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Nature of the Verbal Fluency Task in Concussed Athletes

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Abstract

Background: Verbal fluency is a common test used to assess naming in individuals with brain injury. Troyer (1997) reported that naming components such as phonemic clusters and categorical switching might be more sensitive to the presence of brain injury than a reduction in the total number of words that is commonly used as a measure. Phonemic task refers to the F-A-S naming task while the semantic task refers to the animal naming task because of the frequent production of phonemic cluster on the F-A-S and semantic clusters on the animal naming task (Troyer, 1997).

Purpose: The purpose of this study is to investigate the changes and the nature of post-concussive recovery in terms of the total number of words, mean cluster size, and number of switches in individuals who experienced a sport-related concussion.

Method: The verbal fluency task was administered to concussed and non-concussed individuals. The group of concussed athletes was matched to a control group of individuals with no history of concussion. A group of concussed athletes was tracked from preseason (baseline) to post-concussion testing in order to describe changes and the nature of recovery of the total number of words, mean cluster size, and number of switches in the phonemic and semantic task.

Results: A Mann-Whitney U test between groups showed no difference at baseline testing in total number of words, mean cluster size, and the number of switches in the phonetic or semantic task. In athletes who sustained a concussion, the Wilcoxon Signed Rank test revealed a significant decrease in mean cluster size in the phonemic task from baseline to post-concussion testing 1. After 7-10 days post-concussion, athletes significantly increased their mean cluster size

from post-concussion testing 1. In the semantic task, there was no significant change in the athletes' performance following their concussion.

Conclusion: Mean cluster size scores, in the phonemic task, are a better indicator of post-concussion cognitive deficits compared to total number of words. Therefore, clinicians can use this score to track individual recovery progress for a safe return-to-play decision.

Keywords: concussion, assessment, return to play, verbal fluency task, cognitive-communication, cluster scores, switching scores

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Chapter 1: Literature Review

1.1 Introduction

A concussion, also known as mild traumatic brain injury (mTBI), can be defined as a closed head injury that results in immediate and brief alteration in brain's normal function (Henry & Crawford, 2004). Concussions typically occur when there is acceleration, or deceleration, of the brain. This is when the moving head is stopped suddenly with or without hitting another object. The term concussion is referred to in the literature as mTBI; these terms are typically interchangeable (Salvatore & Fjordbak, 2012). The alteration of the brain may affect the frontal and temporal lobe with diffuse and or focal damage (McDonalds et al., 2002; Zakzanis, McDonald, & Troyer, 2010). One of the primary post injury abnormalities after mTBI is the brain's neurometabolic cascade that correlates with periods of neurocognitive dysfunction. The neurometabolic cascade results in a significant change in cerebral glucose metabolism (Giza & Hovda, 2001). The recovery of mTBI is spontaneous, usually within the first seven to ten days, correlated with the resolution of symptoms and neurocognitive signs.

According to the American Academy of Pediatrics, Emergency Room visits for concussions have risen 200 percent among teenagers between the ages of 14 to 19 in the last decade (Bakhos, 2010). It is critical that coaches, players, and parents are informed of the dangers of an untreated concussion, and for them to have access to an assessment test that can help track the recovery of a concussion. It is important to decide when it is safe for an athlete to return-to-play and return to school after having a concussion. Decisions to release athletes to return to the playing field or the classroom may result in a delayed recovery or more serious consequences, such as diffuse cerebral swelling or second-impact syndrome (Cantu, 1998;

Collins et al., 2002; Guskiewicz et al., 2003). In efforts to assist clinicians with making appropriate back to play recommendations assessments are utilized to aid in the evaluation of the unremitting effects of the injured brain.

The verbal fluency task is a commonly used cognitive-communication assessment of word retrieval in individuals with brain damage. The test measures the individual's ability to search lexical stores and retrieve information from semantic and phonemic memory (Kave, Heled, Vakil, & Agranov, 2011). The test consists of two tasks, a phonemic word retrieval task (naming words that start with letters F, A and S) and a semantic word retrieval task (animal naming). The verbal fluency task test requires individuals to generate as many different words as possible during a time frame. The most commonly used scoring system counts the total number of words generated. However, studies agreed that the total number of words may not provide information about the cognitive processes underlying fluency performance and does not answer the questions as to why a particular patient tends to produce fewer words following a brain injury (Bousfield & Sedgewick, 1944; Troyer, Moscovitch, & Winocur, 1997; Troyer, 2000; Zakzanis, McDonald, Troyer, 2011; Kave et al., 2011).

In response to this finding, Troyer and colleagues (1997) added two additional methods of analyses to the verbal fluency task. These methods of analyses are believed to evaluate a patient's performance in generating words within semantic and phonemic subcategories. According to Troyer et al. (1997), when generating words during the phonemic and semantic fluency tasks, participants produce clusters of phonemically or semantically related words, and once a subcategory is exhausted, they switch to another subcategory. Clustering and switching scores have been evaluated in patients who sustained a mild traumatic brain injury (Zakzanis, McDonald, Troyer, 2011). Results from the Zakzanis, MacDonald, and Troyer (2011) study

revealed that the mean cluster size and number of switching are more sensitive measures of verbal fluency in brain-injured individuals. The Zakzanis' et al. (2011) study is the only study that has evaluated these 3 scoring methods: the total number of words, mean cluster size, and the number of switches in individuals with mild TBI and severe TBI.

1.2 Nature of a Concussion/mTBI

A traumatic brain injury is an occurrence of injury to the brain resulting from a blunt trauma or acceleration-deceleration forces causing brain tissue movements within the skull. Regardless of the point of impact, the anterior and inferior surfaces of the frontal and temporal lobes are vulnerable to the bony shelves of the skull (Levin, Benton, Grossman, 1982). A mild traumatic brain injury (mTBI) is damage at the neuronal level. Therefore, it requires an imaging technique that can detect structural and functional abnormalities. The Computer Tomography (CT) scan is one of the most common radiologic techniques used in the emergency room to rule out cranial bleeding in an individual with traumatic brain injury. The CT scan leaves many mTBIs unidentified (McCrea, 2008, p. 62). CT scans detect blood and edema, but do not detect neuronal dysfunction following a brain injury. Functional Magnetic Resonance Imaging (fMRI) is a better imaging technique for detecting small intracranial structural abnormalities and axonal injury than a CT scan.

However, the fMRI is not used as commonly in hospital's emergency departments and critical care units (McCrea, 2008, p. 63). In addition, fMRI does not provide a perfect predictor of good or poor outcome in the majority of mTBI patients (Shenton et al., 2012). Studies have used fMRI to compare cerebral profile in individuals with mTBI to non-injured individuals. FMRI studies showed the abnormal profile of cerebral activation in mTBI individuals when compared to non-injured individuals. This abnormal activation may reflect inability of the

injured brain to activate or to modulate working memory processing (Birn, Kenworthy, Case, Caravella, Jones, Banderrini, & Martin, 2010; Hirshorn, 2006; McCrea, 2008; Robinson, Shallice, Bozzali, & Cipolotti, 2012). Focal injury and diffuse white matter damage have been observed in individuals with a mTBI (Henry & Crawford, 2004; Jurado, Matro, Verger, Bartumeus, & Junque, 2000). Bigler (2013) reviewed the biomarkers in mTBI and found white matter abnormalities after a brain injury. Diffused white matter is found to be an important determinant of cognitive impairment after a brain injury (Kinnunen, 2010). Studies show that individuals who have sustained a mTBI show abnormal cerebral activation in response to cognitive demands. mTBI individuals showed a decreased activation of select neuronal circuits in the frontal lobes that were associated with executive dysfunctions (McCrea, 2008; Birn et al., 2010; Jurado et al., 2000; Ribinson et al., 2012; Zakzanis et al., 2011). Therefore, changes in cognitive functioning may be present after a brain injury. Cognitive impairments in attention, memory, and executive function are typical post-concussive symptoms (Arciniega, Anderson, Topkoff & McAllister, 2005).

Executive functions involve a complex environmentally- sensitive set of related processes that are responsible for purposeful, goal-directed, and problem-solving behavior (Maillard-Wermelinger et al., 2009). A deficit in the executive domain following a mTBI is likely to affect cognitive, social, and emotional functioning (Maillard-Wermelinger et al., 2009). Howell et al. (2013) analyzed the recovery pattern of attention and executive function in concussed adolescents during a 2-month period post-injury. Results from the study suggest that concussed athletes have difficulty recovering executive functions after an injury. Consequently, evaluation tests that focus on executive functions are useful in identifying changes and tracking recovery following a concussion.

In addition to executive dysfunctions, McAllister et al., (1999) found deficits in working memory following a mTBI. Working memory is the ability to store and manipulate information to be used for cognitive or behavioral guidance (Chen et al., 2012). A study by Christodoulou et al. (2001) examined the pattern of brain activation with the use of an fMRI while performing a working memory task in individuals with TBI. Christodoulou et al. (2001) found that both the TBI and healthy control group showed cerebral activation in regions of the frontal, temporal, and parietal lobes during working memory tasks. Patients with TBI required the recruitment of the right hemispheric regions in an effort to process working memory task, thus creating a difference from normal brain activation. Group differences in lateralized activation were evident in the frontal lobes. Therefore, cognitive and behavioral impairments, which result from executive dysfunction, are often one of the most persistent and prominent impairments after a mTBI (McDonalds, Flashman & Sykin, 2002). Cognitive-communication assessment is used to measure dysfunctions and recovery after a mTBI.

1.3 Sport-related concussions

A sport-related-concussion (SRC), also known as a mTBI, is one of the leading public health problems in the United States with an estimated 4 to 5 million concussions occurring annually, with increases emerging among middle school athletes (ImPACT, 2014; Langlois, Rutland-Brown & Wald, 2006). Sport-related concussion is generally not associated with long-term cognitive or neurobehavioral problems (Belanger & Vanderploeg, 2005; Iverson, 2005; and McCrea et al. 2003). The natural history of concussion is characterized by gradual but complete resolution of symptoms that include cognitive functioning and postural stability within several days to weeks of the injury (McCrea et al. 2003). McCrea and colleagues (2003) studied the acute effects and recovery time following a concussion in collegiate football players. They found

that injured athletes exhibited severe symptoms such as cognitive dysfunction, and balance problems immediately after a concussion. This acute phase was followed by a gradual course of recovery that lasted about 5 to 7 days. Therefore, the athletes required a full 7 days post-concussion for cognitive and balance problems to completely return to baseline and control levels (McCrea et al., 2003).

However, Iverson and colleagues (2006) found that group analyses can obscure slow recovery in some athletes. In the group analyses, performance decrements in neurological testing and symptoms relating to concussion appeared to resolve fully by 10 days. However, individual analysis at 10 days post-injury revealed that 37% of athletes were still showing two or more deficits in their neurocognitive test scores compared to their pre-season scores (Iverson et al., 2006). Thereby highlighting the importance of analyzing individual athletes' test data. Recent research by Henry and colleagues (2015) investigated the nature of recovery after a concussion using a multimodal assessment approach. Henry and colleagues (2015) suggest that the existing literature's methodology is inconsistent, to include how symptoms resolution and clinical recovery are defined. They also state that the studies only examined mostly male football players' symptoms and cognitive recovery outcomes. Henry et al. (2015) used a multimodal assessment that included the evaluation of symptoms, neurocognitive testing, balance, and a vestibular-oculomotor questionnaire. Athletes in the study were tested at one-week post-injury time intervals. Results from this study showed that recovery time across all outcomes was between 21 and 28 days after the injury for most of the athletes. This time frame is longer than the claimed 7 to 14 days that the majority of the literature proposes (McCrea et al., 2003). Finally neurocognitive recovery was highly heterogeneous, with different cognitive domains recovering at different rates.

Athletes who play high contact sports such as ice hockey, football, boxing, and soccer are at a higher risk of sustaining a concussion during their sports season. Untreated concussions can lead to a second injury potentially causing Second Impact Syndrome (SIS). SIS can be fatal since the athlete's brain has not fully returned to a normal metabolic status and the brain loses the ability to auto regulate intracranial and cerebral perfusion pressure (Bey & Ostick, 2009; McCrory, Davis, & Makdissi, 2012). To avoid SIS, the clinician must test if the athlete has returned to a normal neuropsychological state before recommending return-to-play. Therefore, clinicians must use a reliable test that helps with the decision to return-to-play. The primary goal of post-concussion evaluation protocols is to assess and track athletes' recovery to a normal state. Return-to-play decisions are currently based on an athlete's return to normal neuropsychological signs and symptoms scores (Iverson, Brooks, Collins & Lovell, 2006). Concussion symptoms vary and may include confusion, amnesia, headaches, speech impairment, dizziness, nausea, balance disturbances, irritability in response to light and noise, and fatigue (McCrea , 2008; McCrory et al., 2012) . However, Lazzarino et al. (2012) suggest that none of the currently available neuropsychological tests are able to measure metabolic changes that occur following a concussive injury. Lazzarino et al. (2012) and McFarlane et al. (2015) suggest that Magnetic Resonance Spectroscopy (MRS) is a sensitive tool to examine concussions' metabolic cascade. However, many professionals might not have the availability to a MRS, and must use neuropsychologicals tests to evaluate and monitor recovery after a concussion.

Neuropsychological impairments such as memory difficulties, executive dysfunction, and reduced expressive fluency are common sequelae following a concussion (Zakzanis et al., 2011). Verbal fluency has been shown to be a sensitive neuropsychological test that measures impairment after a concussion/mTBI (Belanger et al., 2005; Birn et al., 2010; Borkowski et al.,

1967; Crawford, 2004; Henry & Ross, 2003; Jurado et al., 2000; Kave et al., 2011; Troyer et al., 1997; Mascovitch et al., 1997; Raskin & Rearick, 1996; Tombaugh et al., 1999; Zakzanis et al., 2011). In addition, semantic and phonemic tasks within the verbal fluency task are valuable measurements in cognitive dysfunction after a concussion. A review of the literature demonstrates that researchers failed to examine changes in performance within the concussed groups. None of the reviewed studies have evaluated changes in verbal fluency measures: the total number of words, mean cluster size, and number of switches from athletes' baseline (preseason testing) to post-concussion testing. Every individual is different; comparing athlete's test results to group norms can obscure individual differences, which is why every athlete must be tested pre-season. The majority of studies compared individuals' behavior to a normal control group. Research on individual and group performance from baseline to post-concussion should focus on understanding deficits in sport-related concussions. Baseline testing assessment establishes the athletes' pre-season performance and provides scores for comparison after the injury. Additionally, baseline measures are vital for tracking the athlete's recovery (Guskiewicz et al., 2004).

Athletes can be considered a different population than the individuals used in the normative data, since athletes have higher incidence of sustaining repeated concussions. Previous studies have observed cumulative effects associated with recurrent concussions, 3 or more, in athletes. (Irverson, Gaetz, Lovell & Collings, 2003; Macciocchi, Barth, Littlefield, Cantu, 2001). High contact sports such as hockey, football, and boxing are believed to be sports associated with athlete's multiple hits to the head and long-term problems that can be associated with concussions. Recovery from a single concussion appears to be rapid and full; however, with repeated concussions there is a gradual and permanent residual effect (Peerless and Rewcastele,

1967). Studies have reported a stepwise increase in risk for subsequent concussions based on the number of prior concussions (Guskiewicz et al., 2003). Some of the neuropsychological effects associated with having a history of two or more concussions are poorer processing speed, symptoms scores, auditory processing, cognitive dysfunction, and lower scores on memory tasks (Collins et al., 1999; Echemendia, 2001; Gaetz, Goodman, & Weinberg, 2000; Hinton, Geffen, McFarland, 1997; Iverson et al., 2003; Macciocchi, 2001).

Ommaya and Gennarelli (1974) noted that multiple injuries associated with the acceleration-deceleration of the brain cause an increase in damaged brain cells that may progressively damage deeper brain structures. To support this notion, Iverson (2003) tested athletes who sustained two or more concussions and compared their results to athletes with one or less history of concussions at baseline testing (pre-season). Those athletes who had reported three or more concussions performed significantly lower on memory test scores than those with only one concussion at baseline. However, Macciacchi and colleagues (2001) found no statistical difference in neurophysiological test results between players with a history of two or more concussions than those with one or fewer concussions. Finally, preliminary findings in a study found no permanent impairment on neuropsychological testing 3 months post injury (McCrea, 2008). Overall, there is no definitive answer to the question of whether three or more concussions may increase potential impairment on neuropsychological testing.

Another factor that might cause to the athletes' performance to be different than the normal population is that an athlete might intentionally perform poorly at baseline testing (Bailey &Arnett, 2006; Erdal, 2012; Schatz & Glatts, 2013; Scharz et al., 2012; Szabo, Alosco, Geder, Gustad, 2013). The baseline test documents an individual's strengths and weaknesses at pre-season, which allows for the identification of changes after sustaining a concussion. Recent

research has noted purposely-low baseline performance among athletes, called “sandbagging” (Erdal, 2012; Schatz et al, 2012; Schatz & Glatts, 2013). The athletes’ approach is to sandbag baseline by performing poorly, so that after sustaining a concussion, their post-concussion test results would be similar to the baseline performance (Schatz et al., 2012), allowing them to return to play sooner.

To detect sandbagging of baseline in athletes, Erdal (2012), Schatz et al (2012), and Schatz et al. (2013) have used the composite scores in the ImPACT, a popular computerized neurocognitive test. Erdal et al. (2012) tested undergraduate athletes to find if sandbagging can be predictable based on the test scores. Participants were instructed to perform poorly during the first testing trial, and then retake the test and increase their scores. This study compared athletes’ test scores from the first time they took the test to when they retook the ImPACT test. The study concluded that there was no measurement for detecting purposely-low scores (Erdal, 2012). Szabo and colleagues (2013) wanted to test the validity of baseline testing performance in athletes. Szabo et al. (2013) evaluated prevalence of invalid scores on the ImPACT test after educating the athletes on the importance of a reliable testing at baseline test performance. The study found that educating the athletes on the importance of a reliable test performance for post-concussion comparison did not reduce the frequency of poor effort on the test. Szabo et al. (2013) discusses the need for further research to identify effective strategies to decrease invalid performance in athletes. Ultimately, the final decision in diagnosing sports-related concussion and in making return-to-play recommendations lies on athletes’ neurocognitive test performance and symptoms scores. Consequently, clinicians must use a valid test that is able to measure neurocognitive changes after a concussion.

1.4 Verbal Fluency Task: A Cognitive-Communication Test

A popular cognitive-communication assessment test that requires cognitive control, working memory, and linguistic control is the verbal fluency task also known as a word retrieval task. The verbal fluency task is used in many populations with information processing dysfunction such as Alzheimer's, aphasia, and Parkinson's disease because of its sensitivity to recognize cognitive-linguistic changes (Raskin & Rearick, 1996). This task provides measures of the individual's capability of selecting and retrieving as many words as possible, according to a category or subcategory within a limited period of time. Furthermore, the task requires efficient task initiation, planning, organization, and flexibility (Birn et al., 2010). The verbal fluency task is comprised of phonemic and semantic tasks. Standardized instructions of the verbal fluency task have been formed by Tombaugh, Kozak, & Rees (1999).

Tombaugh's (1999) instructions for the semantic task are for participants to retrieve animals' names within a time frame of 60-seconds. The semantic score is obtained by adding the total number of animal names the participant was able to retrieve. During the phonemic fluency task, the participants must retrieve words that beginning with letters F, A and S, within 60 seconds. This task has restrictions of the types of words that are acceptable. Participants must exclude variants of that same word (e.g. run and running) and words that are proper names. A phonemic score is obtained by adding the total number of words across the three letters F, A, and S. One of the reasons for use of these three letters is due to their number of associations. Borkowski et al. (1966) studied the production of words beginning with specific letters of the alphabet and the relationship between the total number of associations of single letters and the frequency of words that began with each letter in English. Borkowski et al. (1966) used sixty-six adults to produce words that started with the specific letter of the alphabet in sixty seconds. The

number of words retrieved from individuals correlated with both the Thorndike-Large norms (Thornike & Lorge, 1944) and with estimated the number of words in the English dictionary. For the purpose of this study, the term phonemic task will be referring to the letter retrieval F-A-S task and the semantic test to the animal naming.

The purpose of having a phonemic and semantic task is to produce activation in different parts of the brain and thus gain an understanding of the impact of a concussion on different areas of the brain. Studies suggest that word retrieval relies on the coordinated activity of different brain areas, particularly frontal and temporal lobes of the left hemisphere (Raskin and Rearick, 1996; Ribinson et al., 2012; Zakzanis et al., 2011). Researchers indicate that the frontal lobe is responsible for the phonemic retrieval task and the temporal lobe for the semantic retrieval task (Birn et al., 2010; Henry & Crawford, 2004; Jurado et al., 2000; Toryer, Moscovitch & Winocur, 1997). Robinson and colleagues (2012) studied the different roles of the frontal cortex that are responsible for the two tasks in the verbal fluency task. Robinson (2012) found that left frontal lobes are sensitive to verbal tasks especially for phonemic retrieval. Jurado and colleagues (2000) found that semantic retrieval was associated with the integrity of the whole left hemisphere and particularly sensitive to temporal lobe functioning. Jurado et al. (2000) investigated verbal fluency in patients with brain lesions.

The majority of researchers agree that phonemic fluency is facilitated in the frontal lobe whereas semantic fluency is mediated by the temporal lobe (Ross, 2001; Troyer, 2000; Troyer et al., 1997; Troyer Moscovich, Winocur, Alexander, & Stuss, 1998). Nevertheless, there is some controversy as to which verbal fluency task is more sensitive to change after a mTBI. Some research suggests that both phonemic and the semantic tasks are executive tasks. However, the phonemic task has been reported as a more sensitive indicator of change after a lesion (Jurado et

al. 2000; Troyer et al. 1998). The phonemic task requires the function of the left and right hemispheres and because a mTBI can result in bilateral damage, the phonemic task scores tend to be lower than the semantic task when compared to non-injured individuals (Jurado et al., 2000). Studies that have found the semantic task to be a sensitive score in demonstrating change after a mTBI state that this is because a mTBI is not necessarily confined to damage in the frontal regions. Finally, Kave and colleagues (2011) concluded that both fluency tasks involve strategic response initiating, monitoring, shifting, and being flexible. The phonemic and semantic tasks involve an individuals' capability of retrieving words from long-term memory while sustaining attention and executive control of responses. Individuals' capability to retrieve words and sustain attention has been measured by the total number of words.

Comparing patient's total number of words to norms is a useful tool for evaluating current performance to the expected performance. Tombaugh and colleagues (1999) established normative data based on age and education levels for both fluency tasks. The total numbers of words in the semantic and phonemic tasks' scores are compared to normative data and are used to make a clinical decision about cognitive-linguistic dysfunction after an injury. Research has shown that the total number of words may not be able to capture the underlying deficits in the patient's current performance (Henry & Crawford, 2004; Raskin & Rearick, 1996; Ross, 2003; Troyer et al., 1997; Zakzanis et al., 2011). It is argued that the score of total number of word does not provide enough information about the cognitive processes underlying fluency performance and does not indicate why particular individuals reduce their total number of words.

Troyer et al. (2000) argued that optimal fluency performance involves generating words within a phonemic or semantic subcategory and when that subcategory is exhausted, shifting to a new subcategory. In the Troyer's et al. (2000) study they analyzed the type of words generated

by individuals and established two additional scores: clustering and switching. Their rationale for including these two analyses was based on the idea that retrieval of words requires a selection of strategies to facilitate word availability. Generating words within a phonemic or semantic subcategory is identified as a cluster. These clusters are thought to reflect the organization of lexical entries. When one lexical entry is activated, other entries that are connected by either semantic or phonemic relationships will be accessed through a spread of activation. Generations of related words represent the automatic cognitive process (Ledoux et al., 2014). Switching is identified when there is a transition to a new subcategory. An analyses of the clusters is performed by analyzing the phonemic clusters in phonemic fluency and the semantic categorizations in semantic fluency. Switching involves cognitive flexibility in shifting from one subcategory to another. Troyer et al. (1997) suggest that the term cluster represents the individual's stored lexicon while switching reflects the search process.

Clustering and switching scores are utilized based on the fact that the production of words is not evenly distributed over time; words tend to be produced in spurts, or temporal clusters, with a short time interval between words in a cluster and longer pauses between clusters (Bousfield & Sedgewick, 1944). That is, individuals quickly generate several words, then run of out words for a moment, and then again generate a few more words. Vonberg, Ehlen, Fromm, and Klostermann (2014) also support the idea of analyzing clustering and switching based on the concept that word meaning and word sounds form representation nodes in the lexical network. Activation of specific lexical information automatically stimulates words stored in the associated nodes, which results in accessing sequences of words that belong to the same phonemic or semantic subcategory. A cluster is defined as an activation of the lexical network that automatically activates a node and is reflected by the recruitment of related words. Clusters are

generated in the phonemic fluency trials by words that share a phonetic characteristic. Semantic clusters are formulated by words that belong to the same subcategory.

Semantic clusters on the phonemic task are not analyzed because they are not a significant measure as studies have found that these clusters are rarely produced in non-injured and injured individuals (Raskin, Sliwinski & Borod, 1992; Raskin & Rearick 1996). For example, Raskin and colleagues (1992) measured semantic and phonemic scores on each task in individuals with Parkinson's disease and normal individuals. Their results showed that participants in both groups significantly produced more phonemic clusters than semantic clusters in the phonemic task. These same results were found in the semantic task, participants significantly produced more semantic clusters than phonemic clusters. Raskin and Rearick (1996) found the same results after they replicated Raskin's et al. (1992) study comprised of individuals with mTBIs. These two studies demonstrate that individuals tend to generate clusters based on the cues given to them. For this reason, semantic and phonemic clusters are only analyzed in the semantic and phonemic task, respectively.

The purpose of calculating switching scores is based on the concept that switching invokes a controlled processing and search (Ledoux et al., 2014). Normally when generating words, individuals begin with a search of words that belong to a subcategory (clusters). Then when that subcategory no longer elicits the activation of words, a new controlled search is generated. It is thought that switches reflect a higher-level of lexicon search and flexibility. A switching score gives you the number of times an individual can generate a new cluster. Results can then be used to identify any executive decline. Switching has been associated with executive functions and is related to frontal lobe functioning (Ledoux et al., 2014; Troyer et al., 1997; Troyer, 2000). This has been observed in studies that have evaluated verbal fluency in patients

with frontal dysfunction such as Parkinson's disease, Huntington's disease, multiple sclerosis, and schizophrenia (Henry & Crawford, 2004; Troyer et al., 1998).

Kave et al. (2010) study examined switching and clustering in the phonemic and semantic fluency tasks in individuals with traumatic brain injury. The study compared 30 TBI patients aged 19 to 35 that were within six to twenty-four months post-injury to 30 age-matched control participants. This study was the first to find that TBI patients demonstrated greater deficits on the semantic fluency task. Previous studies suggest that the sensitivity of the phonemic fluency tasks in demonstrating frontal region damage may indicate greater impairment in individuals with TBI (Juardo et al., 2000; Troyer et al., 1998). However, Kave et al. (2010) suggested that perhaps a TBI is not necessarily confined to frontal regions. Kave et al. (2000) supports his findings by proposing Henry and Crawford's (2004) study that showed that frontal brain damage leads to similar impairments on both phonemic and semantic tests.

Furthermore, the Kave (2010) study examined individuals with TBI rather than with mTBI. Zakzanis and colleagues' (2011) study was one of the first studies to systematically analyze the total number of words, clusters, and switching scores between normal, mTBI, and TBI individuals. Twenty patients who sustained a mTBI, 20 with TBI, and 54 healthy control participants were included in the study. Participants in the study were at least 3 months post-injury. Individuals were separated into groups based on the severity of the TBI. Severity of injury was established via the Glasgow Coma Scale (GCS). Teasdale and Jennett described this scale in 1974 as a way to examine the level of consciousness of patients after an acute brain injury. The GCS is based on a 15-point scale that measures motor, verbal and eye responses. TBI severity is indicated by GCS scores of 13 to 15 for mild, from 9-12 for moderate, and 3-8 as severe. Zakzanis et al. (2011) study found valuable measures in the performance of verbal

fluency across both the mTBI and the TBI groups. They found that as severity increased, the switching score increased and mean cluster size increased in the phonemic task. Zakzanis et al. (2011) argued that the greatest difference between individuals with mTBI and control participants was seen in the semantic task. Keeping in mind that a mTBI results in the rapid onset of neurological impairments with acute clinical symptoms, this study did not provide information regarding the sensitivity of the verbal fluency task during the acute phase of the injury (McCrory, Meeuwisse, Johnston, Dvorak, Aubry et al., 2009).

1.5 Verbal fluency task and SRC

With the cumulative effects of concussions and the questionable validity of performance from athletes at BL testing, clinicians need evidence of an effective assessment that can be used following a sport-related concussion. With the limited research on an athlete's changes after a concussion, clinicians need a test that is effective in demonstrating cognitive dysfunction. This study will investigate the changes in the performance of total number of words, mean cluster size, and number of switches produced by athletes following a sport-related concussion. Athletes' performance on total number of words, mean cluster size, and the number of switches with a history of concussion will be compared to individuals with no history of concussion at baseline (control group). Finally, literature has not used the verbal fluency task and its components, mean cluster size and number of switches, to track recovery after a sport-related concussion. This information may potentially help a clinician understand the underlying cognitive recovery process after a concussion that in turn may aid in the evaluation of unremitting injuries.

Based on the studies presented, it is assumed that the total number of words generated may not be a sensitive measure. However additional analyses, such as clustering and switching,

may be more sensitive in determining dysfunction in mTBI. To produce as many words as possible, an individual requires sustained attention, cognitive linguistic control, and long-term memory. With the significant change in cerebral glucose metabolism that follows a concussion, the brain is under an alteration due to the release of excitatory neurotransmitters, ionic shifts, altered cerebral blood flow, and impaired axonal function. This results in alterations that are associated with neurobehavioral abnormalities (Giza & Hovda, 2001). Behaviors that can be clinically measured after a concussion include a slowing down of information processing, memory difficulties, executive dysfunction, and reduced expressive fluency (Zakzanis et al., 2011).

The verbal fluency test requires control of impulsivity, memory, and information processing. The *Spreading-Activation Theory of Semantic Processing* developed by Collins and Loftus (1975) states that long-term memory contains interconnected units of information. There are different nodes, which represent concepts, and those nodes are connected by links. These connections produce associations between the units or pathways that control how information is retrieved. Collins and Loftus (1975) state that the connections are based on personal experience. Therefore, when a word is primed, related words become activated in long-term memory, facilitating word retrieval. This availability of related words is known as spreading activation. In addition, Troyer (1997) suggests that clustering may be predicated on the assumption that words are organized in networks. When the network is activated, it may prime the retrieval of a number of related words. The number of words primed is thought to reflect the strength of the initial word that is primed. Therefore, greater initial 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 the activation of words that are weakly related (Troyer, 1997; Troyer et al., 2000).

Therefore, it is hypothesized that after a concussion, an athlete will reduce the number of words. Mean cluster size is also expected to decrease after a concussion because athletes demonstrate difficulties using strategies to name more words that may result in low performance on the task. It is also hypothesized that after an average of one week post-injury, athletes will be recovering and able to use cognitive and linguistic control. This will increase the use of clustering and the total number of words generated in phonemic tasks.

This study will first examine if there is a difference in the total number of words, mean cluster size, and number of switches at baseline performance between athletes with a history of concussion and athletes with no history of concussion. The results of this study will determine if athletes with history of concussion perform within normal ranges at baseline. The purpose of this study was to investigate if there is a change after a concussion in the total number of words, mean cluster size, and the number of switches in a population of athletes who sustained a sports-related concussion. To find individual differences in this study, athletes will be compared to their own preseason testing (baseline) performance. Additionally, the recovery process will be tracked from baseline, days and weeks following the injury.

The following research questions will be investigated:

- Question 1: Is there a statistically significant difference at baseline between athletes with history of concussion and individuals with no history of concussions on the Verbal Fluency test?

- Question 2: Is there a statistically significant difference from baseline to the first and second post-concussion verbal fluency test session in concussed athletes?

Chapter 2: Methods and Procedures

2.1 Participants

Twenty-seven athletes who sustained a concussion and thirty-two healthy control participants were included in this study. Participants were tested at the Concussion Management Clinic (CMC) of the Speech-Language Pathology Program at the University of Texas at El Paso (UTEP). Participants in both groups were selected from the pre-existing CMC database. All participants' information obtained from the CMC database included results from both the verbal fluency task and the neurocognitive Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) at baseline (BL) for all participants.

From the UTEP CMC database, 27 concussed athletes met inclusionary criteria and were selected, see Table 1.1. Athletes were selected if they were tested on the verbal fluency task and ImPACT at BL, and had sustained a concussion during a sport-related activity. The concussed group consisted of 7 female and 20 male athletes. At BL testing, athletes in the concussed group reported having a history of a concussion that ranged from 1 to 5 (M=2.06, SD=1.6). When tested at BL, athletes did not report having a concussion within the past 12 months. In the course of the season, after athletes had sustained a sport-related concussion (SRC) they were referred to the UTEP CMC for weekly evaluations and recommendations. During each weekly post-concussion (PC) follow-up appointment, athletes were re-administered the ImPACT protocol and the word fluency task several. Post-concussion testing 1 (PC1) ranged from 2 to 7 days (M=3.44, SD= 1.62) after the date of the concussion. The twenty-seven athletes were recommended to return to the UTEP CMC on an average of 8 to 10 days (M=9.56, SD= 2.40) after the concussion for post-concussion 2 (PC2) follow-up testing. Concussed athletes were tested in an average of

6.62 days (*SD* =2.19) from PC1 to PC2 testing. From BL testing to PC1, there was no statistical difference in terms of age $t(26)=-.131$, $p=0.897$ and education level $t(26)=-1.837$, $p=0.078$.

Athletes in the concussed group were selected from the pre-existing database at the UTEP CMC, and some data was missing. Twenty-seven athletes were analyzed across BL, PC1, and PC2. Words produced were not transcribed in 11 of the athletes, and only data for the total number of words was recorded. Therefore in the final analysis, of the 27 athletes, 16 had written data to analyze mean cluster size and the number of switches from BL through PC2 in the phonemic task. On the semantic task, out of the initial 27 athletes, 23 had the total number of words from BL through PC2. Only 10 of 23 had written words to be analyzed for mean cluster size and number of switches from BL to PC2, and were used in the final analysis.

The control group was selected in order to compare BLs scores between groups. This was analyzed to rule out sandbagging during BL testing and the cumulative effect of multiple concussions. The control group's average age was 19.56 years (*SD*= 1.82) and included the 13 females and 18 males. The average education level was 12.87 (*SD*= 1.49). All participants in the control group were matched to meet the concussed group's age and education level. Exclusionary criteria for the control group were: current diagnosis of a concussion, history of speech or language disorders, hearing loss, history of drug/alcohol abuse, previous history of psychiatric illness, learning disability, neurological history (seizure, central nervous system neoplasm, or brain tumor), and TBI related to a concussion. There was no statistical difference in terms of age $t(56)=-1.43$, $p=0.158$ or education $t(56)=-.458$, $p=0.649$ between the two groups. The demographic information is presented in Tables 1.2 and 1.3.

Participants in both groups reported that they were English-fluent speakers, and selected English as their testing language. In the concussed group, 3 of the athletes were bilingual.

Spanish was the native language for one athlete and the second language for two other athletes. In the control group, 10 of the participants were bilingual. Spanish was the second language for 8 participants and the first language for 2 others.

Table 1.1: Inclusionary Criteria of Athletes with Concussions

At Baseline	At Post-Concussion
Tested on the verbal fluency	Tested on the verbal fluency task at PC1-PC2
No concussion within the past 12 months	PC1 was within 1 to 7 days post-injury

Table 1.2: Sample Characteristics by group

	Age (years)			Gender				Education Level			
	Concussed (*n=27)*		Control (*n*=31)	Concussed (*n=27)*		Control (*n*=31)		Concussed (*n=27)*		Control (*n*=31)	
	BL	PC1	BL	Female	Male	Female	Male	High School	College	High School	College
n				7	20	13	18	1	26	2	29
M	18.96	19.03	19.56					12.66		12.87	
SD	0.85	2.84	1.83					1.33		1.49	
p		0.158		**0.038**				0.649			

Note. BL= baseline. PC= post-concussion. *n*= number. *M*= mean. *SD*= standard deviation, p= <. 05 are in boldface

Table 1.3: Sport Played across groups

	N of Concussed Athletes	*N* of Control
Football	15	8
Basketball	3	3
Softball	2	1
Soccer	2	8
Ice Hockey	3	0
Cheerleading	2	11

2.2 Procedure

All participants were administered the full testing protocols during baseline and post-concussion testing. The testing included administration of the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), the post-injury concussion questionnaire, post-traumatic stress disorder questionnaire, Romberg test, the 3-D shape copying task, the verbal fluency task, the Wii Basic Balance Test, and a hearing screening.

Administration of the verbal fluency test's instructions followed the Tombaugh et al. (1999) standard instructions. Participants were instructed to produce as many words as possible, beginning with letters F, A and S, within a minute (60 seconds). Participants were not allowed to generate words that were proper names (i.e. anything that starts with a capital letter) and/or repeat root words using different suffixes or prefixes (e.g. friend, friends, friendly). During the animal naming task, participants were instructed to name as many animals as possible within one minute. Examiners were instructed to transcribe each word generated by the participants including errors and repetitions.

Three scores were obtained from each fluency task, F-A-S and the animal task, including total number of correct words, mean cluster size, and the number of switches. Rules for scoring cluster size and switches in the semantic and phonemic tasks were followed under the standardized instructions of Troyer (1997). On the phonemic task, total number of words was calculated by adding the total number of words generated from each of the three letter trials F-A-S to obtain a single score for each individual. To find the mean cluster size, clusters were defined as successively generated words that shared phonemic characteristics such as: beginning with the same first two letters, differing only by a vowel, rhyming, or being a homonym. Only phonemic clusters were counted in the phonemic task. On the semantic task, total number of words was

calculated by adding the total names of animals generated during the 60-second trial for each individual. Cluster size on the animal task (semantic) was defined as two or more consecutive words generated and belonging to the same semantic subcategory; such as pets, zoo, birds, canine, ocean animals, African animals, insects, and so forth. Only semantic clusters were counted. Measures of production from semantic clusters in the phonemic task and phonemic clusters in the semantic task were excluded secondary to the scarcity of these productions as indicated by previous studies (Troyer, Moscovitch, & Winocur, 1997). Detailed rules for scoring cluster size and switches for phonemic and animal fluency are reprinted in Appendix A.

Mean cluster size was calculated by adding the size of each cluster and dividing it by the number of clusters. The counting of cluster size began with the second word in a cluster. A single word was given a cluster size of 0, two words had a cluster of 1, three words had a cluster size of 2, four words had a cluster size of 3, and so forth. The number of switches was calculated as the sum of changes between clusters and included single words for the phonemic and the semantic task. The number of switches indicated the number of times an individual generated a new cluster of names (Troyer, 2000; Troyer et al., 1997).

After athletes sustained a SRC, they were sent to UTEP's CMC for an evaluation of the concussion. During post-concussion testing, each athlete was given the complete CMC test protocol which included administration of the ImPACT test, post-injury concussion questionnaire, post-traumatic stress disorder questionnaire, Romberg test, 3-D shape assessment, verbal fluency task, Computerized Revised Token Test (CRTT), Wii Basic Balance Test, and a hearing screening. It was recommended that all athletes follow a complete rest protocol, which entailed staying out of play, practice, and school until signs and symptoms were resolved. Additionally, keeping hydrated and maintaining a healthy diet were recommended. To reduce the

stimulation of post-concussion symptoms, athletes were advised to wear sunglasses when exposed to sunlight, turn off lights at home, reduce phone calls and texting, avoid loud music, and environments that are typically noisy. The decision to return to practice or school was made once an athlete returned to baseline performance on the ImPACT composite scores, verbal fluency task, CRTT, and the athlete was asymptomatic. Return to baseline is defined as the athlete returning to pre-season cognitive performance. If the athlete had not met these criteria, they were referred to the CMC for follow-up testing until the criteria were met. In this study the average recovery period was 18 days (SD= 6.28).

2.3 Inter-rater reliability

To calculate inter-rater reliability, three raters scored 15% of the data across BL, PC1, and PC2. Raters were trained on the scoring system and were provided with Appendix A. A point-by-point agreement was used on the scoring of cluster size. Below is the point-by-point formula that was used to determine agreement between the raters. The level of reliability for the phonemic task was 98%, 97%, and 95% agreement. On the semantic task there was a 97%, 95%, and 93% agreement on cluster size from the three raters.

Agreement%= Agreements/(Agreement + Disagreement) x 100

2.4 Statistical Analysis

Statistical analyses were conducted with IBM SPSS Statistic software, version23. Participants in both groups were not randomly selected or randomly assigned which did not satisfy the assumption needed for the use of parametric statistical model test (Nezu & Nezu, 2007). Random assignment of participants was not applied in the concussed group due to a limited sample of athletes who were evaluated over BL, PC1, and PC2. A normal distribution test was run to determine the normality of the two groups. This test theoretically reduced the

chances of making a Type I error where a null hypothesis is wrongfully rejected. Parametric procedures rely on the assumption of normal distribution samples from the underlying population and the means and standard deviations of assumed distributions (Hoskin, 2014). To test if the sample deviates from normality, a Kolmogorov-Smirnov test was used. Six dependent variables were analyzed: the total number of words, mean cluster size, and the number of switches in the phonemic and semantic naming tasks. A confidence level of .05 was chosen for all tests. In the phonemic task, the total number of words, $D(37)= .159$, $p= .018$, and the means cluster size, $D(37)= .171$, $p= .008$ deviated significantly from a normal distribution. In the semantic naming task, the total number of words $D(37)= .177$, $p= .005$ significantly deviated from the normal distribution. Mean cluster size, $D(37)= .109$, $p= .200$, and the number of switches, $D(37)= .131$, $p= .106$, in the semantic task did not deviate significantly from the normal distribution. Based on these results, half of the data did not meet the parametric assumption of normal distribution. Therefore, since the assumption of the normal-distributed sample across variables was violated, a non-parametric test was utilized to compare the statistical difference between and within groups.

To analyze any potential differences between the two groups at baseline, a between-group design Mann-Whitney U test was used. The Mann-Whitney U test is considered the non-parametric alternative to the independent sample t-test (Laerd Statistics, 2013). The test was used to determine the difference in medians between the two groups. To compare any change in the verbal fluency task components during each athlete's recovery, the Wilcoxon Signed-Rank test was used. The Wilcoxon Signed-Rank test is a non-parametric test equivalent to the dependent t-test (Laerd Statistics, 2013).

Chapter 3: Results

This study was designed to investigate changes in the verbal fluency measures: the total number of words, mean cluster size, and the number of switches after a sport-related concussion. In addition, the study investigated the nature of post-concussive recovery in athletes who experienced a concussion. Data was collected from the pre-existing data and was analyzed using the athletes' preseason (baseline) and initial post-concussion evaluations. Since this study used athlete's baselines to compare changes postinjury, athletes' baselines were compared to the baselines of participants with no history of concussion to determine the potential influence of a history on concussion on the interpretation of the results.

3.1 Baseline Performance Between Athletes with History of Concussion and Individuals with No History of Concussions

The first question in this study was to determine if there were differences between the two groups at BL in the verbal fluency task measures: the total number of words, mean cluster size and the number of switches. A control group of non-concussed individuals was used to compare their BL performance with the performance of the concussed group to rule out any cumulative effect of head injuries or low baseline performance. Table 3.1 provides the mean and standard deviation for the total words generated, mean cluster size, and the number of switches for both groups.

Table 3.1: Descriptive Performance between Groups at Baseline

		Concussed at baseline *(n=27)*		Control at baseline *(n=31)*	
Score		*M*	*SD*	*M*	*SD*
Phonemic	Total number of words	40.93	9.66	41.35	10.36
	Mean cluster size	1.53	0.40	1.48	0.39
	Number of Switches	28.18	9.77	28.22	6.60
Semantic	Total number of words	21.09	5.47	21.23	3.98
	Mean cluster size	1.79	0.53	1.77	0.42
	Number of Switches	13.47	4.47	11.11	2.77

Note. *M*= mean. *SD*= standard deviation. *N*=number of participants in each group. Phonemic task include F-A-S, semantic includes animal names.

3.1.1 Phonemic Task (FAS)

Thirty-one participants in the control group and 27 concussed athletes were compared at BL testing for the total number of words produced in the phonemic naming task. A Mann-Whitney U test was conducted to determine whether there was a significant difference in the total number of words produced in athletes with a history of concussion compared to athletes without any history of concussion at BL. Results of this analysis indicate that there was no difference in the total number of words produced between the groups at BL testing, $Z=-.156$, $p=.876$. The group of athletes with a history of concussion had an average of 29.13 total number of words at baseline while the control group had an average of 29.85 total number of words. A separate Mann-Whitney U test was used to analyze mean cluster size and the number of switches in the phonemic naming task between 16 concussed athletes who were assessed at BL, PC1, and PC2 were compared to the 31 participants in the control group. BL performance between the two

groups showed no significant difference in mean cluster size, *Z*=-.292, *p*= .770, or the number of switches *Z*=-.191, *p*= .849 at baseline testing.

3.1.2 Semantic Task (Animal Naming)

The total number of words on the semantic task were compared between the concussed athletes to the participants with no history of concussion in the control group at baseline. The Mann-Whitney test revealed no statistically significant difference between the groups in the total number of words at baseline, *Z*=-.475, *p*= .635. The concussed group total number of animal names produced was 26.33 while the control group's total number of animal names was 28.37. Only 10 of the 23 concussed athletes had BL verbal fluency data to analyze mean cluster size and the number of switches to the control group. Therefore, a different Mann-Whitney test was run to compare the 10 concussed athletes at BL to the 31 participants in the control group. Results showed no statistical difference between the groups in mean cluster size *Z*=-.017, *p*= .987 with a mean score of 19.45 and 19.52 in the concussed and control group, respectively. The number of switches between groups also showed no statistical significance, *Z*=-1.069, *p*= .285.

Overall, there was no statistical significance difference between athletes with history of concussion to the participants in the control group. Therefore, the possibility of purposely-low BL performance or accumulative effects of a history of concussion in the concussed group can be ruled out.

Table 3.2*:* Mann-Whitney U test results between the concussed group and control group at baseline

Score		Concussed *N*	Control *N*	Concussed vs. Control at baseline *U*	*z*	Asymp. Sig.
Phonemic	Total number of words	27	31	408.50	-.156	.876
	Mean cluster size	16	31	235.0	-.292	0.770
	Number of Switches	16	31	239.50	-.191	0.848
Semantic	Total number of words	23	31	329.50	-.475	.635
	Mean cluster size	10	31	139.50	-.017	-1.069
	Number of Switches	10	31	104	.987	.285

Note: N=number of participants in each group, U=Mann-Whitney U test.

3.2 Athletes' Performance from Baseline To Post-Concussion 1, and Post-Concussion 2

A within-subject design was used to investigate changes from pre-season (baseline) to post-concussion testing in those athletes (ages ± 19.03, *SD*= 2.84) who experienced a concussion in the course of the season. The data entailed the same participants tested from across time BL to PC1 to PC2 testing. Table 3.3 provides the mean and standard deviation for the total words generated, mean cluster size, and the number of switches for the concussed athletes from BL to PC2. Table 3.4 provides Z-values and the two-tailed value significance levels for the verbal fluency scores in the concussed athletes across post-concussion testing. At PC1, athletes were tested within 4 days (*M*=3.44, *SD*= 1.62) of the date of injury, and tested 10 days (*M*=9.56, *SD*=2.40) after the date of injury at PC2. The average time between testing at PC1 and PC2 was 6.62 days with a SD of 2.19 days.

Table 3.3: Performance within Concussed Athletes from Baseline to Post-Concussions Assessment 2

		Baseline		Post-Concussion1		Post-Concussion2	
		M	*SD*	*M*	*SD*	*M*	*SD*
Phonemic	Total number of words *(n=27)*	39.26	9.01	38.04	11.51	39.86	14.50
	Mean cluster size *(n=16)*	1.53	0.40	1.17	0.36	1.49	0.44
	Number of Switches *(n=16)*	28.18	9.77	29.62	5.78	28.12	7.84
Semantic	Total number of words *(n=23)*	21.09	5.47	18.96	6.20	21.48	6.04
	Mean cluster size *(n=10)*	1.79	0.53	1.62	0.68	1.76	0.38
	Number of Switches *(n=10)*	13.47	4.47	14.80	3.21	11.00	2.70

Note. BL= baseline. PC= post-concussion. *N*= number. *M*= mean. *SD*= standard deviation. Phonemic task include F-A-S. Total number of words group n=27, cluster and switches group n=16.

Table 3.4: Z-values (two-tailed significance) for verbal fluency scores in concussed athletes across testing

		BL to PC1		PC1 to PC2		BL to PC2	
		Z	*p*	*Z*	*p*	*Z*	*p*
Phonemic	Total number of words *(n=27)*	-.814	.416	-1.36	.172	-.439	.661
	Mean cluster size *(n=16)*	-2.78	**.005**	-2.17	**.030**	.000	1.00
	Number of Switches *(n=16)*	-.409	.682	-.313	.755	-.199	0.84
Semantic	Total number of words *(n=23)*	-1.02	.304	-2.09	**.036**	-.541	.589
	Mean cluster size *(n=10)*	-.765	.444	-.533	.594	-.296	.767
	Number of Switches *(n=10)*	-1.48	.138	-1.13	.257	-1.29	.196

Note. Statistical analysis was conducted within each fluency task, across baseline and post-concussion 1 and 2 testing. p= <. 05 are in boldface

3.2.1 Phonemic Task

The 27 athletes who sustained a concussion and had BL data on the total number of words were analyzed using the Wilcoxon Signed-Rank test. The test revealed that the total number of words in the phonemic task from preseason testing (BL) to testing within the acute phase of concussion (PC1 testing), did not show a statistically significant difference, Z=-.814, p= 4.14. No difference was found from PC1 to PC2, Z=-.814, p= 4.14, and BL to PC2, Z=-.439, p= .661 in the total number of words produced on the phonemic naming task.

Sixteen of the 27 athletes with transcribed data were analyzed to determine any changes in mean cluster size and numbers of switches from BL to PC1 to PC2. The Wilcoxon Signed-Rank test revealed a statistically significant difference for mean cluster size in the phonemic naming task from BL to PC1, Z=-2.784, p= .005. Sixty-one percent of the athletes decreased mean cluster size from BL to PC1 testing, 35% increased their scores, and 4% athlete remained the same. Tables 3.5 to 3.7 provide the percentages of athletes who increased, decreased, or had no change in performance from BL to PC1, PC1 to PC2, and BL to PC2.

Similarly, from PC1 to PC2 testing there was a statistical difference in mean cluster size in the phonemic naming task, Z=-2.172, p= .030. From the 16 concussed athletes, eighty-one percent of the participants increased their mean cluster size score and 19% decreased their scores from PC1 to PC2. Finally, to examine if athletes had returned to BL performance, BL to PC2 testing was compared. No statistical difference was found from BL to PC2, Z=-.00001, p= 1.00. Sixty-three percent of the athletes returned to their BL mean cluster size, and 37% did not reach their BL scores.

Numbers of switches across time were also analyzed using the Wilcoxon Signed-Rank test for the same 16 athletes. No statistical difference was found from BL to PC1, Z=-.409, p=

.682, PC1 to PC2, *Z*=-.313, *p*= .755, and BL to PC2, *Z*=-.199, *p*= .842. From BL to PC1 testing, 64% increased their number of switches, 23% decreased, and 13% remained the same. When tested during PC2, 44% of the athletes decreased their switching scores, 50% increased, and 6% scored the same when compared to PC1 testing. Finally, 62% of the athletes returned to their BL number of switches at PC2 testing, and 38% did not return to BL. Table 3.7 provides the percentage of athletes who did or did not return to BL performance at PC2 testing.

3.2.2 Semantic Task

Out of 27 concussed athletes, only 23 had recorded scores for total number of words on the semantic task from BL to PC2 these athletes were included in the Wilcoxon Signed-Rank Test. No statistical difference was found from BL testing to PC1, *Z*=-1.028, *p*= .304, in the total number of words on the semantic task. Fifty-two percent of the 23 athletes decreased the total number of words from BL to PC1. There was, however, a statistical difference from PC1 to PC2, *Z*=2.093, *p*= .036, showing that 74% of the athletes increased their total number of words and 22% athletes decreased their total number of words. Finally, when comparing the 23 athletes, the total number of animal names on the semantic task from BL to PC2 showed no statistical difference, *Z*=-1.028, *p*= .304.

Ten of the athletes had the sufficient data to analyze mean cluster size and the number of switches on the semantic task from BL to PC2. The Wilcoxon Signed-Ranks test was used to compared the 10 athletes within the concussed group from BL testing to PC1 and showed no significant group difference in mean cluster size on the semantic task, *Z*=-.765, *p*= .444. No significant difference was observed from PC1 to PC2, *Z*=-.533, *p*= .594, or from BL testing scores to PC2 testing, *Z*=-.296, *p*= .76. The sum of switches on the semantic task also revealed no statistical differences between testing times. No significant difference was found from BL to

PC1 testing, *Z*=-1.485, *p*= .138, or PC1 to PC2 testing, *Z*=-1.133, *p*= .257, or BL to PC2 testing in terms of the number of switches *Z*=-1.292, *p*= .196.

Figure 3.1: Phonemic task Performance within Concussed Athletes from Baseline to Post-Concussions Assessment 2

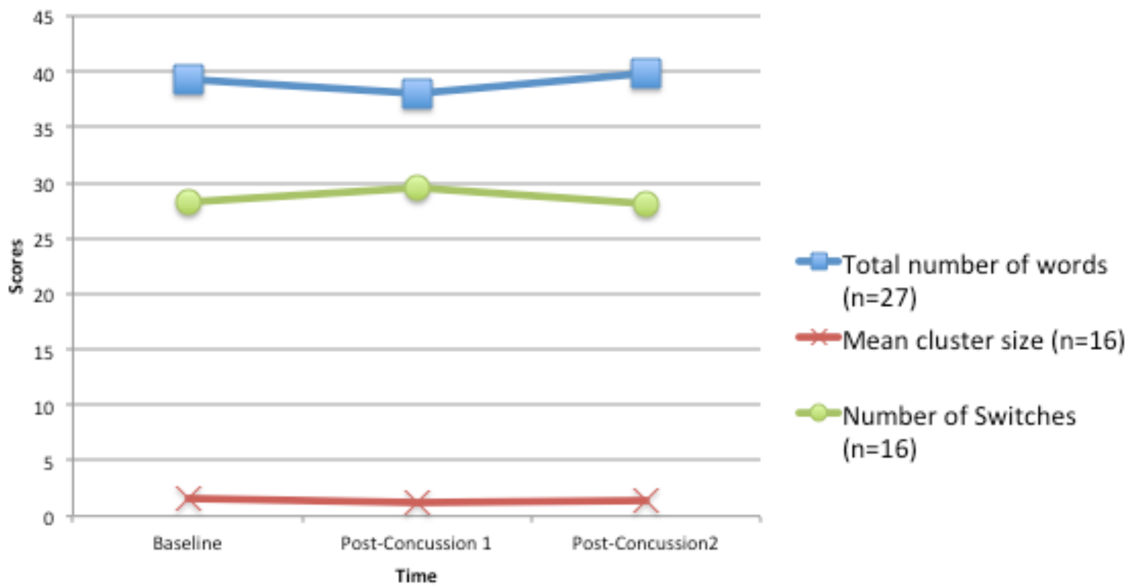

Figure 3.2: Semantic task Performance within Concussed Athletes from Baseline to Post-Concussions Assessment 2

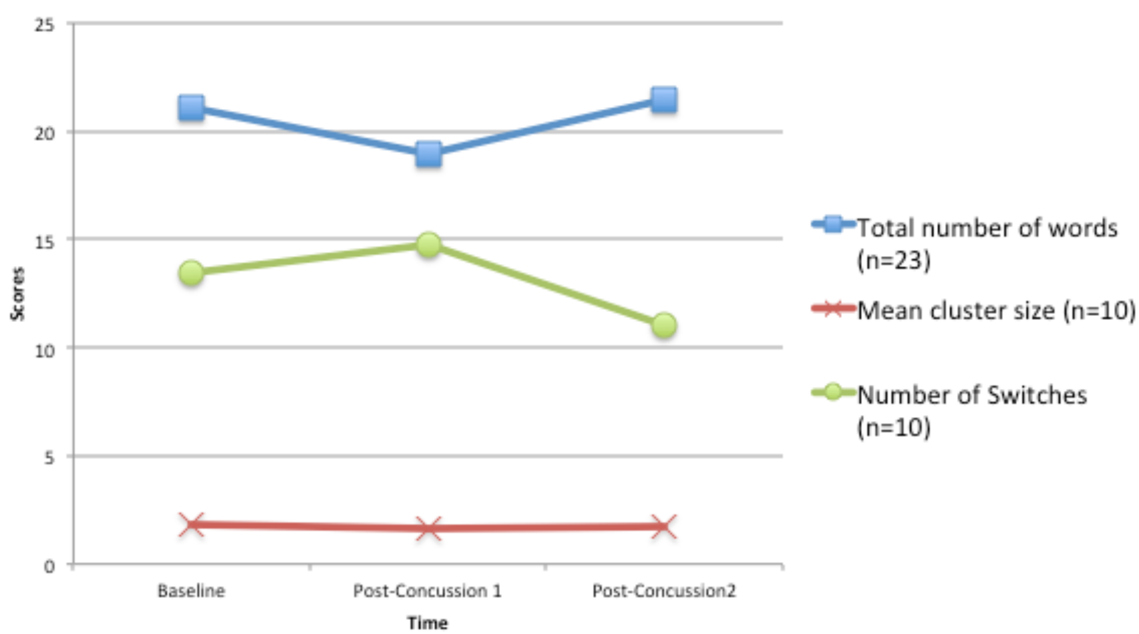

Table 3.5: Percentage of concussed athletes whose performance increased, decreased, or had no change from BL to PC1

Scores	*Increased*	*Decreased*	*No Change*
Phonemic task			
Total number of words *(n=27)*	35%	61%	4%
Mean cluster size *(n=16)*	15%	80%	5%
Number of Switches *(n=16)*	64%	23%	13%
Semantic Task			
Total number of words *(n=23)*	35%	52%	13%
Mean cluster size *(n=10)*	40%	60%	0%
Number of Switches *(n=10)*	40%	60%	0%

Note: Average time period from the date of injury to date of first testing, PC1, was within the acute phase of 2 to 7 days (*M*=3.44, *SD*= 1.62).

Table 3.6: Percentage of concussed athletes whose performance increased, decreased, or had no change from PC1 to PC2

Scores	*Increase*	*Decreased*	*No Change*
Phonemic task			
Total number of words *(n=27)*	59%	37%	4%
Mean cluster size *(n=16)*	81%	19%	0%
Number of Switches *(n=16)*	50%	44%	6%
Semantic Task			
Total number of words *(n=23)*	74%	22%	4%
Mean cluster size *(n=10)*	60%	30%	10%
Number of Switches *(n=10)*	70%	20%	10%

Note: PC2 testing was 8 to 10 days (*M*=9.56, *SD*= 2.40) from day of the injury. The average time between testing at PC1 and PC2 was 6.62 days with a SD of 2.19 days.

Table 3.7: Percentage Of Athletes Who Did Or Did Not Return To Baseline Performance at PC2 testing

Scores	*Returned to BL scores*	*Did not return to BL scores*
Phonemic task		
Total number of words *(n=27)*	59%	41%
Mean cluster size *(n=16)*	63%	37%
Number of Switches *(n=16)*	62%	38%
Semantic Task		
Total number of words *(n=23)*	61%	39%
Mean cluster size *(n=10)*	60%	40%
Number of Switches *(n=10)*	70%	30%

Chapter 4: Discussion

4.1 Overview

The purpose of this study was to investigate the potential changes in a verbal fluency task with concussed athletes. In addition, the nature of the recovery of the verbal fluency task performance in concussed athletes was examined. The following questions were investigated: (1) is there a statistically significant difference at baseline between athletes with history of concussion and individuals with no history of concussions on the verbal fluency tasks? (2) Is there a statistically significant difference from baseline to the first post-concussion testing session and the second post-concussion testing session on the verbal fluency measures in concussed athletes? Hopefully this information on verbal fluency performance may help clinicians in return-to-play decisions.

The first question asked if there were a difference in verbal fluency measures at BL between athletes with a history of concussion and individuals without a history of concussion. The findings showed there is no difference at BL performance in athletes with history of concussion compared to individuals with no history of concussion on the phonemic and semantic tasks in: the total number of words, mean cluster size, or the number of switches. Athletes with a history of concussion performed similar to the non-concussed athletes. Thus, a history of concussion was not related to poor/lower performance in the concussed group when compared to the non-concussed. This finding may allow a clinician to track post-concussion recovery using an athletes' BL performance as an acceptable measure of comparison to their performance at post-concussion testing.

The primary objective of this study was to examine potential changes in the verbal fluency measures following a sports-related concussion. In the current study, only mean cluster

size in the phonemic task showed a significant change in performance following a brain injury. No significant difference was found in the semantic task. One possibility for not finding a significant change in the semantic task post-concussion may be attributed to the fact that the animal naming task requires individuals to retrieve words that are semantically related. That is, according to Collins and Loftus' (1975) it is possible that individuals are more likely to retrieve information from their memory if they are presented with semantically related information. In the current study, individuals were presented with the primed word "animals" as a category; individuals were more likely able to retrieve words within this semantic network because they were presented with the primed word. The concussed group may have retrieved more words from the animal category because of the large pool of words that may be associated with animals, compared to the limited number of words available in memory based on the initial letters of words assessed in the phonemic task. Therefore, after a brain injury, individuals may retrieve fewer numbers of words from long-term memory given only the initial letter of the words to retrieve.

A second possibility for finding a change in the phonemic task and not in the semantic task can be that the phonemic task has more restrictions as to which words are acceptable. Therefore, by placing a higher cognitive demand reflected in the constraints of; (1) proper names or (2) same word with a different ending and (3) limiting the time, 1 minute, required to produce the target words retrieved from long term-memory potentially reduces the efficiency in searching memory for the target words (King et al. 2006; Robinson et al., 2012). For example, neuroimaging studies have found that after a mTBI, individuals show an increase in right hemispheric activation in regions of the frontal lobe in response to demands of higher working memory (Christodoulou et al., 2001; McAllister et al., 1999). Also, based on Christodoulou et al.

(2001) participants showed recruitment of remote regions in the contralateral hemisphere, thus requiring more time to access target words from areas of the brain not previously primary in the coding of word memory. The poor performance in the phonemic task may reflect the constraint of time given the post-concussed participants to access the target words thus reducing the number of words recalled within the one-minute time frame.

Another interesting finding was that after 3 days post-concussions, athletes in the current study did not use clustering to aid them with retrieval of words on the phonemic task. One possible explanation for this finding may be due to the reduced ability of those concussed athletes to efficiently cluster words/letters during the phonemic task. Troyer (1997) and Troyer et al. (2000) suggested that clustering reflects the ability to group words within semantic and phonemic sub-categories. Clustering may be predicted upon the assumption that words comprise a highly structured network that when activated may prime the retrieval of a number of related words. Again in the present investigation, due to the time demands required during the word retrieval task, efficient processing is reduced and is reflected in the reduction of words recalled.

A similar study by Zakzanis et al. (2011) found that mean cluster size and number of switches during the semantic task provide a more sensitive measure of mTBI than the total words. Further, no significant changes were found in the phonemic task in the total number of words, mean cluster size, and number of switches in the mTBI group. Zakzanis' et al. (2011) results are different than the results from the current study. Participants in Zakzanis et al. (2011) differed from the current study in age, level of education, time elapsed between injury and assessment, and etiology of the brain injury. The first major variable that may have contributed to finding different results from those of Zakzanis' et al. (2011) study may be the difference of age of the participants. In Zakzanis' et al. (2011) the mTBI group age ranged from 19 to 58 and

in this study the age ranged from 18 to 22 at PC1 testing. In a related study Troyer and colleagues (1997) investigated the effects of age on the total number of words recalled, and the mean cluster size, and number of switches used by the participants. Troyer et al. (1997) found that older adults (M=22, SD=2.3) generated more words in the verbal fluency tasks than younger adults. It is possible that this age difference may reflect differences in vocabulary size suggested by Troyer et al. (1997). The second variable that may have contributed to the difference in findings between the current study and Zakzanis et al. (2011) is the time frame between the date of injury and the date of testing. In the current study, all athletes were tested within 3 to 10 days after their brain injury, while participants in Zakzanis et al. (2011) were tested 3 months post-injury. At 3 months post-injury one might assume that brain had healed and was not as dysfunctional as those participants with more acute brain injury. The third variable that may have contributed to different results in the current study as compared to Zakzanis et al. (2011) is etiology of the brain injury. The current study consisted of sport-related concussions while Zakzanis' et al. (2011) participants varied in the etiology of the brain injury. In addition, Belanger et al. (2005) suggests that athletes represent a group that differs greatly in terms of motivation to return to play, and are typically more physically fit than the general population. These variables may impact neurocognitive status and recovery rates. As stated by Belanger and Vanderploeg (2005) contact sports-related brain injuries potentially may have a significant impact on neuropsychological functioning.

Finally, the current study investigated the nature of recovery of verbal fluency measures by comparing athlete's verbal fluency performance from PC1-to-PC2 and BL-to-PC2 testing. Concussed athletes significantly increased their mean cluster size in the phonemic task from PC1 to PC2. These findings support the observation that as athletes recover they tend to use more

words within a cluster and reduce their switching from one phonemic category to another. In the current study, concussed athletes were tested 8-10 days post-onset at PC2. When PC2 results were compared to BL performance, 37% of the athletes did not return to premorbid (BL) performance. This evidence that approximately a third of the concussed athletes in the current study showed a delayed recovery rate counters the findings that suggest athletes recover within 5 to 7 days of the brain injury (McCrea et al., 2003). This finding suggests that the average recovery period following a sports-related concussion may extend beyond one week. Clinicians involved in the management of sports-related concussion should analyze clustering and switching scores in addition to the total number of words. Using mean cluster size scores in the phonemic task to evaluate and track recovery of cognitive-communication deficits such as recalling names may aid the clinician's return-to-play decisions.

4.2 Clinical Implications

Neurocognitive testing is commonly used to assess and manage sport-related concussions. Neurocognitive test results play an important role in treating concussion signs and symptoms and contribute to the safe return-to-play decision. Athletes usually return to play once they are symptom-free and their cognitive performance has returned to baseline. To date, no study has compared verbal fluency performance from pre-season to post-concussion testing to analyze the change and the nature of recovery in athletes following a sport-related concussion. The reduced mean cluster size in the phonemic task post-concussion may suggest an underlying cognitive deficit in these individuals. As athletes are recovering from their concussion, their ability to more efficiently access word from long-term via working memory increases. It appears that athletes are able to retrieve more words within a subcategory (cluster sizes) over time as the brain heals. When deciding if it is safe for an athlete to return-to-play, the athlete should

probably return to their BL phonemic mean cluster size and be symptom-free. Further investigation of this finding is needed. However, at this time these results should be considered in a clinician's return-to-play decision.

4.3 Limitations

Several limitations in the study design must be recognized. These factors present a threat to the internal validity of the study. First, participants in both the concussed and control group self-reported history of concussion; therefore the exact number of history of concussions was not controlled in this study. In addition, multiple clinicians administered the verbal fluency task to the athletes, which could have affected responses from each individual. Furthermore, the athletes' responses were not audio recorded, thus raising concern as to the accuracy of the data reflecting their performance. The lack of audio recording is the reason for the limited data for mean cluster size and the number of switches in both phonemic and semantic tasks. In addition, bilingual participants were present in both groups. Two of the participants in the control group and one in the concussed group reported that English was not their first language. All participants that had a first language other than English self-selected English to be tested in. Within bilinguals, data showed no switching to their other language at baseline or after experiencing a concussion. Since the data was selected from a pre-exiting database and there was no recording of athletes responses, no information could be obtained to determine whether a concussed individual produced words in a language other than English.

All participants were recommended to undergo a complete rest protocol, which included no school, no exercise, healthy meals, and complete rest at home. The compliance of the athletes to follow the treatment recommendations given after the concussion was not controlled in this study. This factor might have contributed to a longer recovery period noted in some of the

athletes for this study. Finally, the UTEP CMC examination protocol for concussed individuals consisted of multiple assessment instruments. The verbal fluency task was given following the ImPACT test, which is a 30-45 minute test. The ImPACT test could have increased fatigue and stimulated symptoms, which could have contributed to the participants' verbal fluency performance.

Future studies should address these limitations by including more athletes in the concussed group, audio recording the responses during the verbal fluency task, and randomly selecting participants to alternate the order in which they take the ImPACT test and the verbal fluency task. These limitations could increase the methodology of the study and improve the generalizability of results.

4.4 Summary and Conclusion

Many athletes go back to play without a complete recovery from a concussion. Clinicians must have an effective test that is useful in assessing changes and recovery from a mTBI. The verbal fluency task is a cognitive-communication assessment that examines brain-behavior relationships. Using clustering scores within the phonemic task allows clinicians to understand why an individual reduced their total number of words. Furthermore, this study revealed that after a sport-related concussion, athletes did not use clustering in the phonemic task to aid in the retrieval of words. As athletes recover from their brain injury they are able to produce larger clusters of words to aid their word retrieval performance. Results from this study suggest that the verbal fluency task is a useful tool for evaluating deficits in verbal fluency tasks following a sport-related concussion. Furthermore, the task assists clinicians with making recommendations for the safe-return-to-play decision. Future research should extend the assessment period for a

sport related concussion to provide a better understanding of the recovery process following a concussion.

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Appendix A

Scoring Rules for Clustering and Switching*

Total number of correct words generated. This was calculated as the sum of all words produced, excluding errors and repetitions.

Mean cluster size. Cluster size was counted starting with the second word in a cluster. That is, a single word was given a cluster size of 0, two words had a cluster size of 1, three words had a cluster size of 2, and so forth. Errors and repetitions were included. The mean cluster size was computed across the three phonemic trials and across the one or two semantic trials.

Number of switches. This was calculated as the total number of transitions between clusters, including single words, for the three phonemic trials combined and for the one or two semantic trials combined. Errors and repetitions were included.

Phonemic fluency

Clusters on phonemic fluency trials consisted of successively generated words which shared any of the following phonemic characteristics:

First letters: words beginning with same first two letters, such as ''arm'' and ''art''

Rhymes: words that rhyme, such as ''sand'' and ''stand''

First and last sounds: words differing only by a vowel sound, regardless of the actual spelling, such as ''sat,'' ''seat,'' ''soot,'' ''sight,'' and ''sought''

Homonyms: words with two or more different spellings, such as ''some'' and ''sum,'' as indicated by the participant.

Semantic fluency

Clusters on semantic fluency trials consisted of successively generated words belonging to the same subcategories, as specified below. Commonly generated examples are listed for each subcategory, although listings are not exhaustive.

Animals

African animals: aardvark, antelope, buffalo, camel, chameleon, cheetah, chimpanzee, cobra, eland, elephant, gazelle, giraffe, gnu, gorilla, hippopotamus, hyena, impala, jackal, lemur, leopard, lion, manatee, mongoose, monkey, ostrich, panther, rhinoceros, tiger, wildebeest, warthog, zebra

Australian animals: emu, kangaroo, kiwi, opossum, platypus, Tasmanian devil, wallaby, wombat

Arctic/Far North animals: auk, caribou, musk ox, penguin, polar bear, reindeer, seal

Farm animals: chicken, cow, donkey, ferret, goat, horse, mule, pig, sheep, turkey

North America animals: badger, bear, beaver, bobcat, caribou, chipmunk, cougar, deer, elk, fox, moose, mountain lion, puma, rabbit, raccoon, skunk, squirrel, wolf

Water animals: alligator, auk, beaver, crocodile, dolphin, fish, frog, lobster, manatee, muskrat, newt, octopus, otter, oyster, penguin, platypus, salamander, sea lion, seal, shark, toad, turtle, whale

Beasts of burden: camel, donkey, horse, llama, ox

Animals used for their fur: beaver, chinchilla, fox, mink, rabbit

Pets: budgie, canary, cat, dog, gerbil, golden retriever, guinea pig, hamster, parrot, rabbit

Birds: budgie, condor, eagle, finch, kiwi, macaw, parrot, parakeet, pelican, penguin, robin, toucan, woodpecker

Bovine: bison, buffalo, cow, musk ox, yak

Canine: coyote, dog, fox, hyena, jackal, wolf

Deers: antelope, caribou, eland, elk, gazelle, gnu, impala, moose, reindeer, wildebeest

Feline: bobcat, cat, cheetah, cougar, jaguar, leopard, lion, lynx, mountain lion, ocelot, panther, puma, tiger

Fish: bass, guppy, salmon, trout

Insects: ant, beetle, cockroach, flea, fly, praying mantis

Insectivores: aardvark, anteater, hedgehog, mole, shrew

Primates: ape, baboon, chimpanzee, gibbon, gorilla, human, lemur, marmoset, monkey, orangutan, shrew

Rabbits: coney, hare, pika, rabbit

Reptiles/Amphibians: alligator, chameleon, crocodile, frog, gecko, iguana, lizard, newt, salamander, snake, toad, tortoise, turtle

Rodents: beaver, chinchilla, chipmunk, gerbil, gopher, groundhog, guinea pig, hamster, hedgehog, marmot, mole, mouse, muskrat, porcupine, rat, squirrel, woodchuck

Weasels: badger, ferret, marten, mink, mongoose, otter, polecat, skunk

General Scoring Rules

In the case where two categories overlapped, with some items belonging to both categories, some items belonging exclusively to the first category, and some items belonging exclusively to the second category, the overlapping items were assigned to both categories. For example, for ''dog, cat, tiger, lion,'' the first two items were scored as pets, and the last three items were scored as feline. ''Cat'' was included in both the pet category and the feline category.

In the case where smaller clusters were embedded within larger ones, or two categories overlapped, but all items could correctly be assigned to a single category, only the larger, common category was used. For example, for ''sly, slit, slim, slam'' all begin with ''sl,'' but an additional cluster was not scored for the last two words which differ only by a vowel sound.

*From: Troyer, A. K. (2000). Normative Data for Clustering and Switching on Verbal Fluency Tasks. *Journal Of Clinical & Experimental Neuropsychology*, *22*(3), 370-378.

Curriculum Vita

Paulina Mejia was born in Guadalajara, Jalisco, Mexico, and moved to El Paso, Texas in the year 2000. Paulina graduated from Burges High School in the spring of 2010 and entered The University of Texas at El Paso in the fall. She worked as a research assistant from 2014 to 2015 at the UTEP Concussion Management clinic. She is currently pursing a Master's of Science in Speech-Language Pathology with a Concussion Management Certification and Certificate in Bilingual Speech-Language Pathology at The University of Texas at El Paso.

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