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The present study sought to determine whether participants with moderate to severe traumatic brain injury (MOD/S TBI) would quantitatively and qualitatively differ from participants with no brain damage (NBD) in phonemic and semantic verbal fluency, and whether the potential differences may be attributed to working memory (WM) and information processing speed. Independent *t*-test procedures indicated that the MOD/S TBI group was disproportionately impaired on all test measures when compared to an NBD group. However, when Bonferroni adjustments for multiple comparisons were applied, only two results remained statistically significant. First, the MOD/S TBI group differed significantly from the NBD group on the total number of correct words generated for the letter *S* on the phonemic verbal fluency task, and for the semantic categories of *animals* and *boys' names*. Second, the MOD/S TBI group produced a significantly greater number of word recall errors on a measure of WM when compared to participants with NBD. Moreover, a mixed-analysis of variance (ANOVA) procedures suggested that the MOD/S TBI group was impaired in their performance on tasks of information processing speed and WM, when compared to the NBD group, and these differences were correlated with decrements in performance on tasks of verbal fluency, as indicated by the total number of words produced on these tasks.

THE RELATIONSHIP BETWEEN WORKING MEMORY AND VERBAL FLUENCY FOLLOWING TRAUMATIC BRAIN INJURY

by

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Approved by

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To my parents.

APPROVAL PAGE

This dissertation has been approved by the following committee of the Faculty of The Graduate School at The University of North Carolina at Greensboro.

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CHAPTER I

INTRODUCTION

Traumatic brain injury (TBI) is a disorder of major public health concern secondary to its high prevalence and proclivity for life-long disability, as well as the deleterious impact it may have upon the resumption of daily living activities, including educational and vocational pursuits (Cicerone, Mott, Azulay, & Friel, 2004; Faul, Xu, Wald, & Coronado, 2010; Finkelstein, Corso, & Miller, 2006; Langlois, Rutland-Brown, & Thomas, 2006; McNett, 2007; Rutland-Brown, Langlois, Thomas, & Xi, 2006; Selassie et al., 2008). The Centers for Disease Control and Prevention (CDC) have estimated that 1.7 million traumatic brain injuries occur annually in the United States, of which 1.4 million seek medical attention at an emergency department (Faul et al., 2010). Within this population, males are 1.4 times more likely than females to incur TBI (Faul et al., 2010). Furthermore, males between 25 and 44 years of age and who are in the most productive years of their lives account for approximately 36 percent of TBIs that result in hospitalization, with motor vehicle accidents cited as the primary cause of injury (Faul et al., 2010). A significant number of individuals with TBI report some degree of cognitive-linguistic disturbance following injury, particularly in the domains of attention, memory, and executive function (Alexander, 1995; Finkelstein et al., 2006; Godefroy, 2003; McAllister & Arciniegas, 2002; Riggio &

Wong, 2009; Selassie et al., 2008). Further, TBI is a costly public health concern, with an estimated 76.5 billion spent annually in the United States for the direct and indirect costs associated with medical care and loss of productivity (Coronado, Faul, Sugerman, McGuire, & Pearson, 2012; Finkelstein et al., 2006). Yet, despite its long-term impact and disabling cognitive-linguistic sequelae, TBI remains what is commonly denoted as a silent epidemic as the cognitive and emotional deficits it may produce are often invisible, and as such, the general public is largely unaware of its existence (Langlois et al., 2006; Rutland-Brown et al., 2006).

One cognitive-linguistic function that appears particularly vulnerable to the effects of TBI is verbal fluency (Capitani, Rosci, Saetti, & Laiacona, 2009; Levin, Benton, & Grossman, 1982; Raskin & Rearick, 1996; Ruff, Evans, & Marshall, 1986). Verbal fluency is typically assessed using both phonemic and semantic tasks. Phonemic verbal fluency is defined as the generation of words that begin with a specific letter of the alphabet, such as *F, A, or S* (Benton, 1968; Borkowski, Benton, & Spreen, 1967). Semantic verbal fluency demands the generation of words that belong to a common semantic category, such as *animals* (Newcombe, 1969). Each task allows the individual 60 seconds to generate as many words as possible (Marshall, 1986; Spreen & Strauss, 1991).

Decrements in both semantic and phonemic verbal fluency performance have been associated with severity of TBI (Iverson, Franzen, & Lovell, 1999; Jennett & Bond, 1975; Ruff et al., 1986). For example, individuals with severe brain trauma have been observed to perform more poorly on tasks of verbal fluency, as indicated by the total number of words produced, in comparison to those with mild or moderate brain injuries (Bittner & Crowe, 2006, 2007; Goldstein et al., 1996; Gruen, Frankle, & Schwartz, 1990; Kraus et al., 2007; Mathias et al., 2004; Ruff et al., 1986). While disturbances in verbal fluency performance may be most apparent immediately following injury, there is emerging evidence that these difficulties may persist for many years following injury, particularly in individuals with moderate to severe TBI (MOD/S TBI) (Henry & Crawford, 2004b; Kinnunen et al., 2010; Kraus et al., 2007; Ruff et al., 1986; Whitnall, McMillan, Murray, & Teasdale, 2006).

The chronicity of verbal fluency deficits following TBI may reflect disturbances within the cognitive process that are believed to underlie performance on these types of tasks. For example, the ability to sustain attention to the task at hand, to plan and organize the search for and retrieval of appropriate words, to self-monitor verbal output, and to inhibit errors and repetitions have all been reported as critical for task performance (Birn et al., 2010; Crowe, 1998; Raskin & Rearick, 1996; Ruff, Light, Parker, & Levin, 1997; Troyer, Moscovitch, & Winocur, 1997). It has also been suggested that two factors, working memory (WM) and information processing speed, may also influence performance on verbal fluency tasks, although the extent to which each may contribute to performance is of considerable debate (Azuma, 2004; Bittner & Crowe, 2007; Bryan & Luszcz, 2000; Ponsford & Kinsella, 1992; Rende, Ramsberger, & Miyake, 2002; Rosen & Engle, 1997; Unsworth, Spillers, & Brewer, 2010; Troyer et al., 1997). Hence, elucidating the nature of verbal fluency performance following MOD/S TBI is most important, as identifying and characterizing the processes that underlie it may have implications for the resumption of community functioning (Chevignard et al., 2008; Fortin, Godbout, & Braun, 2003; Troyer, 2000).

To date, a number of studies have demonstrated the application and relevance of verbal fluency skills to activities of daily living in populations with dementia (Loewenstein et al., 1989, 1992; Loewenstein, Rubert, Argüelles, & Duara, 1995), Alzheimer's disease (Farias, Harrell, Neumann, & Houtz, 2003; Razani et al., 2007), schizophrenia (Brekke, Raine, Ansel, Lencz, & Bird, 1997; Buchanan, Holstein, & Breier, 1994; Rempfer, Hamera, Brown, & Cromwell, 2003), and in populations with no brain damage (NBD) (Cahn-Weiner, Boyle, & Malloy, 2002; Cahn-Weiner, Malloy, Boyle, Marran, & Salloway, 2000). Although this relationship has been investigated to a lesser extent in populations with TBI (Chevignard et al., 2008; Fortin, Godbout, & Braun, 2003), the collective results suggest that the ability to generate a greater number of words on tasks of verbal fluency is strongly associated with greater independence in completing functional activities such as financial transactions and shopping tasks (Cahn-Weiner et al., 2002; Farias et al., 2003; Loewenstein et al., 1992, 1995; Razani et al., 2007; Rempfer et al., 2003), managing medication administration (Cahn-Weiner et al., 2002), and in preparing a meal (Chevignard et al., 2008; Fortin et al., 2003).

To illustrate, Fortin and colleagues (2003) compared the performance of 10 participants with mild to severe TBI and a group of healthy participants on written tests of semantic and phonemic verbal fluency, script recitation, meal preparation, and grocery shopping tasks. Both meal preparation and grocery shopping abilities were assessed within a natural context. Briefly, the meal preparation assignment required participants to develop a menu, shop for the groceries, and then prepare the selected meal. Script recitation was assessed in two ways. First, participants were asked to verbally state, in order, a finite number of actions that were critical for the completion of a given activity of daily living. Second, they were asked to create a list of actions that were pertinent to the tasks of *dining out* and *grocery shopping*. The results indicated that performance on script recitation, meal preparation, and grocery shopping tasks approached significance for individuals with TBI. However, the investigators noted a significant association between the number of prospective memory errors that occurred on the meal preparation task and performance on the semantic verbal fluency task only in participants with TBI. Briefly, prospective memory errors were defined as planning and organizational errors (e.g., courses that did not arrive on time, courses that were slow in sequence) that were observed during the course of meal preparation. For this portion of the analysis, Fortin and colleagues (2003) noted that as the number of prospective memory errors increased, the total number of words generated on the semantic verbal fluency task decreased. Their findings suggest that meal preparation, a functional task that may be essential for independent living, and semantic verbal fluency, a task that may be critical for shopping for groceries and preparing the meal selected, may share and depend upon the unique contributions of both organization and planning skills in order to complete the task with success.

More recently, Chevignard and colleagues (2008) investigated the relationship between verbal fluency performance and meal preparation in 45 participants with acquired brain injury, of which 22 had sustained a severe TBI, and a group of 12 participants with NBD. All participants were given a battery of neuropsychological measures, including semantic and phonemic verbal fluency tasks. For this functional task, participants were asked to independently prepare two main entrées and a dessert. The meal preparation task was analyzed both quantitatively and qualitatively. For the quantitative analysis, the investigators examined the total number of errors, including additions, omissions, and perseverations. The total number of errors was further examined in relation to the initial Glasgow Coma Scale (GCS; Teasdale & Jennett, 1974) score and durations of coma in the TBI group. For the qualitative analysis, Chevignard and colleagues (2008) explored the duration of the task, the ability to achieve the goal, the occurrence of dangerous behaviors, and the ability to initiate preparation of each food item. The results suggested that participants with TBI produced a significantly greater proportion of both quantitative and qualitative errors during the meal preparation task, in comparison to individuals with NBD. Specifically, individuals in the TBI group produced a significantly greater number of omissions, additions, and perseverative errors than did healthy controls. Moreover, participants in the TBI group who had lower initial GCS scores and longer duration of coma produced a greater number of errors compared to those participants with higher GCS scores and shorter coma durations. This particular finding suggests that performance on a complex daily living activity such as meal preparation may be compromised by injury severity. In addition, those with TBI were significantly less likely to complete the task within the allotted time frame, to finish preparing both entrées and the dessert, and to begin the meal preparation task within an appropriate time frame, in comparison to those with NBD. Participants with TBI also produced a significantly greater number of dangerous behaviors than did those with NBD. Of note, semantic verbal fluency performance, as indicated by the total number of words generated, significantly predicted the number of perseverative errors produced during meal preparation, for the TBI group only.

Like the findings observed by Fortin and colleagues (2003), the results of the study suggest that the ability to plan and organize, as well as to self-monitor and sequence appropriate actions, may be fundamental not only to functional tasks such as meal preparation, but also to the ability to perform efficaciously on a task of semantic verbal fluency. Together, the results of both studies underscore the relevance of verbal fluency skills to a variety of functional tasks in populations with TBI (Chevignard et al., 2008; Fortin et al., 2003). Moreover, a number of other studies have also demonstrated a relationship between performance on tasks of verbal fluency and the completion of functional activities in populations with dysexecutive syndromes (Brekke et al., 1997; Cahn-Weiner et al., 2002; Farias et al., 2003; Loewenstein et al., 1989, 1992, 1995; Razani et al., 2007; Rempfer et al., 2003). Collectively, these studies have suggested that independent living may be associated with the ability to successfully perform some cognitive-linguistic tasks that may require cognitive mastery, such as verbal fluency.

To illustrate, Rempfer and colleagues (2003) investigated the relationship between phonemic verbal fluency performance and grocery shopping in a group of participants with schizophrenia. Shopping skills were assessed using the Test of Grocery Shopping Skills (TOGSS; Hamera & Brown, 2000), a measure that evaluates performance within the natural context of a grocery store. The investigators found that redundancy, an index of shopping efficiency, was significantly associated with poorer performance on the phonemic verbal fluency task, as indicated by the total number of words produced. As the number of trips to various sections and aisles in the grocery store increased, the total number of words produced on the fluency task decreased. These findings clearly highlight the integrity of verbal fluency skills to the task of grocery shopping, as the ability to plan and organize shopping, along with the ability to understand categories, are all highly pertinent for efficient shopping.

More recently, Razani and colleagues (2007) investigated the relationship between daily functional ability and performance on a phonemic verbal fluency task in a sample of participants with mild dementia and NBD. Activities of daily living were assessed using both informant-rated and performance-based measures. Specifically, the Instrumental Activities of Daily Living (I-ADL; Warren et al., 1989) asks caregivers to rate both intermediate (e.g., shopping, financial management) and basic (e.g., grooming, feeding) abilities using a three-point scale. For this measure, higher scores indicate greater functional impairment. The Direct Assessment of Functional Status (DAFS; Loewenstein et al., 1989) is a performance-based measure that assesses seven functional areas, including financial management and shopping. For this measure, higher scores represent greater independence on these tasks. The results suggested that phonemic verbal fluency performance, as indicated by the total number of words generated, was a significant predictor of the outcome scores on the DAFS Financial and Shopping Subtests for those with mild dementia. A greater number of words generated on the verbal fluency task was associated with greater independence in completing both financial and shopping tasks. In addition, phonemic verbal fluency was significantly associated with caregiver ratings on the I-ADL for participants with mild dementia, a finding that may reflect the pertinence of initiation, planning, and organizational skills that may be critical for the successful completion of these real-world tasks. Of note, these findings are in accordance with previous reports from Farias and colleagues (2003) and Loewenstein and colleagues (1992, 1995) that have suggested that the skills that mediate verbal fluency performance are also critical to the ability to complete complex, functional tasks.

The relevance of verbal fluency skills may also be integral to the completion of functional activities in individuals with NBD (Cahn-Weiner et al., 2000, 2002). To illustrate, Cahn-Weiner and colleagues (2002) explored the relationship between phonemic verbal fluency performance and functional independence in a sample of community-dwelling older participants. Daily living activities were assessed using the Occupational Therapy Assessment of Performance and Support (OTAPS; Brinson, 1996), a performance-based measure that examines everyday functioning in four areas: safety, medication administration, meal planning and preparation, and financial management. In addition, functional abilities were also assessed using a modified version of the Instrumental Activities of Daily Living and Physical Self-Maintenance Scale (LB-IADL, LB-PADL; Lawton & Brody, 1969), a measurement tool that asks caregivers to rate participant skills in basic (e.g., grooming, dressing) and instrumental (e.g., medical administration, financial management) activities. The investigators founds that performance on the phonemic verbal fluency task, as indicated by the total number of words produced, was significantly associated with scores reported by caregivers on the LB-IADL. Successful performance on the verbal fluency task was associated with greater independence in the ability to manage both medication and finances, as reported by caregivers. Of interest, the investigators found no significant relationship between verbal fluency performance and scores on the LB-PADL or the OTAPS. However, the investigators postulated that older individuals who reside within the community will often complete these types of tasks with minimal, if any, assistance rendered by others. Therefore, caregiver ratings of these functional skills may provide a more accurate assessment of an older individual's ability to perform these types of functional tasks.

Collectively, these studies have indicated that efficacious performance on verbal fluency tasks, as indicated by the total number of words generated, may be associated with an individual's level of independence in completing functional tasks. Within this context, tasks of verbal fluency may offer a unique means by which to predict who may or may not have difficulties in managing cooking, shopping, and other types of functional tasks following a brain injury such as TBI.

CHAPTER II

LITERATURE REVIEW

The Mechanism of Injury in Traumatic Brain Injury

Disturbances in semantic and phonemic verbal fluency are commonly observed following TBI (Iverson et al., 1999; Jennett & Bond, 1975; Ruff et al., 1986). One potential account for the presence of these deficits may rest in the mechanism of injury by which MOD/S TBI typically occurs (Alexander, 1995; Greve & Zink, 2009; Maas, Stocchetti, & Bullock, 2008; McAllister, 2011; Werner & Engelhard, 2007). The pathophysiology associated with MOD/S TBI reflects the impact of both primary and secondary injuries to the cerebral cortices (Curry, Viernes, & Sharma, 2011; Maas et al., 2011; Zappalà, Thiebaut de Schotten, & Eslinger, 2011). Together, these injuries may induce rapid deformation of both cortical and subcortical tissue (Maas et al., 2011; Zappalà et al., 2011). Primary injuries reflect a combination of mechanisms that may initiate a cascade of events that in turn, may produce widespread, multifocal, and diffuse damage that will vary according to the severity of impact (Zappalà et al., 2011). In the existing literature, two mechanisms of primary injury have been described (Curry et al., 2011; Zappalà et al., 2011). First, physical and mechanical forces following a coup-contrecoup impact may occur due to acceleration – deceleration or rotational forces, resulting in skull fracture, cerebral contusion, diffuse axonal injury (DAI), or expanding intracranial hematoma (Curry et al., 2011; McAllister, 2011; Zappalà et al., 2011). It is the acceleration – deceleration and rotational forces that induce movement of brain mass that, due to its inertia, will lag behind or continue to move in relation to the cranium, producing damage most prominently within frontotemporal, occipital, and subcortical regions (McAllister, 2011; Zappalà et al., 2011). Of note, the resultant damage is believed to be greater for closed or nonpenetrating head injury where the skull remains intact, thus allowing for a potential increase in intracranial pressure that may further compromise neural integrity (Curry et al., 2011; Maas et al., 2008; McAllister, 2011; Zappalà et al., 2011). Moreover, the primary injury may produce a number of physiological events, including inflammatory processes, edema formation, and excitotoxicity, that may further exacerbate the increase in intracranial pressure (Curry et al., 2011). Second, shearing, straining, and stretching forces are thought to further contribute to the presence of DAI (Zappalà et al., 2011). DAI is characterized by widespread subcortical white matter degeneration, particularly within the frontal lobes (Marquez de la Plata et al., 2011; Zappalà et al., 2011). Moreover, the integrity of white matter tissue is believed to be correlated with both the severity of the injury, as well as the outcome (Kraus, Susmaras, Caughlin, Walker, Sweeney, & Little, 2007). To illustrate, Kraus and colleagues (2007) found that global white matter neuropathology, as evidenced by diffusion tensor imaging (DTI), was associated with decrements in performance on a number of cognitive-linguistic tasks, including memory, attention, and phonemic and semantic verbal fluency, in participants with mild to severe TBI. In addition to the primary injury, secondary injuries occur as a consequence of the physiological insults initiated by the primary injury and may evolve over a variable period of time following the initial trauma (Curry et al., 2011; Maas et al., 2008; McAllister, 2011; Zappalà et al., 2011). Secondary injuries may include a complex cascade of biochemical events that lead to the development of cerebral edema, increased intracranial pressure, and traumatic hematomas that are activated by the initial traumatic injury (Curry et al., 2011; Greve & Zink, 2009; McAllister, 2011; Zappalà et al., 2011). In essence, it is the presence of secondary injuries that may further compromise both cortical and subcortical tissue, extending from cortex to brain stem, and that may worsen the outcomes for survivors of MOD/S TBI (Curry et al., 2011; Greve & Zink, 2009; McAllister, 2011). The delineation of events that occur during and after MOD/S TBI clearly underscores the notion that brain injury is not a static event, but rather, a continuous and progressive injury (Kim & Gean, 2011). Together, primary and secondary injuries may disrupt multiple, widely distributed neural networks that may compromise a number of cognitive-linguistic functions, including phonemic and semantic verbal fluency, working memory (WM), and information processing speed (Kraus et al., 2007; McAllister, 2011; Zappalà et al., 2011).

While a number of critical neural areas may be compromised by MOD/S TBI, the areas most noted to incur damages are the frontal-subcortical circuits and their associated connections, areas that are believed to mediate a variety of cognitive-linguistic functions, including semantic and phonemic verbal fluency (Baldo & Shimamura, 1998; Birn et al., 2010; Troyer, Moscovitch, Winocur, Alexander, & Stuss, 1998; McAllister, 2011; Zappalà et al., 2011). Three primary frontal-subcortical networks have been identified in the existing literature (McAllister, 2011). First, a circuit that comprises the dorsolateral prefrontal cortex is thought to subserve a variety of executive functions, including working memory (WM), attention, speed of information processing, reasoning, problem solving, and mental flexibility (McAllister, 2011; Zappalà et al., 2011). Next, a circuit arising from the orbitofrontal cortex may play an integral role in the ability to self-monitor and self-correct during the execution of cognitive-linguistic tasks. Last, the anterior cingulate, along with its projections to the prefrontal cortex, parietal cortices, amygdala, and hypothalamus, are believed to mediate motivation, decision making, memory, and error detection. In addition, these neural regions may be further supported by medial temporal areas that may have a prominent role in episodic memory, new learning, and the validation of stimulus salience (McAllister, 2011). Within this context, the key regions that are particularly susceptible to damage following MOD/S TBI overlap with a number of areas within frontal subcortical circuits (McAllister, 2011; Zappalà et al., 2011). Thus, the presence of deficits within a number of cognitive-linguistic functions, including phonemic and semantic verbal fluency, may be reasonably anticipated following MOD/S TBI (Godefroy, 2003; McAllister, 2011; Wood, 2004).

Theories of Verbal Fluency Performance

The integrity of verbal fluency performance is believed to be predicated on the ability to adequately search for and retrieve relevant words from the appropriate phonemic or semantic category (Abwender, Swan, Bowerman, & Connolly, 2001; Birn et al., 2010; Crowe, 1998; Raskin & Rearick, 1996; Ruff et al., 1997; Stuss et al., 1998; Troyer et al., 1997). Two theories have been posited in an effort to more clearly elucidate the neural organization, activation, and retrieval of words and their related associates (Anderson & Pirolli, 1984; Bousfield & Sedgewick, 1944; Collins & Loftus, 1975; Gruenewald & Lockhead, 1980; Rosen & Engle, 1997; Schwartz, Baldo, Graves, & Brugger, 2003; Wixted & Rohrer, 1994). First, the spreading activation account of semantic processing postulates that words are grouped by their relatedness to form an integrated semantic network of all related words. To illustrate, the word *tiger* may be grouped with similar words, such as *bear* and *lion*, to form the larger category or semantic network of *animal names* (Anderson & Pirolli, 1984; Collins & Loftus, 1975). The second theory proposes that the retrieval of words begins with an initial search for a relevant category, such as *animal names*. Once the appropriate category has been retrieved, words within that particular category, such as *dog* or *cat*, will be produced (Gruenewald & Lockhead, 1980; Herrmann & Pearle, 1981; Unsworth et al., 2010; Wixted & Rohrer, 1994). Together, these theories suggest that words and the semantic categories to which they belong are organized in anatomically discrete yet highly interactive neural areas (Farah

& McClelland, 1992; Thompson-Schill, Aguirre, D'Esposito, & Farah, 1999). Further, it is the functional organization of these semantic networks or categories that may subserve the formation of distinct conceptual categories (Barsalou, 1992; Caramazza & Shelton, 1998; Warrington & Shallice, 1984).

The spreading activation account of semantic processing attempts to account for the manner in which words are organized (Anderson & Pirolli, 1984; Collins & Loftus, 1975). This theory postulates that words form a structured semantic network that consists of all related words (Anderson & Pirolli, 1984; Collins & Loftus, 1975). The process of spreading activation occurs when a word or a collection of highly similar words serve to activate or prime a local network of highly related words (Anderson & Pirolli, 1984; McClelland & Rumelhart, 1989). To illustrate, a single word (e.g., *dog*) is organized or grouped amongst similar words (e.g., *cat*, *fish*) to form a larger semantic category (e.g., *animals*). Some words, such as *dog* and *cat*, share greater similarities than do words, such as *bread* and *milk*, that come from a different semantic category (e.g., *foods*). As such, words are grouped based on similarity and attribute to form distinct semantic categories (Anderson & Pirolli, 1984; Collins & Loftus, 1975).

The strength of relatedness between individual words is further thought to reflect the Hebbian principle (Hebb, 1949), a theory that suggests that neurons or neuronal networks that underlie the retrieval of related words and that are wired together, will fire together. In accordance with the assumptions of Collins and Loftus (1975), the activation of one word may automatically activate or prime a network of closely related words contained within a subcategory that is embedded within a larger parent category. As an illustration, retrieval of the word *dog* may prime the retrieval of closely associated words, such as *cat* and *fish*, all of which belong to the greater category of *animals* but that also belong to the common subcategory of *pets*.

The extent and degree of the spread of activation is further thought to depend, in part, on the strength of the initial activation of the word. Greater initial activation or priming will produce a greater spread of priming from one word to the next, including activation within distantly or weakly related subcategories (Collins & Loftus, 1975; Glass & Holyoak, 1986). As an example, retrieval of the word *dog* may not only activate the names of other types of *pets*, but may also prime the retrieval of words that share similar features with the word *dog*, such as *wolf, coyote*, and *fox*.

The spreading activation theory may account for the structure and arrangement of words generated on tasks of verbal fluency (Schwartz & Baldo, 2001; Schwartz et al., 2003; Troyer, 2000). For example, individuals with NBD will tend to produce clusters or groups of words that are semantically or phonemically related (Bousfield & Sedgewick, 1944; Gruenewald & Lockhead, 1980; Raskin, Sliwinski, & Borod, 1992; Wixted & Rohrer, 1994). The retrieval of words is further constrained by rules that provide structure to the memory search, such as avoiding proper names and repetitions (Borkowski et al., 1967; Delis, Kaplan, & Kramer, 2001; Glass & Holyoak, 1986). In essence, individuals who are free from brain damage do not typically generate free verbal associations or engage in random memory searches when completing tasks of verbal fluency. Rather, effective performance is thought to be predicated on the ability to retain and follow specific rules, to employ methodical category search and retrieval processes, and to rapidly produce as many unique words as possible (Benton, 1968; Borkowski et al., 1967; Collins & Loftus, 1975; Delis et al., 2001).

Schwartz and colleagues (2003) clearly demonstrated the concept of spreading activation during verbal fluency performance in a group of adult participants with NBD. In this study, participants were instructed to name as many nouns as possible that began with the letters *A* or *F*, and for the categories of *animals* or *fruits*. Participants were encouraged to switch between the letters and categories as often as they chose. An analysis of the types of words generated suggested that participants most often grouped words according to size, domesticity, and prototypicality on the semantic verbal fluency task, and along an animate-inanimate dichotomy on the phonemic verbal fluency task. As an illustration, one type of pattern observed on the semantic verbal fluency task indicated a clustering of relatively large items, such as *watermelon, giraffe,* and *elephant,* followed by a clustering of much smaller items, such as *raspberry, strawberry,* and *mouse.* In contrast, clusters of words generated on the phonemic verbal fluency task tended to be animate or living, as in the example *ant, anteater,* and *animal,* or inanimate, as in the trio *air, floor,* and *airplane*. These results suggest that words generated on both types of fluency tasks were guided by semantic organization that further reflected the principal of spreading activation. Within this context, two factors appeared to govern word production in this study. First, the structure of semantic networks appeared to activate words according to their semantic proximity. Second, the time constraints imposed upon task performance may have restricted the search process to the retrieval of only those words that were highly similar and readily activated.

A second theory, closely associated with the spreading activation model, may also account for the retrieval of appropriate words during tasks of verbal fluency. In this model, retrieval of relevant words occurs in a two-stage, cyclical search process wherein individuals will first search for appropriate subcategories, then search for specific words within those subcategories (Gruenewald & Lockhead, 1980; Herrmann & Pearle, 1981; Unsworth et al., 2010; Wixted & Rohrer, 1994). For example, individuals who are instructed to generate as many words as possible for the category of *animals* will first search for specific subcategories of *animals* (e.g., *pets*), then search for specific items from within that particular subcategory (e.g., *dog, cat*) (Gruenewald & Lockhead, 1980; Herrmann & Pearle, 1981; Wixted & Rohrer, 1994). Once a given subcategory is exhausted, they will then initiate a new search for a different subcategory (e.g., *farm animals*) and retrieve the words contained within the new subcategory (e.g., *cow, sheep*). The processes of search and retrieval suggest that individuals will generate clusters of semantically related items that are further characterized by distinct pauses between clusters as they search for relevant words (Bousfield &

Sedgewick, 1944; Gruenewald & Lockhead, 1980). Within this context, individuals who are asked to complete a verbal fluency task will rapidly recall semantically and phonemically related items in succession.

In addition, the two-stage search framework has received substantial support in the literature (Gruenewald & Lockhead, 1980; Rosen & Engle, 1997; Unsworth et al., 2010; Wixted & Rohrer, 1994). In a seminal study, Gruenewald and Lockhead (1980) investigated the free recall abilities of two groups of participants with NBD. One sample of participants generated as many words as possible within a 15 minute time limit for one of four categories: *animals, birds, foods*, or *cold foods*. The second group of individuals produced as many words as possible for the broad category of *animals* within 30 minutes. The results indicated that the number of words produced, regardless of semantic category, decreased as a function of time, with clusters of semantically related words produced in rapid succession. In addition, time between clusters increased as time on task increased, a finding that may reflect the search for appropriate semantic fields. Thus, these results are consistent with the proposed two-stage model of word retrieval in that participants will first search for a semantic field, and then produce the items contained within this particular field.

The Neural Correlates of Verbal Fluency Performance

Within this context, a number of studies have attempted to identify the neural correlates of verbal fluency performance in populations with and without acquired brain damage (Baldo & Shimamura, 1998; Birn et al., 2010; Bonelli et al., 2011; Chen et al., 2009; Costafreda et al., 2006; Cuenod et al., 1995; Goldstein, Obrzut, John, Hunter, & Armstrong, 2004; Kircher, Nagels, Kirner-Veselinovic, & Krach, 2011; Libon et al., 2009; Sanchez-Castaneda et al., 2010; Schweizer, Alexander, Gillingham, Cusimano, & Stuss, 2010; Senhorini et al., 2011; Sheldon & Moscovitch, 2011; Troyer, Moscovitch, Winocur, Alexander, et al., 1998; Yogarajah et al., 2010). Some findings have implicated the frontal cortices in the mediation of phonemic verbal fluency performance, via the use of phonemic or lexical cues for appropriate word generation (Birn et al., 2010; Ho et al., 2002; Troyer, 2000). Patients with lesions confined to the frontal lobes and those with frontal lobe dysfunction, as is often observed in patients with Parkinson’s disease, have demonstrated disproportionate impairment on phonemic verbal fluency tasks, in comparison to semantic verbal fluency tasks (Baldo, Shimamura, Delis, Kramer, & Kaplan, 2001; Flowers, Robertson, & Sheridan, 1995; Stuss et al., 1998; Troyer, Moscovitch, Winocur, Alexander, et al., 1998). In addition, impairment has also been noted to be particularly pronounced when lesions are confined to the left frontal lobe (Baldo et al., 2001; Henry & Crawford, 2004a; Stuss et al., 1998; Troyer, Moscovitch, Winocur, Alexander, et al., 1998).

For example, Baldo and colleagues (2001) investigated the relationship between phonemic and semantic verbal fluency performance in a group of participants with focal, frontal lobe lesions and a group of participants with NBD. Participants were instructed to generate as many words as possible within a 60-

second time limit for the letters *F, A*, and *S*, and for the categories of *animals* and *boys' names*. In addition, participants were also asked to generate as many words as possible while switching between the semantic categories of *fruits* and *furniture*. The critical measure of performance for all fluency tasks was the total number of words produced. The results suggested that participants with frontal lobe lesions produced significantly fewer correct words on both types of verbal fluency tasks, with decrements most notably observed on the phonemic task, in comparison to healthy controls. All participants, regardless of group, were significantly impaired on the switching task. Of particular interest is the finding that participants with lesions confined to the left frontal lobe performed significantly more poorly on both phonemic and semantic verbal fluency tasks, in comparison to those with lesions localized in the right frontal lobe. Together, these results suggest that the frontal cortices, and in particular, the left frontal lobe, are fundamental to efficacious performance on these types of tasks, with performance on the phonemic task noted to be most adversely affected by the presence of frontal lobe lesions.

The results observed by Baldo and colleagues (2001) are in agreement with previous studies that have also demonstrated a prominent role for the frontal cortices in performance on phonemic verbal fluency tasks (Jurado, Mataro, Verger, Bartumeus, & Junque, 2000; Monsch et al., 1994; Stuss et al., 1998; Troyer, Moscovitch, Winocur, Alexander, et al., 1998). As an example, Stuss and colleagues (1998) examined phonemic verbal fluency performance in groups of participants with NBD and with focal brain lesions. Those with focal brain lesions were further divided according to standard neural regions, such as right and left frontal and nonfrontal areas. The investigators observed that individuals in the bifrontal and left frontal lobe groups produced significantly fewer total words, compared to those with NBD. In contrast, those with nonfrontal lobe lesions, and in particular, those whose lesions were confined to the right hemisphere, were not impaired on the phonemic task, as indicated by the total number of words produced.

Yet, the existent literature does not unequivocally support a preferential bias for the frontal lobes in tasks of phonemic verbal fluency (Baldo & Shimamura, 1998; Benton, 1968; Butler, Rorsman, Hill, & Tuma, 1993; Goldstein et al., 2004). For example, Baldo and Shimamura (1998) explored the relationship between phonemic and semantic verbal fluency performance in a group of participants with unilateral prefrontal lesions and a group of participants with NBD. Participants were asked to generate as many words as possible within a 60-second time limit for the letters *F, A*, and *S*, and for the categories of *animals, fruits*, and *occupations*. The critical measure of performance was the total number of words generated for each verbal fluency task. The results suggested that participants with frontal lobe lesions did not exhibit disproportionate impairment on the phonemic verbal fluency task in comparison to the semantic verbal fluency task. Rather, those with frontal lobe lesions produced significantly fewer correct words on both types of fluency tasks in comparison to the NBD group. In addition, the investigators did not observe a significant interaction between type of fluency task and participant group, a finding that suggests that participants' impairment on both types of fluency tasks was comparable. Together, these findings suggest that the frontal lobes are integral to the retrieval of all types of words, regardless of whether they are elicited by first letter or by category cues.

More recently, Goldstein and colleagues (2004) investigated performance on tasks of phonemic and semantic verbal fluency in participants with low-grade brain tumor confined to either the left hemisphere (LH) or right hemisphere (RH), and a group of healthy controls. Participants with brain tumor were further divided into combined anterior (i.e., left and right) and combined posterior (i.e., left and right) groups. All participants were asked to generate as many words as possible for three letters of the alphabet and for the category of *animal names* within a 60 second time limit. The investigators found that participants in the LH group performed significantly worse than those in the RH group and healthy controls, as indicated by the total number of words produced, on the semantic verbal fluency task. In contrast, no significant hemispheric group differences were observed on the phonemic verbal fluency task. However, healthy controls produced a greater number of words on the phonemic verbal fluency task, followed by the RH group, then the LH group, who produced the fewest responses. In examining performance differences relative to tumor region (e.g., right anterior, left anterior, right posterior, and left posterior), the investigators found no significant differences on either phonemic or semantic verbal fluency, as indicated by the total number of words produced, compared to healthy controls. When Goldstein and colleagues (2004) compared performance between the combined anterior, combined posterior, and control groups, they observed significant group differences between the two diagnostic groups and healthy controls on both the phonemic and semantic verbal fluency tasks. Specifically, healthy controls produced a greater number of words for both verbal fluency tasks, followed by the combined posterior group, and then the combined anterior group. No significant differences between the combined anterior and combined posterior groups were observed on either verbal fluency task. These findings suggest that both types of verbal fluency tasks may be mediated by multiple or parallel routes throughout cortical areas of the brain, although semantic verbal fluency may be particularly compromised by the presence of left hemispheric lesions, regardless of location.

Disturbances in phonemic verbal fluency have also been documented in participants with NBD during concurrent and divided attention tasks, both of which are believed to simulate frontal lobe dysfunction (Martin, Wiggs, Lalonde, & Mack, 1994; Moscovitch, 1992; Rosen & Engle, 1997; Troyer et al., 1997). For example, Martin and colleagues (1994) predicted that the performance of a concurrent motor sequencing task would interfere with the retrieval of words by initial letter, but not by category, as indicated by the total number of words generated. Both phonemic verbal fluency and motor performance tasks are believed to tap frontally mediated resources such that the concurrent performance of both produces decrements in performance on each task.

In this study, Martin and colleagues (1994) asked participants with NBD to generate as many words as possible for the letters *C, F*, and *L* and for the semantic categories of *animals, furniture*, and *clothing,* under three conditions: baseline, motor sequencing, and object decision making. In the baseline condition, participants simply generated words for each verbal fluency task. In the motor sequencing condition, participants were instructed to tap four adjacent keys on a keyboard while generating words for the verbal fluency tasks. In the object decision task, participants were asked to judge the plausibility of an object while producing words for each fluency task.

The results lent support to the predictions of Martin and colleagues (1994) as the concurrent performance of a motor sequencing task significantly reduced the total number of words generated on the phonemic verbal fluency tasks only. In contrast, the object decision condition significantly disrupted performance on the semantic verbal fluency tasks only, although the effect of interference was not as great as that observed for phonemic verbal fluency – motor sequencing condition. In general, the investigators found that participants generated a greater number of words for the semantic verbal fluency tasks, relative to the number of words generated on the phonemic verbal fluency tasks, regardless of condition. These findings suggest that retrieval by initial letter and by semantic category may be differentially disrupted by the concurrent performance of tasks that may tap shared resources that are fundamental to the performance of each type of verbal fluency task. In this study, Martin and colleagues (1994) found that performance on the phonemic verbal fluency tasks, as indicated by the total number of words generated, was particularly susceptible to disruption by the concurrent performance of a motor sequencing task, compared to the differential effect observed on the semantic verbal fluency tasks. This particular finding suggests that both phonemic verbal fluency and motor performance depend upon the integrity of the frontal cortices for efficacious performance. While performance decrements on the semantic verbal fluency – object decision condition were not as great, performance nonetheless appears to rely upon frontal lobe mediated processes to some degree. Further, the finding that all participants, regardless of condition, generated a greater number of total words for the semantic verbal fluency task, in comparison to the phonemic verbal fluency task, is supported by previous research that has also found that generation by initial letter requires greater effort than generation by semantic category (Crowe, 1998; Kemper & Sumner, 2001; Kozora & Cullum, 1995; Monsch et al., 1994; Troyer et al., 1997). Of note, the superiority effect of semantic category over initial letter, relative to total number of words produced, has also been observed in populations with TBI (Capitani et al., 2009; Goldstein et al., 1996; Lannoo et al., 1998; Raskin & Rearick, 1996) and focal frontal lesions (Baldo et al., 2001; Jurado, et al., 2000).

In contrast, the temporal lobes may have a prominent role in the mediation of semantic verbal fluency performance (Birn et al., 2010; Laisney et al., 2009; Monsch et al., 1994; Sheldon & Moscovitch, 2011; Troyer, Moscovitch, Winocur, Leach, & Freedman, 1998). Semantic verbal fluency is believed to be predicated upon the ability to search and retrieve semantic knowledge that is thought to be housed within temporal areas (Ho et al., 2002; Troyer, 2000). Patients with lesions confined to the temporal lobes and those with conditions that are believed to compromise temporal lobe integrity, such as Alzheimer's disease (AD), have demonstrated disproportionate impairment on semantic verbal fluency tasks, in comparison to phonemic verbal fluency (Monsch et al., 1994; Troyer, Moscovitch, Winocur, Alexander, et al., 1998; Troyer, Moscovitch, Winocur, Leach, et al., 1998). Further, impairment has been found to be particularly marked when lesions are confined to the left temporal lobe (Troyer et al., 1998a).

As an example, Troyer, Moscovitch, Winocur, Alexander, and Stuss (1998) investigated phonemic and semantic verbal fluency performance in participants with either focal frontal lobe (FL) or focal temporal lobe (TL) lesions, and a group of participants with NBD. The diagnostic groups were further divided according to specific lesion site. For example, those with focal frontal lesions were grouped by the presence of lesions in the left dorsolateral frontal area (LDLF); right dorsolateral frontal region (RDLF); superior medial frontal area (SMF); and inferior medial frontal region (IMF). Participants with temporal lobe lesions were divided into two groups: unilateral left temporal lobe lesions (LTL) and unilateral right temporal lobe lesions (RTL). For the phonemic verbal fluency task, all participants were asked to generate as many words as possible for the letters *F, A*, and *S*. For the semantic verbal fluency task, they generated as many words as possible for the category of *animals*. The results indicated that individuals in the LDLF and SMF subgroups were significantly impaired on the phonemic fluency task, as indicated by the total number of words produced, in comparison to participants in the RDLF and IMF subgroups and healthy controls. In addition, participants in the LDLF group performed significantly worse, compared to the other FL subgroups and participants with NBD, on the semantic verbal fluency task, as indicated by the total number of words generated. However, the investigators noted that all FL subgroups exhibited some degree of diminished performance on the semantic verbal fluency task, in comparison to those with NBD. In examining the performance of those in the TL group, the investigators found no significant group differences on the phonemic verbal fluency task, as indicated by the total number of words generated. However, individuals in the LTL group were significantly impaired on the semantic verbal fluency task, in comparison to participants with NBD. These findings suggest that phonemic verbal fluency performance is predicated on the integrity of the frontal cortices, as participants with FL lesions, but not TL lesions, were markedly impaired in their performance on this task. Further, the observation that both diagnostic groups were impaired on the semantic verbal fluency task suggests that performance is not specific to temporal lobe functioning. Rather, performance on this particular task may require the integrity of both frontal and temporal areas for efficacious performance (Henry & Crawford, 2004a; Laws, Duncan, & Gale, 2010).

More recently, Laisney and colleagues (2009) explored the relationship between phonemic and semantic verbal fluency performance and the neural mechanisms that are thought to underlie these tasks in participants with frontal variant of frontotemporal dementia (fv-FTD), semantic dementia (SD), and a group of participants with NBD. Participants were instructed to generate as many words as possible within a two-minute time frame for the letter *P* and the category *animals*. In addition, participants in both diagnostic groups completed a resting positron emission tomography (PET) examination. The results of this particular analysis were then used to compare the resting-state glucose uptake in the whole brain with the verbal fluency scores for each diagnostic group. The findings demonstrated that both diagnostic groups performed significantly more poorly than healthy controls on both types of verbal fluency tasks, but with different patterns of performance. For example, participants in the fv-FTD group produced a significantly greater number of total words on the semantic verbal fluency task only than did participants in the SD group. No significant differences were observed between the diagnostic groups on the phonemic verbal fluency task, as indicated by the total number of words produced, compared to healthy controls. In addition, those in the SD group were equally impaired on both types of verbal fluency tasks. The results of the PET examination also correlated with performance on both verbal fluency tasks in the diagnostic groups. Participants with fv-FTD demonstrated a significant increase in metabolic activity in the frontal cortices during performance on both verbal fluency tasks, a finding that suggests a preferential role for these areas in efficacious performance on these types of tasks. This particular finding may reflect the influence of executive processes, including strategic search and retrieval from semantic stores, which are believed to be mediated by the frontal lobes. In contrast, individuals with SD exhibited a significant increase in resting-state glucose levels within the left temporal lobe only, a finding that may implicate a role for semantic memory in this task. The investigators postulated that this particular finding may reflect the integrity of the left temporal lobe in the ability to search and retrieve from specific semantic categories. Collectively, the results further suggest that verbal fluency performance relies upon the coordinated activity of a number of neural regions, most notably in the frontal and temporal cortices of the left hemisphere.

In a similar study, Libon and colleagues (2009) compared the performance of participants with behavioral/dysexecutive disorder secondary to frontotemporal lobar degeneration (bvFTLD), semantic dementia (SemD), and progressive nonfluent aphasia (PNFA) on tasks of phonemic and semantic verbal fluency. Briefly, participants were asked to generate as many words as possible for the letters *F, A,* and *S* for the phonemic condition, and for the semantic category of *animals*, while undergoing MRI. Performance was predicated on the total number of correct words generated for both tasks. The investigators further employed normalization and template-based cortical MRI scans previously obtained from a sample of healthy control participants to compare the imaging data from the diagnostic groups. Relative to task performance, the results indicated that participants with PNFA produced fewer words on the phonemic verbal fluency task than did those in the bvFTLD and SemD groups. For the semantic verbal fluency task, Libon and colleagues (2009) found that the SemD group produced fewer words than either the bvFTLD or PNFA groups. Participants with bvFTLD and PNFA were noted to be equally impaired on both verbal fluency tasks. In addition, the presence of cortical atrophy as indicated by MRI was correlated with performance on both types of verbal fluency tasks for the diagnostic groups. Specifically, participants with SemD had significant bilateral anterior temporal lobe atrophy, a finding that may, in part, account for their diminished performance on the semantic verbal fluency task. In addition, the SemD group also evidenced atrophy in both anterior and inferior left temporal regions during performance on both verbal fluency tasks. For the bvFTLD group, the investigators observed distributed cortical atrophy in bifrontal and bitemporal regions that was most prominent in the right cerebral hemisphere. Specifically, for the bvFTLD group, performance on the phonemic verbal fluency task was related to frontal lobe atrophy bilaterally, while performance on the semantic verbal fluency task was related to left frontal and temporal lobe atrophy. Participants in the PNFA group evidenced significant frontal lobe atrophy bilaterally that was most extensive within the left cerebral hemisphere, a finding that is in accordance with previous studies that have also reported a relationship between frontal lobe impairment and diminished performance on phonemic verbal fluency tasks (Baldo et al., 2001; Flowers et al., 1995; Stuss et al., 1998; Troyer, Moscovitch, Winocur, Alexander, et al., 1998). For the PNFA group, the investigators found that performance on the semantic verbal fluency task was related to right frontal and left temporal lobe atrophy, while performance on the phonemic verbal fluency task was associated with left temporal lobe atrophy. The results of this study indicate that both types of verbal fluency tasks demand the integrity of frontal and temporal cortices for effective performance.

The observations made by Laisney and colleagues (2009) and Libon et al. (2009) have been previously documented in studies that have employed neuroimaging techniques to investigate the relationship between neural areas and verbal fluency performance in participants with NBD (Birn et al., 2010; Cuenod et al., 1995; Elfgren & Risberg, 1998; Hirshorn & Thompson-Schill, 2006; Parks et al., 1988). For example, Birn and colleagues (2010) investigated the differential involvement of frontal and temporal areas during phonemic and semantic verbal fluency performance in a group of individuals with NBD. Participants completed five task conditions while undergoing functional magnetic resonance imaging (fMRI): retrieval from single letter, single semantic category, two letters, two categories, and a baseline condition. For the baseline condition, participants were instructed to name the months of the year. For the single letter and single category conditions, participants generated as many words as possible that begin with an initial letter or that belonged to a semantic category. During the two letters and two categories conditions, participants produced as many words as possible while alternating between two given letters or categories. Birn and colleagues (2010) observed greater activation in the left cerebral hemisphere during the category and letter fluency tasks, and in the right hemisphere during the baseline condition. In addition, both letter and category conditions produced activation across frontal and temporal areas. Specifically, the letter fluency condition produced robust activation in the left inferior frontal gyrus, bilateral superior parietal lobe, and in the bilateral occipitotemporal cortex. In contrast, the category fluency condition produced greater activation in the occipital cortex, the left fusiform gyrus of the temporal lobe, and the left medial frontal gyrus. In addition, the switching condition activated a number of the same neural areas, including the left medial frontal gyrus, left superior parietal cortex, the left fusiform gyrus of the temporal lobe, and the precuneus. The findings from this study lend robust support to the theory that phonemic and semantic verbal fluency tasks depend upon the differential involvement of a number of distinct areas within frontal and temporal cortices for successful performance. The robust activation observed in the left cerebral hemisphere for both types of verbal fluency tasks suggests that this neural area may be integral in the search for and retrieval of appropriate words, as well as for the articulation of the retrieved words. Further, while both types of verbal fluency tasks share many of the same cognitive processes for effectuation, including sustaining attention, search and retrieval of appropriate words, and inhibiting errors and repetitions, there are also important differences. For example, phonemic verbal fluency is thought to require the ability to search and retrieve appropriate words based on orthographically encoded information (Collins & Loftus, 1975; Cuenod et al., 1995; Elfgren & Risberg, 1998; Frith, Friston, Liddle, & Frackowiak, 1991).

In contrast, semantic verbal fluency is believed to depend on the ability to search and retrieve from semantic stores (Butters, Granholm, Salmon, Grant, & Wolfe, 1987; Ober, Dronkers, Koss, Delis, & Friedland, 1986; Troester, Salmon, McCullough, & Butters, 1989). In this study, Birn and colleagues (2010) found that the letter category condition elicited greater activation in the frontal cortices, neural areas that have been previously implicated in phonemic verbal fluency performance. In contrast, they found that the semantic category condition elicited greater neural response in temporal areas and to a lesser degree, in frontal regions, a finding that suggests that both neural areas are necessary for task performance.

More recently, two studies have examined the neural correlates of phonemic and semantic verbal fluency performance (Kircher et al., 2011), and of phonemic verbal fluency performance only (Senhorini et al., 2011), in non-English speaking populations. While some evidence suggests that performance on these types of tasks may vary depending on the language spoken (Paulesu et al., 1996; Machado et al., 2009; Sumiyoshi et al., 2004), it is unclear if these differences may be associated with differences in patterns of neural activation.

Senhorini and colleagues (2011) investigated patterns of regional cerebral activation via fMRI in 21 Portuguese participants with NBD who completed a phonemic verbal fluency task that had two levels of difficulty. Participants generated as many words as possible for the letters *P, F, M, C, L, B* and *T* in the easy condition, and for the letters *N, I, D, R, V, G,* and *A* in the difficult condition. The letters were selected based upon the results of a previous validation study (Senhorini, Amaro, Ayres, Simone, & Busatto, 2006). Performance was analyzed for each condition based upon the total number of errors produced. The results suggested that participants produced a significantly greater number of errors during the difficult condition in comparison to the easy condition, with the most common error being the utterance of the word “pass” during those trials in which a participant was unable to produce any words that began with a specific letter. An analysis of the fMRI data indicated activation in the medial temporal gyrus, hippocampus, insula, left putamen, and right medial frontal cortex during the easy condition. For the difficult condition, the investigators observed activation in the right medial temporal gyrus, left ventrolateral prefrontal cortex, and anterior cingulate cortex. Together, both conditions elicited robust activation across a distributed neural network, including the left inferior and middle frontal cortices, left prefrontal cortex, anterior cingulate cortex, putamen, thalamus, insula, and cerebellum. These findings are in accordance with previous studies of verbal fluency conducted in English that have also observed similar widespread cerebral activation during word generation tasks (Birn et al., 2010; Cuenod et al., 1995; Elfgren & Risberg, 1998; Parks et al., 1988; Sheldon & Moscovitch, 2011).

In addition, Kircher and colleagues (2011) observed similar areas of neural activation across a distributed language network for both phonemic and semantic verbal fluency tasks in a group of 15 German-speaking participants with NBD. Participants were asked to complete three different verbal fluency tasks while undergoing fMRI. In the phonemic condition, participants generated as many words as possible that began with the letter *D*. For the semantic verbal fluency task, participants produced as many words as possible that belonged to the category of *animals*. In the third task, they were asked to generate as many words as possible that rhymed with a pseudoword. Relative to task performance, the investigators found that participants generated a significantly greater number of words for the semantic category of *animals*, followed by the letter *D*. Participants generated the fewest words in the rhyming verbal fluency condition. The results of the fMRI analysis suggested a robust activation in the left and right medial frontal and precentral gyrus, and right middle and superior temporal gyri, for the phonemic verbal fluency task. In contrast, the investigators observed activation in the right superior frontal and left medial frontal gyri, and the left superior temporal and postcentral gyri during the semantic verbal fluency task. Collectively, all three verbal fluency tasks evidenced activations in the left inferior frontal gyrus, middle and superior temporal gyrus, and bilateral motor cortical areas. While temporal areas were significantly more activated during the semantic verbal fluency task, in comparison to the phonemic verbal fluency task, the results are in accordance with previous findings that have suggested that both types of verbal fluency, regardless of the language spoken by participants, depend upon a distributed neural network for efficacious performance (Birn et al., 2010; Sheldon & Moscovitch, 2011; Sumiyoshi et al., 2004).

Verbal Fluency Performance Following Traumatic Brain Injury

Verbal fluency performance has also been extensively studied in participants who have diffuse cerebral damage, as is often observed in populations with TBI (Bittner & Crowe, 2006, 2007; Capitani et al., 2009; Goldstein et al., 1996; Gruen et al., 1990; Jurado et al., 2000; Kavé, Heled, Vakil, & Agranov, 2011; Lannoo et al., 1998; Mathias et al., 2004; Raskin & Rearick, 1996; Ruff et al., 1986; Zakzanis, McDonald, & Troyer, 2011). The results of some of these studies have indicated that both phonemic and semantic verbal fluency performance are equally disturbed following TBI (Henry & Crawford, 2004b; Jurado et al., 2000; Lannoo et al., 1998; Raskin & Rearick, 1996).

For example, Raskin and Rearick (1996) instructed a group of participants with mild TBI (MTBI) and healthy controls to generate as many words as possible for the letters *F, A*, and *S*, and for the category of *animals*. In addition, participants were given the California Verbal Learning Test (CVLT; Delis, Kramer, Kaplan, & Ober, 1987) to assess verbal learning and recall abilities; the Wisconsin Card Sorting Test (WCST; Heaton, Chelune, Talley, Kay, & Curtiss, 1993) to assess executive function; and the Paced Auditory Serial Addition Test

(PASAT; Gronwall, 1977) to measure sustained and divided attention. The results illustrated that participants with MTBI were significantly different from those with NBD relative to the total number of words generated on both types of verbal fluency tasks. While individuals with MTBI generated fewer words for the semantic verbal fluency task in comparison to the phonemic task, there were no significant differences in the total number of words produced for each task, a finding that suggests that both types of fluency are equally impaired following MTBI. Further, the total number of words recalled on the list-learning task from the CVLT was significantly associated with the total number of words produced on the semantic verbal fluency task for individuals with MTBI only. In contrast, the total number of words produced on the phonemic task was not related to the number of words learned and recalled on the CVLT for those in the MTBI group. The investigators found no significant associations between the total number of words produced on either verbal fluency task and performance on the WCST and PASAT for the MTBI group, despite more than half of MTBI participants exhibiting impaired performance on the PASAT.

In a more recent study, Jurado and colleagues (2000) investigated phonemic and semantic verbal fluency performance in 13 participants with mild to severe TBI, characterized by the presence of unilateral or bifrontal focal frontal lobe lesions, and 26 individuals with NBD. Participants generated as many words as possible for the letters *F, A*, and *S*, and for the categories of *animals* and *supermarket goods*. The outcome of interest for both participant groups was the total number of words produced on each task. In addition, verbal fluency performance for the TBI group was further analyzed relative to the site of lesion (i.e., right, left, and bilateral frontal lobes). As a group, participants with TBI produced fewer total words on both tasks of verbal fluency, compared to healthy controls, with significant differences noted between the groups on the phonemic portion of the task only. Of particular interest is the finding that some individuals with TBI demonstrated marked impairment on both types of verbal fluency tasks, while others performed within functional range. As an example, six of the thirteen individuals in the TBI group produced as many words as healthy controls on the phonemic task, whilst another seven from this diagnostic group produced as many words as those with NBD on the semantic task. In examining performance based on site of lesion, Jurado and colleagues (2000) found that participants with lesions localized in the left frontal lobe and those with bilateral lesions generated a greater number of words for the semantic verbal fluency task in comparison to the phonemic task. This particular finding is in accordance with previous studies that have also demonstrated a preferential role for the left frontal lobe during semantic verbal fluency performance (Birn et al., 2010; Frith et al., 1991). In contrast, those with lesions isolated in the right frontal lobe generated a greater number of words for the phonemic verbal fluency task, in comparison to the semantic task. Of note, the investigators did not perform any statistical analyses to determine the level of significance between the diagnostic subgroups based on site of lesion. Jurado and colleagues (2000) found that frontal lesion size was significantly associated with performance on the semantic verbal fluency task only. As the size of the lesion increased, the total number of words produced on the semantic task decreased. The investigators speculated that semantic verbal fluency performance may be predicated on the ability to access and retrieve words from a highly distributed neural network that may be most prominently mediated by the temporal lobes. The results also suggest that while phonemic verbal fluency performance relies greatly upon the integrity of the frontal cortices, both types of verbal fluency tasks appear to use frontal lobe-mediated processes for efficacious performance. These findings are in accordance with previous postulations made by Frith and colleagues (1991) who suggested that verbal fluency performance may be predicated on the dynamic interaction between frontal and temporal areas. According to their model, the frontal cortices initiate and monitor the search and retrieval of words that are believed to be housed within temporal areas. Further, it is the highly structured semantic networks contained within temporal regions that are believed to impose certain constraints on word retrieval, such that only appropriate words are retrieved.

Yet, in contrast to the findings observed by Jurado and colleagues (2000), other studies have noted greater impairment in phonemic verbal fluency performance, compared to semantic verbal fluency performance, in individuals with TBI (Capitani et al., 2009; Levin & Goldstein, 1986). As an example, Capitani and colleagues (2009) compared phonemic and semantic verbal fluency performance, as indicated by the total number of words produced on each fluency task, in groups of individuals with TBI of unknown severity, with AD, and with NBD. In this study, participants generated as many words as possible that began with the letters *P, F*, and *L*, and for the category *animals*. The investigators employed two different methods of analysis for the total number of words generated on each fluency task. First, they calculated three types of normality scores that allowed each participant to be classified based on individual performance: impaired, borderline impairment, and within functional range. Second, Capitani and colleagues (2009) calculated an index score termed the Fluency Type Index (FTI) that served to quantify the level of proficiency of each participant on both phonemic and semantic verbal fluency tasks.

Relative to the normality analysis, the investigators found that individuals with AD exhibited greater impairment on the semantic verbal fluency task, compared to the phonemic verbal fluency task, than participants with TBI and NBD. The opposite pattern of performance was noted in participants with TBI. In addition, participants with NBD demonstrated a significant advantage on both verbal fluency tasks, as indicated by the total number of words produced, in comparison to either diagnostic group. In comparing the performance of the two diagnostic groups, Capitani and colleagues (2009) found no significant differences between the groups' performance on either task. In analyzing the data using the FTI calculation, the investigators found that participants with AD performed significantly more poorly on both types of verbal fluency tasks than did participants with NBD and TBI. This observed discrepancy in performance was particular marked between participants with AD and those with TBI. In addition, the FTI calculation also suggested significant differences in performance on both fluency tasks between individuals with TBI and healthy controls.

To date, only one study has found that individuals with TBI are differentially impaired on semantic verbal fluency, in comparison to performance on phonemic verbal fluency (Goldstein et al., 1996). In this study, Goldstein and colleagues (1996) investigated the verbal responses produced by participants with mild to moderate TBI, probable AD, and those with NBD on tasks of phonemic and semantic verbal fluency. Briefly, participants were instructed to generate as many words as possible for the letters *F* and *A*, and for the semantic categories of *animals* and *fruits/vegetables*. The results indicated that participants with NBD performed significantly better, as indicated by the total number of words generated, than individuals with TBI and AD on both types of verbal fluency tasks. Further, individuals in the TBI group generated a significantly greater number of total words on both phonemic and semantic verbal fluency tasks than did those with AD. While Goldstein and colleagues (1996) found no significant differences in the total number of words produced on either verbal fluency task for participants in the TBI group only, they observed a trend towards greater impairment on semantic verbal fluency than phonemic verbal fluency. Goldstein and colleagues (1996) speculated that their findings may reflect the inclusion of older participants in their study, as a number of studies have indicated a clear relationship between healthy aging and decrements in performance on tasks of semantic verbal fluency (Brickman et al., 2005, 2006; Haugrud, Lanting, & Crossley, 2009; Kozora & Cullum, 1995; Lanting, Haugrud, & Crossley, 2009; Libon et al., 1994; Parkin & Lawrence, 1994; Tomer & Levin, 1993; Troyer, 2000; Troyer et al., 1997). Of note, this diminished pattern of performance on semantic verbal fluency, compared to phonemic verbal fluency, has also been observed in individuals with AD (Capitani et al., 2009; Henry, Crawford, & Phillips, 2004) and with focal temporal cortical lesions (Henry & Crawford, 2004; Troyer et al., 1998a). Taken together, the results suggest that decremental performance may, in fact, reflect the presence of age-related temporal lobe atrophy (Raz et al., 1997; Scahill et al., 2003).

The Analyses of Verbal Fluency Performance

Given the variability observed in task performance following TBI, some researchers have employed both quantitative and qualitative analyses in order to explore the types of words generated and how they are organized on tasks of verbal fluency (Borkowski et al., 1967; Troyer, 2000). The most common measure employed is a quantitative analysis, defined simply as the total number of words generated on each type of fluency task (Benton, 1968; Borkowski et al., 1967). Yet, there are a number of limitations with this particular type of analysis. First, the use of a quantitative analysis does not provide a comprehensive view of the individual’s performance, including the cognitive processes that may underlie efficacious performance. Second, it fails to account for the nature and extent of deficits on these types of tasks. Last, a quantitative analysis does not fully explain why a particular diagnostic group may display diminished performance on verbal fluency tasks (Troyer, 2000). For example, some research has suggested that decrements in performance may reflect differences in participant age (Bolla, Gray, Resnick, Galante, & Kawas, 1998; Crossley, D’Arcy, & Rawson, 1997; Goldstein et al., 1996; Kozora & Cullum, 1995; Tombaugh, Kozak, & Rees, 1999; Troyer, 2000; Troyer et al., 1997), lesion site (Birn et al., 2010; Frith et al., 1991; Jurado et al., 2000), working memory (Azuma, 2004; Lam, Ho, Lui, & Tarn, 2006; Rosen & Engle, 1997; Sands, Phinney, & Katz, 2000; Unsworth et al., 2010; Witt et al., 2004; Zahodne et al., 2008), and information processing speed (Bittner & Crowe, 2007; Bryan, Luszcz, & Crawford, 1997; Bryan & Luszcz, 2000; Hedden, Lautenschlager, & Park, 2005; Miotto et al., 2010; Unsworth et al., 2010; Vikki & Holst, 1994). Given these limitations, a number of investigators have gone beyond the traditional word count by attempting to characterize the features of verbal fluency performance via a qualitative exploration of words produced (Raskin et al., 1992; Troyer, 2000; Troyer et al., 1997). These analyses have include the types of words produced, the clustering of words by semantic features, the number of clusters produced, and how frequently subcategories are exhausted and switched in favor of a new subcategory (Raskin et al., 1992; Troyer, 2000; Troyer et al., 1997).

It is well accepted in the existing literature that the generation of words on tasks of both phonemic and semantic verbal fluency tends to occur in bursts, with words typically organized according to their semantic relatedness (Bousfield &

Sedgewick, 1944; Gruenewald & Lockhead, 1980). This postulation appears to be particularly valid on semantic verbal fluency tasks, as words that are produced for a common category, such as *animals*, are frequently grouped into meaningful subcategories, such as *farm animals or pets* (Troyer, 2000; Troyer et al., 1997). Yet, semantic influences have also been found to extend to phonemic verbal fluency tasks as well (Schwartz et al., 2003). For example, Schwartz and colleagues (2003) noted that individuals with NBD grouped words that began with a common initial letter by using an animate-inanimate arrangement. To illustrate, the words *ant, anteater,* and *animal* represent an animate clustering, while the words *air, airplane,* and *act* represent an inanimate grouping. Further, the production of words for both types of fluency tasks is guided by two distinct processes: the search for relevant subcategories and then the generation of words within that particular subcategory. As subcategories are exhausted and then switched in favor of a new subcategory, the overall production and frequency of words decreases as a function of time (Bousfield & Sedgewick, 1944; Crowe, 1998; Gruenewald & Lockhead, 1980; Rosen & Engle, 1997; Unsworth et al., 2010; Wixted & Rohrer, 1994). In addition, Troyer (2000) and Troyer and her colleagues (1997) have noted that words generated on tasks of phonemic verbal fluency may also be characterized by a number of phonemic characteristics, including *first letters,* where words begin with the same first two letters, and *first and last sounds*, where words differ only by a single vowel sound.

Troyer and colleagues (1997) expanded upon these previous assertions by proposing a qualitative scoring method for analyzing the responses produced on tasks of verbal fluency. According to their method, optimal performance is predicated on the ability to generate large numbers of words within semantic or phonemic subcategories and then to move from one subcategory to another, once a subcategory has been exhausted. They defined these components as clustering and switching, respectively. These components are regarded as discrete yet complimentary strategies that are critical for task performance and that may be further used to gain insight into an individual’s performance (Gruenewald & Lockhead, 1980; Troyer et al., 1997). The components of clustering and switching share a number of common features with previous postulations that have attempted to account for optimal verbal fluency performance (Anderson & Pirolli, 1984; Bousfield & Sedgewick, 1944; Collins & Loftus, 1975; Gruenewald & Lockhead, 1980; McClelland & Rumelhart, 1989; Wixted & Rohrer, 1994). To illustrate, the processes that underlie clustering may reflect the initial identification of an appropriate subcategory, followed by the retrieval of specific words within that particular subcategory. The retrieval of a word may then serve to prime the retrieval of additional, highly related words that form a unique cluster of words that are highly similar (Anderson & Pirolli, 1984; Collins & Loftus, 1975; Gruenewald & Lockhead, 1980). Troyer (2000) has extended these postulations by proposing that the ability to effectively cluster is further predicated on the ability to organize words by the features that they share on semantic verbal fluency tasks, and to group words based upon common phonemic features, such as the clustering of common letters, on phonemic verbal fluency tasks. As an example, Troyer (2000) has suggested that efficacious clustering on tasks of semantic verbal fluency is characterized by the ability to group words that share similar attributes, as in the specific subcategories of *pets* and *zoo animals*. For tasks of phonemic verbal fluency, Troyer (2000) has postulated that effective phonemic analysis demands the ability to group words that share initial phonemes (e.g., *arm, ark*), rhyme (e.g., *sand, stand*), are homonymous (e.g., *some, sum*), or that differ by a single vowel sound (e.g., *sat, seat*). In contrast, the process of switching is clearly elucidated in the two-stage, cyclical search process model initially proposed by Gruenewald and Lockhead (1980). According to this theory, specific words are retrieved from a given subcategory until the subcategory is exhausted. Then, a search for a new subcategory is initiated and once identified, words will be generated from the new subcategory. Troyer (2000) has suggested that the processes associated with switching require considerable cognitive effort as they command the integrity of mental flexibility for successful shifting between subcategories. Hence, the ability to switch during tasks of verbal fluency has been characterized by distinct pauses, reflective of the process of mental flexibility, between clusters of successively generated words as the individual searches for a new relevant subcategory (Bousfield & Sedgewick, 1944; Crowe, 1998; Gruenewald & Lockhead, 1980; Troyer et al., 1997).

The components of switching and clustering in verbal fluency performance have been noted to be differentially affected in a number of neurological disorders. For example, clustering is thought to be mediated by the integrity of temporal areas, as decrements in the ability to cluster have been observed in populations with temporal lobe dysfunction, including individuals with temporal lobectomy for intractable epilepsy (Troyer, Moscovitch, Winocur, Alexander, et al., 1998) and Alzheimer's disease (Troyer, Moscovitch, Winocur, Leach, et al., 1998). In contrast, switching appears to depend upon the integrity of the frontal lobes, as the ability to switch between clusters of words on both types of fluency tasks has been found to be reduced in participants with focal frontal lesions (Davidson, Gao, Mason, Winocur, & Anderson, 2008; Troyer, Moscovitch, Winocur, Alexander, et al., 1998). In addition, disturbances in the ability to switch have also been documented in participants with neurological conditions that may compromise the integrity of the frontal cortices, including Parkinson's disease (Troester et al., 1998; Troyer, Moscovitch, Winocur, Leach, et al., 1998, multiple sclerosis (Troester et al., 1989), and schizophrenia (Robert et al., 1998).

The method set forth by Troyer and colleagues (1997) has also been used to examine the clustering and switching abilities of individuals with NBD (Abwender et al., 2001; Bolla, Lindgren, Bonaccorsy, & Bleecker, 1990; Haugrud et al., 2009; Hughes & Bryan, 2002; Kavé, Kigel, & Kochva, 2008; Lanting et al., 2009; Raboutet et al., 2009; Troyer, 2000; Troyer et al., 1997; Weiss et al., 2006). For example, Troyer (2000) instructed a group of healthy adult participants between 18 and 91 years of age to generate as many words as possible for the letters *F, A*, and *S*, or *C, F*, and *L*, and for the semantic categories of *animals* and *supermarket items*. Responses for the three phonemic fluency trials (i.e., *F, A, S* and *C, F, L*) were combined into a single score for each participant. Likewise, responses from both semantic categories were also combined into a single score. The data were analyzed relative to the total number of words generated on each fluency task, as well as for the types and sizes of clusters and the total number of switches produced.

Briefly, clusters on the semantic portions of the task were defined as consecutively generated words that belonged to the same semantic subcategory, such as *pets* and *birds* for the category of *animals*, and *fruits* and *vegetables* for the category of *supermarket items*. Cluster size was calculated beginning with the second word in each cluster. As an example, the consecutive production of the words *dog, cat*, and *hamster*, for the subcategory of *pets,* would receive a cluster size score of two. For the phonemic task, clusters were defined as consecutively generated words that began with the same initial two letters (e.g., *arm, ark*), differed only by a vowel sound (e.g., *seat, soot*), rhymed (e.g., *sand, stand*), or were homonyms (e.g., *some, sum*). As with the semantic portion of the task, cluster size was calculated beginning with the second word in each cluster. For each verbal fluency task, mean cluster size was calculated by summing the size of each cluster and then dividing by the total number of clusters produced. In addition, errors were included in the calculations of cluster size and switching, as they were believed to provide information about the use of strategy during performance, as well as the underlying cognitive substrates that may mediate performance. Last, Troyer (2000) analyzed the data for the potential contributions of age, and level of education to verbal fluency performance. Consistent with previous observations (Brickman et al., 2005; Crowe, 1998; Kemper & Sumner, 2001; Kozora & Cullum, 1995; Martin et al., 1994; Monsch et al., 1994; Troyer et al., 1997), all participants generated a greater number of total words for the semantic verbal fluency task than for phonemic verbal fluency task. Relative to the influence of age on performance, Troyer (2000) found that age had a minimal effect size on the total number of words produced on the phonemic verbal fluency task, but a large effect size for the total number of words produced in the semantic verbal fluency. That is, younger participants generated a greater number of words on the semantic verbal fluency task, compared to older participants. In contrast, age had no effect on the total number of words produced on the phonemic verbal fluency task for either group. These findings are consistent with other studies that have also demonstrated that age is a strong predictor of the total number of words produced on semantic verbal fluency tasks, in comparison to phonemic verbal fluency tasks (Bolla et al., 1998; Crossley et al., 1997; Kozora & Cullum, 1995; Tombaugh, Kozak, & Rees, 1999; Tomer & Levin, 1993). Age also significantly contributed to the total number of switches produced on the semantic verbal fluency task only. Specifically, increased age was associated with a decrease in the total number of switches produced. Of note, this effect was particularly prominent for the semantic category of *animals* only. In contrast, Troyer (2002) found that age had a minimal effect on clustering for all verbal fluency tasks, although in general, increased age was correlated with slightly larger cluster sizes. These findings are partially supported by previous observations made by Troyer and colleagues (1997). In exploring age-related differences, Troyer and colleagues (1997) found, as did Troyer (2000) that increased age was associated with a decrease in the total number of switches produced on tasks of semantic verbal fluency. In contrast to the present findings, Troyer and colleagues (1997) found that older participants produced significantly larger cluster sizes than did their younger counterparts. Years of formal education had the greatest influence on the total number of words produced for all verbal fluency tasks, a finding that is in accordance with other studies that have also observed the same relationship (Brickman et al., 2005; Crossley et al., 1997; Kempler, Teng, Dick, Taussig, & Davis, 1998; Tombaugh et al., 1999). Level of education also contributed to cluster size and number of switches, albeit to a lesser degree. As an example, Troyer (2000) noted that a higher level of education was correlated with larger cluster size, as well as a greater number of words produced, on the phonemic verbal fluency task only. On the semantic verbal fluency tasks and in particular, for the *animals* category only, Troyer (2000) found that higher levels of education were associated with an increase in the number of switches, as well as the total number of words produced. Hence, both clustering and switching may also be fundamental in accounting for the total number of words generated.

Although previous research has demonstrated a clear relationship between the integrity of frontal and temporal areas to switching and clustering abilities, the literature is less clear in the presence of distributed brain injury that may be observed following MOD/S TBI. Troyer (2000) has postulated that individuals with pervasive brain dysfunction may be equally impaired on both clustering and switching, although impairment in one component tends to predominate. To illustrate, Troyer, Moscovitch, Winocur, Leach, and Freedman (1998) found that participants with Alzheimer’s disease were uniformly impaired on both clustering and switching on a task of semantic verbal fluency, but impaired only in clustering on a task of phonemic verbal fluency. To date, there is an emerging body of research that has noted similar variations in clustering and switching performance in participants with TBI (Kavé et al., 2011; Zakzanis et al., 2011).

Recently, Zakzanis and colleagues (2011) investigated the sensitivity of clustering and switching scores to accurately discriminate between individuals with mild TBI (MTBI), moderate TBI (MOD TBI), severe TBI (S/TBI), and a group of individuals with NBD. Participants were instructed to generate as many words as possible for the letters *F, A, S* on the phonemic verbal fluency task, and for the category of *animals* on the semantic verbal fluency task. The results indicated that the effect sizes of both clustering and switching scores were larger for both phonemic and semantic verbal fluency tasks than for the total number of words generated, regardless of group. Further, the effect size for the component scores for semantic verbal fluency were larger than those observed for phonemic verbal fluency for all participant groups. In exploring score differences between the four participant groups, the investigators observed the largest effect size on the semantic mean cluster size variable for both NBD and MTBI groups. In contrast, the largest effect size variable that distinguished those with MTBI from those with MOD TBI, and for participants with MTBI and S/TBI, was the semantic switches variable. Of particular interest is the finding that there were no significant differences between any of the groups relative to the total number of words generated for both the phonemic and semantic verbal fluency tasks. These results suggest that both clustering and switching, when compared to the total number of correct words produced, may be particularly useful in discriminating patterns of verbal fluency performance amongst individuals with TBI and those with NBD (Zakzanis et al., 2011).

The results obtained by Zakzanis and colleagues (2011) were partially supported by the observations made by Kavé et al. (2011). In this study, the investigators examined the effects of clustering and switching in phonemic and semantic verbal fluency tasks in 30 Hebrew-speaking participants with MOD/S TBI and 30 aged-matched individuals with NBD. Responses from all verbal fluency tasks for both groups were then analyzed for the total number of correct words, mean cluster size, number of switches, and number of clusters. In contrast to observations made by Zakzanis and colleagues (2011), Kavé et al. (2011) found that individuals with MOD/S TBI produced significantly fewer total correct words, compared to those with NBD, for both the phonemic and semantic verbal fluency tasks. While Zakzanis and colleagues (2011) noted large effect sizes for clustering in semantic verbal fluency only, Kavé and colleagues (2011) observed no significant group differences for either the mean phonemic or semantic cluster size. In addition, they also noted that participants with MOD/S TBI produced significantly fewer switches and clusters on both tasks of verbal fluency, in comparison to healthy controls. Similar to Zakzanis et al. (2011), Kavé and colleagues (2011) noted that the strongest effect size that differentiated the two groups was the number of semantic switches, with participants with NBD producing a significantly greater number of semantic switches than did those with MOD/S TBI. To determine the sensitivity of verbal fluency tasks to the presence of MOD/S TBI, the investigators calculated specificity scores, based on a selected cutoff score of 1.5 standard deviations below the mean normative score, for the total number of correct words generated for each type of fluency task. The results suggested that semantic verbal fluency was the most sensitive indicator of MOD/S TBI, with approximately 80 percent of participants in this group scoring below the cutoff score.

Previously, Cralidis, Lundgren, Brownell, and Cayer-Meade (2010) examined clustering and switching in a population with chronic TBI. In this study, the investigators examined the verbal responses generated by seven adult participants one or more years post MOD/S TBI on a semantic verbal fluency task. Responses were generated before and after their participation in The Metaphor Training Program (Lundgren, Brownell, Cayer-Meade, Milione, & Kearns, 2010), an intensive training program that uses single words and their associates to help develop the skills needed to interpret figurative language. For the verbal fluency task, participants generated words for the category of *animals* within a 60-second time limit. The results indicated that participants produced a greater number of clusters and fewer switches after training, in comparison to pre-training performance. This finding suggests that a semantically-based training program may help improve verbal fluency for semantic categories. Further, all participants generated words by primarily drawing from three subcategories: *non-native animals, pets*, and *farm animals*. This particular finding was previously observed by Troyer and colleagues (1997) in their qualitative analysis of the types of subcategories produced by younger and older NBD participants.

In a separate study, Cralidis and Lundgren (2009) investigated the types of subcategories produced by a group of five adult participants with MOD/S TBI who were part of a larger treatment study (Lundgren, Brownell, Roy, & Cayer-Meade, 2006). The participants were given the Generative Naming Subtest from the Cognitive Linguistic Quick Test (CLQT; Helm-Estabrooks, 2001). They were asked to generate as many words as possible for the semantic category of *animals* and for the initial letter *M*. In applying the method set forth by Troyer and colleagues (1997), the investigators found that individuals with MOD/S TBI produced subcategories for the semantic verbal fluency task that differed from those produced by the normative sample of Troyer et al. (1997). For example, some participants generated names for the category of *animals* in *alphabetical order*, a pattern that we defined simply as the consecutive generation of names that began with each letter of the alphabet, beginning with the letter *A*. Another prominent pattern that emerged was *alphabet generation*, defined as the production of animal names that began with only the first letter of the alphabet. In contrast, Troyer and colleagues (1997) noted that their participants generated names for the category of *animals* by using specific subcategories of *animals*, such as *beasts of burden, fur, bovine*, and the like. Cralidis and Lundgren (2009) also observed clustering patterns on the phonemic portion of the task that deviated from those reported by Troyer and colleagues (1997). For example, one prominent pattern observed was *animal name generation*, defined as the generation of animal names that began with the letter *M*. This particular pattern was deemed noteworthy as the phonemic task was given to participants immediately following the semantic verbal fluency condition. While this pattern appears to be unique, it is also unclear, given the limited number of participants, whether the pattern truly reflects a unique form of clustering or is more reflective of the presence of stuck-in set perseveration, defined as the inappropriate maintenance of a current category or framework (Sandson & Albert, 1984). However, a pattern of clustering that is in accordance with one previously observed by Troyer and colleagues (1997) was also noted. The pattern, *phonemic chunking*, defined as the presence of two identical phonemes grouped together within words, as in the example *monkey – model*, characterized the verbal responses of all participants in the Cralidis and Lundgren (2009) study. This pattern of word clustering is highly similar to what Troyer et al. (1997) called *first letters*, defined as words that began with the same first two letters. The pattern observed by Cralidis and Lundgren (2009) differs from that reported by Troyer et al. (1997) in that phonemic chunking was observed not only in the initial position within words, but also in the middle and at the end of words. In addition, Troyer and her colleagues (1997) also noted three additional patterns that were not present in our own data: *rhymes, first and last sounds*, and *homonyms*. Cralidis and Lundgren (2009) have postulated that the response differences in findings may reflect sample differences (i.e., participants with MOD/S TBI versus NBD).

Last, one additional means by which verbal fluency performance has been qualitatively explored is via self-report of strategy use (Elfgren & Risberg, 1998). Yet, despite its potential relevance in discerning the underlying cognitive processes that may mediate performance, strategy use has only been investigated in one study. In this study, Elfgren and Risberg (1998) asked participants with NBD to freely describe their strategy use following completion of a phonemic verbal fluency task. Participants were also asked a series of direct questions, developed specifically for this study, to probe the use of verbal, visual, and mixed (i.e., verbal and visual) strategies. Approximately half of the participants reported using a verbal strategy, defined as the search and retrieval of words that began with combinations of different syllables. In addition, some participants reported using a mixed strategy. No participants reported using only a visual strategy, defined as the mental visualization of different items that begin with the initial target letter. Notably, the investigators found that participants who reported using a verbal strategy only generated a significantly greater number of words than those who used a mixed strategy. These findings suggest that strategy use may be highly relevant for optimal performance, with certain types of strategies associated with better performance.

The Influence of Working Memory on Verbal Fluency Performance

A number of studies have indicated that working memory (WM) may influence performance on both phonemic and semantic verbal fluency tasks, not only in populations with NBD (Azuma, 2004; Hedden et al., 2005; Rende, Ramsberger, & Miyake, 2002; Rosen & Engle, 1997; Unsworth et al., 2010), but also in populations with Parkinson's disease (Witt et al., 2004; Zahodne et al., 2008), Huntington's disease (Larsson, Almkvist, Luszcz, & Robins Wahlin, 2008), and Alzheimer's disease (Lam et al., 2006; Sands et al., 2000). Collectively, these studies have suggested that WM underlies the ability to search and retrieve a larger number of total words whilst monitoring for errors and suppressing previous responses on these types of tasks.

Briefly, WM refers to a multicomponent, limited-capacity system that is responsible for the active maintenance, manipulation, and retrieval of task-relevant information in the presence of continuous processing and/or distraction (Baddeley, 1986, 2003; Baddeley & Hitch, 1974; Conway et al., 2005; Kane, Bleckley, Conway, & Engle, 2001; Kane & Engle, 2002). Indeed, Baddeley and Hitch (1974) postulated that WM is critical for the temporary storage and completion of computational processes on mental representations that are essential for successful task performance. The continual maintenance of information is often associated with a number of processes that operate simultaneously, including modality-specific storage and rehearsal processes and domain-general attentional processes (Conway et al., 2005). Within this context, the degree and extent of skill and attention that is required to complete a particular task will vary as a function of individual ability and task context (Conway et al., 2005; Kane et al., 2001). For example, a novice chess player will often devote a greater amount of domain-general skill to the maintenance of specific game information, such as the tracking of recent moves, than on domain-specific skills, such as learned strategies. In contrast, an expert chess player will often rely upon domain-specific skills, such as his awareness of position patterns, for maintenance of information. Yet, under particularly demanding circumstances, such as playing the game within a limited time constraint, an expert chess player may also employ executive attentional skills to maintain game-related information (Conway et al., 2005; Rosen & Engle, 1997).

One measure of WM that is frequently reported in the literature is the Reading Span Task developed by Daneman and Carpenter (1980). This task measures WM by asking participants to listen to a series of sentences of increasing length, determine the veracity of each by indicating true or false, then recall the last word in each sentence. WM, expressed as an individual's span score, is then calculated on the number of words that are accurately recalled. In a seminal study, Daneman and Carpenter (1980) investigated the relationship between WM capacity, reading comprehension, and self-reported scores from the Verbal Scholastic Aptitude Test (Verbal SAT) in a group of NBD participants. Following the Reading Span Task, participants were divided into high- and low-span groups. High-span participants recalled four or more words while low-span participants recalled three words or less. The results suggested that WM capacity was strongly correlated with all experimental measures, with low-span participants performing significantly worse than those with high spans. Daneman and Carpenter (1980) argued that this particular task served as an effective measure of WM because of its ability to measure the simultaneous processing and storage of information, two components that are critical to the concept of WM. Furthermore, they postulated that individuals will vary in their ability to manage both task components, and it is these differences that may account for differences in WM capacity.

More recently, Tompkins, Bloise, Timko, and Baumgaertner (1994) developed the Working Memory Task (WMT), specifically for assessing WM capacity in individuals with acquired brain damage. The WMT is an auditory measure of WM that was adapted from the original work of Daneman and Carpenter (1980). As with the original version from Daneman and Carpenter (1980), the revised task permits the examination of simultaneous processing and storage of common, spoken words. The stimuli are comprised of 42 simple declarative sentences, each of which ends in a different, common noun, adjective, or verb. Sentences are grouped across four levels of difficulty, beginning with Level 2. As the level of difficulty increases, each set of sentences increases in length. At each level, three sets of sentences are presented. To illustrate, Level 2 contains three sets of sentences, each of which has 2 sentences. At Level 3, three sets of sentences are given, each of which consists of 3 sentences, and so forth to the last level, Level 5. To assess processing abilities, participants are first asked to judge the truthfulness of each sentence. To measure the storage component of the task, participants are then asked to remember and recall the final word of each sentence at the conclusion of a particular set. The total number of words that are accurately recalled and the total number of accurate true/false answers are then used as an index of the individual’s WM span score.

In a seminal study, Tompkins and colleagues (1994) explored the relationship between WM and comprehension of written and auditory stimuli that required revision for accurate interpretation, in participants with right hemisphere disorder (RHD), left hemisphere disorder (LHD), and with NBD. Relative to performance on the WMT (Tompkins et al., 1994), the investigators found that healthy controls performed significantly better than did those with RHD and LHD. No significant differences were observed between the diagnostic groups on the WMT (Tompkins et al., 1994). In examining performance on the interpretive tasks, the investigators found that incongruent stimuli were more difficult for all participants, regardless of group. However, both diagnostic groups performed significantly more poorly than did those in the NBD group. This trend in performance degradation was most apparent as task processing requirements increased, and was particularly prominent for those in the RHD group only. In exploring performance of the groups on the WMT (Tompkins et al., 1994) and the discourse tasks, Tompkins and her colleagues (1994) found a strong correlation between the WMT and the processing of incongruent stimuli only for those in the RHD group. As performance diminished on the incongruent portion of the discourse task, scores on the WMT also decreased, for those in the RHD group only.

The WMT has also been used to investigate the relationship between WM and auditory comprehension in adolescents with TBI (Moran & Gillon, 2005; Moran, Nippold, & Gillon, 2006). To illustrate, Moran and Gillon (2005) compared the performance of six adolescents with TBI and 6 age-matched healthy peers on the WMT and an auditory inference comprehension task. The inference comprehension task consisted of seven, four-sentence stories, each of which described a common situation, such as cleaning a house. There were three conditions for each story. In the Distant Condition, the predictive sentence was placed early in the story such that participants were required to store the inference over time in order to derive an accurate interpretation. In the Recent Condition, the predictive sentence occurred in the final position of the story, a placement that allowed for the immediate recall of the inference. The Control Condition contained four sentences without a predictive sentence. Following each story, a comprehension question was asked to probe for the participants' understanding of the inference or content information. The number of questions correctly answered was used as an index of auditory comprehension. The WMT of Tompkins and her colleagues (1994) was administered in accordance with procedures set forth for test administration. The number of words accurately recalled was then used as an index of WM span score. On the inference comprehension task, the findings indicated that participants with TBI did not differ significantly from healthy controls on the Recent Condition only. However, the TBI group performed significantly worse on the Distant Condition, in comparison to the control group. These findings suggest that when storage demands are low, as in the Recent Condition, participants with and without TBI perform similarly. In contrast, when storage demands are great, as in the Distant Condition, participants with TBI exhibit diminished performance in their ability to accurately infer the meaning of the story. Of interest, no significant differences were found between the groups on the total number of words accurately recalled on the WMT; therefore, the investigators combined the groups for subsequent analysis.

The results suggested a significant correlation between WM span and performance on the Distant Condition only. Participants, regardless of group, who recalled fewer correct words on the WMT also performed more poorly on the Distant Condition, a finding that may reflect the increased storage demands on the task due to increased text distance. No significant correlations were observed between WM span and performance on either the Recent or Control Conditions.

More recently, Moran and colleagues (2006) investigated the relationship between WM and comprehension of novel proverbs in participants with and without TBI. Participants were asked to listen to and interpret a series of short stories, half of which contained a novel proverb and half of which contained a concrete proverb. Following presentation of the story, participants were asked to select a meaning for the proverb from four choices. Then, they were asked to complete the WMT. The number of words accurately recalled on the WMT was then calculated and used as an index of WM span. The results indicated that participants with TBI differed significantly from healthy controls in their ability to interpret both novel and concrete proverbs. No significant differences between the groups were observed in their ability to understand and interpret concrete versus novel proverbs. Relative to performance on the WMT, the results suggested that participants with TBI performed significantly worse, as indicated by the total number of words correctly recalled, in comparison to healthy controls. In addition, the investigators observed a significant correlation between novel and concrete proverb interpretation and WM span for both groups. Specifically, participants, regardless of group, who had lower WM span scores, differed significantly in their ability to accurately interpret both types of proverbs, in comparison to participants with higher WM span scores. Collectively, the results of both studies suggest that WM demands may influence performance on tasks of auditory comprehension, particularly when storage demands are great.

To date, two unpublished master's theses have employed the WMT as a measure of WM in an adult population with TBI (Baumgarten, 2009; Johnson, 2011). Baumgarten (2009) investigated the performance of 13 participants with mild to severe TBI and 10 healthy controls on auditory *n*-back and digit span tasks and the WMT. For the *n*-back task, participants monitored a series of auditorily presented consonants and then verbally indicated when a presented letter was identical to one that was presented *n* trials earlier. The number *n* was specified in three conditions: 0-back, 1-back, and 2-back. Three sets of scores were computed for the n-back task: an *n*-back adjusted accuracy score, total number of *n*-back omissions, and total number of *n*-back false positives. Briefly, *n*-back adjusted accuracy scores were calculated to correct for false positive errors such that a participant would receive a score of 0 if the proportion of false positive errors and true positive responses were the same. Omissions on the *n*-back task were defined as the failure to respond. False positive errors were defined as the incorrect identification of a non-target consonant. For the digit span task, participants were asked to recall a series of digits forward and digits backward. Scores were then calculated for the total number of digits called in each condition, and also for both conditions combined. The WMT was administered in accordance with the procedures set forth by Tompkins and colleagues (1994). The total number of recall and true/false errors was then calculated, with the total number of recall errors serving as an index of WM span. For the *n*-back task, the results indicated no significant differences between the groups for adjusted accuracy score, total number of omission errors, or false positive errors. However, both participant groups produced a significantly greater number of errors on the *n*-back task as time on task increased. For the digit span task, no significant differences were observed between the groups on digits forward, digits backward, or the total digit span scores. For the WMT task, the findings suggested that participants with TBI produced a significantly greater number of recall errors on the WMT when compared to healthy controls. The number of errors produced on the WMT was further analyzed relative to set length. The findings indicated that both participant groups produced a significantly greater number of recall errors as a function of time on task. As set length increased, so did the number of recall errors.

More recently, Johnson (2011) employed the same methods and procedures used by Baumgarten (2009) except for an additional analysis by type of error for the recall errors on the WMT, using a modified version of a method set forth by Tompkins and colleagues (1994). Words that were recalled in error on the WMT were classified as either omission or intrusion errors. Briefly, omission errors were defined simply as the inability to accurately recall the target word. Intrusion errors were coded using a modified version of the intrusion error definitions given in the CVLT - II (Delis, Kramer, Kaplan, & Ober, 2000). The investigator identified four types of intrusion errors: categorical, within-task, phonemic, and non-categorical errors. Categorical errors were identified as target and non-target words that belonged to the same semantic category. Within-task errors were words that were found in any of the sentences previously given in the task. Phonemic intrusion errors were identified as non-target words that were phonemically similar to the target word. Last, non-categorical errors were defined as non-target words that were phonemically and semantically unrelated to the target word, and that had not appeared in any of the previous sentences in the task. The results indicated that participants with TBI made a significantly greater number of total recall errors when compared to the control group. Further, all participants, regardless of group, produced a significantly greater number of errors as time on task increased. Participants with TBI also produced significantly more omission errors, in comparison to intrusion errors, than did healthy controls. Relative to the specific types of intrusion errors, the investigator found that the TBI group made more total within-task errors than did healthy controls, although the results were not significant. Since intrusion errors occurred infrequently, further statistically analyses were not performed.

In addition, a number of other span tasks, including operation and counting span tasks, have been subsequently developed to measure the capacity of WM (Conway et al., 2005; Rosen & Engle, 1997; Turner & Engle, 1989). Together, these types of WM tasks, coupled with the Reading Span Task (Daneman & Carpenter, 1980) and WMT (Tompkins et al., 1994), also measure the dual components of processing and storage via the common requirement that the to-be-remembered information is concurrently presented with a task that is unrelated to the information that must be recalled. However, the tasks differ in the nature of the processing activity and the types of information that must be sequentially recalled. For example, differences in the nature of the processing tasks include reading or listening to sentences, solving arithmetic problems, and counting objects in different colors (Conway et al., 2005). Further, these tasks also differ in the type of information that must be recalled, including digits, letters, words, and shapes. Yet, despite these differences, these WM tasks have been found to correlate with a number of complex cognitive-linguistic processes that are thought to depend on WM resources, including reading comprehension (Ackerman, Beier, & Boyle, 2005; Daneman & Carpenter, 1980; Waters & Caplan, 1996), novel reasoning (Ackerman, Beier, & Boyle, 2002; Ackerman et al., 2005), and verbal fluency (Azuma, 2004; Rende et al., 2002; Rosen & Engle, 1997; Unsworth et al., 2010).

For example, Rosen and Engle (1997) investigated semantic verbal fluency performance in groups of individuals with NBD under four different WM conditions. In this study, participants were asked to generate as many words as possible for the category of *animals* within a 15-minute time limit. To assess WM, participants completed an operation-span task where they were asked to verify the accuracy of a series of mathematical operations and then recall a word. Participants were divided into high- and low-span groups based on the total number of words they were able to accurately recall. The critical measures of interest were the total number of words produced on the fluency task, along with the size and number of clusters produced, based upon a previous method set forth by Troyer and her colleagues (1997). Recall that clustering was defined as the consecutive generation of words that belonged to the same semantic subcategory (Troyer et al., 1997). In the first experiment, participants with higher WM spans generated a significantly greater number of total words on the semantic verbal fluency task, in comparison to those with low WM spans. In applying the method from Troyer and colleagues (1997), the investigators also found that participants with high-spans produced a greater number of clusters that were larger than those produced by participants in the low-span group. In addition, those with high-spans were also faster in retrieving clusters of words, in comparison to those with low-spans. In a second experiment, participants were again divided into high- and low-span groups based on their performance on the operation-span task. Then, half the participants in each span group generated names for the category of *animals* for 10 minutes without performing a concurrent task, whilst the other half in each span group were asked to track a series of digits while generating *animal* names. The results suggested that the dual-task group, regardless of span, generated significantly fewer animal names than did those who did not perform the concurrent task. In examining performance differences based on span length, the investigators found that those with high-span who also performed the digit tracking task generated fewer total words and produced fewer and smaller clusters than did high-span participants who were in the single task group. In essence, as attentional resources were reduced, performance on the semantic verbal fluency task was also reduced, as indicated by the total number of words generated.

In a third experiment, Rosen and Engle (1997) investigated whether previously memorized items, termed a “preload,” would affect performance on the semantic verbal fluency task. As with the previous experimental conditions, participants were divided into low- and high-span groups based on their performance on the operation-span task. Then, within each group, approximately half the participants were instructed to memorize a list of 12 words that came from either the same semantic category of *animals*, or that came from a different category, *building-part names*. During word generation on the semantic verbal fluency task, participants were instructed to avoid naming any *animal* names that were on the preload list. The results failed to show a significant effect for preload type (e.g., same versus different semantic category) for the total number of words generated for any of the groups. As with the previous experiments, those in the high-span group generated a significantly greater number of *animal* names, and also produced larger cluster sizes, compared to those with low-spans. Of notable interest is the finding that both preload conditions reduced the total number of *animal* names retrieved by participants in the high-span group only. In contrast, neither preload list had any significant effect on the total number of words generated on the semantic verbal fluency task for those in the low-span group. These findings suggest that memorization of the words on each preload list interfered or competed with the retrieval of novel *animal* names for those in the high-span group only. In the last experiment, Rosen and Engle (1997) instructed high- and low-span participants to generate as many words as possible for the category of *animals* while performing a digit-tracking task. Unlike the second experimental condition, all participants were encouraged to repeat previous responses produced on the semantic verbal fluency task. The results indicated that participants in the low-span group produced a significantly greater number of repetitions than did those in the high-span group, a finding that may suggest differences in the task instructions. Further, the investigators calculated a ratio between novel versus previously retrieved responses and found that those in the low-span group only were as likely to retrieve a previous response as a novel response.

Collectively, the findings from the four experimental conditions suggest that four components are necessary for retrieval in a semantic verbal fluency task: (a) activation that spreads automatically to related items; (b) self-monitoring of generated responses to prevent repetitions and other types of errors; (c) suppression of previously generated responses; and (d) self-generation of subcategory cues to access and retrieve novel names. Rosen and Engle (1997) have suggested that these components reflect the continuous interaction between search and retrieval processes in the effective mediation of verbal fluency performance. Further, the components of self-regulation and inhibition may also optimize performance on these types of tasks. As such, successful performance on tasks of verbal fluency may be predicated on a number of processes upon which individuals may differ and in which the integrity of WM figures most prominently.

More recently, Unsworth and colleagues (2010) investigated the relationship between phonemic and semantic verbal fluency performance and WM in a sample of participants with NBD. In this study, participants were asked to generate as many words as possible for the letters *F* and *S*, and for the categories of *animals* and *supermarket items,* with a 60-second time limit imposed for each task. To assess WM, participants were asked to complete mathematical operation and reading span tasks. However, in contrast to the method employed by Rosen and Engle (1997), Unsworth and colleagues (2010) combined the scores for both measures of WM and then examined verbal fluency performance with WM held as an exploratory factor. Additionally, the investigators also examined phonemic and semantic verbal fluency performance relative to the total number of items produced on each task and the total number of repetitions, as well as cluster size and number of switches, in accordance with the method set forth by Troyer et al. (1997). Recall that Troyer and her colleagues (1997) defined switching as the generation of new subcategories after a previous subcategory has been exhausted. In general, Unsworth and colleagues (2010) found that all participants generated a greater number of total words for the semantic verbal fluency tasks than for the phonemic tasks, a finding that is in accordance with previous studies that have also observed this same trend in total word production in populations with NBD (Crowe, 1998; Kemper & Sumner, 2001; Kozora & Cullum, 1995; Monsch et al., 1994; Troyer et al., 1997). In examining the relationship between the total number of words produced and clustering and switching, the investigators found that switching, in comparison to clustering, was highly correlated with the total number of words generated for both fluency tasks, a finding that was previously reported by Troyer et al. (1997). Likewise, a negative correlation between clustering and switching was also observed for both fluency tasks, a finding that indicates that the production of larger cluster sizes is associated with less frequent switching. Relative to the total number of repetitions, Unsworth and colleagues (2010) found that the number of errors was not significantly related to the total number of words produced, nor to cluster size or total number of switches. This particular finding is noteworthy, as individual differences in WM, as related to performance on verbal fluency tasks, have been found to be strongly associated with the ability to suppress production of errors (Azuma, 2004; Perret, 1974; Rosen & Engle, 1997). In exploring the relationship between WM and verbal fluency performance, the investigators found that WM was strongly associated with the total number of words produced for both types of verbal fluency tasks. Further, WM was also significantly related to both cluster size and switching abilities, a finding that suggests that variation in WM may be an important contributor to both components of verbal fluency and as such, may be a principal factor in overall performance. These results are consistent with previous findings from Rosen and Engle (1997), who found that WM was critical for performance on tasks of verbal fluency, particularly due to the need to self-generate category cues and to self-monitor performance.

To date, only one study has explored the relationship between WM and verbal fluency performance in individuals with TBI and with NBD (Bittner & Crowe, 2007). In this study, 63 participants with mild to severe TBI were grouped according to impairment on a task of phonemic verbal fluency. For the fluency task, participants were instructed to generate as many words as possible for the letters *F, A*, and *S* within a 60-second time limit. Using a clinical cut-off score, the investigators then divided participants with TBI into *FAS impaired* versus *FAS intact* groups. WM was assessed using the digit span forward and backward subtests from the Wechsler Adult Intelligence Scale – III (WAIS-III; Wechsler, 1997). Bittner and Crowe (2007) found that participants with TBI, in the *FAS impaired* group, performed significantly worse on all three letters on the fluency task, as indicated by the total number of words produced for each letter, in comparison to those in the *FAS intact* and NBD groups. A time segment analysis also suggested that those in the *FAS impaired* group were significantly impaired across all four time slices, compared to the other two groups, as indicated by a decrease in the total number of words generated. In the time slice analysis, word generation was greatest during the first time segment, and then decreased as a function of time over the next three time slices. In addition, Bittner and Crowe (2007) found that WM performance was strongly correlated with the total number of words generated on the phonemic verbal fluency task for those in the TBI group only. In contrast, the investigators found that level of education was strongly associated with verbal fluency performance for those with NBD, but not for those with TBI. Together, the findings suggest that different cognitive processes influence performance on phonemic verbal fluency tasks for individuals with and without TBI. In addition, the findings also suggest that individuals may differ both qualitatively and quantitatively in their performance on phonemic verbal fluency tasks. Yet, to date, no studies have examined the relationship between WM and performance on tasks of semantic verbal fluency in populations with TBI.

The Influence of Information Processing Speed on Verbal Fluency Performance

Additionally, a number of studies have also implicated speed of information processing in verbal fluency performance in populations with NBD (Bryan et al., 1997; Bryan & Luszcz, 2000; Hedden et al., 2005; Unsworth et al., 2010), and in populations with focal brain lesions (Vilkki & Holst, 1994) and TBI (Bittner & Crowe, 2007; Miotto et al., 2010). Collectively, these studies have suggested that increased age and the presence of acquired brain injury, particularly when the injury is confined to the left cerebral hemisphere, may adversely affect information processing speed on these timed tasks of verbal fluency, resulting in a decrease in the total number of words produced during a 60 second interval. Yet, the conclusions drawn about the relationship between speed of information processing and verbal fluency performance have been largely predicated on the total number of words produced on tasks of phonemic verbal fluency only.

For example, Bryan and Luszcz (2000) invested phonemic verbal fluency performance as a mediator of age-related declines in a sample of older participants with NBD who ranged in age from 72 to 95 years. In this study, participants were asked to generate as many words as possible for the letters *F* and *A* within a 60-second time limit. The total number of correct words generated for each letter was then combined to yield a total initial letter fluency score. Speed of information processing was measured using the Digit Symbol Substitution Test (DSST; Wechsler, 1981), a test that asks participants to substitute a symbol for a random series of numbers within a 90 second time limit. The number of correctly completed substitutions is then used as an index of the individual's processing speed, with higher scores indicative of faster processing speed. The results suggested an effect of age on verbal fluency performance, with younger participants generating a greater number of total words than older participants. In addition, better performance on the verbal fluency task, as indicated by the total number of words produced, was also associated with higher DSST scores. The association between verbal fluency performance and speed of information processing was particularly prominent amongst younger participants, in comparison to older participants. These findings are in accordance with previous observations made by Bryan and colleagues (1997), who found that information processing speed accounted for a greater percentage of the age-related variance in performance on a phonemic verbal fluency task in a group of older participants.

To date, only two studies have explored the relationship between information processing speed and verbal fluency performance in individuals with TBI (Bittner & Crowe, 2007; Miotto et al., 2010). Previously, Bittner and Crowe (2007) investigated this relationship in a group of individuals with mild to severe TBI and a group of participants with NBD. In this study, participants were asked to generate as many words as possible for the letters *F, A*, and *S*. Participants in the TBI group only were further divided into *impaired FAS* or *intact FAS* based on their performance on the fluency task. To assess processing speed, participants were given the Processing Speed Index (PSI) from the Wechsler Adult Intelligence Scale – III (WAIS – III; Wechsler, 1997). Briefly, the PSI requires participants to sequentially order visual information within a two-minute time limit. The results suggested that while processing speed was an important factor in verbal fluency performance for both groups of participants, it was particularly important for those with TBI. In this study, a number of factors, including processing speed, word knowledge, and level of education, were found to significantly influence performance for participants with NBD only. In contrast, WM and a processing speed significantly contributed to fluency performance for the TBI group only. This particular finding suggests that phonemic verbal fluency tasks are demanding for those who have sustained a TBI, and that word knowledge and level of education no longer influence performance to the same degree as observed in those with NBD.

To date, only one study has investigated the relationship between both phonemic and semantic verbal fluency performance and speed of information processing in individuals with TBI (Miotto et al., 2010). In this study, Miotto and colleagues (2010) instructed six participants with mild TBI and six with moderate TBI to generate as many words as possible for the letters *F, A*, and *S* and for the category of *animals*. Processing speed was assessed using the Symbol Digit Modalities Test (SDMT; Smith, 1991), a measurement that asks participants to pair specific numbers with given geometric figures within a 90-second time limit. Higher scores on the SDMT indicate faster information processing abilities. Performance on these tasks was evaluated relative to the localization of brain lesions, with eight participants displaying lesions located in the left cerebral hemisphere and four with lesions located in the right cerebral hemisphere. As a group, participants with lesions isolated to the left cerebral hemisphere demonstrated marked impairment on information processing speed and both semantic and phonemic verbal fluency tasks, in comparison to those with predominant right cerebral hemisphere lesions. In examining individual differences, the investigators found significant impairments on information processing speed and phonemic verbal fluency performance, as indicated by the total number of words produced, in those with lesions located in the left and right frontal-temporal region and the left parietal-occipital area. In contrast, they observed significant impairment in both information processing speed and semantic verbal fluency performance, as indicated by the total number of words generated, in one participant with lesions isolated to the left temporal-parietal area. These findings partially corroborate previous research that has also demonstrated decrements in performance on tasks of semantic verbal fluency in individuals with temporal lobe dysfunction (Birn et al., 2010; Laisney et al., 2009; Monsch et al., 1994; Troyer, Moscovitch, Winocur, Leach, et al., 1998), and on tasks of phonemic verbal fluency in participants with frontal lobe dysfunction (Baldo et al., 2001; Birn et al., 2010; Ho et al., 2002; Stuss et al., 1998; Troyer, 2000; Troyer, Moscovitch, Winocur, Alexander, et al., 1998). Yet, there are two critical limitations that may negate the ability to formulate distinct conclusions about the relationship between speed of information processing and verbal fluency performance in this particular population. First, Miotto and colleagues (2010) employed a small number of participants, most of whom differed relative to lesion site. As such, conclusions were often predicated on the performance of a sole participant with one particular type of lesion. Second, participants represented a range of ages, from 25 to 68 years. Previous research has indicated a positive association between younger age and performance on tasks of verbal fluency, and in particular, on semantic verbal fluency tasks (Brickman et al., 2005, 2006; Haugrud et al., 2009; Tombaugh et al., 1999; Troyer, 2000).

Hence, one cannot discount the potential influence that age may have had on performance in this population. To date, no studies have investigated the influence that processing speed may have on verbal fluency performance in a population with MOD/S TBI.

Hypotheses

The hypotheses presented below relate to the effect of WM and information processing speed on phonemic and semantic verbal fluency performance in a group of participants with moderate to severe TBI (MOD/S TBI) and a group of NBD participants.

Hypothesis 1: Participants with MOD/S TBI will generate a greater total number of word recall errors on a measure of WM and will produce smaller mean cluster sizes and generate fewer switches on tasks of verbal fluency, in comparison to participants with NBD.

Hypothesis 2: Verbal fluency performance, defined as the total number of correct words generated, will be correlated with the total number of word recall errors produced on a measure of WM.

Hypothesis 3: Participants with MOD/S TBI will produce fewer total numbers of subcategories on tasks of verbal fluency, in comparison to participants with NBD.

Hypothesis 4: Verbal fluency performance, defined as the total number of words generated during a 60-second interval, will be correlated with efficient information processing speed, as indicated by test scores on a measure of information processing speed for both groups.

CHAPTER III

METHODS

Participants

A total of 50 adults participated in this study, of whom 25 had documented moderate to severe traumatic brain injury (MOD/S TBI group) and 25 had no brain damage (NBD group). The participants consisted of 12 females and 38 males. All participants were paired so that they did not significantly differ relative to age, education, or gender. Demographic information for all participants is presented in Table 1.

Participants with MOD/S TBI were recruited from area support groups for survivors of TBI. Participants with NBD were recruited from area support groups for spouses, friends, and caregivers of TBI survivors, and from the community at large. All participants met the following inclusion criteria: (a) Adults between 21 and 40 years of age; (b) Native speaker of American English; (c) Completion of high school; (d) Right handed; (e) Able to give legal consent to participate; (f) No significant history of drugs, alcohol, or other substance abuse; (g) No history of any psychiatric or neurological disorder other than TBI; (h) No history of learning or developmental disability; (i) Medically stable at the time of the study; (j) No presence of dysarthria; and (k) Normal or corrected vision and hearing. In addition, participants in the MOD/S TBI group also met the following inclusion criteria: (a) Diagnosis of a moderate to severe traumatic brain injury (MOD/S TBI), as confirmed by written documentation from the participant's physician; and (b) At least six months or more post-brain injury.

Table 1

Demographic Information for MOD/S TBI and NBD Participants

	MOD/S TBI				NBD		
ID	**Age**	**Sex**	**Educ.**	**Etiology**	**Age**	**Sex**	**Educ.**
P1	27	F	16	MVA*	28	F	16
P2	30	M	15	MVA	31	M	16
P3	40	F	17	MVA	38	F	18
P4	26	M	12	MVA	25	M	14
P5	35	M	12	MVA	34	M	14
P6	38	M	12	MVA	37	M	14
P7	38	M	16	MVA	38	M	16
P8	32	M	13	MVA	32	M	12
P9	24	M	12	MVA	24	M	14
P10	25	M	16	MVA	25	M	16
P11	28	F	13	MVA	29	F	13
P12	30	M	14	MVA	30	M	15
P13	24	M	12	MVA	23	M	13
P14	26	M	15	FALL	26	M	15
P15	34	F	14	MVA	32	F	14
P16	29	F	12	MVA	28	F	13
P17	36	M	13	MVA	36	M	13
P18	40	M	12	MVA	40	M	13
P19	28	M	14	MVA	30	M	15
P20	29	M	12	MVA	29	M	13
P21	38	M	13	ASSAULT	37	M	15
P22	23	F	14	MVA	25	F	16
P23	27	M	16	MVA	25	M	15
P24	32	M	16	MVA	31	M	15
P25	27	M	14	MVA	26	M	13

*MVA = Motor Vehicle Accident

Procedure

After obtaining informed consent, all participants were given the following test measures: (a) Verbal Fluency Subtest and Color-Word Interference Subtest (CWIS) from the *Delis-Kaplan Executive Function System* (D-KEFS; Delis et al., 2001) to assess phonemic and semantic verbal fluency, category switching, and information processing speed; (b) *Self-Report of Strategy Use Questionnaire* (Elfgren & Risberg, 1998) to assess strategy use following the verbal fluency tasks; (c) *Working Memory Task* (WMT; Tompkins et al., 1994) to assess auditory-verbal WM capacity; (d) *World Health Organization Alcohol, Smoking, and Substance Use Involvement Screening Test – 3* (WHO – ASSIST – 3; WHO ASSIST Working Group, 2010) to screen substance abuse history; and (e) *Boston Naming Test – Short Form* (BNT – Short Form; Kaplan, Goodglass, & Weintraub, 2001) to rule out anomia. All measures were presented both orally and in written format, and all responses were written and audiotaped for later analysis.

The Verbal Fluency Subtest from the D-KEFS was employed as a measure of phonemic (i.e., Letter Fluency) and semantic (i.e., Category Fluency) verbal fluency. In the Letter Fluency condition, participants were instructed to generate as many words as possible that began with a particular letter of the alphabet. In this condition, the letters *F, A, and S* were presented individually. Participants were asked to refrain from generating names of people (e.g., *Fred*), places (e.g., *Alaska*), or numbers (e.g., *five*). In the Category Fluency condition, participants were asked to generate as many words as possible for two specific categories: a*nimals* and *boys' names*. For this condition, each category was presented separately. Participants were given 60 seconds to complete each trial under each condition.

The Color Word Interference Subtest (CWIS) was chosen because it was adapted from the classic Stroop procedure (Stroop, 1935) in that the names of colors are printed in dissonant ink colors (Lippa & Davis, 2010; Struchen et al., 2008). The CWIS serves as a measure of verbal interference effects by evaluating the individual's ability to inhibit an overlearned response (i.e., reading the printed words) in order to generate the conflicting response of naming the dissonant ink colors in which the words are printed. It also serves as a measure of information processing speed as individuals are instructed to name the colors of words as quickly as possible.

Participants were asked to complete four different test conditions, two that served as baseline conditions and two that measured two principal executive functions, inhibition and inhibition/cognitive flexibility. In Condition 1, Color Naming, participants were given a stimulus page with patches of color and asked to say the names of the colors aloud. In Condition 2, Word Reading, participants were shown a stimulus page with the names of colors printed in black ink. Participants were instructed to read aloud the names of the colors. In Condition 3, Inhibition, participants were shown a stimulus page that contained rows of color names printed in dissonant ink colors. Participants were asked to name the color of the ink that the letters were printed in, and to avoid reading the word. In Condition 4, Inhibition/Switching, participants were given a stimulus page that contained rows of color names printed in dissonant ink colors, of which half were enclosed in rectangles. Participants were instructed to name the color of the ink that the letters were printed in, except when the word was contained within a rectangle. For words contained in rectangles, participants were asked to simply read the word and not name the color of the ink. For all conditions, participants were asked to complete the tasks as quickly as possible, without skipping any items or making any mistakes.

The Self-Report of Strategy Use Questionnaire was employed as a measure of strategy use on the Verbal Fluency Subtest. This measure was administered immediately following completion of the Verbal Fluency Subtest. The questionnaire contained free-recall and forced-choice conditions. In the free recall condition, participants were asked an open-ended question and encouraged to freely describe their ways of generating words. In the forced-choice condition, participants were given two direct questions to probe for the specific use of a verbal strategy, a visual strategy, or a mixed strategy (i.e., verbal and visual strategies). The answer given on the free recall condition was used to corroborate the answers given in the forced-choice condition.

The Working Memory Task (WMT) is an auditory task that is a modified version of the original working memory measure from Daneman and Carpenter (1980). It was employed as an estimate of auditory-verbal working memory capacity where participants were asked to simultaneously process and store spoken propositions that consisted of 42 simple, active, declarative sentences. All sentences were developed using common knowledge (e.g., “You sit on a chair”) and ended in a different, familiar lexical term comprised of a one- to two-syllable noun, verb, or adjective. The stimuli were grouped into sets that increased in length during presentation, with three sets presented at each of four levels of difficulty. As an example, participants were given two sentences at Level 2, three sentences at Level 3, and so on through Level 5. The stimuli for this task were presented using a Dell Precision M90 laptop computer equipped with an Intel® Core™ Duo Processor and Microsoft® Windows® XP operating system. Participants were given two practice sets that consisted of two sentences each before beginning the test. As described by Tompkins and colleagues (1994), each set was introduced with the set number followed by an alert signal (i. e., “Ready?”) to inform participants that the task would start. There was a one-second interval between the alerting word and the presentation of the first stimulus sentence. A three-second interval was given between sentences, with a five-second interval between sets. All stimuli were presented by a speaker of Standard American English who was practiced in administering the task. Participants were instructed to listen to each sentence, determine the veracity of each by verbally indicating *true or false*, and then remember the last word of each sentence. At the end of each set, participants were prompted by the examiner to recall the final word of each sentence. Participants were not restricted as to the order of final word recall.

The World Health Organization Alcohol, Smoking, and Substance Use Involvement Screening Test – 3 (WHO – ASSIST – 3) was administered to probe for the use of substance abuse, including the use of alcohol, tobacco products, and other non-prescribed drugs. Participants were first asked to indicate their use of these substances by verbally indicating *yes or no* to a series of probe questions. Next, participants were asked to rate their frequency of use, using a Likert type scale, during the past three months. Then, participants were asked to rate, using a Likert type scale, the concerns of significant others over their drug use as well as efforts to control or cease their use.

The Boston Naming Test – Short Form (BNT) is a standardized, confrontation naming assessment tool that was used to screen for the presence of word finding deficits. The test consisted of 15 black-and-white line drawings that were presented individually across a continuum of difficulty. Participants were shown pictures one at a time, and asked to verbally state the name of the picture.

Scoring

Responses from the Verbal Fluency Subtest from the D-KEFS were analyzed for the following: (a) Letter Fluency *F* total correct responses; (b) Letter Fluency *A* total correct responses; (c) Letter Fluency *S* total correct responses; (d) Letter Fluency total correct raw score; (e) Category Fluency *Animals* total correct raw score; (e) Category Fluency *Boys' Names* total correct raw score; (f) Category Fluency total correct raw score; (g) Comparison of Letter Fluency and Category Fluency across the four time intervals; (h) Letter Fluency total number of set loss errors; (i) Letter Fluency total number of repetition errors; (j) Category Fluency total number of set loss errors; and (k) Category Fluency total number of repetition errors. These analyses were completed in accordance with the procedures delineated in the examiner's manual for the D-KEFS.

In addition, responses from the Letter Fluency condition and the semantic category *animals* were submitted to a qualitative analysis to explore the specific types of subcategories and words generated during these tasks, using a modification of the method proposed by Troyer and colleagues (1997). The modified version is based upon a previous analysis of verbal fluency performance in a group of individuals with MOD/S TBI, completed by Cralidis and Lundgren (2009). In this version, subcategories generated by these participants was observed to be different from those subcategories generated by participants used in the Troyer et al. (1997) study. In addition, we calculated three sets of scores on the Letter Fluency task and on the semantic category of *animals*, in accordance with a procedure set forth by Troyer and her colleagues (1997): (a) Total number of correct words generated, excluding errors and repetitions; (b) Mean cluster size; and (c) Total number of switches. Briefly, clusters were defined as successively generated groups of words that met the criteria for a subcategory. As an illustration, subcategories within the semantic category *animals* may include *water animals, pets, reptiles*, and the like. For the Letter Fluency task, subcategories for each of the three letters may share any of the following phonemic characteristics: *first letters, rhymes, first and last sounds*, and *homonyms*. For both fluency tasks, cluster size was then calculated beginning with the second word in a cluster. As an illustration, a single word was given a cluster size score of 0, two words received a cluster size score of 1, and so forth. Mean cluster size was then calculated by dividing the total cluster size by the total number of clusters. All words, including errors and repetitions, were recorded in the order of when they were generated. For the mean cluster size and total number of switches only, we included errors and repetitions in our calculations as these are believed to provide information about the cognitive processes that may underlie performance on these types of tasks (Troyer et al., 1997). Switches were simply calculated as the number of transitions from one cluster to another, including single words (Troyer et al., 1997).

Responses from the four conditions on the CWIS were analyzed for the completion time for each condition, measured in seconds, in accordance with procedures set forth in the test manual.

The Self-Report of Strategy Use Questionnaire was analyzed in accordance with procedures established by Elfgren and colleague (1998). Responses from the free-recall condition were transcribed and then ordered by strategy subcategories that included the following: (a) Environmental (e.g., immediate setting, home, grocery store); (b) Alphabetical order; (c) Familiar people (e.g., friends, family); (d) Bible; (e) Specific subcategories (e.g., reptiles, pets, household items); (f) Consonant blends; (g) Hobbies (e.g., hunting, fishing); (h) Rhymes; and (i) No strategy. Responses from the forced-choice condition were analyzed according to the *yes or no* response given to ascertain the use of a verbal, visual, or mixed strategy. A verbal strategy was defined as a response of *yes* on the forced-choice question for verbal associations, and a *no* response on the forced-choice question for visual representations. A verbal response of *yes* only on the visual memory representation question was scored as a visual strategy. A mixed strategy was defined as an affirmative response on both the verbal association and visual representation questions.

Data from the WMT were analyzed for the total number of word recall errors, out of a maximum of 42 responses, on the true/false and recall conditions of the task. Recall errors were further classified into one of five possible error categories, using a classification method set forth by Tompkins and her colleagues (1994). Briefly, an error was classified as *related* if the recall word was related to the target word. *Repetition* errors were defined as a target word that was recalled earlier in the same stimulus set. *Intrusion* errors were defined as any target word from a previous set. An error was scored as *nontarget* if the error was any nonfinal word from a stimulus within the same set. Last, an error was scored as *unclassified* if the error did not meet the criteria for the other four error categories.

Responses from the WHO – ASSIST – 3 were calculated in one of two ways in accordance with scoring procedures specified in the test administration book. First, a Specific Substance Involvement Score was calculated to determine the use of a specific substance including alcohol, tobacco, and non-prescribed drugs. Second, a Risk Level Score was calculated for each self-report of any specific substance reported during test administration.

Responses on the BNT – Short Form were analyzed for the total number of spontaneously given correct responses, out of a maximum possible of 15, in accordance with administration procedures. In addition, errors were analyzed for the presence of the following: (a) Nonword phonemically based paraphasia; (b) Real word phonemically based paraphasia; (c) Verbal paraphasia, semantically related to the target word; (d) Unrelated verbal paraphasia; (e) Neologism; (f) Multi-word paraphasic or paragrammatic error; (g) Other off-target utterance; (h) Perseveration; and (i) Perceptual.

Statistical Analyses

This study sought to determine whether participants with MOD/S TBI would differ from an NBD group in terms of WM, information processing speed, and verbal fluency. For this objective, the independent variable was participant group. The dependent variables were the scores obtained from measures of WM, information processing speed, and verbal fluency. A second objective was to determine whether WM, information processing speed, and verbal fluency would be correlated with one another. For this objective, the predictor variable was WM and the criterion variables were information processing speed and verbal fluency.

Quantitative Procedures

Description of the groups. To determine whether the MOD/S TBI and NBD groups differed in terms of age, number of years of education, picture naming ability, and verbal fluency, independent *t*-test procedures were conducted. To determine whether the MOD/S TBI and NBD groups differed in terms of proportion of gender and strategy use, chi-square procedures were conducted.

First hypothesis. Independent *t*-test procedures were conducted to determine whether the MOD/S TBI and NBD groups differed in terms of WM total number of word recall errors, and the total number of words produced on tasks of phonemic and semantic verbal fluency.

Second hypothesis. Pearson-product moment correlations were conducted to determine whether the total number of word recall errors on the WM measure would be significantly associated with the total number of words produced on tasks of phonemic and semantic verbal fluency.

Third hypothesis. Independent *t*-test procedures were conducted to determine whether the MOD/S TBI and NBD groups differed in terms of the total number of subcategories produced on phonemic and semantic verbal fluency tasks.

Fourth hypothesis. Pearson-product moment correlations were conducted to determine whether information processing speed would be significantly associated with the total number of words produced on tasks of phonemic and semantic verbal fluency.

Exploratory analyses. Several exploratory analyses procedures were conducted. First, a mixed-analysis of variance (ANOVA) procedures were conducted to determine whether differences between information processing speed and the total number of correct words produced on tasks of verbal fluency would vary across participant groups. Second, Pearson-product moment correlations procedures were conducted to determine whether the total number of word recall errors on the WM measure would be associated with the total number of subcategories produced on tasks of phonemic and semantic verbal fluency. Third, independent *t*-test procedures were conducted to determine whether the number of subcategories generated for tasks of verbal fluency would differ across participant groups. Given the number of multiple comparisons in the present investigation, Bonferroni corrections were conducted on the data in order to provide protection against Type I error. Specifically, planned comparisons were conducted for each of the 11 test variables in order to compare performances between the groups. Bonferroni corrections were applied using an alpha value of .05 divided by the 11 test variables, which yielded a critical alpha value of .004.

Qualitative Procedures

To establish reliability on the qualitative analysis of verbal fluency responses, two speech-language pathologists who were certified by the American Speech-Language-Hearing Association (ASHA) and who were also blind as to the purpose of this study, were trained in the modified method (Cralidis & Lundgren, 2009), based on the original method of Troyer and colleagues (1997), for the scoring of this data. Both raters received training in the identification of types of subcategories, and calculation of mean cluster size and total number of switches. Interjudge agreement for both raters was established on 20 percent of the verbal fluency data, in accordance with procedures used in similar studies (Cordes, 1994; Leon et al., 2005; McGregor & Schwartz, 1992; Rather, 1992).

To establish reliability on the strategies reported under the free recall condition of the Self-Report of Strategy Use Questionnaire, two speech-language pathologists, certified by the American Speech-Language-Hearing Association (ASHA) and blind as to the purpose of this investigation, were trained in the identification of the types of strategies reported. Interjudge agreement for both raters was established on 20 percent of the strategy response data.

CHAPTER IV

RESULTS

Quantitative Results

Introduction

This study investigated the effects of WM and information processing speed on phonemic and semantic verbal fluency performance in participants with and without MOD/S TBI. In the section below, the statistics describing the MOD/S and NBD groups will be presented. Then, the results for each of the hypothesis tests will be summarized.

Demographic Characteristics of the MOD/S TBI and NBD Groups

The means and standard deviations for age and number of years of formal education for the MOD/S and NBD groups are presented in Table 2. There were no significant differences between the groups for age (t (48) = .19, p = .05, *NS*) or education (t (48) = -1.47, p = .05, *NS*).

Table 3 summarizes the frequencies and percentages for the number of males and females within each group. The proportion of males to females did not vary significantly across participant group, χ^2 (1) = .00, *NS*.

Screening Variables

WHO – ASSIST – 3. All participants, regardless of group, obtained a score of 1 or less on the on the Specific Substance Involvement Score measure, indicating no specific substance use, and a “low” Risk Level Score for self-report of any specific substance use. Therefore, no formal statistical analyses were conducted on this measure.

Table 2

Means, Standard Deviations, and *t*-test Results for Age and Education (in Years) Across Participant Group

	TBI		NBD			
Variable	***M***	***SD***	***M***	***SD***	***df***	***t***
Age	30.64	5.33	30.36	5.05	48	.19
Education (in years)	13.80	1.66	14.44	1.42	48	-1.47

Table 3

Frequencies and Percentages for Males and Females across Participant Group

	TBI		NBD	
Gender	**N**	**%**	**N**	**%**
Male	19	76	19	76
Female	6	24	6	24

Note: Proportion of males to females did not vary significantly across participant group, χ^2 (1) = .00, p = 1.00.

BNT. The means, standard deviations, *t*-test results, and Bonferroni corrections for multiple comparison for the total correct number of pictures named on the BNT by both participant groups are depicted in Table 4. The findings indicated that participants with MOD/S TBI named significantly fewer pictures (*M* = 14.08, *SD* = .91) than NBD (*M* = 14.60, *SD* = .58; t (41) = -2.41, p = .020, Bonferroni adjusted p = .004), although these results were not significant after a Bonferroni correction for multiple comparisons was made. Errors on the BNT occurred infrequently; therefore, no statistical analyses were performed.

Table 4

Means, Standard Deviations, and *t*-test Results for the Total Number of Correct Pictures Named on the BNT across Participant Group

	TBI		NBD			
Variable	***M***	***SD***	***M***	***SD***	***df***	***t***
Total Correct	14.08	.91	14.60	.58	41	-2.41*

*p < .05 (two-tailed). *Note.* Comparisons (*t*-tests) of MOD/S TBI and NBD participants were corrected for multiple comparisons with the Bonferroni technique (p < .05/11 = p < .004). The comparison did not attain significance.

Verbal Fluency: Number of Words Generated for Phonemic and Semantic Verbal Fluency Tasks

Phonemic verbal fluency. The means, standard deviations, *t*-test results, and Bonferroni corrections for multiple comparisons for the total number of correct words generated by the MOD/S TBI and NBD groups on the phonemic verbal fluency tasks are presented in Table 5. The findings indicated that the MOD/S TBI group generated significantly fewer total correct words (*M* = 29.80, *SD* = 12.89) than did those in the NBD group (*M* = 38.88, *SD* = 13.16; t (48) = -2.46, p = .017, Bonferroni adjusted p = .004), although the result could not withstand a Bonferroni correction. In examining the total number of correct words produced for the letters *F, A,* and *S*, individually, the results indicated that participants with MOD/S TBI produced significantly fewer total correct words that began with the letter *S* (*M* = 10.48, *SD* = 5.25) when compared to the NBD group (*M* = 10.48, *SD* = 5.25; *t* (48) = -3.29, *p* = .002, Bonferroni adjusted *p* = .004), and this finding remained statistically significant after a Bonferroni correction was conducted. There were no significant differences between the groups on the total number of correct words produced for the letters *F* and *A*.

Table 5

Means, Standard Deviations, and t-test Results for the Total Number of Correct Words Generated on the Phonemic Verbal Fluency Task across Participant Group

	TBI		NBD			
Variable	***M***	***SD***	***M***	***SD***	***df***	***t***
Total correct *F* words	9.68	4.94	12.08	4.89	48	-1.73
Total correct *A* words	9.64	4.73	11.72	5.06	48	-1.50
Total correct *S* words	10.48	5.25	15.08	4.61	48	-3.29**
Total Raw Score	29.80	12.89	38.88	13.16	48	-2.46**

**p* < .05 (two-tailed). ***p* < .01 (two-tailed). *Note*. Comparisons (*t*-tests) of MOD/S TBI and NBD participants were corrected for multiple comparisons using the Bonferroni technique. The total number of correct words for the letter *S* remained statistically significant following a Bonferroni adjustment (*p* = .004)

Semantic verbal fluency. As shown in Table 6, an equivalent pattern of performance was noted for participants with MOD/S TBI on the total number of correct words generated on the semantic verbal fluency task. The MOD/S TBI group generated significantly fewer total correct words for both category conditions combined, *animals* and *boys' names* (M = 33.79, SD = 10.40), when compared to the NBD group (M = 45.60, SD = 9.56; t (48) = -4.19, p = .001, Bonferroni adjusted p = .004). In examining the total number of words generated for each individual semantic category, the results suggested that the MOD/S TBI group generated significantly fewer total correct words for the semantic category of *animals* (M = 15.88, SD = 5.30), compared to the NBD group (M = 22.52, SD = 5.30; t (48) = -4.13, p = .001, Bonferroni adjusted p = .004), and for the category of *boys' names* (M = 17.88, SD = 6.18), in comparison to the NBD group (M = 23.04, SD = 6.18; t (48) = 3.21, p = .002, Bonferroni adjusted p = .004). Moreover, these results remained statistically significant after a Bonferroni adjustment for multiple corrections was conducted.

Table 6

Means, Standard Deviations, and *t*-test Results for the Total Number of Correct Words Generated on the Semantic Verbal Fluency Task across Participant Group

	TBI		NBD			
Variable	***M***	***SD***	***M***	***SD***	***df***	***t***
Total *Animals* correct	15.88	5.30	22.52	5.30	48	-4.13***
Total Boys' *names* correct	17.88	6.18	23.04	6.18	48	-3.21**
Total Raw Score	33.79	10.40	45.60	9.56	48	-4.19**

*p < .05 (two-tailed). **p < .01 (two-tailed). ***p < .001 (two-tailed). *Note.* These results were significant after Bonferroni correction.

Verbal Fluency: Word Production over Time

Phonemic verbal fluency. The means, standard deviations, *t*-test results, and Bonferroni corrections for multiple comparisons for word production over time for the phonemic verbal fluency task are presented in Table 7. The MOD/S TBI group generated significantly fewer mean total correct words during the first time segment (*M* = 12.24, *SD* = 4.53) than did the NBD group (*M* = 15.84, *SD* = 5.37; *t* (48) = -2.56, *p* = .014, Bonferroni adjusted *p* = .004), and in the fourth time segment (*M* = 4.92, *SD* = 3.24), in comparison to the NBD group (*M* = 7.16, *SD* = 3.77; *t* (48) = -2.25, *p* = .029, Bonferroni adjusted *p* = .004). Both groups generated a greater mean total number of correct words during the first time segment, in comparison to the mean total number of words produced during the remaining three time segments. The MOD/S TBI group generated a greater mean total number of correct words for the third time segment than for the fourth time segment. Responses were also analyzed for the total number of set-loss and repetition errors. The findings indicated that the MOD/S TBI group produced a significantly greater number of set-loss errors (*M* = 1.56; *SD* = 2.38) than did the NBD group (*M* = .32, SD = .75; *t* (48) = 2.48, *p* = .019, Bonferroni adjusted *p* = .004), as well as a significantly greater number of repetition errors (*M* = 1.80, *SD* = 2.36), when compared to the NBD group (*M* = .64, *SD* = .91; *t* (48) = 2.29, *p* = .029, Bonferroni adjusted *p* = .004). After making Bonferroni adjustments for multiple comparisons, none of the results significantly distinguished the MOD/S TBI group from the NBD group.

Table 7

Means, Standard Deviations, and *t*-test Results for the Phonemic Verbal Fluency Time Segment Analysis across Participant Group

	TBI		NBD			
Variable	***M***	***SD***	***M***	***SD***	***df***	***t***
1st Time Segment	12.24	4.53	15.84	5.37	48	-2.56*
2nd Time Segment	7.28	3.46	9.40	4.72	44	-1.81
3rd Time Segment	5.36	3.65	6.48	3.22	48	-1.15
4th Time Segment	4.92	3.24	7.16	3.77	48	-2.25*
Set-loss Errors	1.56	2.38	.32	.75	48	2.48*
Repetition Errors	1.80	2.36	.64	.91	48	2.29*

*$p < .05$ (two-tailed). *Note*. After a Bonferroni correction for multiple comparisons was applied, none of the results attained significance.

Semantic verbal fluency. The means, standard deviations, *t*-test results, and Bonferroni corrections for multiple comparisons for word production over time for the semantic verbal fluency task are presented in Table 8. The results indicated that the MOD/S TBI group generated significantly fewer total correct words across all four time segments (1st: *M* = 13.84, *SD* = 4.70; 2nd: *M* = 8.28, *SD* = 3.18; 3rd: *M* = 6.08, *SD* = 2.43; 4th: *M* = 5.56, *SD* = 2.99), in comparison to the NBD group (1st: *M* = 17.64, *SD* = 4.10; 2nd: *M* = 11.28, *SD* = 3.16; 3rd: *M* = 8.24, *SD* = 3.00; 4th: *M* = 8.40, *SD* = 3.95). As observed on the time segment analysis for the phonemic verbal fluency task, none of the findings remained statistically significant after a Bonferroni adjustment was conducted.

Table 8

Means, Standard Deviations, and *t*-test Results for the Semantic Verbal Fluency Time Segment Analysis across Participant Group

	TBI		NBD			
Variable	***M***	***SD***	***M***	***SD***	***df***	***t***
1st Time Segment	13.84	4.70	17.64	4.10	48	-3.08**
2nd Time Segment	8.28	3.18	11.28	3.16	48	-3.35**
3rd Time Segment	6.08	2.43	8.24	3.00	48	-2.80**
4th Time Segment	5.56	2.99	8.40	3.95	48	-2.87**
Set-loss Errors	.12	.33	.08	.28	48	.46
Repetition Errors	1.24	1.23	.96	1.14	48	.84

** $p < .01$ (two-tailed). *Note*. None of the results were statistically significant following a Bonferroni adjustment for multiple comparisons.

Consistent with the observations made on the phonemic verbal fluency task, both groups of participants generated the greatest mean number of total correct words during the first time segment, although this finding could not withstand a Bonferroni adjustment. No significant differences between the groups were observed for the number of set-loss and repetition errors produced on the semantic verbal fluency task.

Verbal Fluency: Correlations between the Total Number of Words Generated, Number of Switches, and Mean Cluster Size

To determine a relationship between phonemic and semantic verbal fluency tasks and the number of switches and mean cluster sizes produced on each verbal fluency task, Pearson-product moment correlations procedures were conducted. The results are presented in Table 9.

Table 9

Pearson Correlations between Verbal Fluency, Number of Switches, and Cluster Size (*N* = 50)

Variable	Phonemic Fluency	Semantic Fluency
F switches	.79***	----
A switches	.67***	----
S switches	.76***	----
Animal switches	----	.60***
F cluster size	.03	----
A cluster size	.53***	----
S cluster size	.23	----
Animal clusters	----	.02

*** $p < .001$ (two-tailed).

The findings indicated that the total number of correct words generated on the phonemic verbal fluency task were positively associated with the number of switches on the letter *F* ($r = .79$, $p = .001$), the letter *A* ($r = .67$, $p = .001$), and the letter *S* ($r = .76$, $p = .001$). The total number of correct words produced on the phonemic verbal fluency task was positively associated with mean cluster size only for the letter *A* ($r = .53$, $p = .001$). Moreover, the total number of correct words generated for the semantic category of *animals* was positively correlated only with the number of switches produced for the category of *animals* (r = .36, p = .001).

Strategy Use

The frequencies and percentages for type of strategy reported on the Self-Report of Strategy Use Questionnaire for the verbal fluency tasks are reported in Table 10. The findings indicated that the type of strategy did not vary significantly between the two groups. However, both groups reported using no formal strategy more frequently than a verbal or mixed strategy. An analysis of the types of responses given on the free-recall condition indicated that participants with MOD/S TBI used the subcategories of *familiar people* in generating *boys' names*, and *no strategy* for the letters *F, A, S*, and for *animals*. In contrast, the NBD group reported using the subcategory of *familiar people* to generate *boys' names*, *specific subcategories* to generate words for the category of *animals*, and *no strategy* for the letters *F, A, S*.

Table 10

Frequencies and Percentages for Strategy Used Across Participant Group

	TBI		**NBD**	
Strategy	***N***	**%**	***N***	**%**
None	18	72	17	68
Verbal	2	8	0	0
Mixed	5	20	8	32

Note: Type of strategy did not vary significantly across participant group, χ^2 (2) = 2.72, p = .257.

Working Memory in Participants with MOD/S TBI (First Hypothesis)

It was hypothesized that participants with MOD/S TBI would generate a greater total number of word recall errors on a measure of WM and would produce smaller mean cluster sizes and generate fewer switches on tasks of verbal fluency when compared to participants with NBD.

Working memory total number of word recall errors. The means, standard deviations, range of scores, *t*-test results, and Bonferroni corrections for multiple comparisons for the total number of word recall errors on the WMT are displayed in Table 11. The results indicated that participants with MOD/S TBI performed significantly worse on the WMT when compared to the NBD group (t (39) = -4.13, p = .001, Bonferroni adjusted p = .004). The MOD/S TBI made significantly more errors (M = 16.84, SD = 8.38) than the NBD group (M = 8.76, SD = 5.04). Moreover, these findings remained statistically significant after a Bonferroni correction for multiple comparisons was applied. Errors on the true/false portion of the WMT were so rare that they were not submitted to a statistical analysis.

Table 11

Means, Standard Deviations, Range of Scores, and *t*-test Results for the WMT across Participant Group

	TBI			NBD				
Variable	***Range***	***M***	***SD***	***Range***	***M***	***SD***	***df***	***t***
WMT total errors	2 to 33	16.84	8.38	1 to 20	8.76	5.04	39	4.13^{***}

*** p < .001 (one-tailed). *Note*. The results were significant after Bonferroni correction.

Verbal fluency.

***Number of switches*.** The means, standard deviations, *t*-test results, and Bonferroni corrections for multiple comparisons for the total number of switches produced for the letters *F, A*, and *S* on the phonemic verbal fluency task and for the category of *animals* on the semantic verbal fluency task are summarized in Table 12. The findings indicated that the MOD/S TBI group produced significantly fewer switches on the letter *S* (*M* = 8.44, *SD* = 3.43) than the NBD group (*M* = 10.32, *SD* = 3.73; *t* (48) = -1.86, *p* = .034, Bonferroni adjusted *p* = .004).

Table 12

Means, Standard Deviations, and *t*-test Results for the Total Number of Switches on the Phonemic and Semantic Verbal Fluency Tasks Made across Participant Group

	TBI		NBD			
Variable	*M*	*SD*	*M*	*SD*	*df*	*t*
F switches	8.08	4.31	9.16	3.46	48	-.98
A switches	8.56	3.86	8.36	3.40	48	.19
S switches	8.44	3.42	10.32	3.73	48	-1.86*
Animal switches	8.20	3.16	10.48	4.13	48	-2.19*

* *p* < .05 (one-tailed). *Note*. The results were not significant after a Bonferroni adjustment for multiple comparisons was conducted.

However, these results could not withstand a Bonferroni correction for multiple comparisons. No significant differences between the groups were observed for the total number of switches made on the letters *F* or *A.* For the semantic category of *animals*, the results suggested that the MOD/S TBI group produced significantly fewer switches (*M* = 8.20, *SD* = 3.16) than the NBD group (*M* = 10.48, *SD* = 4.13; *t* (48) = -2.19, *p* = .017, Bonferroni adjusted *p* = .004). Likewise, these findings were not significant after a Bonferroni correction for multiple comparisons was conducted.

Mean cluster size. As shown in Table 13, the MOD/S TBI group produced significantly smaller mean cluster sizes on the phonemic verbal fluency task for the letter *A* (*M* = .22, *SD* = .21), in comparison to the NBD group (*M* = .48, *SD* = .44; *t* (48) = -2.69, *p* = .005, Bonferroni adjusted *p* = .004). After making Bonferroni adjustments for multiple comparisons, this finding did not significantly differentiate the MOD/S TBI group from the NBD group. No significant differences between the groups were observed for mean cluster size for the letters *F* or *S*, or for the semantic category of *animals*.

Table 13

Means, Standard Deviations, and *t*-test Results for the Mean Cluster Size for the Phonemic and Semantic Verbal Fluency Tasks across Participant Group

	TBI		NBD			
Variable	***M***	***SD***	***M***	***SD***	***df***	***t***
F mean cluster size	.42	.32	.37	.23	48	.57
A mean cluster size	.22	.21	.48	.44	48	-2.69**
S mean cluster size	.47	.41	.60	.49	48	-1.08
Animal mean cluster size	1.42	1.71	2.05	3.99	48	-.72

***p* < .01 (one-tailed). *Note*. The results were not significant after a Bonferroni adjustment for multiple comparisons was made.

Summary. The first hypothesis was partly supported in that the MOD/S TBI group produced a significantly greater total number of word recall errors on the WMT when compared to the NBD group. Moreover, these results remained statistically significant after a Bonferroni adjustment for multiple comparisons was made.

The Relationship between Verbal Fluency and Working Memory (Second Hypothesis)

It was hypothesized that verbal fluency, defined by the total number of correct words generated, would be correlated with the total number of word recall errors produced on a measure of WM.

The findings in Table 14 indicated that the total number of word recall errors produced on the WMT was negatively correlated with the total number of correct words generated for the letters *F, A*, and *S* combined (r = -.55, p = .001). The total number of word recall errors produced on the WMT was also negatively associated with the total number of correct words generated for the categories of *animals* and *boys' names* (r = -.60, p = .001). Thus, the second hypothesis was fully supported.

Table 14

Pearson Correlations between WMT Total Number of Word Recall Errors and Total Number of Correct Words Generated on the Verbal Fluency Tasks (*N* = 50)

Variable	1	2
1 WMT total errors		

Table 14 (cont.)

Variable	1	2
2 Total correct *F, A, S* words	-.55***	
3 Total correct *animal* and *boys' names*	-.60***	.66***

*** p < .001 (two-tailed).

Number of Subcategories for Participants with MOD/S TBI (Third Hypothesis)

It was hypothesized that participants with MOD/S TBI would produce fewer total numbers of subcategories, in applying the method set forth for this analysis by Troyer and colleagues (1997), than NBD participants. As depicted in Table 15, participants with MOD/S TBI produced significantly fewer subcategories for the phonemic verbal fluency task (M = 1.96, SD = 1.02) than NBD participants (M = 2.52, SD = .96; t (48) = -2.00, p = .026, Bonferroni adjusted p = .004). They also produced fewer subcategories for the semantic category of *animals* (M = 5.44, SD = 1.94) than the NBD group (M = 6.56, SD = 2.18; t (48) = -1.92, p = .030, Bonferroni adjusted p = .004). The total number of subcategories produced by the MOD/S TBI group (M = 7.40, SD = 2.38) was significantly lower than the total number of subcategories produced by the NBD group (M = 9.08, SD = 2.22; t (48) = -2.58, p = .017, Bonferroni adjusted p = .004). These findings did not reach statistical significance after a Bonferroni correction was applied.

Table 15

Means, Standard Deviations, and *t*-test Results for the Number of Subcategories Produced across Participant Group

	TBI		NBD			
Category	***M***	***SD***	***M***	***SD***	***df***	***t***
F, A, S subcategories	1.96	1.02	2.52	.96	48	-2.00*
Animal subcategories	5.44	1.94	6.56	2.18	48	-1.92*
Total subcategories	7.40	2.38	9.08	2.22	48	-2.58*

* $p < .05$ (one-tailed). *Note*. None of the comparisons attained statistical significance after a Bonferroni correction for multiple comparisons was conducted.

The means, standard deviations, *t*-test results, and Bonferroni corrections for multiple comparisons for the number of subcategories produced for the semantic category of *animals* across the three major category divisions set forth by Troyer et al. (1997) are presented in Table 16. The findings indicated that participants with MOD/S TBI generated significantly fewer subcategories that belonged to the major category of *living environment* (M = 3.92, SD = 2.10), when compared to the NBD group (M = 5.36, SD = 2.78; t (48) = -2.07, p = .044, Bonferroni adjusted p = .004). However, these findings were no longer statistically significant after a Bonferroni correction was applied. No significant differences between the groups were observed for the number of subcategories that belonged to the major categories of *human use* or *zoological*.

Table 16

Means, Standard Deviations, and *t*-test Results for the Number of Semantic Subcategories Generated for the Major Category Divisions across Participant Group

Category	TBI		NBD			
	M	*SD*	*M*	*SD*	*df*	*t*
Living environment	3.92	2.10	5.36	2.78	48	-2.07*
Human use	1.24	.83	1.24	.78	48	.00
Zoological	2.56	1.50	3.04	2.17	48	-.91
Total	7.72	3.18	9.64	4.41	48	-1.76

* $p < .05$ (one-tailed). *Note*. The results were not statistically significant after a Bonferroni correction for multiple comparisons was conducted.

The means, standard deviations, *t*-test results, and Bonferroni adjustment for multiple comparisons for the type of subcategories produced on the phonemic verbal fluency task, using characteristics previously described by Troyer et al. (1997) for this type of analysis, are presented in Table 17. The findings indicated that the number of subcategories produced for the letter *F* on the phonemic verbal fluency task varied significantly across participant group, t (40) = -1.71, p = .047, Bonferroni adjusted p = .004. The MOD/S TBI group produced significantly fewer subcategories (M = 1.76, SD = 1.05) than the NBD group (M = 2.44, SD = 1.69). The number of subcategories generated for the letters *A* and *S* on the phonemic verbal fluency task did not vary significantly across participant group. However, the total number of subcategories produced on the phonemic verbal fluency task differed significantly across participant group, *t* (48) = -2.26, *p* = .014, Bonferroni adjusted *p* = .004. The MOD/S TBI group produced fewer total subcategories on this task (*M* = 5.20, *SD* = 2.94) than did the NBD group (*M* = 7.20, *SD* = 3.30). However, the results failed to attain statistical significance after a Bonferroni correction was applied. Thus, the third hypothesis was not supported.

Table 17

Means, Standard Deviations, and t-test Results for the Number of Phonemic Subcategories Generated by Type across Participant Group

	TBI		NBD			
Variable	***M***	***SD***	***M***	***SD***	***df***	***t***
F subcategories	1.76	1.05	2.44	1.69	40	-1.71*
A subcategories	1.28	1.34	1.92	1.50	48	-1.59
S subcategories	2.16	1.72	2.84	1.72	48	-1.39
Total number of subcategories	5.20	2.94	7.20	3.30	48	-2.26*

* $p < .05$ (one-tailed). *Note*. The results were not significant after a Bonferroni correction for multiple comparisons was applied.

The Relationship between Verbal Fluency and Information Processing Speed (Fourth Hypothesis)

It was hypothesized that verbal fluency performance, defined as the total number of correct words generated, would be correlated with efficient information processing speed, as indicated by test scores on a measure of information processing speed for both groups. As shown in Table 18, phonemic verbal fluency, as determined by the total number of correct words produced, was negatively associated with the amount of time to complete the Color Naming condition (*r* = -.48, *p* = .001), the Word Reading condition (*r* = -.59, *p* = .001), the Inhibition condition (*r* = -.57, *p* = .001), and the Inhibition/Switching condition (*r* = -.49, *p* = .001). Moreover, semantic verbal fluency, as indicated by the total number of correct words generated, was negatively associated with Color Naming (*r* = -.53, *p* = .001), Word Reading (*r* = -.61, *p* = .001), Inhibition/Switching (*r* = -.51, *p* = .001), and Inhibition/Switching (*r* = -.46, *p* = .001). Thus, the fourth hypothesis was supported.

Table 18

Pearson Correlations between Verbal Fluency and Information Processing Speed (*N* = 50)

CWIS Measure (In Seconds)	Phonemic Fluency	Semantic Fluency
Color Naming	-.48***	-.53***
Word Reading	-.59***	-.61***
Inhibition	-.57***	-.51***
Inhibition/Switching	-.49***	-.46***

*** $p < .001$ (two-tailed).

Exploratory Analyses

The relationship between information processing speed and phonemic verbal fluency performance in participants with MOD/S TBI. To determine whether the difference between phonemic verbal fluency performance, as indicated by the total number of correct words generated, and information processing speed, measured in seconds, would vary across participant groups, a

2 x 2 mixed analysis of variance (ANOVA) procedures were conducted. The between-subjects factor was participant group (MOD/S TBI vs. NBD) and the within-subjects factor was task (CWIS measure vs. phonemic verbal fluency).

Color Naming speed vs. phonemic verbal fluency. The means and standard deviations for Color Naming speed and phonemic verbal fluency total scores are presented in Table 19. The mixed-ANOVA results are summarized in Table 20. The findings indicated a significant interaction between task and participant group, F (1, 48) = 17.05, p = .001. As depicted in Figure 1, MOD/S TBI participants had lower phonemic verbal fluency scores than NBD participants, and were also slower at naming colors, in comparison to NBD participants.

Table 19

Means and Standard Deviations for Total Phonemic Verbal Fluency Raw Scores (PVFRS) and CWIS Color Naming Speed across Participant Group

	TBI		**NBD**	
Variable	***M***	***SD***	***M***	***SD***
Total PVFRS	29.80	12.89	38.88	13.16
CWIS Color Naming	43.08	18.43	26.44	4.74

Table 20

Mixed ANOVA Results for Total Phonemic Verbal Fluency Raw Scores (PVFRS) and CWIS Color Naming (CN) Speed across Participant Group (*N* = 50)

Source	*df*	*MS*	*F*
Between subjects			
Participant Group	1	357.21	3.29
Error	48	108.46	
Within subjects			
CN vs. PVFRS (CN/PVFRS)	1	4.41	.02
CN/PVFRS x Participant Group	1	4134.49	17.05^{***}
Error	48	242.43	

*** $p < .001$.

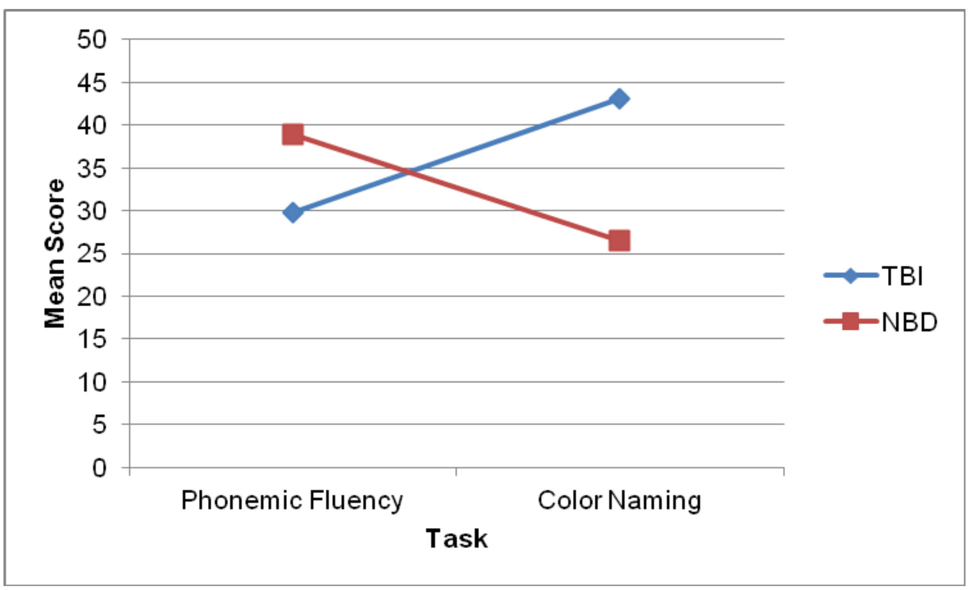

Figure 1. Total Phonemic Verbal Fluency Raw Scores and Color Naming Speed across Participant Group

***Word Reading speed vs. phonemic verbal fluency*.** The means and standard deviations for Word Reading speed and the phonemic verbal fluency scores are presented in Table 21. The mixed-ANOVA results are summarized in Table 22. As shown in these tables, there was a significant main effect for type of task (*F* (1, 48) = 10.68, *p* = .01). Moreover, there was a significant interaction between participant group and type of task. As illustrated in Figure 2, the difference between the scores on both tasks varied significantly by participant group (*F* (1, 48) = 11.71, *p* = .001). Participants with MOD/ S TBI had similar phonemic verbal fluency and Word Reading scores. However, the NBD group had higher scores on the verbal fluency task when compared to the MOD/S TBI group, a finding that indicates that the NBD group generated a greater total number of correct words on this task. Moreover, the NBD group also had lower scores on the Word Reading task, indicating faster performance, in comparison to the MOD/S TBI group.

Table 21

Means and Standard Deviations for Total Phonemic Verbal Fluency Raw Scores (PVFRS) and CWIS Word Reading Speed across Participant Group

	TBI		**NBD**	
Variable	***M***	***SD***	***M***	***SD***
Total PVFRS	29.80	12.89	38.88	13.16
CWIS Word Reading	30.24	13.36	19.80	4.83

Table 22

Mixed ANOVA Results for Total Phonemic Verbal Fluency Raw Scores (PVFRS) and CWIS Word Reading (WR) Speed across Participant Group (*N* = 50)

Source	*df*	*MS*	*F*
Between subjects			
Participant Group	1	11.56	.17
Error	48	64.70	
Within subjects			
WR vs. PVFRS (WR/PVFRS)	1	2171.56	10.68**
WR/PVFRS x Participant Group	1	2381.44	11.71***
Error	48	203.33	

** $p < .01$. *** $p < .001$.

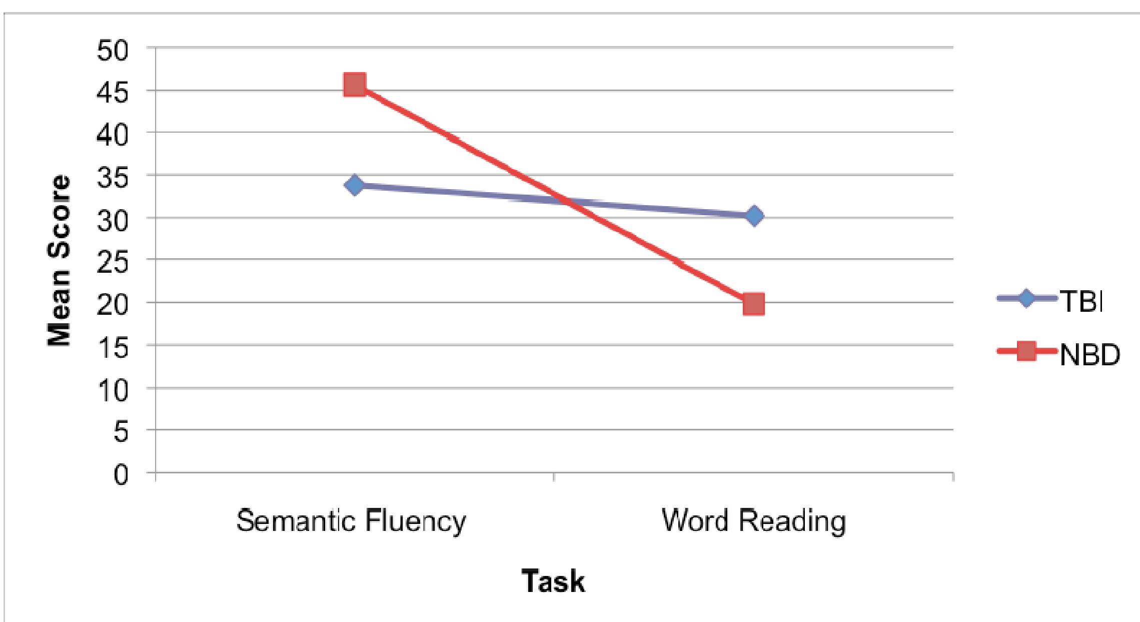

Figure 2. Total Phonemic Verbal Fluency Raw Scores and Word Reading Speed across Participant Group

***Inhibition speed vs. phonemic verbal fluency*.** The means and standard deviations for Inhibition speed and the phonemic verbal fluency task are presented in Table 23. The results of this analysis are presented in Table 24. Both the main effects for participant group and type of task were statistically significant, as well as the interaction effect between these two variables (F (1, 48) = 11.48, p = .001). As shown in Figure 3, the NBD group had similar phonemic verbal fluency and Inhibition scores. In contrast, the MOD/S TBI group had lower total phonemic verbal fluency scores, and higher Inhibition speed scores, indicating that those with MOD/S TBI took a longer time to complete the Inhibition task in comparison to the NBD group.

Table 23

Means and Standard Deviations for Total Phonemic Verbal Fluency Raw Scores (PVFRS) and CWIS Inhibition Scores across Participant Group

	TBI		NBD	
Variable	***M***	***SD***	***M***	***SD***
Total PVFRS	29.80	12.89	38.88	13.16
CWIS Inhibition	74.64	41.13	46.64	9.74

Table 24

Mixed ANOVA Results for Total Phonemic Verbal Fluency Raw Scores (PVFRS) and CWIS Inhibition (Inhibit) Speed Across Participant Group (*N* = 50)

Source	*df*	*MS*	*F*
Between subjects	1	2237.29	6.64*
Participant Group	48	337.21	
Error			
Within subjects	1	17292.25	23.83***
Inhibit vs. PVFRS (IN/PVFRS)	1	8593.29	11.84***
IN/PVFRS x Participant Group	48	725.58	
Error			

* $p < .05$. *** $p < .001$.

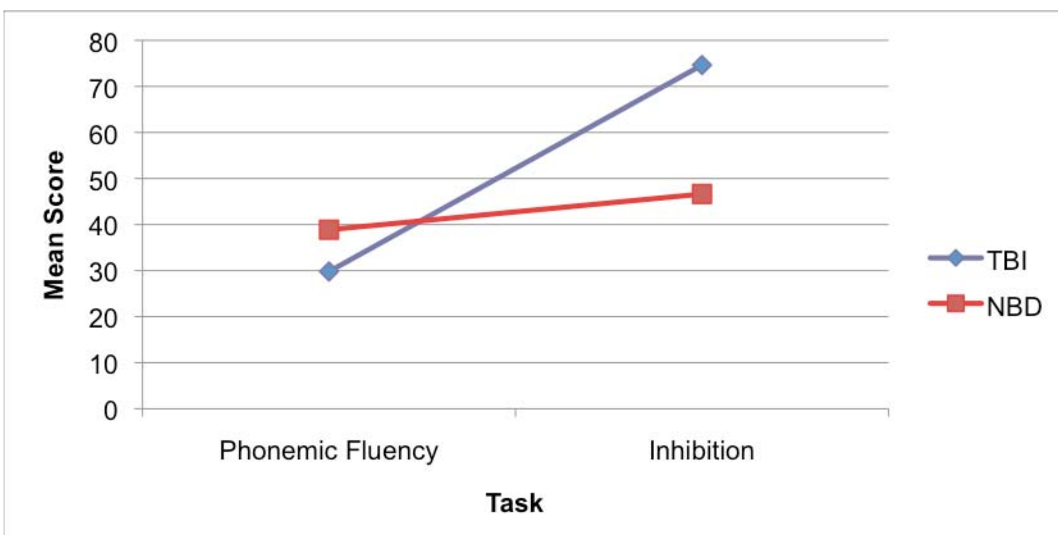

Figure 3. Total Phonemic Verbal Fluency Raw Scores and Inhibition Speed across Participant Group

***Inhibition/Switching vs. phonemic verbal fluency*.** The means and standard deviations for Inhibition/Switching speed and the phonemic verbal fluency scores are presented in Table 25. The results of the mixed-ANOVA are summarized in Table 26. As shown in Table 26, there was a significant main effect for type of task (F (1, 48) = 78.86, p = .001). Moreover, there was a significant interaction between participant group and type of task (F (1, 48) = 25.16, p = .001). As illustrated in Figure 4, the difference observed between phonemic verbal fluency scores and Inhibition/Switching speed varied significantly by participant group. Although the NBD group had similar scores on both tasks, participants in the MOD/S TBI group had lower total phonemic verbal fluency scores and higher Inhibition/Switching speed scores.

Table 25

Means and Standard Deviations for Total Phonemic Verbal Fluency Raw Scores (PVFRS) and CWIS Inhibition/Switching Speed across Participant Group

	TBI		**NBD**	
Variable	***M***	***SD***	***M***	***SD***
Total PVFRS	29.80	12.89	38.88	13.16
CWIS Inhibition/Switching	99.36	38.79	57.60	12.29

Table 26

Mixed ANOVA Results for Total Phonemic Verbal Fluency Raw Scores (PVFRS) and CWIS Inhibition/Switching (In/Switch) Speed Across Participant Group (*N* = 50)

Source	*df*	*MS*	*F*
Between subjects			
Participant Group	1	6674.89	18.77***
Error	48	355.62	
Within subjects			
Inhibit vs. PVFRS (IN/PVFRS)	1	48708.49	78.86***
IN/PVFRS x Participant Group	1	16154.41	25.16***
Error	48	642.10	

*** $p < .001$.

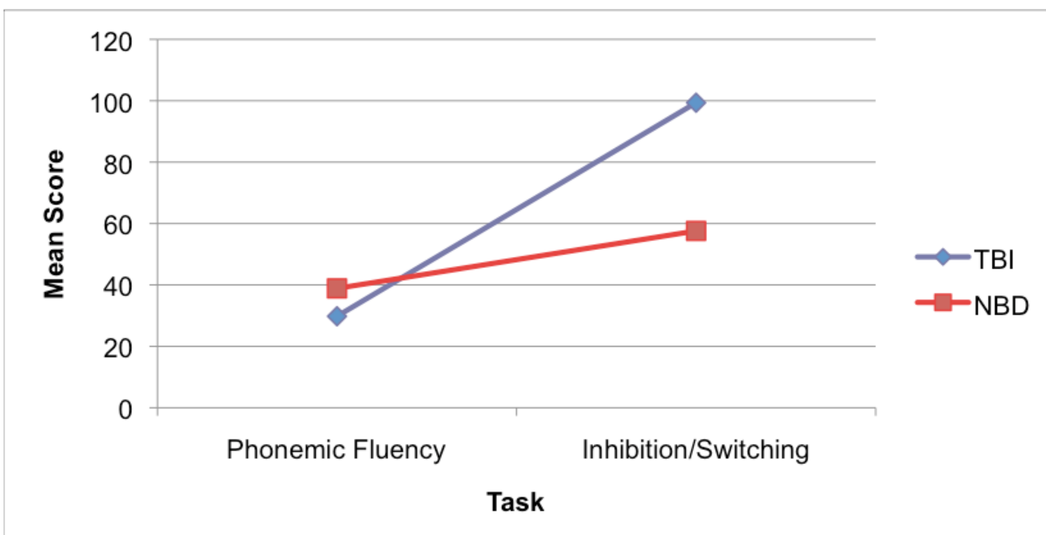

Figure 4. Total Phonemic Verbal Fluency Raw Scores and Inhibition/ Switching Speed across Participant Group

The relationship between information processing speed and semantic verbal fluency in participants with MOD/S TBI. To determine whether the difference between semantic verbal fluency performance, as indicated by the total number of correct words generated, and information processing speed, measured in seconds, would vary across participant groups, a 2 x 2 mixed analysis of variance (ANOVA) procedures was conducted. The between-subjects factor was participant group (MOD/S TBI vs. NBD) and the within-subjects factor was task (CWIS measure vs. semantic verbal fluency).

***Color Naming vs. semantic verbal fluency*.** The means and standard deviations for Color Naming speed and semantic verbal fluency scores are presented in Table 27. The results of the mixed-ANOVA are given in Table 28. As depicted in Table 28, there was a significant interaction between task and participant group, F (1, 48) = 26.99, p = .001.

Table 27

Means and Standard Deviations for Total Semantic Verbal Fluency Raw Scores (SVFRS) and CWIS Color Naming Speed across Participant Group

	TBI		**NBD**	
Variable	***M***	***SD***	***M***	***SD***
Total SVFRS	33.76	10.34	45.60	9.56
CWIS Color Naming	43.08	18.43	26.44	4.74

Table 28

Mixed ANOVA Results for Total Semantic Verbal Fluency Raw Scores (SVFRS) and CWIS Color Naming (CN) Speed across Participant Group (*N* = 50)

Source	*df*	*MS*	*F*
Between subjects	1	144.00	1.55
Participant Group	48	93.02	
Error			
Within subjects			
Inhibit vs. PVFRS (IN/PVFRS)	1	605.16	3.22
IN/PVFRS x Participant Group	1	5069.44	26.99***
Error	48	187.86	

*** $p < .001$.

As depicted in Figure 5, participants with MOD/S TBI had lower semantic verbal fluency scores than NBD participants and higher Color Naming scores, a finding that indicates that those with MOD/S TBI took a longer period of time to name colors.

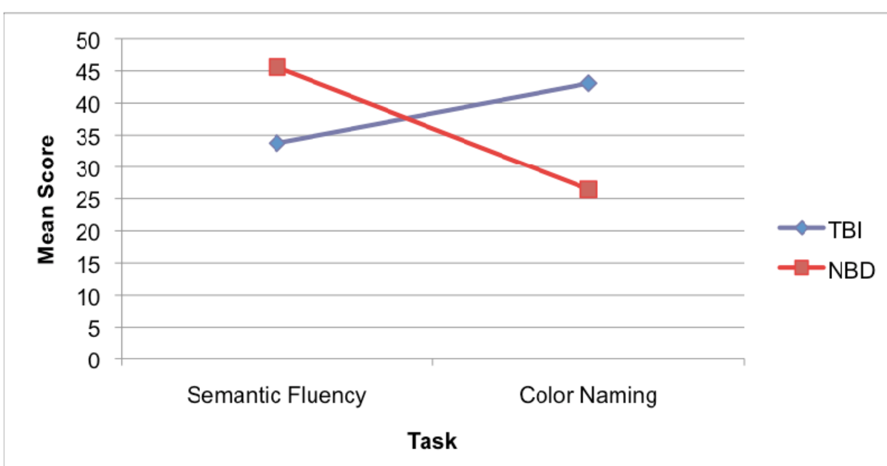

Figure 5. Total Semantic Verbal Fluency Raw Scores and Color Naming Speed across Participant Group

Word Reading speed vs. semantic verbal fluency**.** The means and standard deviations for Word Reading speed and the semantic verbal fluency scores are presented in Table 29. The mixed-ANOVA results are summarized in Table 30. As shown in these tables, there was a significant main effect for type of task (F (1, 48) = 36.03, p = .001). Further, there was a significant interaction between participant group and type of task (F (1, 48) = 20.81, p = .001). As illustrated in Figure 6, the difference between the scores on both tasks varied significantly by participant group The MOD/S TBI group generated fewer total correct words on the verbal fluency task and had higher Word Reading scores, indicating that they were slower in performing this task, when compared to the NBD group.

Table 29

Means and Standard Deviations for Total Semantic Verbal Fluency Raw Scores (SVFRS) and CWIS Word Reading Speed across Participant Group

	TBI		NBD	
Variable	***M***	***SD***	***M***	***SD***
Total SVFRS	33.76	10.40	45.60	9.56
CWIS Color Naming	30.24	13.36	19.80	4.83

Table 30

Mixed ANOVA Results for Total Semantic Verbal Fluency Raw Scores (SVFRS) and CWIS Word Reading (WR) Speed across Participant Group (*N* = 50)

Source	*df*	*MS*	*F*
Between subjects			
Participant Group	1	12.25	.24
Error	48	51.63	
Within subjects			
Inhibit vs. PVFRS (IN/PVFRS)	1	5372.89	36.03***
IN/PVFRS x Participant Group	1	3102.49	20.81***
Error	48	149.11	

*** $p < .001$.

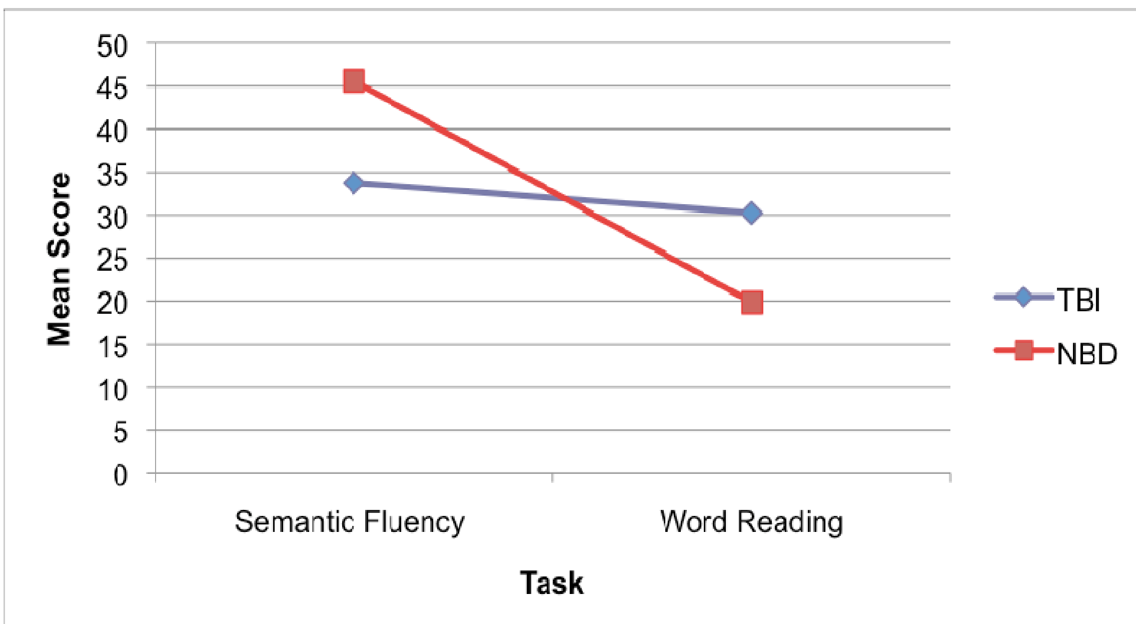

Figure 6. Total Semantic Verbal Fluency Raw Scores and Word Reading Speed across Participant Group

***Inhibition speed vs. semantic verbal fluency*.** The means and standard deviations for Inhibition speed and the semantic verbal fluency task are presented in Table 31. The results of the analysis are presented in Table 32. There was a significant main effect for type of task (*F* (1, 48) = 18.11, *p* = .001). Moreover, there was a significant interaction between participant group and type of task (*F* (1, 48) = 16.36, *p* = .001). As shown in Figure 7, the MOD/S TBI group generated fewer total correct words on the verbal fluency task, and was slower in completing the Inhibition task when compared to the NBD group.

Table 31

Means and Standard Deviations for Total Semantic Verbal Fluency Raw Scores (SVFRS) and CWIS Inhibition Speed across Participant Group

	TBI		**NBD**	
Variable	***M***	***SD***	***M***	***SD***
Total SVFRS	33.76	10.40	45.60	9.56
CWIS Inhibition	74.64	41.13	46.64	9.74

Table 32

Mixed ANOVA Results for Total Semantic Verbal Fluency Raw Scores (SVFRS) and CWIS Inhibition (Inhibit) Speed across Participant Group (*N* = 50)

Source	*df*	*MS*	*F*
Between subjects			
Participant Group	1	1632.16	4.22*
Error	48	386.46	
Within subjects			
Inhibit vs. PVFRS (IN/PVFRS)	1	10983.04	18.11***
IN/PVFRS x Participant Group	1	9920.16	16.36***
Error	48	606.33	

* $p < .05$. *** $p < .001$.

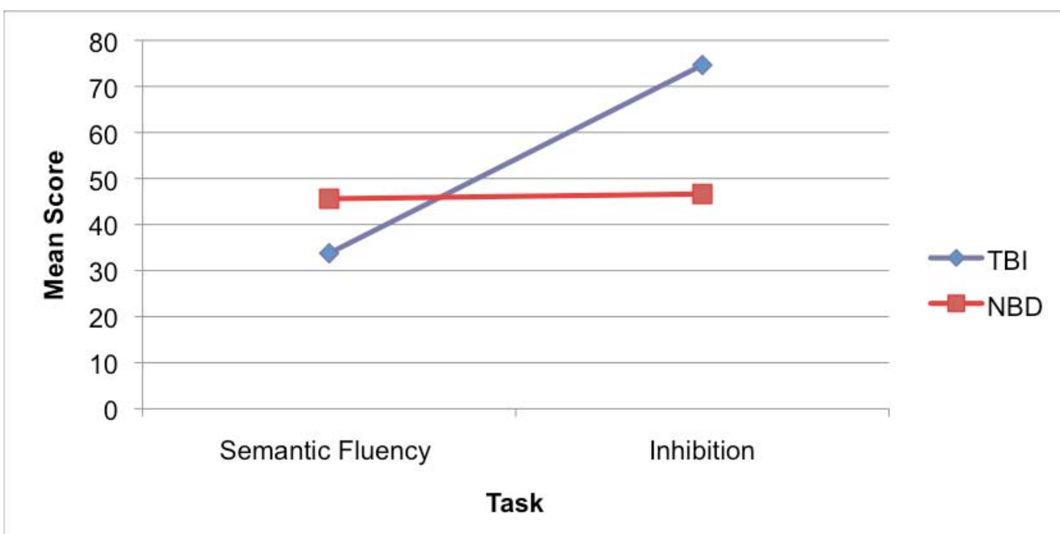

Figure 7. Total Semantic Verbal Fluency Raw Scores and Inhibition Speed across Participant Group

***Inhibition/Switching vs. semantic verbal fluency*.** The means and standard deviations for Inhibition/Switching speed and the semantic verbal fluency scores are presented in Table 33. The results of the mixed-ANOVA are summarized in Table 34. There was a significant main effect for type of task (F (1, 48) = 71.29, p = .001). More importantly, there was a significant interaction between participant group and type of task (F (1, 48) = 34.01, p = .001). As illustrated in Figure 8, the difference observed between phonemic verbal fluency scores and Inhibition/Switching speed varied significantly by participant group. Participants with MOD/S TBI generated fewer total correct words on the verbal fluency task, and had higher Inhibition/Switching scores, indicating that they were slower to complete this task, in comparison to the NBD group.

Table 33

Means and Standard Deviations for Total Semantic Verbal Fluency Raw Scores (SVFRS) and CWIS Inhibition/Switching Speed across Participant Group

	TBI		**NBD**	
Variable	***M***	***SD***	***M***	***SD***
Total SVFRS	33.76	10.40	45.60	9.56
CWIS Inhibition/Switching	99.36	38.79	57.60	12.29

Table 34

Mixed ANOVA Results for Total Semantic Verbal Fluency Raw Scores (SVFRS) and CWIS Inhibition/Switching (In/Switch) Speed across Participant Group (*N* = 50)

Source	*df*	*MS*	*F*
Between subjects			
Participant Group	1	5595.04	13.99***
Error	48	399.76	
Within subjects			
Inhibit vs. PVFRS (IN/PVFRS)	1	37636.00	71.29***
IN/PVFRS x Participant Group	1	17956.00	34.01***
Error	48	527.96	

*** $p < .001$.

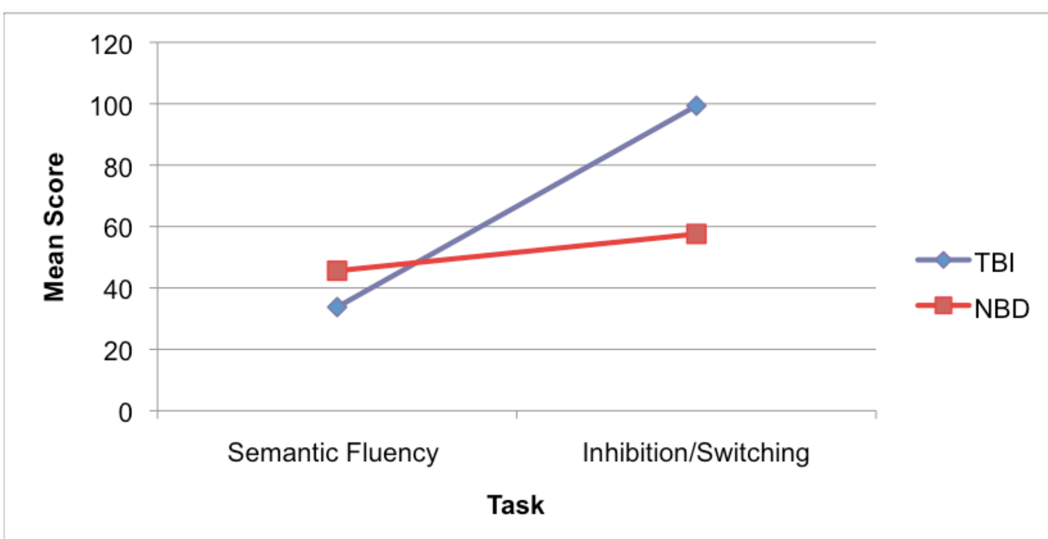

Figure 8. Total Semantic Verbal Fluency Raw Scores and Inhibition/ Switching Speed across Participant Group

Qualitative Results

To explore the multifactorial nature of verbal fluency tasks, responses from the phonemic verbal fluency task and the semantic category *animals* were submitted to a qualitative analysis to explore the specific types of subcategories employed by the two groups, using a modified version of a method proposed by Troyer and her colleagues (1997). For this analysis, successively generated words, including errors and repetitions, for each verbal fluency task were analyzed to determine whether any unique subcategories were present. In accordance with the postulations of Troyer and her colleagues (1997), a subcategory was identified if it contained two or more words.

The initial analysis of words generated on the phonemic verbal fluency task suggested that there were 37 unique subcategories that characterized the responses given for the letters *F, A*, and *S*. Specifically, there were 12 subcategories identified for the letter *F*, 12 for the letter *A*, and 13 for the letter *S*. However, upon further examination, the majority of these subcategories failed to describe a sufficient number of the total responses given by all participants. To illustrate, many of the subcategories identified only characterized the responses of one or two participants, regardless of group. A second analysis of the types of subcategories produced on the phonemic verbal fluency task included an investigation of those subcategories that were common to all three letters in this task. In this analysis, three subcategories were used across the three letters: *word association, synonyms*, and *words that differ by a single letter*. Of these three, the subcategory of *word association*, defined as a noun phrase wherein one word serves to stimulate the production of an associative word, as in the example *first* – *foremost*, characterized the responses of 18 participants, regardless of group. As with the initial analysis of responses, the other two common subcategories identified also characterized the responses of only a few participants. Similar observations were made in the analysis of the types of subcategories produced by participants on the semantic verbal fluency task. On this task, 18 unique subcategories were identified, the majority of which also failed to sufficiently capture a number of responses.

In a pilot study, Cralidis and Lundgren (2009) investigated the types of subcategories produced by a small sample of adult participants with MOD/S TBI. Briefly, participants generated as many words as possible for the letter *M* and for the semantic category of *animals*. The analysis of the types of subcategories produced by participants for the category of *animals* indicated a deviation from the types of subcategories that were observed in the normative sample of Troyer and her colleagues (1997). To illustrate, Cralidis and Lundgren (2009) identified one subcategory entitled *alphabet generation*, defined as the production of animal names that began with the letter *A*, that characterized the responses of a majority of participants. When applied to the current investigation, however, this modified version of the original scoring method first proposed by Troyer et al. (1997) appears to be invalid. One potential reason for this discrepancy may be due to differences in the sample sizes between the pilot study, the current investigation, and in the normative data examined by Troyer (2000). Troyer (2000) previously investigated the types of subcategories produced by a sample of 411 healthy adult participants on tasks of phonemic and semantic verbal fluency. She found that participants primarily grouped words on the semantic task by using specific subcategories, such as *African animals, water animals, pets*, and the like. On the phonemic verbal fluency task, Troyer (2000) found that participants clustered words based on a number of phonemic characteristics, such as grouping by first initial letters, by words that rhyme, and so forth. Previously, Troyer and her colleagues (1997) investigated the types of subcategories produced on tasks of phonemic and semantic verbal fluency by a sample of 54 older and 41younger healthy participants. The investigators found that the responses on the semantic category of *animals* could be divided across three major category divisions: *living environment, human use*, and *zoological categories*. Then, within each of the three categories, they identified a number of smaller subcategories. To illustrate, the category of *living environment* included animals from *Africa, farm animals*, and *water animals*. For *human use*, Troyer and colleagues (1997) identified *beasts of burden* and *pets*. The *zoological* category was further divided into a number of subcategories, including *birds, feline*, and *reptile/amphibian*. On the phonemic verbal fluency task, the investigators found that participants grouped words that shared the following characteristics: *first letters, rhymes, first and last sounds*, and *homonyms*. Briefly, *first letters* described successively generated words that began with the same first two letters, as in the word pair *arm* and *art*. *Rhymes* were defined simply as words that rhymed, as in the example *sand* and *stand*. *First and last sounds* were defined as words that differed by a single vowel sound, as in the words *sat* and *seat*. Last, *homonyms* were defined as words that were identical in sound, but that had different spellings and meanings, as in the example *sum* and *some*. To date, Troyer and colleagues (1997) have not examined the frequency with which individual subcategories are used by healthy participants when completing tasks of verbal fluency.

To this end, an additional analysis, using the original scoring method of Troyer (2000) and Troyer et al. (1997), was conducted on the responses from the phonemic and semantic verbal fluency tasks observed in the present investigation. On the phonemic verbal fluency task, successively generated words for the letters *F, A*, and *S*, combined, were examined. The analysis indicated that participants, regardless of group, primarily generated words using the characteristics *first letters,* followed by *first and last sounds*. Participants in the NBD group produced a greater number of successively generated words using both characteristics than did the MOD/S TBI group. On the semantic verbal fluency task, all participants, regardless of group, generated more words that belonged to the greater category of *living environment*, followed by *zoological*, and then *human use*. In the category of *living environment*, both groups generated the greatest number of words that belonged to the subcategory of *African animals*. While participants in the NBD group generated a greater number of words that belonged to the category of *farm animals*, followed by *water animals* in the *living environment* category, the opposite pattern of performance was observed in the MOD/S TBI group. In the category *human use*, both groups generated the greatest number of responses for the subcategory of *pets*, in comparison to the number of words generated for the subcategories of *beasts of burden* and *animals with fur*. For the *zoological* category, the NBD group generated the greatest number of words by drawing from three subcategories: *birds*, followed by *fish*, and then *reptile/amphibian*. In contrast, the MOD/S TBI group generated words for the category of *zoological* by drawing from four subcategories: *birds*, followed by *fish*, then *rodent*, and *reptile/amphibian*.

One feature of word generation on tasks of verbal fluency that has yet to be explored is the potential relationship between WM and the number of subcategories generated on these types of tasks. In the present investigation, Pearson-produce moment correlations procedures were conducted to determine the relationship between the total number of word recall errors on the WMT and the total number of subcategories produced on each verbal fluency task. The results of this analysis are presented in Table 35. As illustrated in this table, the total number of word recall errors on the WMT was negatively associated with the number of subcategories produced on the phonemic verbal fluency task ($r = -.34$, $p = .018$), and with the number of subcategories produced on the semantic verbal fluency task ($r = -.31$, $p = .031$). These findings indicate that participants, regardless of group, who generate a greater number of words on tasks of verbal fluency, tend to produce fewer total word recall errors on the WMT.

Table 35

Pearson Correlations between Working Memory and Number of Subcategories Generated (*N* = 50)

Variable	1	2
1 WMT total number of errors		
2 Number of phonemic subcategories	-.34*	
3 Number of semantic subcategories	-.31*	.09

* *p* < .05 (two-tailed).

CHAPTER V

DISCUSSION

Verbal Fluency and Working Memory

The present investigation sought to account for the number of independent *t*-test procedures conducted on the data by applying a Bonferroni correction for multiple comparisons. After this correction was applied, only two findings remained statistically significant. First, participants with MOD/S TBI significantly differed from the NBD group on the total number of correct words produced on the semantic verbal fluency task, and on the letter *S* on the phonemic verbal fluency task. Second, the MOD/S TBI group produced a significantly greater number of total word recall errors on the WMT when compared to the NBD group. Moreover, a comparison between performance on the WMT and the verbal fluency tasks suggested that the total number of word recall errors on the WMT was negatively correlated with the total number of correct words generated on both verbal fluency tasks. In essence, participants who generated a greater number of total correct words on the verbal fluency tasks also made fewer total word recall errors on the WMT. Conversely, the generation of fewer words on the verbal fluency tasks was associated with a greater number of total word recall errors on the WMT.

Although Bonferroni corrections for multiple comparisons have not been consistently applied or reported in the existing literature that has addressed verbal fluency and WM following TBI, there are a few studies that have applied this rigorous analysis and that offer support for the findings in the present investigation. To illustrate, Wallesch and colleagues (2001) examined phonemic and semantic verbal fluency performance, as indicated by the total number of correct words generated, in a group of native German speakers with mild to moderate TBI who were further divided based upon site of lesion and the presence of DAI. After applying a Bonferroni correction to the data, the investigators found that all participants were impaired on a task of semantic verbal fluency only. In contrast, no significant differences were observed in performance on either task of verbal fluency after participants were divided based upon lesion site and the presence or absence of DAI. Relative to WM, the investigators observed no significant differences in performance on digit span forward and backward tasks when compared to the initial Glasgow Coma Scale (GCS; Teasdale & Jennett, 1974) score or when the group was divided based upon lesion site or the presence or absence of DAI, after a Bonferroni adjustment was applied. However, performance on the digit span forward task only remained statistically significant, following a Bonferroni correction, when the test scores on this task were compared between the post-acute and outcome assessment time periods, after dividing participants based upon the presence of DAI. More recently, Kavé and colleagues (2011) examined phonemic and semantic verbal fluency performance, as measured by the total number of correct words produced, in 30 native Hebrew speakers with MOD/S TBI and a group of 30 participants with NBD. The investigators found that the MOD/S TBI group produced significantly fewer total correct words on both tasks of verbal fluency when compared to the NBD group, and these findings remained statistically significant after a Bonferroni adjustment for multiple comparisons was applied.

Moreover, a number of studies that have examined the relationship between WM and verbal fluency, as indicated by the total number of correct words produced, in participants with NBD, also offer support for the findings observed in the present investigation. As an illustration, Weiss and colleagues (2006) investigated the influence of gender on tasks of phonemic and semantic verbal fluency, as indicated by the total number of correct words generated, and WM, as indicated by test scores on the Digit Symbol test (Wechsler, 1981), in a group of participants with NBD. The investigators observed a correlation between the total number of correct words generated on both tasks of verbal fluency and scores from the Digit Symbol test in male participants only, and these findings remained statistically significant following a Bonferroni adjustment. While female participants generated a significantly greater number of total words for the phonemic verbal fluency task only, when compared to male participants, it is unknown whether these findings may have remained statistically significant following a Bonferroni correction for multiple comparisons. Further, Rosen and Engle (1997) found that participants with NBD who produced fewer errors on a measure of WM also generated a significantly greater number of words for the semantic category of *animals*. Likewise, Unsworth and colleagues (2010) observed that for an NBD group, WM performance, as indicated by the number of errors produced, and phonemic and semantic verbal fluency performance, expressed as the total number of correct words produced, were strongly associated.

Yet, it is of notable concern that a number of investigations that have explored verbal fluency and WM following TBI have not routinely reported Bonferroni corrections for multiple comparisons in their findings. It is well accepted that in multiple testing, the threshold criteria should be adjusted in order to account for the number of statistical tests that are conducted on the same data set (Bennett, Wolford, & Miller, 2009). The application of the Bonferroni technique would identify the probability of false positives that may be present in the reported results. Neglecting to report the presence of false positives may have a number of negative consequences. First, investigations that have employed a liberal significance threshold may be quite difficult to replicate (Bennett et al., 2009). Within this context, there is warranted concern for the uncertain amount of time and resources that may have been employed in effort to extend results that simply do not exist (Bennett et al., 2009). Second, the inability to replicate the findings from an existing investigation may negate one's ability to dispel the null results, thus confirming the notion that false positives may be quite difficult to dispute once they have been published (Bennett et al., 2009).

Moreover, the infrequent application of the Bonferroni technique to verbal fluency and WM data may also reflect a concept referred to as the “File Drawer Problem” (Rosenthal, 1979), a publication bias that postulates that only investigations that impart significant findings will be published (Bennett et al., 2009). While publication of null findings is not improbable, it is generally regarded as the exception rather than the rule (Bennett et al., 2009). To this end, it may be difficult to balance the number of true positives while minimizing false reports. To insure that all findings are true positives would require stringent statistical thresholds that would elucidate only the most robust results. However, one postulation asserts that the goal of efficacious research is not to completely eliminate false positives, but rather, to accept the notion that there is an inherent risk of false positives when conducting multiple comparisons within the same data set. Within this context, it may be most critical to specify the relative probability of false positives within a particular data set, and to further communicate this information to the reader (Bennett et al., 2009).

Verbal Fluency and Strategy Use

Relative to strategy use, under the forced choice condition of the Self-Report of Strategy Use Questionnaire, a majority of participants in both groups reported using no specific strategy to guide the generation of words for the verbal fluency tasks. The absence of any specific strategy reported may be due, in part, to the phrasing of the questions on this measure that were used to probe for the distinct use of a visual, verbal, or mixed strategy during performance on these tasks. As an illustration, participants were asked if they combined syllables, searched for visual associations, or searched for visual memory representations while generating words for both verbal fluency tasks. It is possible that the terminology employed may have been unfamiliar to some participants, thus confounding their understanding of the probe questions. These speculations were partly confirmed under the free recall condition of the task where participants were asked to freely report the use of any strategies used during word generation. In contrast to the responses from the forced choice condition, an evaluation of responses from the free recall condition suggested that some participants did employ strategies to govern word production. As observed in the forced choice condition, a majority of participants in both groups indicated using no specific strategy to guide the generation of words on the phonemic verbal fluency task. The two exceptions to this were for the semantic categories of *boys' names* and *animals*. For the category of *boys' names*, a majority of participants in both groups reported using the names of familiar people, such as friends, family, and the like, to generate words for this task. For the category of *animals*, participants with MOD/S TBI were more likely to report no strategy use, while the NBD group indicated using specific subcategories of animals to guide their production of words on this particular task. Of note, the latter finding may further account for the differences observed between the groups in the total number of correct words generated for the semantic category of *animals*. In the present investigation, the MOD/S TBI group generated significantly fewer total correct words for the category of *animals*, when compared to the NBD group, and this finding remained statistically significant following a Bonferroni adjustment. Taken together, the findings of this study are not fully supported by the previous findings of Elfgren and Risberg (1998). In examining the responses of an NBD group on the forced choice condition, Elfgren and colleagues (1998) found that those who reported using a verbal strategy generated a significantly greater number of words on a task of phonemic verbal fluency when compared to those who employed a mixed strategy. Moreover, the investigators did not examine the types of strategies reported by their participants under the free recall condition. In the present investigation, the NBD group reported using specific strategies to guide the production of words for both semantic categories. In contrast, the MOD/S TBI group reported using strategy only for the semantic category of *boys' names*. Given the differences observed between the groups relative to the total number of words produced on both types of verbal fluency tasks, it appears that instruction in the use of strategy to govern word production may have a beneficial impact in the performance of the MOD/S TBI group.

Collectively, these findings suggest that participants with MOD/S TBI perform differently from the NBD group on a task of semantic verbal fluency and on the letter S on a phonemic verbal fluency task, as indicated by the total number of words generated, after a Bonferroni correction for multiple comparisons was applied to the data. Moreover, the observed discrepancy in performance may be further confounded by the absent or ineffective use of strategy to govern the generation of words on both types of verbal fluency tasks, but most notably during the semantic category of *animals*, for the MOD/S TBI group. Hence, it appears that during word generation, participants with MOD/S TBI may be disproportionately impaired in the ability to search, retrieve, and generate words, in comparison to an NBD group. These observations may be partly accounted for by the two-stage, cyclical search model proposed by Gruenewald and Lockhead (1980), wherein individuals first search for appropriate subcategories, then search and recall specific words in rapid succession within those subcategories. Once a subcategory has been exhausted, a new search is initiated for a different subcategory and words are then retrieved from the new subcategory. This cyclical process continues until the semantic stores are exhausted, or the time limitations for the task expire. A number of investigations in pathological conditions have demonstrated support for these postulations as performance on tasks of verbal fluency, while differentially sensitive to the presence of brain lesions in different neural areas, has also been shown to be mediated by multiple neural areas (Baldo & Shimamura, 1998; Birn et al., 2010; Goldstein et al., 2004; Laisney et al., 2009; Libon et al., 2009). Within this context, the presence of widespread brain dysfunction, as is often observed in MOD/S TBI, may account for decrements in performance on tasks of verbal fluency (Jurado et al., 2000; Raskin & Rearick, 1996).

Verbal Fluency, Number of Switches, and Mean Cluster Size

After making Bonferroni corrections for multiple comparisons, the mean cluster size produced on the phonemic and semantic verbal fluency tasks did not distinguish the MOD/S TBI group from the NBD group. However, the total number of correct words produced on the phonemic verbal fluency task was positively correlated with the mean cluster size for the letter *A*. This finding suggests that a greater number of words generated on the phonemic verbal fluency task was associated with a larger mean cluster size for the letter *A*. Likewise, a Bonferroni adjustment conducted on the total number of switches generated on both tasks of verbal fluency did not significantly differentiate the groups. However, the total number of correct words generated on the phonemic and semantic verbal fluency tasks was positively correlated with the number of switches produced for the letters *F, A*, and *S*, and for the semantic category of *animals*, respectively. These findings suggest that generating a greater number of words on both tasks of verbal fluency is associated with a greater number of switches.

Taken together, the observations made relative to clustering and switching in both tasks of verbal fluency are only partially supported by the existing literature. Previously, Troyer and her colleagues (1997) found that both clustering and switching were highly correlated with the total number of words generated on a semantic verbal fluency task in younger and older participants with NBD. In contrast, the present investigation observed a significant correlation only between clustering on the letter *A* and the total number of correct words produced on a task of phonemic verbal fluency. Moreover, Troyer et al. (1997) observed a strong correlation between the number of switches produced and the total number of words generated on a task of phonemic verbal fluency. Similarly, the present investigation found a significant correlation between switching and the total number of words generated on both tasks of verbal fluency.

Troyer (2000) has posited that participants with pervasive brain damage, as many be observed following MOD/S TBI, may be equivocally impaired on both clustering and switching, although one type of impairment tends to predominate. In the present investigation, this postulation was clearly demonstrated in that no significant associations were observed between clustering on the letters *F* and *S* in the phonemic verbal fluency task and the total number of words generated on this task, or for the semantic category of *animals*, in relation to the total number of words generated on the semantic verbal fluency task. These observations suggest a decrement in the ability to cluster effectively. Previous research has suggested that cluster size is assumed reflect the integrity of both the phonemic and semantic stores, and may be strongly mediated by the temporal lobes (Birn et al., 2010; Laisney et al., 2009; Monsch et al., 1994; Sheldon & Moscovitch, 2011; Troyer, 2000; Troyer & Moscovitch, 1996; Troyer, Moscovitch, Winocur, & Leach, et al., 1998). Moreover, clustering is thought to be predicated on the ability to organize words by common features on tasks of semantic verbal fluency, and by common phonemic features, such as the grouping of common letters, on tasks of phonemic verbal fluency (Troyer, 2000; Troyer et al., 1997). Optimal performance, as indicated by the total number of words produced on both tasks of verbal fluency, is further based on the ability to produce large numbers of words within semantic and phonemic subcategories (Troyer, 2000; Troyer et al., 1997). In participants with NBD, both switching and clustering have been found to contribute equally to successful performance on tasks of semantic verbal fluency, whereas switching has been found to strongly relate to performance on phonemic verbal fluency tasks (Troyer et al., 1997). To this end, Troyer and colleagues (1997) speculated that cluster size most clearly reflects the ability to access and retrieve those words contained within phonemic and semantic subcategories, while switching reflects the ability to switch from one subcategory to another. In the present investigation, participants appeared to exhibit greater difficulty in the ability to cluster, in comparison to the ability to switch, on both tasks of verbal fluency, as indicated by the absence of a significant correlation between the mean cluster size produced for the letters *F* and *S* on the phonemic verbal fluency task, and for the semantic category of *animals*, and the total number of correct words generated on both verbal fluency tasks. However, the observed relationship between switching and the number of words generated on both tasks of verbal fluency support the postulations of Troyer and her colleagues (1997).

One theory that may account for the discrepancy observed between clustering and switching in the present investigation is predicated upon the assumption that words comprise a highly structured network that when activated, may prime the retrieval of a number of related words (Anderson & Pirolli, 1984; Collins & Loftus, 1975). Once activated, the strength of the relatedness between words may serve as a catalyst for the retrieval of other highly salient words that are grouped within specific subcategories that belong to a greater parent category. The number of words generated is thought to reflect the strength of the initial word that is primed. Thus, greater priming will result in the activation of a greater number of words, beginning with those that are most strongly related to the prime word, followed by activation of words that are distantly or weakly related to the initial prime. In the current investigation, the reduction in the mean cluster size on both tasks of verbal fluency may indicate a disruption in the integrity of the semantic store, or the inability to access these stores.

Verbal Fluency and Information Processing Speed

The findings from the present investigation suggested a negative correlation between phonemic and semantic verbal fluency, as indicated by the total number of words generated, and the test scores from the conditions of the CWIS. In general, participants, regardless of group, who generated a greater number of words on tasks of verbal fluency, were also faster in completing the four conditions of the CWIS, and vice versa. In comparing group performances, the MOD/S TBI group generated significantly fewer words for both the phonemic and semantic verbal fluency tasks, and took a longer period of time to complete all four conditions of the CWIS, in comparison to the NBD group.

These findings are in accordance with previous research that has demonstrated a relationship between performance on verbal fluency tasks and information processing speed in participants with TBI (Bittner & Crowe, 2007; Miotto et al., 2010; Wallesch et al., 2001). To illustrate, Bittner and Crowe (2007) found that information processing speed was particularly critical for performance on a task of phonemic verbal fluency, as indicated by the total number of words generated, for participants with mild to severe TBI. In contrast, they observed that a number of additional factors, most notably level of education and word knowledge, contributed to successful performance on the phonemic verbal fluency task in participants with NBD. These findings suggest that a phonemic verbal fluency task may be particularly demanding for those who have sustained a TBI, and that information processing speed appears to be the critical factor in determining successful performance, as indicated by the total number of words generated. While these findings may be particularly relevant, Bittner and Crowe (2007) noted that their investigation was exploratory in nature and as such, the significance levels were not adjusted for multiple comparisons using the Bonferroni technique. Within this context, it is unknown whether these findings may have remained statistically significant following a Bonferroni correction. More recently, Miotto and colleagues (2010) found that 12 participants with mild to moderate TBI were differentially impaired on both information processing speed and a task of phonemic verbal fluency, as indicated by the total number of correct words generated, when lesions were confined to the left and right frontotemporal and left parietal-occipital regions. In contrast, performance on a task of semantic verbal fluency, as indicated by the total number of correct words generated, and information processing speed were compromised when the lesion was isolated in the left temporoparietal area. However, the conclusion drawn about the relationship between semantic verbal fluency and information processing speed was predicated on the performance of a single participant. Moreover, the investigators noted that the small sample size precluded the completion of more robust statistical analyses on the data set, including the application of a Bonferroni adjustment for multiple comparisons. As noted with the findings of Bittner and Crowe (2007), it is unknown whether the results observed by Miotto and colleagues (2010) would have remained statistically significant if they had accounted for the number of multiple comparisons by applying a Bonferroni technique. In contrast, Wallesch and colleagues (2001) found that information processing speed, as measured by performance on a modified version of the Stroop Naming Task (Oswald & Fleischmann, 1995), remained statistically significant following a Bonferroni adjustment for multiple comparisons, in a group of participants with mild to moderate TBI who were divided based upon the presence or absence of DAI. However, it is unknown whether this finding was correlated with performance on tasks of phonemic and semantic verbal fluency. Despite these limitations, the current investigation extends and confirms these findings that diminished performance on a task of information processing speed may negatively impact performance on tasks of verbal fluency in participants with MOD/S TBI.

A cornerstone in the successful completion of verbal fluency and speeded processing tasks is the ability to perform as quickly as possible within an allocated time limit. Together, successful performance on these types of tasks is mediated by a number of common executive functions, including the ability to self-monitor and verbally inhibit; to employ mental flexibility; to retain a number of rules; to engage in rapid mental processing; and to maintain attention (Benton, 1968; Borkowski et al., 1967; Delis et al., 2001; Marshall, 1986; Spreen & Straus, 1991). Moreover, tasks of verbal fluency may rely upon the executive processes of search and retrieval, along with the ability to organize responses by their relatedness, in order to produce as many words as possible (Collins & Loftus, 1975; Gruenewald & Lockhead, 1980). Verbal ability, and the extent of word knowledge, may further influence performance on tasks of verbal fluency (Crowe, 1998; Ruff et al., 1997). Within this context, verbal fluency may reflect the extent of an individual's information processing speed, with efficient information processing strategies serving to optimize performance. In the present investigation, the poorer performance of participants with MOD/S TBI, in comparison to the NBD group, may reflect disturbances in one or several of the aforementioned executive functions. Lezak (2004) has previously postulated that participants with TBI will typically display decrements in a number of executive functions, with one or two being particularly prominent.

The Qualitative Analysis of Verbal Fluency Performance

The present investigation sought to identify the presence of any unique subcategories that could not be accounted for by using the original scoring method proposed by Troyer and colleagues (1997). Previously, Cralidis and Lundgren (2009) piloted a modified version of the Troyer et al. (1997) scoring method and identified a number of subcategories, dissimilar from those originally identified by Troyer et al. (1997), that characterized the responses generated by participants with MOD/S TBI on the semantic category of *animals*. However, when applied to the current investigation, the modified version of the original scoring method of Troyer and colleagues (1997) failed to characterize a majority of the responses on both tasks of verbal fluency. It is possible that these differences may reflect differences in the sample sizes employed between the pilot study (Cralidis & Lundgren, 2009), the present investigation, and the normative work of Troyer (2000). Thus, the modified scoring version was abandoned in favor of the original scoring method (Troyer et al., 2000) for this type of analysis.

Previously, Troyer (2000) identified a number of subcategories that characterized the responses of a group of participants with NBD on tasks of phonemic and semantic verbal fluency. To illustrate, she found that participants primarily grouped words for the semantic category of *animals* by using specific subcategories such as *African animals, pets*, and the like. On a task of phonemic verbal fluency, Troyer (2000) identified a number of phonemic characteristics that defined the word clusters generated by the NBD group, including *first letters, first and last sounds, rhymes*, and so forth. In applying this analysis to the present investigation, all participants, regardless of group, primarily generated words using the characteristics *first letters*, followed by *first and last sounds*, on the phonemic verbal fluency task. On the semantic verbal fluency task, all participants, regardless of group, produced the greatest number of words that belonged to the subcategory of *African animals*. The frequent sampling of this particular subcategory by both groups may reflect the typicality of members associated with this subcategory. In other words, both groups may have accessed and then retrieved members from this particular subcategory because of the large pool of words that may be associated with it, in comparison to subcategories that may have fewer words, such as *pets*. Within this context, a number of researchers have speculated that the effect of category size reflects variations in the degree of semantic relatedness amongst category members (Collins & Quillian, 1970; Freedman & Loftus, 1971; Landauer & Meyer, 1972). Moreover, the size of the memory set for a given subcategory may account for the differences in the mechanisms of retrieval and production (Landauer & Meyer, 1972).

Another explanation that may account for the discrepancy in performance noted between the MOD/S TBI and NBD groups may be accounted for by differences in WM. Indeed, the present investigation observed a negative correlation between the total number of word recall errors on the WMT and the total number of subcategories produced on both verbal fluency tasks. This finding suggests that participants, regardless of group, who generate a greater number of subcategories on verbal fluency tasks, will produce fewer total word recall errors on the WMT, when compared to those participants who generate fewer subcategories. This inverse relationship suggests that efficacious performance on both WM and verbal fluency tasks, as indicated by the number of subcategories produced, may share a number of common skills. To illustrate, the generation of subcategories is thought to be predicated on the ability to search and retrieve relevant words that share a number of similarities, while remembering rules that serve to govern performance, such as avoiding proper names, alterations of a word by adding suffixes or prefixes, and repetitions (Borkowski et al., 1967; Bousfield & Sedgewick, 1944; Delis et al., 2001; Glass & Holyoak, 1986; Gruenewald & Lockhead, 1980; Spreen & Straus, 1991). The ability to retain these rules may reflect the integrity of WM so that random memory searches are avoided. Within this context, WM has been previously described as a system of limited capacity, where the capacity must be shared between the task at hand and the memory for the particular task, and between the processing and storage demands of the task that depend upon the integrity of WM (Baddeley, 1981, 1986; Baddeley & Hitch, 1974; Daneman & Carpenter, 1980). In the present investigation, the diminished performance of the MOD/S TBI group may reflect disturbances within those anatomical regions, namely the dorsolateral prefrontal cortex, that are believed to mediate WM.

Limitations

A number of limitations in the present investigation warrant consideration. First, this investigation included only those participants in the moderate to severe TBI range, thereby limiting the generalization of these findings to the TBI population in general. A second limitation is the size of the samples. It is possible that the lack of statistical significance detected for some of the comparisons may reflect a lack of power to detect statistical significance, due to small sample sizes, as opposed to an absence of a difference. Third, the etiology of MOD/S TBI varied amongst some participants in the study. In light of this observation, it is further possible that the extent and distribution of diffuse axonal injury that often accompanies MOD/S TBI may have varied amongst participants as well, thus potentially confounding performance outcomes. Another consideration is the potential influence of premorbid intelligence quotient (IQ) on performance in the MOD/S TBI group. Despite pairing the samples for age and years of education, the present investigation did not match the samples based upon a formal assessment of IQ, making it difficult to determine whether performance differences may have been due to a consequence of injury or preceded it. A failure to match the groups based upon IQ, despite pairing participants by years of education, may reflect the fact that some participants in the NBD group may have represented the upper end of the IQ distribution whilst some participants in the MOD/S TBI group may have represented the lower end of the IQ distribution or vice versa.

Conclusion

The present investigation demonstrated that participants with MOD/S TBI are disproportionately impaired on tasks of verbal fluency, working memory, and information processing speed, in comparison to a group of participants with NBD, when a standard statistical model was applied. However, when the data was re-analyzed after making Bonferroni adjustments for multiple comparisons, only two of the findings remained statistically significant. Specifically, the MOD/S TBI group was disproportionately impaired on a task of semantic verbal fluency and on the letter *S* on a phonemic verbal fluency task, as indicated by the total number of words generated, and on the total number of word recall errors produced on a measure of WM, compared to the NBD group. Moreover, participants with MOD/S TBI displayed diminished performance on tasks of information processing speed and WM, and these differences in performance were associated with decrements in performance on both tasks of verbal fluency, as indicated by the total number of correct words produced on these tasks.

Future Directions

There are a number of considerations to guide future research. First, the development of a comprehensive protocol to measure specific strategy use during word production on tasks of verbal fluency is indicated. Specifically, this protocol should include a greater number of forced choice strategies, as well as clear and concise instructions to guide the free recall of strategy use. A comparison of group performance based upon reported strategy use on verbal fluency tasks is warranted in order to determine the potential efficacy of strategy training as a means to improve performance. Second, pairing the groups based on performance on a measure of IQ is indicated to determine whether the factor of IQ may contribute to performance differences on tasks of verbal fluency. Third, the observed differences between the groups on WM and information processing speed tasks should be further examined to determine the relative weight of contribution of each factor on verbal fluency tasks. Indeed, the exploration of these differences may contribute greatly toward the understanding of verbal fluency performance. Moreover, an exploration of the association between WM and information processing speed, individual and group differences in these factors, and their neural substrates may provide a greater understanding of how these factors work in concert to support the generation of words on tasks of verbal fluency.

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