48$, $p < .05$), the WCST Perseveration Errors (Pearson’s $r = -.46$, $p
< .05$), the WCST Number of Categories (Pearson’s $r = .45$, $p < .05$), and the WASI
Matrix Reasoning subtest (Pearson’s $r = .55$, $p < .01$) in a convenience neuropsychology
referral sample. The BSAT is also significantly correlated with the Hayling Sentence
Completion Task (Pearson’s $r = .53$, $p < .01$) and the Key Search Test from the
Behavioral Assessment of Dysexecutive Syndrome (BADS; Pearson’s $r = .26$, $p < .01$)
after controlling for FSIQ on the WAIS-III in a brain injury sample (Wood & Liossi,
2007) and is correlated with other executive measures including the Color Trails Test,
Part 2 (Pearson’s $r = .21$, $p < .001$) and the Letter Series Test (Pearson’s $r = .34$, $p < .001$)
within the normal population (De Frias et al., 2006). These results demonstrate adequate
construct validity with other more established executive measures.

The BSAT measure has been validated with several clinical populations. Shallice
et al. (2002) found the BSAT test to be sensitive to children with Attention Deficit
Hyperactivity Disorder (ADHD) insofar as patients with ADHD performed significantly worse on the measure than controls. Another study found that patients with eating disorders performed significantly worse on the BSAT test than controls, arguing that performance was affected by impairment in cognitive flexibility (Tchanturia et al., 2004). Van den Berg et al. (2009) explored the sensitivity of the BSAT measure with several clinical populations, while controlling for age, gender, and years of education, before conducting their analyses. Their findings revealed that patients with Korsakoff’s Syndrome and psychiatric diagnoses perform worse on the BSAT test than controls. They did not find a difference in performance in patients with mild cognitive impairment or with patients with diabetes and controls. However, they found that stroke patients performed significantly worse than controls (Van den Berg et al.). Researchers at the Wallace Kettering Neuroscience Institute also found that stroke survivors performed significantly worse on the BSAT test than other patient samples (Doninger et al., 2008). Furthermore, they found that the BSAT test demonstrated sensitivity to acuity of brain damage, in that patients in the acute rehabilitation unit of the hospital performed significantly worse than stroke patients in the outpatient neuropsychology clinic (2008). While the measure has been validated with several clinical populations, there have been no studies to date exploring the predictive validity of the BSAT with functional status. Furthermore, existing research examining anatomical correlates and lateralization effects on BSAT performance is limited and results have been mixed.

**Anatomical correlates.** Burgess and Shallice (1996) found that patients with anterior lesions performed significantly worse on the BSAT than patients with posterior lesions and the control group. Furthermore, the authors examined the types of errors that
were committed across groups. Results indicated that patients with anterior lesions committed a higher number of bizarre errors: a random guess that does not incorporate the logic of the current rule or any previous rules (i.e., not a misclassification or a perseveration).

**Lateralization.** Both Van den Berg et al. (2009) and Doninger et al. (2008) compared the BSAT performance of patients with left versus right hemisphere. While they did not find a significant difference between hemispheres, it is important to note that the authors used only a gross lesion classification by hemisphere only and did not differentiate between anterior and posterior lesions. This may have influenced their absence of effects, given the importance of the anterior regions in executive functioning. Burgess and Shallice (1996) examined BSAT performance with patients with different cerebral lesion locations, and classified lesions more specifically than just by hemisphere. They classified patient lesions into four groups: left anterior, right anterior, left posterior, and right posterior. Their patient lesion sample was of mixed etiology, with 77% of lesions resulting from tumor. Their analyses did not find a significant lateralization effect between the left and right anterior groups or between the left and right posterior groups. However, their lesion sample was of relatively young patients with mixed etiology lesions, which primarily consisted of tumors. The clinical presentation of patients with tumors can involve a more diffuse impairment, as discussed earlier. The presence of a tumor can lead to displacement of other surrounding brain structures and midline shift, which could have impacted the findings of Burgess and Shallice (1996).

Reverberi et al. (2005) examined the performance on a revised BSAT measure, also using patients with mixed etiology lesions, but classified patients more narrowly
than the above mentioned studies. They examined patients with anterior lesions only and classified them into the following groups: left dorsolateral, right dorsolateral, inferior medial, and superior medial lesions. This classification method allows a more specific comparison of anterior lesions. This method excludes lesions involving medial structures from the left and right dorsolateral groups, allowing a more focal examination of the frontal lobe structures in isolation. The authors used a revised version of the traditional BSAT test for their study. Administration was done through a computer monitor screen and involved the patients touching the circle of choice on the screen, allowing them to record reaction time (2005). This version of the BSAT was also revised from the standard measure in that it involved an additional component. In addition to the original 56 BSAT pages, the authors devised and included a second half to the test which involved an “interference task”, increasingly the difficulty level of the measure. These authors analyzed the patients’ performance on the first half (without the interference) separately from performance on the second half (with the interference component) and for the purposes of the current study, only their results using the original 56 BSAT stimuli will be discussed. On the original portion of the test, they found that patients with left dorsolateral lesions performed significantly worse with a higher total error score than the right dorsolateral group, the superior medial group, the inferior medial group, and the controls (2005). There were no significant differences in error types committed among lesion groups on the original task. These findings provide support for the lateralization theory of executive functioning within the frontal lobes and argue the need for future research on the matter (2005).
A preliminary analysis was conducted on a portion of the current study’s sample for the purpose of poster presentation and laterality effects were found. After excluding patients with severe levels of impairment, analyses demonstrated that patients with right hemisphere lesions performed worse with a higher number of errors than those with left hemisphere lesions, which is contradictory to Reverberi et al.’s (2005) findings. However, a gross classification by hemisphere only was used, and it is unclear whether this effect will remain with greater localization of the lesions and with a larger sample size. It is apparent that further examination of performance is needed with more specific classifications of lesion locations and a greater sample size to further the development of this research area.

**Conclusion.** In summary, there are a variety of reasons to explain why previous researchers may not have found a laterality effect on the BSAT. As mentioned, the studies that did not find laterality effects used only gross classification methods by hemisphere only and did not differentiate between patients with anterior and posterior lesions which may have influenced their absence of effect. Additionally, the samples used in these studies were relatively small and in most instances the lesions were of mixed etiology which could result in nonlocal injuries and lack of effect. With the use of a more specific classification method, Reverberi et al. (2005) found significant lateralization effects. They found that patients with left dorsolateral lesions performed worse than the right dorsolateral group and lesion groups with medial lobe involvement. However, their study used a revised version of the BSAT measure involving a computer format and an addition of an interference task following the initial administration. It is unclear if the results found in their study will be replicated with the traditional
standardized format of the BSAT measure. The lesion group used by Reverberi et al. (2005) was also of mixed etiology, including tumor, stroke, and traumatic brain injury, and it is uncertain whether a specific type of lesion created the significant effect. Thus, by looking exclusively within the stroke population for the current study, a more acute and focal lesion-type will be used to analyze lesion effects. In addition to examining performance differences on the BSAT between those with right versus left anterior cortical or subcortical lesions, to the knowledge of the author, no studies have explored the BSAT’s relation to functional status.
Chapter II

Rationale and Hypotheses

Executive functioning has been defined as the functional abilities that enable a person to program, initiate, and control one’s own behaviors in an independent, purposive, and conscious way (Lezak et al., 2004). The aspects of executive functioning affected by injury include volition, planning, purposive action, effective performance, working memory, supervisory attention, cognitive flexibility, concept formation, cue-directed behavior, task analysis, strategy control, monitoring, goal setting, initiation, inhibition, problem-solving, abstract thinking, creativity, reflection, reasoning, shifting, and visual and verbal fluency (Jurado & Rosselli, 2007; Royall et al., 2002; Suchy, 2009). While the clinical presentation of executive dysfunction can vary, three common executive features have been noted. First, individuals with executive dysfunction often demonstrate difficulties in generating plans and strategies needed to solve a given problem (Jodzio & Biechowska, 2010; Levine et al., 2008). Second, they may also demonstrate poor monitoring of their behavior (Levine et al., 2008; Milner & Petrides, 1984). In other words, they have difficulty both monitoring whether their actions are successful or unsuccessful and have difficulty incorporating this feedback from their environment into their decision-making process (Jodzio & Biechowska, 2010). The final feature of executive dysfunction is inflexible thinking.

Approximately 50% of patients have varying degrees of problems with executive functioning following their first stroke (Jodzio & Biechowska, 2010; Zinn et al., 2007).
Executive dysfunction can result in poorer functional outcomes including greater supervision needs (Benge et al., 2007) and lower occupational productivity (Ownsworth & Shum, 2008). Because of the real world implications, it is important to assess executive functioning in stroke survivors (Jodzio & Biechowska, 2010; Zinn et al., 2007).

Executive dysfunction can occur as a result of injury outside the frontal lobes because the prefrontal cortex has important connections that allow communication with the parietal, temporal, and occipital cortices, and subcortical structures including the basal ganglia and thalamus (Collette & van der Linden, 2002; Koziol & Budding, 2009; Lezak et al., 2004). Nevertheless, the frontal lobes and frontal system circuitry have been implicated in many executive functions (Levine et al., 2008; Jurado & Rosselli, 2007; Stuss & Levine, 2002; Suchy, 2009). Furthermore, the location of the stroke within the frontal lobes (i.e., right versus left side) can affect clinical presentation. For example, left frontal lesions have been associated with higher incidence rates of perseveration on tasks, which is the inability to shift from a previous task and adapt to a new one, while right frontal lesions have been associated with poor monitoring of behavior (Milner & Petrides, 1984). In addition, the left frontal lobe has been associated with the initiation of internal cues such as self-generated plans and strategies, whereas the right frontal lobe has been associated with incorporating external environmental cues on problem solving tasks (Goldberg et al., 1994; Milner & Petrides, 1984).

The purpose of this study is to provide further evidence for the validity of a relatively new and under-researched measure of executive functioning, the Brixton Spatial Anticipation Test (BSAT; Burgess & Shallice, 1997). Although a limited number of studies have examined performance differences between those with damage to right
versus left anterior regions on the BSAT, the results have been mixed, which likely is due to methodological differences, including samples with mixed etiology (i.e., tumor, stroke, traumatic brain injury). Furthermore, there have been no studies with the BSAT examining the impact of lateralized subcortical lesions on executive performance or its relationship with functional outcomes. The aim of this study is twofold. First, the differences in performance on the BSAT by lesion location (i.e., left versus right anterior lesions) in a stroke sample will be examined. Second, the relationship between performance on the BSAT and functional outcome measures will be assessed.

The following null hypotheses will be examined:

Ho1: There is no significant difference in performance on the total error raw score of the BSAT between stroke patients with left-sided anterior lesions and stroke patients with right-sided anterior lesions.

Ho2: There are no significant correlations between the total error raw score of the BSAT and the scores on the FIM cognitive scale or the FIM motor scale at the time of discharge in the stroke sample.
Chapter III

Method

Power Analysis

A power analysis was conducted for a one-way fixed effects analysis of variance with two levels. The criterion for significance (alpha) has been set at .05. The analysis of variance is non-directional (i.e., two-tailed) which means that an effect in either direction will be interpreted. Adequate power for detecting a significant effect is .80. To obtain a .80 power level, with a large effect size (.40) at a .05 alpha level, a total sample size of 52 is needed for an ANOVA involving 2 groups. In the event that one of the demographic variables (age, education, etc.) is found to be correlated with BSAT performance, an ANCOVA will be conducted to control for any covariate. A total sample size of 52 is also needed for an ANCOVA involving 2 groups to obtain a .80 power level, with a large effect size (.40) at a .05 alpha level and does not change the needed sample size.

Participants

A convenience sample will be used for this study and will be comprised of inpatients in the rehabilitation unit at the Kettering Medical Center. Patients included in this study will be those admitted to the unit secondary to unilateral cerebrovascular accident (CVA). As part of the comprehensive rehabilitative care provided on the unit, cognitive functioning evaluations are conducted for patients following a CVA. The BSAT is routinely administered as part of the standard test battery. Patients who are
disoriented or too cognitively impaired to comprehend the instructions of the task are not administered the measure according to routine procedures on the unit and thus will not be considered for inclusion. The patient medical charts of those individuals with an admitting diagnosis of CVA and who were administered the BSAT as part of their evaluation will then undergo a review process for the exclusion criteria. Patients with a documented history of seizure disorder, traumatic brain injury, brain tumor, or dementia in their medical chart prior to the CVA will be excluded from the study. However, in an effort to capture a representative sample of acute stroke patients, those with hemiparesis or language disruption will not be excluded on this basis alone.

The following represents demographics for the entire patient database from the rehabilitation unit. Older adults are well-represented in this convenience sample, as is typical of most hospital rehabilitation units. The average age for inpatients with an admitting diagnosis of CVA is 71.62 years old ($SD = 13.96$). The average number of years of education obtained by the patients is 12.66 years ($SD = 3.08$). Males and females are equally represented on the unit. Although there are patients with a variety of medical conditions represented on the unit, CVA is one of the most common admitting diagnoses.

The medical center from which this convenience sample is derived is located in the suburban town of Kettering, Ohio. The demographics of the entire patient population served at the medical center are limited in respect to diversity. The patient population is predominantly Caucasian. Furthermore, the variability of educational attainment may be limited in comparison to other geographic locations. The limited diversity of this
convenience sample and its impact on generalizability will be further discussed in the limitations section.

Measures

**Brixton Spatial Anticipation Test.** The BSAT is a rule attainment task and involves the executive functions of strategy generation, monitoring feedback from the environment, and set-shifting. It involves a stimulus book containing 56 pages with identical 2x5 display of ten circles, of which one is filled blue. The location of the circle that is filled-in blue changes throughout the task according to the given rule sequence. The examinee is instructed to predict which of the ten circles will be blue on the subsequent page. The task requires the examinee to learn and apply the current rule in order to predict correctly, and takes approximately 15 minutes to administer (Burgess & Shallice, 1997). After completion of the task, scoring will be done manually by counting the number of errors committed by the examinee.

The BSAT was normed on a sample of 121 healthy individuals, aged 18 to 80 (Burgess & Shallice, 1997). The standard scores presented in the BSAT manual are not specific to age groups and subsequent studies have demonstrated age effects on the measure, consistent with other tests of executive functioning. Bielak et al. (2006) explored the use of the BSAT test with 457 older adults aged 53-90 and developed age-based norms to use for performance comparison. However, the previous research done on the BSAT used only the total error raw score for their analyses rather than using converted scaled scores. Therefore, the analyses of the current study will be conducted with both methodologies, once with the total error raw score and once with the converted age-based scaled scores.
Research has found that the BSAT total error raw score is significantly correlated with other existing measures of executive functioning (de Frias, Dixon, & Strauss, 2006; Doninger et al., 2008; Wood & Liossi, 2007), including the Dementia Rating Scale (DRS) Initiation subtest (Pearson’s $r = 0.48$, $p < .05$), the WCST Perseveration Errors (Pearson’s $r = -0.46$, $p < .05$), the WCST Number of Categories (Pearson’s $r = 0.45$, $p < .05$), the WASI Matrix Reasoning subtest (Pearson’s $r = 0.55$, $p < .01$), the Hayling Sentence Completion Task (Pearson’s $r = 0.53$, $p < .01$), the Key Search Test from the Behavioral Assessment of Dysexecutive Syndrome (BADS; Pearson’s $r = 0.26$, $p < .01$), the Color Trails Test, Part 2 (Pearson’s $r = .21$, $p < .001$), and the Letter Series Test (Pearson’s $r = .34$, $p < .001$). These results demonstrate adequate construct validity with other more established executive measures. Split-half reliability has been found to be marginal at .62, likely due to the differing rules among the halves and test-retest reliability has been demonstrated to be adequate at .71 (Burgess & Shallice, 1997).

**Functional Independence Measure.** The Functional Independence Measure (FIM; Uniform Data System for Medical Rehabilitation, 1993) is a widely used and accepted measure of functional status within hospitals, skilled nursing facilities, and rehabilitation facilities. The FIM allows clinicians to track changes in the patient’s functional status with routine activities of daily living throughout their rehabilitation from admission to discharge (Chumney et al., 2010). It takes less than thirty minutes to complete and consists of 18 items, 13 of which are related to motor functioning and 5 items are related to cognitive functioning (Uniform Data System for Medical Rehabilitation, 1993). A score from 1 to 7 is given to rate the patient’s level of independence in completing tasks such as dressing and bathing, where 1 represents total
dependence and 7 indicates complete independence. Total scores range from 18 to 126, with higher scores reflecting greater functional independence. The use of a 7 point scale on the FIM allows for greater variability as compared to other disability scales (Barak & Duncan, 2006).

Research has demonstrated that the FIM yields acceptable distribution, high internal consistency, high concurrent validity, and clinical utility within the stroke population (Hsuch, Lin, Jeng, & Hsieh, 2002). Although scores can be affected by rater bias, the FIM has overall demonstrated excellent reliability of .95 for interrater reliability and .95 for test-retest reliability in a review of eleven studies (Barak & Duncan, 2006). The FIM has been widely researched within the stroke population and there is substantial support for its accuracy in predicting outcomes in post-stroke patients (Chumney et al., 2010). In a review of multiple studies, the FIM scores demonstrate change over time that is consistent with the gains demonstrated by the patient in rehabilitative therapies, and is predictive of caregiver demands and supervision needs upon discharge in the stroke population (Barak & Duncan, 2006; Chumney et al., 2010).

Procedure

Neuropsychological evaluations are routinely conducted on the rehabilitation unit as part of the comprehensive care provided to patients. Depending on patient mobility, the neuropsychological test battery is administered in the patient’s room or in a private testing room. All administrations are conducted in an environment with minimal distractions. The BSAT is included in the standard test battery, which lasts a total of approximately 45 minutes. All administrations of the BSAT are conducted by the clinical
neuropsychologist on staff or by an advanced clinical psychology doctoral student, both
of whom have been formally trained on the standardized administration of the test.

The data that will be used in this study is collected as part of routine patient care.
There currently exists archival patient data on BSAT performance and patient data will
continue to accumulate in conjunction with hospital admissions. There will be no
additional data collection for the sole purpose of research. Data will be accessed through
the electronic charting system which contains all patient files for the hospital. Included
in these patient charts are the MRI and CT scans conducted upon hospital admission for
patients who suffer a CVA. The therapy notes written by the occupational therapists and
nurses on the unit are also available to review through the electronic patient charts.
Functional Independence Measure (FIM) scores are contained in these notes and easily
accessed. The following variables will be collected from the patient medical charts
during the review process: date of hospital admission (used as proxy for date of CVA),
date of neuropsychological testing, age, sex, education, handedness, FIM scores at
admission to the rehabilitation unit, FIM scores at discharge from the rehabilitation unit,
and BSAT total error raw score. Additionally, the scores from the remaining
neuropsychological measures administered as part of the routine test battery will be
collected from patient charts and include the RBANS Index scores, Trail Making Test
scores, and Verbal Fluency Test scores.

**Lesion classification.** Neuroimaging scans will be used to classify stroke lesions
by location. Neuroimaging is conducted routinely for patients admitted to the hospital
secondary to CVA. In most cases, an MRI scan of the brain is conducted. However, in
some cases, a patient is not able to undergo an MRI scan and a CT scan of the brain is
conducted as an alternative. This study will use data from files that include the BSAT, FIM, and either an MRI or CT scan. Brain scans will be examined and classified by a neurosurgeon and a neuroradiologist who have volunteered their expertise to assist in the study. They will blindly classify the scans according to region (anterior vs. posterior), laterality, and structural involvement (cortical vs. subcortical). All patients with CVAs that involve bilateral damage will be excluded. Furthermore, all patients with cortical CVAs located posterior to the central sulcus and subcortical strokes outside of the anterior fossa (i.e. cerebellum, brain stem, and midbrain) will be excluded from the study, consistent with how previous researchers have classified anterior lesions (Wilde, 2010).

**IRB approval.** After the dissertation has been successfully proposed, the study will be submitted to the Kettering Medical Center’s Institutional Review Board for the use of patient data. Once permission is granted from the Kettering Medical Center’s review board, the study will be submitted to Xavier University’s Institutional Review Board for review.
Chapter IV

Proposed Analysis

Between group analyses will be performed on demographic characteristics that may influence performance on the BSAT. Categorical data (e.g., sex, handedness) will be analyzed with a chi-square analysis and interval data (e.g., education and age) will be analyzed using an analysis of variance (ANOVA). A correlation matrix will be calculated for all of the demographic variables to determine the level of correlation among these variables and their level of correlation with the dependent variable (BSAT total error raw score). The scores from the other neuropsychological measures administered as part of the standard test battery (e.g., RBANS, Trail Making Test, and Verbal Fluency Test) will also be included in the correlation matrix to assess their level of correlation with the DV. The demographic variables (e.g. age, sex, handedness, or education) demonstrating significant correlations with BSAT scores and not correlated with each other will be used as covariates in the examination of the first hypothesis. Tabachnick and Fidell (2007) recommend choosing the covariate with the highest correlation with the dependent variable if covariates are substantially correlated with each other and the dependent variable.

To examine the first hypothesis, two analyses will be performed. First, an analysis of covariance (ANCOVA) will be performed to determine if the two lesion groups (left-sided anterior lesions vs. right-sided anterior lesions) differ in performance on the BSAT, using the demographic variables mentioned above as covariates. If there
are no significant correlations between any of the demographic variables and BSAT scores, an ANOVA will be performed. The total error raw score will be used as the dependent variable and a .05 alpha level will be used for the overall group effect. Secondly, an ANCOVA will be performed comparing performance between the two lesion groups, using standard scores calculated according to the age-based mean scores published by Bielak et al. (2006) as the dependent variable and any remaining significant demographic variables (e.g. sex, handedness, or education) as covariates.

In examination of the second hypothesis, the relationship between BSAT performance and performance on the FIM scale will be analyzed. The FIM scale consists of 18 domains, in which a score from 1 to 7 is given for each domain. Pearson’s correlations will be utilized to compare the relationship between the BSAT total error raw score and the FIM cognitive score (5 items) and the FIM motor score (13 items). If a significant relationship is discovered for either FIM score, post-hoc analyses will be conducted examining the Pearson’s correlations between the BSAT total error score and the individual items included in the significant FIM score.

Lastly, three supplementary analyses will be conducted. First, if the sample size permits, a supplementary 2 x 2 ANCOVA will be conducted to explore the nature of any group effect found in the examination of the first hypothesis using the same demographic variables as covariates. To obtain a .80 power level, with a large effect size (.40) at a .05 alpha level, a total sample size of 73 is needed for a 2 (laterality) x 2 (cortical vs. subcortical) ANCOVA. Secondly, an ANCOVA involving only two groups will be conducted comparing performance according to structural involvement (cortical vs. subcortical lesions), irrespective to laterality using the same demographic variables as
covariates. Finally, if there is sufficient data available, Pearson's correlations will be conducted examining the relationship between the BSAT total error raw score and the amount of change between the time of admission to the rehabilitation unit and the time of discharge on the FIM total, motor, and cognitive scores.
References


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	note


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Appendix A

**Instruments Used**

The Brixton Spatial Anticipation Test (BSAT) is protected by copyright so it is not reproduced in this document. This measure is available through Pearson Education, Inc. at [www.pearsonassessments.com](http://www.pearsonassessments.com).
Appendix B

Instruments Used

The Functional Independence Measure (FIM) is protected by copyright so it is not reproduced in this document. This measure is available through Uniform Data System for Medical Rehabilitation at www.udsmr.org.
Chapter V

Dissertation

Abstract

The purpose of this study was to examine executive functioning performance on the Brixton Spatial Anticipation Test (BSAT) according to lesion location within a stroke sample and assess the measure's clinical utility within a rehabilitative setting. Participants were 57 patients in a subacute rehabilitation unit who had experienced a unilateral frontal lobe or subcortical stroke. Patients were tested on average 13.56 days post-stroke (SD = 6.70) and were assessed using the Functional Independence Measure (FIM) upon discharge from rehabilitation. Age was correlated with BSAT performance and used as a covariate. There were no differences in BSAT scores between patients with left-sided and right-sided stroke lesions. However, patients with subcortical strokes performed significantly worse than patients with frontal lobe strokes. This finding supports recent research highlighting the role of subcortical structures in frontal lobe circuitry and executive functioning. Within the total sample, BSAT performance was significantly correlated with the FIM Cognitive Subscale at discharge, supporting the clinical utility of the BSAT for predicting cognitive functional outcomes post-stroke.
Laterality Effects in Anterior Stroke: Brixton Spatial Anticipation Test and Functional Outcomes

Executive functioning is an elusive and multi-faceted term that involves many aspects of higher order cognitive functioning (Chan, Shum, Toulopoulou, & Chen, 2008; Jurado & Rosselli, 2007; Royall et al., 2002; Suchy, 2009). In their review of the literature, Jurado and Rosselli (2007) identified over 30 components of executive functions including planning, working memory, cognitive flexibility, initiation, inhibition, problem-solving, and abstract thinking. Although definitions vary, there is a general agreement within neuropsychology that executive functioning involves complex cognitive functions that are requisite for many of our instrumental activities of daily living, such as driving and managing finances (Chan et al., 2008; Royall et al., 2002).

The most common cause of acquired executive dysfunction is a cerebrovascular accident (CVA; aka stroke) with approximately 50% of first-time stroke patients experiencing executive problems at varying levels of severity (Jodzio & Biechowska, 2010; Zinn, Bosworth, Hoenig, & Swartzwelder, 2007). Executive dysfunction can result in poorer functional outcomes for stroke patients including greater supervision needs (Benge, Caroselli, & Temple, 2007) and lower occupational productivity (Ownsworth & Shum, 2008). Because of the real world implications, it is important to assess executive functioning in stroke survivors (Jodzio & Biechowska, 2010; Zinn et al., 2007).

Executive dysfunction can occur as a result of injury within the frontal lobes and outside the frontal lobes because of the frontal system circuitry (Jurado & Rosselli, 2007; Stuss & Levine, 2002; Suchy, 2009). Across studies, lesions in the frontal areas of the
brain have been correlated with poor performance on a variety of neuropsychological tests that measure executive functions, such as abstract reasoning, cognitive flexibility and verbal fluency (Alvarez & Emory, 2006; Jodzio & Biechowska, 2010; Stuss et al., 2000). Executive dysfunction can occur as a result of injury outside the frontal lobes because the prefrontal cortex, which is implicated in executive functioning, has important connections that allow communication with the parietal, temporal, and occipital cortices as well as subcortical structures (Collette & van der Linden, 2002). Regarding subcortical structures, the striatum of the basal ganglia plays an integral role in the dorsolateral prefrontal circuit (DLPFC; Chow and Cummings, 2007) and lesions of the basal ganglia have been associated with executive dysfunction (Hochstenbach, van Spaendonck, Cools, Horstink, & Mulder, 1998; Su, Chen, Kwan, Lin, Guo, 2007). Furthermore, the ventral anterior nuclei (VA) and medial dorsal nucleus (MD) of the thalamus are also involved in the DLPFC and lesions to these thalamic nuclei have been associated with executive dysfunction including impaired problem solving and set-shifting (Van der Werf et al., 2003; Van der Werf, Witter, Uylings, & Jolles, 2000).

Overall, there is evidence that strokes occurring in subcortical structures can result in executive dysfunction, which can be explained by the high density of frontal lobe circuitry within these structures (Koziol & Budding, 2009). However, research regarding the exact impact of subcortical strokes on executive functioning is lacking and is an area in need of further exploration (Wilde, 2010).

The location of the stroke within the frontal lobes (i.e., right versus left side) can affect clinical presentation. For example, left frontal lesions have been associated with higher incidence rates of perseveration on tasks, which is the inability to shift from a
previous task and adapt to a new one, while right frontal lesions have been associated with poor monitoring of behavior (Milner & Petrides, 1984). In addition, the left prefrontal cortex has been associated with the initiation of internal cues such as self-generated plans and strategies, whereas the right prefrontal cortex has been associated with incorporating external environmental cues on problem solving tasks (Goldberg, Podell, & Lovell, 1994; Milner & Petrides, 1984).

One of the most common assessment measures of executive functioning is the Wisconsin Card Sorting Test (WCST; Heaton, 1981), which requires flexibility on the part of the participant to switch response pattern as the demands of the task change (Warrington, 2000). Lesion studies indicate that patients with both frontal lobe strokes and subcortical strokes perform worse on the WCST (Jodzio & Biechowska, 2010; Stuss et al., 2000; Su et al., 2007). Specifically, patients with hemorrhagic basal ganglia strokes have been found to demonstrate poorer executive functioning performance on the WCST, including higher perseverative errors, lower conceptual level responses, number of categories completed, and total correct responses (Su et al., 2007). In addition, patients with frontal lobe damage perform significantly worse on the WCST than controls or patients with nonfrontal lesions (Jodzio & Biechowska, 2010; Stuss et al., 2000).

The WCST has several limitations. With respect to laterality within the frontal lobe, the measure’s effectiveness in distinguishing left versus right frontal lobe damage is equivocal. Several studies have demonstrated that patients with left frontal lesions perform worse and commit more perseverative errors than patients with right frontal lesions (Drewe, 1974; Jodzio & Biechowska, 2010; Milner, 1964; Taylor, 1979). In contrast, other studies have found that patients with right frontal lesions perform worse
on the WCST (Robinson, Heaton, Lehman, & Stilson, 1980; Stuss et al., 2000).

Although the results mentioned have been mixed, these studies suggest that there is
evidence of some differentiation between the role of the left frontal lobe and the role of
the right frontal lobe in the executive functioning system, and the exact nature requires
further research. Moreover, the WCST has some clinical limitations when used with
stroke patients. Specifically, the WCST involves only three categories with five
switches and high functioning participants often obtain a ceiling score because a high
proportion of individuals achieve all six categories (Warrington, 2000). Furthermore,
the WCST takes approximately 45 minutes to administer and score, which can be a poor
fit for a bedside evaluation of stroke patients in an acute rehabilitation setting.

Similar to the WCST with respect to requiring strategy generation, monitoring
feedback, and set-shifting to new rules, a relatively new measure, the Brixton Spatial
Anticipation Test (BSAT; Burgess & Shallice, 1997) may have greater clinical utility. A
benefit of the BSAT is that the test involves nine rules to follow compared to three on the
WCST, and is thus more sensitive to executive dysfunction. It is portable with brief
administration of approximately 15 minutes and immediate scoring, allowing for
convenient use for bedside assessments. Administration of the BSAT can be easily
modified for patients with motor deficits or expressive language deficits, common
symptoms in stroke. Studies have supported the validity of the BSAT on several clinical
samples, including patients diagnosed with Attention Deficit Hyperactivity Disorder
(Shallice et al., 2002), eating disorders (Tchanturia et al., 2004), Korsakoff’s Syndrome,
psychiatric disorders, and stroke (Van den Berg et al., 2009). Burgess and Shallice
(1997) found that patients with frontal lesions were significantly impaired on the BSAT
and differed from non-frontal lesion patients in regard to error type in that they were more likely to commit random errors.

A limited number of studies have examined the BSAT’s efficacy in discriminating between right-sided and left-sided lesions, but the results have been mixed, which may be due to methodological differences. Van den Berg et al. (2009) compared performance on the BSAT of stroke patients with lesions in the right hemisphere versus the left hemisphere. They did not find differences in performance, which is likely a result of their gross hemispheric classifications considering substantial research demonstrating frontal lobe involvement in executive functioning tasks (Berman et al., 1995; Burgess & Shallice, 1996; Marocco, Coppola, Daniel, Zigun, & Weinberger, 1993; Royall et al., 2002). Burgess and Shallice (1996) explored laterality differences with primarily tumor patients on the BSAT. Their lesion classifications were more specific than Van den Berg et al. (2009), as they differentiated anterior lesions from posterior lesions. They did not find a laterality effect within the anterior group or within the posterior group. However, these findings could again be influenced by the limited specificity of lesion classification and nature of the lesion, namely tumor. The clinical presentation of patients with tumors can involve a more diffuse impairment due to mass effect and midline shift which can damage surrounding tissue (Lezak, Howieson, & Loring, 2004). Reverberi, Lavaroni, Gigli, Skrap, and Shallice (2005) classified lesions more specifically than the aforementioned authors by examining anterior lesions localized to the left dorsolateral prefrontal cortex, right dorsolateral prefrontal cortex, inferior medial region, and superior medial region. They found that patients with left dorsolateral lesions performed significantly worse on the BSAT than patients with right
dorsolateral lesions, inferior medial lesions, and superior medial lesions, characterized by greater number of total errors. These findings are consistent with other studies demonstrating the involvement of the dorsolateral prefrontal cortex on executive measures (Berman et al., 1995; Cummings & Mega, 2003; Nagahama et al., 1996). The sample used by Reverberi et al. (2005) was of mixed etiology, including tumor, stroke, and traumatic brain injury, and it is unclear whether a specific type of lesion created the significant effect.

In conclusion, a limited number of studies have examined performance differences between those with damage to right versus left anterior regions on the BSAT. The results have been mixed, which is likely due to methodological differences, including samples with mixed etiology (i.e., tumor, stroke, traumatic brain injury). Laterality effects on the BSAT have not yet been explored in patients with anterior strokes only. In addition, there have been no studies, to this author’s knowledge, exploring the impact of subcortical strokes (i.e., thalamus or basal ganglia) on BSAT performance. Furthermore, there have been no studies examining the relationship between BSAT performance and functional outcomes post-stroke. The aim of this study was twofold. First, we examined BSAT performance by lesion location (i.e., left versus right anterior lesions; frontal lobe versus subcortical lesions) in a stroke sample. Second, we examined the relationship between BSAT performance approximately two weeks post-stroke and functional outcomes measured by the Functional Independence Measure at discharge from the rehabilitation unit.
The following null hypotheses were examined:

Ho1: There is no significant difference in BSAT performance between stroke patients with left-sided anterior lesions and patients with right-sided anterior lesions.

Ho2: There are no significant correlations between BSAT performance and the scores on the FIM Cognitive Subscale or the FIM Motor Subscale within the total sample at the time of discharge.

Method

Participants

A convenience sample was used of 57 inpatients admitted to a physical medicine rehabilitation unit secondary to unilateral ischemic cerebrovascular accident (CVA). The medical center from which this convenience sample was derived is located in a suburban town in the Midwest. Patients who were disoriented or too cognitively impaired to comprehend the instructions of the task were not administered the BSAT, according to routine procedures on the unit and thus were not included in the current study. The medical charts of all patients admitted to this unit were reviewed and patients with a documented premorbid history of seizure disorder, traumatic brain injury, brain tumor, dementia, or schizophrenia were also excluded from the study. However, in an effort to capture a representative sample of acute stroke patients, patients with hemiparesis or nonfluent patients were not excluded on this basis alone.

A total of 57 patients were included in the study (27 men and 30 women). Their mean age was 67.02 years old \( (SD = 13.47) \) and ranged from 31 to 89 years old. Their mean number of years of education was 12.61 \( (SD = 2.56) \) and ranged from 6 to 20 years; 55 of the patients were Caucasian and 2 were African American; 51 of the patients were
right-handed, 1 was left-handed, and 5 did not have handedness indicated in their chart (See Table 1).

During classification procedures, 29 patients were classified as having left-sided lesions and 28 patients as right-sided lesions; 17 patients were classified as having cortical lesions and 40 were classified as subcortical. Chi-square analyses revealed that the lesion groups (left vs. right; cortical vs. subcortical) did not significantly differ with regard to sex, handedness, or race. ANOVAs revealed that the groups did not significantly differ with regard to age, education, or number of days post-stroke in which the testing occurred (See Tables 2 and 3).

**Measures**

**Brixton Spatial Anticipation Test** (BSAT: Burgess & Shallice, 1997). The BSAT is a rule attainment task and involves the executive functions of strategy generation, monitoring feedback from the environment, and set-shifting. It involves a stimulus book containing 56 pages with identical 2x5 displays of ten circles, of which one is solid blue. The location of the solid blue circle changes throughout the task according to the given rule sequence. The patients were instructed to predict which of the ten circles will be blue on the subsequent page. The task requires the examinee to learn and apply the current rule in order to predict correctly, and took approximately 15 minutes to administer (Burgess & Shallice, 1997). After completion of the task, scoring was done manually by counting the number of errors committed by the examinee.

The BSAT was normed on a sample of 121 healthy individuals, aged 18 to 80 (Burgess & Shallice, 1997). The standard scores presented in the BSAT manual are not specific to age groups, although subsequent studies have demonstrated age effects on the
measure, consistent with other tests of executive functioning. Bielak, Mansueti, Strauss, and Dixon (2006) explored the use of the BSAT test with 457 older adults aged 53-90 and developed age-based norms to use for performance comparison. However, the previous research done on the BSAT used only the total error raw score for their analyses rather than using converted scaled scores. Therefore, the analyses of the current study were conducted with both methodologies, once with the total error raw score and once with the converted age-based scaled scores. Previous studies have found that the BSAT total error raw score is significantly correlated with other existing measures of executive functioning (de Frias, Dixon, & Strauss, 2006; Doninger, Dennis, Jewell, & Newman, 2008; Wood & Liossi, 2007), including the Dementia Rating Scale Initiation subtest (Pearson’s $r = 0.48, p < .05$), WCST Perseveration Errors (Pearson’s $r = -0.46, p < .05$), WCST Number of Categories (Pearson’s $r = 0.45, p < .05$), WASI Matrix Reasoning (Pearson’s $r = 0.55, p < .01$), Hayling Sentence Completion Task (Pearson’s $r = 0.53, p < .01$), Key Search Test from the Behavioral Assessment of Dysexecutive Syndrome (BADS; Pearson’s $r = 0.26, p < .01$). Color Trails Test, Part 2 (Pearson’s $r = .21, p < .001$), and Letter Series Test (Pearson’s $r = .34, p < .001$). These results demonstrate adequate construct validity with other more established executive measures. Split-half reliability has been marginal at .62, likely due to differing rules among the halves, and adequate test-retest reliability has been demonstrated at .71 (Burgess & Shallice, 1997).

**Functional Independence Measure** (FIM; Uniform Data System for Medical Rehabilitation, 1993). The FIM is a widely used and accepted measure of functional status within hospitals, skilled nursing facilities, and rehabilitation facilities. The FIM allows clinicians to track changes in the patient’s functional status with routine activities
of daily living throughout their rehabilitation from admission to discharge (Chumney et al., 2010). It takes less than thirty minutes to complete and consists of 18 items, 13 of which are related to motor functioning and 5 items are related to cognitive functioning (Uniform Data System for Medical Rehabilitation, 1993). A score from 1 to 7 is given to rate the patient’s level of independence in completing tasks such as dressing and bathing, where 1 represents complete dependence and 7 indicates complete independence (1=Total Assist, 2=Maximal Assist, 3=Moderate Assist, 4=Minimal Assist, 5=Supervision, 6=Modified Independence, 7=Complete Independence). Total scores range from 18 to 126, with higher scores reflecting greater functional independence. Stair Climbing, one of the motor domains was not assessed with the patients in this study. Consequently, the FIM data used in this study reflect 12 motor domains and 5 cognitive domains, with total scores ranging from 17 to 119.

Hsueh, Lin, Jeng, and Hsieh (2002) demonstrated that the FIM yields acceptable distribution, high internal consistency, high concurrent validity, and clinical utility within the stroke population. Although scores can be affected by rater bias, the FIM has overall demonstrated excellent reliability of .95 for Interrater reliability and .95 for test-retest reliability in a review of eleven studies (Barak & Duncan, 2006). The FIM has been widely researched within the stroke population and there is substantial support for its accuracy in predicting outcomes in post-stroke patients (Chumney et al., 2010). In a review of multiple studies, the FIM scores demonstrate change over time that is consistent with the gains demonstrated by the patient in rehabilitative therapies, and is predictive of caregiver demands and supervision needs upon discharge in the stroke population (Barak & Duncan, 2006; Chumney et al., 2010).
Procedure

The BSAT was administered as part of the routine neuropsychological evaluation of patients admitted to a physical medicine rehabilitation unit. The standard test battery included the Brixton Spatial Anticipation Test (Burgess & Shallice, 1997), Repeatable Battery for the Assessment of Neuropsychological Status (RBANS; Randolph, 1998), Trail Making Test (Reitan, 1956), and Verbal Fluency Test (FAS and Animals; Halstead & White, 1950), lasting approximately 45-60 minutes. Depending on patient mobility, the neuropsychological test battery was administered in the patient’s room or in a private testing room by a neuropsychology staff member. Data were collected from medical charts including neuropsychological test scores, brain scans, date of hospital admission (used as proxy for date of CVA), date of neuropsychological testing, age, sex, education, handedness, FIM scores at admission to the rehabilitation unit, and FIM scores at discharge from the rehabilitation unit.

A power analysis was conducted for an independent samples t-test with the significance criterion (alpha) set at .05. The t-test was non-directional (i.e., two-tailed) meaning that an effect in either direction was interpreted. Adequate power for detecting a significant effect is .80. To obtain a .80 power level, with a large effect size (.80) at a .05 alpha level, a total sample size of 52 was needed for an independent samples t-test.

Lesion classification. Neuroimaging scans were used to classify stroke lesions and in most cases (n = 46), an MRI scan of the brain was used. For the remainder (n = 11), a CT scan of the brain was used as an alternative when a patient was unable to undergo an MRI scan. Brain scans were examined and location of CVA was blindly classified by a neuroradiologist. Location was classified according to region (anterior vs.
posterior), laterality (left vs. right), and structural involvement (cortical vs. subcortical).

All patients with CVAs involving bilateral damage were excluded (n = 5). Furthermore, all patients with cortical CVAs located posterior to the central sulcus (n = 9) and subcortical strokes outside of the anterior fossa (i.e., cerebellum, pons, medulla; n = 7) were excluded, consistent with how previous researchers have classified anterior lesions (Wilde, 2010). A total of 21 patients did not meet inclusion criteria based on blind neuroimaging classifications and were excluded from the study. Of the current sample (n = 57) who met inclusion criteria, 29 patients were classified as having left-sided lesions and 28 patients were classified as having right-sided lesions; 17 patients were classified as having a lesion in the frontal lobe cortex and 40 patients were classified as having subcortical lesions (i.e., basal ganglia and thalamus).

Results

Correlates of BSAT Performance

Performance on the BSAT ranged from 8 to 39 for the total errors raw score (M = 20.82, SD = 7.29). Age was significantly correlated with BSAT total errors raw score (Pearson’s r = .42, p < .001). Education and gender were not correlated with BSAT total errors raw score, although women (M = 22.60, SD = 7.23) trended towards poorer performance than men (M = 18.85, SD = 6.95; Pearson’s r = .26, p = .05). Although limited variability, race and handedness were not correlated with BSAT performance (See Table 1). Of the neuropsychological tests administered as part of the routine test battery, BSAT raw scores were significantly correlated with RBANS Visuoconstruction Index (Pearson’s r = -.36, p = .04), RBANS Delayed Memory Index (Pearson’s r = -.36, p = .04), and Trail Making Test, Part B, T-score (Pearson’s r = -.53, p = .006), as shown
in Table 4. BSAT age-based T-scores were significantly correlated with RBANS Attention Index (Pearson’s $r = .40, p = .03$), RBANS Visuconstruction Index (Pearson’s $r = .48, p = .005$), RBANS Delayed Memory Index (Pearson’s $r = .40, p = .02$), and T-scores on Trail Making Test, Part A (Pearson’s $r = .48, p = .005$), and Trail Making Test, Part B, (Pearson’s $r = .52, p = .007$) as shown in Table 5.

**Laterality Effects**

Independent samples $t$-test comparing BSAT raw scores between left-sided lesions ($M = 21.28, SD = 6.63$) and right-sided lesions ($M = 20.36, SD = 8.00$) did not yield statistically significant differences $t(55) = .47, p = .64$. A second $t$-test comparing BSAT T-scores between left-sided and right-sided lesions also did not yield statistically significant differences $t(55) = -.19, p = .85$. (See Table 6).

**Subcortical Involvement of Stroke Lesions**

Independent samples $t$-test comparing BSAT raw score between the cortical lesion group ($M = 17.24, SD = 5.31$) and the subcortical lesion group ($M = 22.35, SD = 7.53$) yielded significantly poorer BSAT scores for patients with subcortical lesions $t(55) = -2.54, p = .01$. A second $t$-test comparing BSAT T-scores between cortical lesions and subcortical lesions also found that the subcortical group had significantly poorer scores $t(55) = 2.14, p = .04$. (See Table 6).

**Functional Outcomes**

Of the total sample ($N=57$), 22 patients were admitted to the unit prior to the use of the FIM as part of routine patient care. Consequently, 35 patients had FIM data available for review. None of the patients received scores on the Stair Climbing domain of the FIM and as a result, only 17 of the 18 FIM domains are included in the Total FIM
Discharge scores. Mean Total FIM Discharge scores for the 17 domains was 95.17 ($SD = 14.28$), ranging from 62 to 119. Mean of the FIM Motor Subtotal Discharge Score was 67.46 ($SD = 12.56$) and mean of the FIM Cognitive Subtotal Discharge Score was 27.71 ($SD = 4.07$). BSAT raw score was significantly correlated with FIM Cognitive Subtotal Discharge Score (Pearson’s $r = -.46$, $p = .005$) but was unrelated to FIM Motor Subtotal Discharge Score (See Table 7). Of the FIM Cognitive domains, BSAT raw score was significantly correlated with the Comprehension (Pearson’s $r = -.48$, $p = .003$), Social Interaction (Pearson’s $r = -.48$, $p = .004$), Problem Solving (Pearson’s $r = -.41$, $p = .02$), and Memory (Pearson’s $r = -.41$, $p = .01$) domains, but not correlated with Expression ($p = .10$; See Table 7). Additional correlations were conducted with BSAT T-scores, and BSAT performance was significantly correlated with FIM Cognitive Subtotal Discharge Score and the Comprehension and Social Interaction domains, but not the Problem Solving or Memory domains (See Table 8). As shown in Tables 9 and 10, correlations were also conducted between FIM scores and the other neuropsychological tests that were administered as part of the test battery.

Independent samples $t$-test comparing FIM Cognitive Subtotal Discharge Scores between left-sided lesions ($n = 17$; $M = 25.71$, $SD = 4.34$) and right-sided lesions ($n = 18$; $M = 29.61$, $SD = 2.75$) yielded significantly lower FIM Cognitive Subtotal Discharge Scores for patients with left-sided lesions $t(33) = 3.20$, $p = .003$. Independent samples $t$-test comparing FIM Cognitive Subtotal Discharge Scores between patients with cortical lesions ($n = 11$; $M = 28.00$, $SD = 5.35$) and subcortical lesions ($n = 24$; $M = 27.58$, $SD = 3.46$) did not differ significantly $t(33) = .28$, $p = .78$. 
Lastly, scores were calculated for change in FIM Motor Subscale Scores ($M = 18.29$, $SD = 10.31$) and FIM Cognitive Subscale Scores ($M = 3.69$, $SD = 3.23$) from admission to the rehabilitation unit to discharge. BSAT raw scores were not correlated with the amount of change between the time of admission to discharge from the hospital for the FIM Motor Subtotal Scores (Pearson’s $r = -.25$, $p = .15$) or the FIM Cognitive Subtotal Scores (Pearson’s $r = -.19$, $p = .28$; See Table 7).

**Discussion**

Very few studies have compared the performance on the BSAT according to location of stroke lesion or evaluated the measure’s clinical utility to predict functional outcomes. The purpose of this study was to examine: 1) differences in performance on the BSAT based on stroke lesion location (i.e., left versus right anterior lesions; frontal lobe versus subcortical lesions); and 2) the relationship between performance on the BSAT and functional outcomes as measured by the Functional Independence Measure. The first null hypothesis stated that there would be no significant difference in BSAT performance between stroke patients with left-sided anterior lesions and right-sided anterior lesions. The second null hypothesis stated that there would be no significant correlations between BSAT performance and the FIM Cognitive Subscale or the FIM Motor Subscale at the time of discharge.

The results of the current study did not find significantly different performances based on lesion laterality and thus, we were unable to reject the first null hypothesis. Our results are consistent with other studies examining laterality effects in which gross lesion classification methods were used and performance differences were not found (Burgess & Shallice; 1996; Van den Berg et al., 2009). Reverberi et al. (2005) classified lesions
more specifically than the aforementioned authors, within the dorsolateral prefrontal cortex only, and found that patients with left dorsolateral lesions performed worse on the BSAT than patients with right dorsolateral lesions. Thus, it is possible that the laterality effect found by Reverberi et al. (2005) is specific to the dorsolateral prefrontal cortex only and one explanation for why their finding was not replicated in the current study is that the gross classifications used (frontal lobe and subcortical lesions) were not specific enough to detect a laterality effect. A second possible explanation involves the methodological differences between studies, in that the sample used by Reverberi et al. (2005) was of mixed etiology, including tumor, stroke, and traumatic brain injury. In contrast, the current sample was entirely of stroke patients, and it is unclear whether a specific type of lesion created the significant effect found by Reverberi et al. (2005). Furthermore, another explanation for the absence of a laterality effect may be due to a limited sample size with a wide range and variability of BSAT performance which could have made a laterality effect difficult to detect. With a larger sample size, the standard deviation of BSAT performance may have reduced allowing performance differences to be more easily detected. Lastly, a fourth explanation for why a laterality effect was not demonstrated is that the BSAT involves both strategy generation, which has been associated with the left frontal lobe (Goldberg, Poddell, and Lovell, 1994) and monitoring of behavior and feedback, which has been associated with the right frontal lobe (Milner & Petrides, 1984) and thus, successful performance on the task may rely on preserved functioning of both sides of the frontal lobe.

Additional analysis examined performance on the BSAT between those with subcortical stroke lesions and frontal lobe lesions. Results revealed that patients with
subcortical stroke lesions had significantly poorer scores on the BSAT than patients with frontal lobe stroke lesions. This finding is consistent with recent studies demonstrating the high involvement of the subcortical circuitry in executive functioning (Koziol & Budding, 2009). Specifically, the subcortical lesion group in this study consisted of patients with lesions to the thalamus or basal ganglia. The current finding is consistent with other studies demonstrating executive deficits in patients with lesions to the thalamus, particularly the ventral anterior nuclei (VA) and medial dorsal nucleus (MD) (Van der Werf, Scheltens et al., 2003; Van der Werf, Witter et al., 2000), as well as lesions to the basal ganglia, of which the striatum is integral to the frontal-subcortical circuitry (Hochstenbach et al., 1998; Su et al., 2007). This executive dysfunction is the result of the high density of frontal lobe circuitry in these subcortical structures, particularly the dorsolateral prefrontal circuit (DLPFC; Chow & Cummings, 2007; Koziol & Budding, 2009). Consequently, infarctions to the thalamus and basal ganglia have been shown to disrupt the circuitry and indirectly reduce metabolic rates of the frontal lobes, particularly in the dorsolateral prefrontal cortex, resulting in executive deficits (Koziol & Budding, 2009; Kumar Lavretsky, & Haroon, 2005; Reed et al. 2004). This frontal-subcortical relationship is further supported by the cognitive profile most associated with subcortical ischemic vascular disease (SIVD), in which the primary deficits observed are executive dysfunction (Jokinen et al., 2006; Kramer, Reed, Mungas, Weiner, & Chui, 2002; Libon et al., 2009). Overall, the findings of the current study support the recent research demonstrating executive deficits following a stroke of the subcortical structures (Hochstenbach et al., 1998; Su et al., 2007; Van der Werf, Scheltens et al., 2003; Van der Werf, Witter et al., 2000). Interestingly, in the current
study patients with subcortical lesions performed significantly worse than patients with frontal lobe lesions, a comparison that has not been fully examined in the research. This finding suggests that strokes of the thalamus and basal ganglia can potentially result in more profound executive deficits than lesions to the frontal lobe. The high density of frontal lobe circuitry in the subcortical structures (Chow & Cummings, 2007; Koziol & Budding, 2009) is a possible explanation for this finding. Future research should continue exploring the nature of the executive deficits associated with subcortical lesions.

BSAT performance was correlated with cognitive functional outcomes measured by the FIM and we were able to reject the second null hypothesis. In contrast, BSAT performance was not correlated with motor functional outcomes. To this author’s knowledge, this is the first study to examine the relationship between the BSAT and functional outcomes. The correlation between BSAT performance and FIM cognitive outcomes is consistent with other studies that demonstrate a relationship between executive dysfunction and post-stroke performance of instrumental activities of daily living (Pohjasvarra et al., 2002; Stephens et al., 2005), such as driving or managing finances. Of the specific FIM Cognitive domains, BSAT performance was correlated with Comprehension, Social Interaction, Problem Solving, and Memory, but not Expression, which could suggest that BSAT performance is not influenced by expressive language deficits. The results of the current study promote the ecological validity of the BSAT for identifying factors of cognitive prognosis in ischemic stroke. Specifically, factors of cognitive prognosis play a critical role in treatment planning during rehabilitation, expectations of patient improvement, discharge planning, and caregiver education (Stephens et al., 2005). Previous studies have argued for the importance of
establishing early cognitive screening measures of executive functioning to identify stroke patients who are at risk for functional disability (Donovan et al., 2008; Pohjasvarra et al., 2002; Stephens et al., 2005). The findings of the current study support the use of the BSAT as a screening measure of executive functioning to predict functional outcomes within the rehabilitative setting. Future research needs longitudinal studies to examine the utility of the BSAT to predict functional outcomes over time (i.e. 6 months to 18 months post-stroke).

Given that the BSAT is brief, portable, and can be modified for immobile or nonfluent patients, the current findings strengthen its clinical utility for stroke patients within the rehabilitative setting. Consistent with prior research (de Frias et al., 2006; Doninger et al., 2008; Wood & Liossi, 2007), the current study supports the BSAT’s construct validity with other measures of executive functioning. Specifically, BSAT performance was correlated with performance on Trail Making Test, Part B (Reitan, 1956), an executive functioning test that involves divided attention and set switching. BSAT performance was also correlated with subtests of the RBANS (Randolph, 1998), that involve components commonly associated with executive functions (Jurado & Rosselli, 2007). BSAT scores were correlated with the RBANS Delayed Memory Index which involves frontal-subcortical memory retrieval processes. Similarly, BSAT performance was correlated with the RBANS Visuoconstruction Index, which is partially based on the Figure Copy subtest, a task involving the executive functions of planning and organization. Lastly, BSAT performance was correlated with the RBANS Attention Index and Trail Making Test, Part A, which both involve attention and processing speed,
also components of executive functioning. Overall, the results of the current study further support the construct validity of the BSAT.

In regard to limitations, a convenience sample was used in the current study and data was collected as part of routine clinical practice. Consequently, not all patients admitted to the rehabilitation unit were tested. For example, some patients were not tested if determined by the examiner to be too disoriented or cognitively impaired to undergo testing. In some instances the BSAT was attempted and test instructions were administered, but the task was discontinued if the patient could not comprehend the instructions. As a result, the current sample reflects a subset of patients who possessed the cognitive abilities required to complete testing and may not represent the entire stroke population. Furthermore, not every patient received an identical test battery which was influenced by test preferences among the examiners and also the specific abilities of the patient (i.e., Verbal Fluency Test not administered with a nonfluent patient).

Consequently, there are differing sample sizes for each neuropsychological test which could influence the analyses comparing patient performances across tests. Additionally, the participants used in the current study were predominately Caucasian, and there was little heterogeneity regarding race. BSAT performance among different racial groups has not been adequately explored to date. As a result, the generalizability of the current findings to ethnic minority groups remains unclear. Despite the racial homogeneity of the study’s sample, we feel that the relationships between lesion location, BSAT performance, and functional outcomes are meaningful.

In the current study, participants were not classified according to the size of stroke lesion. Thus, the lesion size was not controlled for in the analyses. Given the lack of
resources required to employ more specified classification procedures regarding lesion size (i.e., the Curry software by NeuroScan) and the limited sample size, creating classifications according to lesion size were beyond the feasibility of the current study. The total length of stay on the acute hospital unit prior to rehabilitation admission was used as a proxy for lesion severity and the lesion groups did not differ in their length of stay on the acute unit. More specified examinations of lesion size and severity should be used in future studies looking at laterality effects or impact of subcortical lesions on executive functioning.

Although additional research is needed to gain a more complete understanding of the relationship between lesion location and BSAT performance, the current study provides a framework for future studies. Specifically, our findings provide additional support and further our understanding of the role of subcortical structures in the executive functioning system. In addition, the current study supports the clinical utility of a relatively new and under-researched measure of executive functioning as not only a convenient and conducive measure for stroke patients, but also an ecologically valid predictor of functional disability post-stroke.
References


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doi:10.1682/JRRD.2009.08.0140


doi:10.1016/S0022-3999(98)00034-8


Table 1

**Correlations between BSAT Raw Scores and Demographic Variables**

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*Note. BSAT = Brixton Spatial Anticipation Test.*  
*p < .01.
Table 2

*Demographic Variables According to Lesion Laterality*

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*Note.* ANOVA and Chi-square analyses examining group differences on demographic variables according to lesion laterality.
Table 3

*Demographic Variables According to Subcortical Involvement*

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*Note.* ANOVA and Chi-square analyses examining group differences on demographic variables between cortical lesion group and subcortical lesion group.
Table 4

Correlations between BSAT Raw Scores and Neuropsychological Tests

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*Note. BSAT = Brixton Spatial Anticipation Test; RBANS = Repeatable Battery for the Assessment of Neuropsychological Status. Trail Making Test T-scores and Verbal Fluency T-scores were calculated based upon Halstead-Reitan (2004) published norms. *$p < .05$. **$p < .01$*
Table 5

_Correlations between BSAT T-Scores and Neuropsychological Tests_

<table>
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<tr>
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<td>11.96</td>
<td>.48</td>
<td>.005*</td>
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<td>FAS T-score</td>
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<td>.28</td>
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<td>Animals T-score</td>
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<td>11.29</td>
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*Note.* BSAT = Brixton Spatial Anticipation Test; RBANS = Repeatable Battery for the Assessment of Neuropsychological Status. Trail Making Test T-scores and Verbal Fluency T-scores were calculated based upon Halstead-Reitan published norms. BSAT T-scores were calculated based upon norms published in Bielak et al. (2006). *p < .05. **p < .01
Table 6

BSAT Performance Differences based on Lesion Location

<table>
<thead>
<tr>
<th>Measure</th>
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<th>$t$</th>
<th>$p$</th>
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<tr>
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<td>Right ($n = 28$)</td>
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<td>.01*</td>
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<td><strong>BSAT T-Score</strong></td>
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<td></td>
<td></td>
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<td>Left ($n = 29$)</td>
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<td>Subcortical ($n = 40$)</td>
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*Note. BSAT = Brixton Spatial Anticipation Test. Differences in means were examined using $t$-tests according to lesion location (left vs. right; cortical vs. subcortical). BSAT T-scores were calculated based upon norms published in Bielak et al. (2006). *$p < .05$*
Table 7

*Correlations between BSAT Raw Scores and FIM Scores*

<table>
<thead>
<tr>
<th>Measure</th>
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<th>SD</th>
<th>Pearson's r</th>
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<td>.004**</td>
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*Note. BSAT = Brixton Spatial Anticipation Test; FIM = Functional Independence Measure. Change Scores were calculated based on the differences in FIM scores from admission to discharge. *p < .05. **p < .01*
Table 8

*Correlations between BSAT T-Scores and FIM Scores*

<table>
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<tr>
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<th>SD</th>
<th>Pearson’s r</th>
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<td>4.07</td>
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<td>1.10</td>
<td>.30</td>
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*Note. BSAT = Brixton Spatial Anticipation Test; FIM = Functional Independence Measure. BSAT T-scores were calculated based upon norms published in Bielak et al. (2006). *p < .05. **p < .01*
Table 9

*Correlations between Neuropsychological Tests and FIM Motor Subscale*

<table>
<thead>
<tr>
<th>Measure</th>
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<th>M</th>
<th>SD</th>
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*Note.* BSAT = Brixton Spatial Anticipation Test; RBANS = Repeatable Battery for the Assessment of Neuropsychological Status. Trail Making Test T-scores and Verbal Fluency T-scores were calculated based upon Halstead-Reitan published norms. BSAT T-scores were calculated based upon norms published in Bielak et al. (2006).

*p < .05*
Table 10

*Correlations between Neuropsychological Tests and FIM Cognitive Subscale*

<table>
<thead>
<tr>
<th>Measure</th>
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<td>Part A T-score</td>
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<tr>
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<td>FAS T-score</td>
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*Note.* BSAT = Brixton Spatial Anticipation Test; RBANS = Repeatable Battery for the Assessment of Neuropsychological Status. Trail Making Test T-scores and Verbal Fluency T-scores were calculated based upon Halstead-Reitan published norms. BSAT T-scores were calculated based upon norms published in Bielak et al. (2006).

*p < .05. **p < .01
Figure 1. Differences in mean BSAT errors based on lesion location. Standard errors are represented in the figure by the error bars attached to each column at the 95% confidence intervals.
## Appendix A

### Approval Letter from Kettering Health Network IRB

**IRB APPROVAL NOTICE**

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<thead>
<tr>
<th>DATE:</th>
<th>July 27, 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>TO:</td>
<td>Christopher Contardo, PhD</td>
</tr>
<tr>
<td>FROM:</td>
<td>Kettering Health Network Institutional Review Board</td>
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<tr>
<td>IRB REFERENCE #:</td>
<td>12-040</td>
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<tr>
<td>STUDY TITLE:</td>
<td>[304] 10-1: The Effects of Stroke on Prospective Memory</td>
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<td>July 21, 2012</td>
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<td>July 27, 2013</td>
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Thank you for your submission of the materials referenced above for this research study. The Kettering Health Network Institutional Review Board has approved your submission based on applicable federal regulations. All research must be conducted in accordance with this approved submission.

This project has been determined to be **Minimal Risk** and requires Continuing Review by the IRB on an annual basis.

The following materials were acknowledged and/or approved:

- Application Form - Application for Approval of Research (UPDATED: 05/18/2012)
- Data Collection - Data Collection Tools Spreadsheet (UPDATED: 04/03/2012)
- HIPAA Waiver - HIPAA Waiver (UPDATED: 05/20/2012)
- Investigator Agreement - PI Agreement - Duninger (UPDATED: 03/20/2012)
- Investigator Agreement - PI Agreement - Vagnuson (UPDATED: 03/20/2012)
- Investigator Agreement - PI Agreement - Contardo (UPDATED: 03/20/2012)
- Letter - Vordenberg Letter for Educational Purpose (UPDATED: 06/18/2012)
- Letter - Magnuson Letter for Educational Purpose (UPDATED: 06/11/2012)
- Letter - IC Submission Letter to IRB (UPDATED: 03/20/2012)
- Other - Independent Investigator Form - Vordenberg (UPDATED: 06/18/2012)
- Other - Investigator Checklist (UPDATED: 07/20/2012)
- Other - Independent Investigator Form - Magnuson (UPDATED: 06/11/2012)
Appendix B

Approval Letter from Xavier University IRB

October 3, 2012

Jessica Vordenberg
4111 32nd Ave
Cincinnati, OH 45209

Dear Ms. Vordenberg,


If you wish to modify your study, including any changes to the approved Informed Consent form, or if there will be any research assistants added it will be necessary to obtain IRB approval prior to implementing the modification. The research assistants will need to complete the NIH training and submit the certificates to our office along with a modification request form. If any adverse events occur, please notify the IRB immediately.

We apologize for the delay in responding to this protocol and we wish you success with your research!

Sincerely,

[Signature]

Morell E. Mullins, Jr., Ph.D
Chair, Institutional Review Board
Xavier University

MEM/sb

c: John Barrett, Advisor
Appendix C

Instruments Used

The Brixton Spatial Anticipation Test (BSAT) is protected by copyright so it is not reproduced in this document. This measure is available through Pearson Education, Inc. at www.pearsonassessments.com.
Appendix D

Instruments Used

The Functional Independence Measure (FIM) is protected by copyright so it is not reproduced in this document. This measure is available through Uniform Data System for Medical Rehabilitation at www.udsmr.org.
Summary

Title: Laterality Effects in Anterior Stroke: Brixton Spatial Anticipation Test and Functional Outcomes

Problem. Limited studies have explored performance differences on the Brixton Spatial Anticipation Test (BSAT) according to location of stroke lesion. Although a few studies have examined laterality effects on the BSAT, results have been mixed which is likely due to methodological differences and samples involving lesions of mixed etiology (Reverberi et al., 2005; Van den Berg et al., 2009). Moreover, previous studies have not explored laterality effects with frontal lobe and subcortical lesions within the stroke population only. Finally, there are no known studies examining the relationship between performance on the BSAT and functional outcomes as measured by the Functional Independence Measure (FIM). The current study was designed to examine executive functioning performance on the BSAT according to lesion location within the stroke population and to assess the measure's clinical utility within a rehabilitative setting.

Methods. Participants were 57 patients in a subacute rehabilitation unit diagnosed with unilateral anterior stroke. The mean age for those patients included in the sample was 67.02 years old (SD = 13.47). Of the total sample, 29 patients were classified as having left-hemisphere lesions and 28 patients were classified as having right-hemisphere lesions. Seventeen patients were classified as suffering a stroke lesion in the frontal lobe and 40 patients suffered subcortical strokes (i.e., basal ganglia and thalamus). Patients were assessed using the BSAT and other brief neuropsychological measures on average 13.56 days post-stroke (SD=6.70) and were assessed using the Functional Independence Measure (FIM) upon discharge from the rehabilitation unit.
An ANCOVA was conducted to examine possible differences in BSAT performance based on lesion laterality. Age was correlated with BSAT performance and used as a covariate. Pearson's correlations were conducted to examine the relationship between BSAT performance and motor and cognitive functional outcomes at discharge. Finally, an ANCOVA was conducted as a supplementary analysis to examine possible differences in BSAT performance based on frontal lobe lesion or subcortical lesion, with age used as covariate.

**Findings.** Results showed no significant difference in BSAT performance between patients with left-sided lesions and those with right-sided lesions. However, patients with subcortical stroke lesions performed significantly worse than patients with frontal lobe stroke lesions ($p < .05$). Within the overall sample, BSAT performance was not correlated with motor functional outcomes. However, BSAT performance was significantly correlated with overall cognitive functional outcomes ($p < .01$). Of the specific cognitive domains, BSAT performance was correlated with comprehension, social interaction, problem solving, and memory.

**Implications.** The current study provides useful information regarding executive functioning performance within the stroke population. Failure to find a laterality effect in this study suggests that patients with left-sided anterior strokes and right-sided anterior strokes demonstrate similar performance on the BSAT. Moreover, the failure to find a laterality effect may indicate that the gross classifications used in this study (frontal lobe and subcortical lesions) were not specific enough to detect the laterality effect which was demonstrated in a previous study (Reverberi et al., 2005). However, the current finding
suggests that subcortical strokes of the thalamus and basal ganglia can potentially result in more profound executive deficits than lesions to the frontal lobe. Lastly, the findings of the current study support the use of the BSAT as a screening measure of executive functioning to predict cognitive functional outcomes post-stroke within the rehabilitative setting.