Gait and Cognition: Exploring Cognition and Dual-task Costs in a Group of Community Dwelling Alzheimer's Disease Patients over 6 Months

by

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Abstract

Alzheimer's disease is a progressive neurological disorder resulting in cognitive decline affecting many activities of daily living including gait. Many tools exist to monitor AD progression, including cognitive examinations, and functional tests of mobility. The purpose of the present study is to analyse a diverse group of 18 community dwelling AD patients at baseline, 3 months, and 6 months to monitor changes to select cognitive and functional tests; to examine dual-task costs to specific gait parameters; and examine possible correlations between cognitive scores and dual-task costs to gait. Three cognitive tests were used: Mini Mental State Examination (MMSE), Montreal Cognitive Assessment (MoCA), and two subsets of the Cognigram Cogstate Brief Battery (CBB1 and CBB2). Gait was assessed using a GAITRite electronic walkway under single-task and dual-task conditions. Previous research has identified some of the costs to gait due to dual-tasking in cognitively impaired older adults compared to healthy older adults includes: decreases to gait speed, cadence, stride length; increases to stride time, and stride time variability. In the present study, these measures were assessed as a percentage change between their preferred walk (PW) and their dual-task walk (DTW); this percentage change while dual-tasking is referred to as their dual-task costs (DTC).
Results: dual-task costs to gait and cognitive data show no significant change over the 6 month time period. Correlation coefficients between cognition and dual-task costs showed mixed results, suggesting a partial relationship between cognitive scores and some gait measures of dual-task costs, with the MoCA being most highly correlated. The animal fluency dual-task created statistically significant changes to all gait measures including means and coefficients of variation; all these changes were associated with poorer gait kinematics. Some gait variables showed consistent results amongst participants, while others showed high ranges of variability, expressed through the range of standard deviations. High levels of variability may suggest that those measures are more sensitive to differences between participants, and may therefore make them valuable measures to explore more thoroughly in the future. Gait variability DTCs were not correlated with any cognitive tests.

Preface

This thesis is an original work by Christopher Davis. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Health Research Ethics Board, Evaluating Cognitive and Functional Impairment in Alzheimer's Dementia with a Ketogenic Diet (Gait amendment) (Pro00054165_AME6), November 25, 2015.

Data from this study was collected as an amendment to a study directed by Dr. Angela Juby (Professor, Department of Medicine, Division of Geriatrics, University of Alberta). Dr. Juby was responsible for the recruitment of participants, obtaining ethics approval, and the supervision of data collection and study completion. Data collected for this study was obtained with the support and equipment provided by Dr. Richard Camicioli (Professor, Department of Medicine, Division of Neurology, University of Alberta). Cognitive testing was performed by Toni E. Blackburn (RN). Participant scheduling was done by Debbie Smith (Alberta Health Services, Division of Geriatrics). Gait data was collected by me, with Natalie Ravid providing technical support in the exporting and compiling of the data. I was responsible for the analysis of the data and manuscript composition. None of the gait data in this study has been previously published.

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Introduction

Research into the understanding of varying levels of behavioural changes associated with disease progression is beholden to the efficacy of the paradigms that test disease state. When testing cognitive changes it is important to understand the factors that both improve and hinder cognition, as well as the specificity and sensitivity of the testing tools, both in the short term, and over time. It is usually beneficial to use a multifaceted approach to gain a more holistic view of the participants' cognitive state. In the case of Alzheimer's disease, it is important to understand how a diverse group of patients would perform on various cognitive and behavioural tests to provide insight into the best tools, or parameters, for distinguishing between individuals. Firstly, this paper begins with an overview of some of the common understandings in AD pathology. Following this, background information on the various cognitive tests used in this study provides insight into the relative strengths and weaknesses of each of the tests. An overview of executive functions links performance on cognitive tests with specific cognitive processes, and elaborates on the link between cognition, gait, and cognitive impairment. Gait is further explored as individual gait parameters are compared between AD and healthy older adults. Dual-tasking, a method to further task executive functions, is explored as a method to test levels of cognitive impairment by analysing gait parameters while performing a simultaneous secondary verbal task; dual-task costs, the change in performance from normal walking to dual-task walking is defined, and proposed as valuable measure for cognitive assessment. Finally, the practical implications of monitoring gait under dual-task conditions as a predictor of fall risk will be elaborated on for clinical or rehabilitative practicality.

1. Background

1.1 Alzheimer's Disease

Alzheimer's disease (AD) is a neurodegenerative disease, and is the most common cause of dementia accounting for 60-70% of cases (World Health Organization, 2021). Over time, AD progresses impairing neurological function, decreasing cognitive abilities, altering behaviour, and ultimately decreasing quality of life. The most widely recognized symptoms are short-term memory loss, language problems/word-finding difficulties, and difficulty learning and consolidating new information. In the early stages of the disease, AD patients may be asymptomatic despite the presence of biomarkers of AD, and only once the disease has progressed to a later stage do more traditionally characteristic symptoms appear (Thal et al., 2002). AD symptoms typically progress from mild memory or cognitive impairment in the early stages of the disease to

being highly impairing and debilitating cognitive and behavioural changes in the later stages, leading to a loss of function required for activities of daily living (Galvin & Sadowsky, 2012). This process can take several decades with symptoms worsening as the disease progresses (Braak et al., 2011).

Diagnosis of AD may be done through a combination of the following: medical history, clinical examination, neuropsychological testing, and laboratory assessments (McKhann et al., 1984).

The exact cause of AD is unknown, although there are many potential risk factors for the development of AD and other forms of dementia. Many of the risk factors for dementia are modifiable, including cardiovascular health, and lifestyle choices; increases in physical activity, and positive dietary choices can help prevent the development of dementia (Baumgart et al., 2015). Although still uncertain, it has been proposed that AD may be the result of a neuroinflammatory response to pathogens in the brain, leading to a chronic activation of the body's innate immune system (Henekat et al., 2015; VanItallie, 2017). Limiting exposure to other environmental factors including neurotoxic heavy metals, nanoparticles, or pesticides may prevent the development of AD and dementia (Rahman et al., 2020).

Pathogenesis of AD results in an accumulation of intraneuronal tau protein (commonly called tau tangles), and the extracellular protein fragment beta-amyloid (called beta-amyloid or amyloid plaque)(Nelson et al., 2009). It is a common belief that neuronal death found in AD may be the result of a buildup of beta-amyloid plaque disrupting interneuronal synaptic function, and/or tau tangles disrupting the transport of nutrients and other essential molecules inside neurons (Alzheimer’s Association, 2019). In the preclinical phase of AD, tau tangles may provide insight into the stage of the disease, originating first in the medial temporal lobe, and progressing to other regions of the brain as the disease develops (Braak & Braak, 1991). Deposition of amyloid beta in the brain predates clinical memory problems decades before the onset of cognitive disturbances (Jack Jr. et al., 2013). The exact interaction between amyloid plaque and neurofibrillary tangles is not yet known, as one does not necessarily precede the other (Braak & Braak, 1991).

There is discussion on whether symptoms of AD are a result of excessive amyloid deposition, or whether amyloid plaque is simply a precursor to an inflammatory cascade which ultimately results in the symptoms associated with AD (Chen, 2018). Microglia are immune cells that clear the brain and central nervous system of toxic agents, and dead or dying cells. In an AD brain, the accumulation of amyloid plaque leads to an increased demand from the microglia, with this response being localised to areas with high levels of amyloid plaque and neurofibrillary tangles (Akiyama et al., 2000). This demand may be too much for these cells, potentially leading to inflammation caused by an excessive buildup of the toxic amyloid plaque (Alzheimer’s Association, 2019). Another line of thinking believes that the symptoms of AD may be a direct result of the inflammatory response of the brain, through the neurotoxic and proinflammatory byproducts produced by the microglia found in an AD patient's brain (discussed in Akiyama et al., 2000). Proliferation of microglia in an AD brain may lead to the formation of divergent microglia that promote chronic

neuroinflammation (Heneka et al., 2015). Evidence to support the strong relationship between amyloid plaque buildup and neuroinflammation can be drawn through the link between the localization of the upregulated inflammatory response to regions of the brain showing high levels of AD pathology (Rogers et al., 1988). The presence of high levels of plaques and tangles alone may not lead to dementia in the absence of inflammatory markers, further supporting the role of inflammation in symptom manifestation (Lue et al., 1996).

Reduced cerebral blood flow may also be another cause, or result, of neural damage caused by AD. Cerebral blood flow is reduced in the frontal lobe and basal ganglia of AD patients with an associated impairment to gait and stability (Nakamura et al., 1997). This may partially explain the poorer gait seen in AD when compared to age matched controls (see section 1.4).

Although the exact mechanism remains unclear, pathophysiology of AD leads to neuronal cell death resulting in atrophy of the affected brain regions. Atrophy first occurs in the medial temporal lobe, progressing to the lateral temporal lobe, the parietal lobe, and then the sensory and motor cortices (Pini et al., 2016). Hypometabolism of a diverse range of brain regions is also found in AD patients, but the mechanism causing this and the interconnectedness of these brain regions is still uncertain (Mosconi, 2005).

Behaviourally, despite AD not being considered a motor disorder, many studies have found decreased motor performance assessed through gait and balance when compared to healthy older adults (see section 1.4). AD and other neurological disorders like Parkinson's Disease (PD) and Huntington's Disease (HD) influence factors like gait variability, but to varying extents (Moon et al., 2016). A possible explanation for that difference might be AD affecting the prefrontal cortex, and therefore executive functions, resulting in a decrease in attentional control of gait (Baudic et al., 2006). This is in contrast to PD which more so affects the basal ganglia reducing the automaticity of gait (Belghali et al., 2017). These findings support that gait and motor control involves higher cognitive function affected by a diverse range of brain regions, with each regulating the motor control of gait differently. Due to the complexity of neural control of gait, It has been proposed that the focus should be on examining both motor and executive function impairment on a behavioural instead of a neuroanatomical level (Baddeley, 2017).

The previously mentioned pathophysiological changes to the brain begin to occur in the preclinical phase of the disease. It is only as the disease has progressed to later stages does symptoms begin to appear. Some symptoms include memory loss, confusion or disorientation, depression, personality changes, and apathy (Alzheimer's Association, 2019). Memory symptoms are linked to neurological changes to the medial temporal lobe and hippocampus, areas associated with declarative memory (Squire, 1992). Ultimately, impairment due to AD can leave the person bedridden, frail, or otherwise unable to perform necessary activities for survival, like swallowing food. Death due to AD occurs from complications that arise from the disease symptoms: choking on their food; pneumonia; infections from bed sores; organ failure due to systemic inflammation (Alzheimer's Association, 2019).

1.2 Cognitive Tests

Due to the progressive nature of AD and other forms of dementia, tests were developed to screen for, and monitor, cognitive state. One application of these tests is the monitoring of symptoms to assess treatment efficacy. Because of the neurological impact associated with AD, cognitive tests are commonly used as they screen for many cognitive domains affected in AD like memory, visuospatial skills, and language. Cognitive tests, in general, can differentiate healthy controls from those with mild cognitive impairment or AD (Roalf, et al., 2013). Poor performance on a cognitive test may support a clinicians further investigation into that patient's biomarkers of AD (neural levels of beta-amyloid), or more in depth analysis of the patients behaviour and history for probable AD diagnosis. Behavioural and cognitive changes should be monitored as biomarkers of AD do not assure progression into AD (bennet et al., 2006). It is important to note that some patients with AD may not notice cognitive changes due to cognitive reserve compensating for decreased cognitive function; this may be based largely on years of education (Buckner, 2004; Stern, 2012). Although there is no guarantee of a solid diagnosis using a cognitive test, cognition declines as a result of AD pathophysiology at a higher rate than the expected age-related change (Hensel et al., 2007; Suh et al., 2004). This makes longitudinal evaluations of cognition another tool for the diagnosis of probable AD. A large variety of tests of cognition have been developed for the monitoring and diagnosis of cognitive impairment that target specific subdomains of cognition, or more global tests of cognitive function like the MMSE and MoCA.

The Mini-Mental State Examination (MMSE) was developed by Folstein et al. (1975) as a practical tool for clinicians to monitor cognitive state, and is still used today. Tests for validity and reliability were done by the authors. The test is composed of two sections: section one requires verbal responses, and covers orientation, memory, and attention; section two requires the following of verbal and written commands, language testing through sentence writing, and a visuo-spatial test of copying a complex polygon. Folstein et al., (1975) found a mean score of 9.7 out of a possible 30 points in their group of dementia participants. This is compared to a mean score of 27.6 in their unimpaired older adults. While low scores might be highly indicative of dementia, it is not a necessity. Spering et al., (2012) identified the specificity and sensitivity of different MMSE cutoffs for detecting probable or possible AD. The traditional cutoff of <24 only had a sensitivity of 0.58 of detecting AD. As the cutoff was lowered specificity is increased while sensitivity is decreased, meaning it more specifically detected AD, but was more likely to provide a false-negative of AD. The reverse was also shown, when the cutoff was raised sensitivity was increased while specificity decreased. They proposed that a cutoff of <27 may provide the most balance between sensitivity and specificity. Even with this fairly high cutoff, MMSE is still not 100% sensitive in identifying AD, and it is even possible for patients with AD to have a perfect score on this test (Shiroky et al., 2007). The rate of cognitive decline in AD does not appear to have a linear relationship with the rate of decline in MMSE scores (Doody et al., 2001; Mendiondo et al., 2000). Mendiondo et al. (2000) have

partially accredited this non-linear relationship to be due to the point weighting of each cognitive subdomain in the MMSE, resulting in a higher sensitivity to changes in the middle and late stages of AD. Longitudinal assessment with the MMSE may also be unable to notice meaningful changes in time frames less than 3 years as there is a certain degree of variability in scores due to measurement error and individual variability (Clark et al., 1999)

The Montreal Cognitive Assessment (MoCA) was developed as a more specific and sensitive cognitive assessment than the MMSE (Nasreddine et al., 2005). Although the MMSE is still being used, the MoCA has been shown to be a superior tool for global assessments of cognition (Roalf et al., 2013). Many individuals who have mild cognitive impairment (MCI) do not have an abnormal score on the MMSE (Nasreddine et al., 2005). Scores of the MoCA of 25 or less, out of a possible 30, indicate cognitive impairment. The authors attributed the higher sensitivity of the MoCA to multiple factors including: it's more demanding memory task, involving more words, fewer learning trials, and longer delay before recall; the more demanding and numerous tests of executive functions, higher-level language abilities, and complex visuospatial processing. In the presence of cognitive complaints, the authors further reinforced the value of using the MoCA when MMSE scores are normal. The MoCA also shows a higher rate of decline in cognitively impaired individuals compared to healthy older adults (Krishnan et al., 2017).

The Cogstate Brief Battery (CBB) is a computerised test of cognition developed for repeated test-retest use (Fredrickson et al., 2010). The CBB uses playing cards displayed on a screen with tasks focusing on psychomotor function, attention, learning, and working memory. The psychomotor function task is a reaction based task where participants click a button once a card turns over on the screen; performance is based on reaction time. The attention task consists of participants responding to a card being flipped over and deciding whether that card that flipped is red or not, and pushing a corresponding button; performance is based on reaction speed of correct responses. The learning task consists of participants answering yes or no to whether the card being flipped has been seen before previously in this part of the test; performance is based on proportion of correct responses. The Final task, the working memory task, asks the participants to respond on whether the card being flipped is the same as the previous card; performance is based on time to react, and the proportion of correct responses. The CBB was divided into 2 parts: the first part included the psychomotor function and attention tasks (hereafter referred to as CBB1); the second part consisted of the learning and working memory tasks (hereafter referred to as CBB2). Scores were out of a possible 200, and were relative to normal ranges: 0-80 was considered abnormal; >80-85 borderline; >85-200 normal. The CBB has been found to be sensitive to varying degrees of cognitive impairment (Lim et al., 2012; Lim et al., 2013; Maruffet al., 2013), and shows high test-retest reliability and stability over 3 months (Lim et al., 2013). In AD participants, performance on all tasks was worse than those with MCI, and this performance decrement was worse in the working memory and learning task (CBB2) (Maruff et al., 2013). Monitoring performance longitudinally on the

CBB is associated with a determining risk for developing AD, and can be used to monitor cognition over time due to its test retest reliability in healthy older adults (Darby et al., 2012).

Although cognitive tests may provide valuable insight in cognitive state, they have potential limitations. One potential problem associated with cognitive tests is the possibility for learning effects, and the lower precision of some of these tests (Hensel et al., 2007), although evidence shows no learning effect in the CBB (Lim et al., 2013), tests like the MMSE, although used fairly often, may be imprecise for diagnosing dementia (Shiroky et al., 2007). Another large limitation is the cognitive reserve, largely related to years of education, which may delay the onset of noticeable changes to cognitive scores (Buckner, 2004; Stern, 2012). Once changes are noticeable through cognitive assessments in highly educated patients, the disease may have progressed to such an extent that cognition will decrease at a much faster rate (Mendiondo et al., 2000). Research has moved towards more comprehensive protocols for monitoring changes associated with neural degeneration. Screening for diagnosing AD now includes a mix of multiple different cognitive assessments, while also monitoring behavioural and motor changes as well (Galvin & Sadowsky, 2012).

1.3 Executive Function

One of the cognitive domains affected by AD is executive function. The central executive, which encompasses executive functions, can be viewed as a subdomain of working memory (Baddeley, 1992). Chan et al. (2008) summarised executive functions with the following definition:

“Executive functions” is an umbrella term comprising a wide range of cognitive processes and behavioural competencies which include verbal reasoning, problem-solving, planning, sequencing, the ability to sustain attention, resistance to interference, utilisation of feedback, multitasking, cognitive flexibility, and the ability to deal with novelty. (p.201)

A review by Yogev-Seligmann et al. (2008) identified, and expanded on, similar components of executive functions to Chan et al. (2008) including: volition, self-awareness, planning, response inhibition, response monitoring, attention/dual-tasking. Executive functions, alongside memory, attention, language, and visuospatial abilities, are important measures because they are impaired in even very mild AD (Baudic et al., 2006). Deterioration to executive function occurs in the early phases of AD with memory impairments preempting language and visuospatial problems (Allain et al., 2013). The previously mentioned tests, like the MMSE, MoCA, and the CBB, all contain a component measuring executive function. However, executive function encompasses a broad range of functions which are not universally impaired in AD, with divided attention (being able to focus on several relevant stimuli simultaneously) being most susceptible to impairment (Baudic et al., 2006; Grober & Sliwinski, 1991). It is also important to note that tests of executive function

usually target specific subdomains within executive functions, and that a more balanced examination of executive functions may be more useful to clinicians (Chan et al., 2008).

Executive function has been linked to gait control in healthy older adults, and gait is now more commonly believed to be a complex task involving multiple cognitive resources, including executive function (Beauchet et al., 2012; Hausdorff et al., 2005). Gait may have higher attentional and executive function demands when there is a change in sensory information or a conscious involvement of working memory while walking (Sheridan & Hausdorff, 2007). In more complex environments, executive function is correlated with gait speed, likely due to the relationship between executive function and goal-directed behaviours (Ble et al., 2005). The inclusion of gait to clinical assessments of executive function may therefore provide a more holistic understanding of executive impairment when paired with the already commonly used cognitive tests. The link between gait, executive function, and AD, reinforces the values of gait assessment in AD as a tool for monitoring executive function impairment.

The brain area most commonly associated with executive functions is the frontal lobe; more specifically the prefrontal cortex (Gilbert & Burgess, 2008). It is important to note that although executive function impairment is associated with damage to the frontal lobe, it does not reject the claim that executive function may be affected by a broad range of brain regions (Baddeley, 2017; Yogev-Seligmann et al., 2008).

1.4 Single-task Gait and AD

Gait is the footfall patterns or biomechanical properties that define walking (Mirelman et al., 2018). Gait can be divided into spatial and temporal components that define specific subcomponents of the gait cycle. As previously mentioned, motor control of gait is now believed to be controlled by higher level cognitive functions and more specifically executive function when there is conscious awareness (Badgaiyan, 2000). When action is goal-directed, descending cortical tracts control muscle activation to produce the spatiotemporal components of locomotion (Drew et al., 2004). Intent is relevant for all clinical tests of gait because once asked by an assessor to walk, the participant becomes goal-directed and more consciously aware of their gait.

Lord et al. (2013), proposed a five factor model for understanding gait which uses: pace, rhythm, variability, asymmetry, and postural control. This model was adjusted for discussion purposes for this study. Gait parameters associated with pace consist of stride length, stride time, velocity, cadence, and stance time. The previously mentioned pace factors contribute either spatially, temporally, or both, to the time it takes to walk a set distance. Our study consolidates rhythm and variability into consistency, and is assessed using the coefficient of variation of all gait parameters. Asymmetry is not assessed in this study, as gait in this study is primarily examined as a change in individual performance, so individual asymmetries will be negated. Postural

control was assessed using the stance centre of pressure path efficiency, a dynamic measure of posture tracking foot pressure from heel plant to toe off.

Although not considered a motor disease, patients diagnosed with AD exhibit signs of motor impairments even in normal walking when contrasted with healthy older adults. There has been some research that links greater hippocampal volume, an area commonly affected by AD, with gait parameters like increased stride length and decreased stride length variability, even in a generally healthy elderly population (Zimmerman et al., 2009). A wide range of spatial and temporal measures of gait are used when assessing AD patients. Gait parameters are typically subdivided into either mean values or measures of variability. The most commonly used variability measure is coefficient of variation (CV), which can be calculated using the equation: (standard deviation (SD) / mean) * 100%. Gait measures like gait speed, stride length, and stride length variability, can be used prospectively to predict risk of developing dementia (Doi et al., 2019), although there is inconsistency in these findings in regards to AD in particular (Verghese et al., 2007).

When compared to healthy older adults, patients with AD or dementia show the following alterations to their gait related to pace: slower gait speed/velocity (Allali et al., 2016; Barbieri et al., 2015; Hsu et al., 2014; Lin et al., 2016; Maquet el al., 2010; Merory et al., 2007; Nadkarni et al., 2009a; Nadkarni et al., 2009b; Gillain et al., 2009; Goldman et al., 1999; Gras et al., 2015; Nakamura et al., 1997; Simieli et al., 2015; Suttanon et al., 2012; Tanaka et al., 1995; Visser, 1983); shorter stride length (Allali et al., 2016; Barbieri et al., 2015; Gillain et al., 2009; Hsu et al., 2014; Maquet et al., 2010; Merory et al., 2007; Nadkarni et al., 2009a; Nakamura et al., 1997; Simieli et al., 2015); shorter step length (Gras et al., 2015; Suttanon et al., 2012; Tanaka et al., 1995; Visser, 1983); longer stance time (Allali et al., 2016; Gras et al., 2015; Hsu et al., 2014); longer stride time (Allali et al., 2016; Lin et al., 2016; Simieli et al., 2015); increased double support time (Allali et al., 2016; Barbieri et al., 2015; Merory et al., 2007; Nadkarni et al., 2009a; Nakamura et al., 1997; Simieli et al., 2015; Visser, 1983); shorter stride frequency (Maquet et al., 2010); decreased cadence (Lin et al., 2016; Nadkarni et al., 2009a).

Consistency of gait is also impaired in AD compared to healthy controls shown through: decreased regularity (Maquet et al., 2010); increased CV of stride length (Allali et al., 2016; Barbieri et al., 2015;); increased CV of stride time (Allali et al., 2016; Barbieri et al., 2015; Choi et al., 2011; Nakamura et al., 1997); increased CV of stride velocity (Allali et al., 2016); increased CV of stance time (Allali et al., 2016;); increased CV of double support time (Allali et al., 2016; Barbieri et al., 2015;).

The following gait parameters discriminated between varying stages of AD (ex.mild, moderate, severe), with more severe AD showing: slower gait speed (Coelho et al., 2012; Nakamura et al., 1996; Ries et al., 2009); shorter stride length (Coelho et al., 2012; Nakamura et al., 1996); increased CV of stride length (Nakamura et al., 1996). The gait differences between AD and non-AD patients are fairly well established, showing the

negative impact of AD on gait. This, again, relates back to the higher cognitive involvement in motor control of gait, which appears to be impaired in AD.

1.5 Dual-task Gait and AD

Dual-tasking is used as another method to further stress the relationship between gait and cognition. Dual-tasking in a practical sense can be viewed as the simultaneous performing of two tasks, requiring the division of attention (Yogev-Seligmann et al., 2008). Pragmatically, many activities of daily living require the ability to dual-task, therefore, making it an ecologically valid measure (Yogev-Seligmann et al., 2008). Dual-tasking assessments usually involve the combination of a motor task (usually considered the primary task) with some attentionally demanding secondary task (usually verbally performing arithmetic or other verbal fluency tasks) (Amboni et al., 2013). Performing the verbal dual-task requires cognitive resources, interfering with the performance of the motor task. The performance decrement, or dual-task cost, of each task is largely impacted by the degree of difficulty of both the cognitive and motor task (Montero-Odasso et al., 2012a; Muir et al., 2012b). As the difficulty or complexity of the cognitive component of the dual-task increases, the sensitivity to changes in the motor component also increases (Beauchet et al., 2005). Walking is commonly used as the motor task in most clinical studies incorporating dual-tasking. Even amongst healthy older adults dual-tasking results in impairment to gait, and the extent of impairment correlates with executive function (Hausdorff et al., 2008). The Canadian Consortium on Neurodegeneration and Aging (CCNA) proposed the use of a standardised gait assessment protocol that incorporates 3 different verbal tasks: counting backwards by 1's, naming animals, and counting backwards by 7's (Cullen et al., 2018).

Belghali et al. (2017) reviewed dual-tasking impairments to gait and found the following differences when comparing those with clinically diagnosed AD and healthy older adults: decreases in gait speed (Camicioli et al. 1997; Sheridan et al. 2003; Cocchini et al. 2004; Ijmker & Lamoth, 2012; Pettersson et al. 2007; Maquet et al. 2010; Muir et al. 2012b; Rucco et al. 2017), cadence (Coelho et al. 2012; Rucco et al. 2017), stride length (Rucco et al. 2017); increases in stride width (Rucco et al. 2017), double support time (Muir et al. 2012b; Rucco et al. 2017), swing time (Rucco et al. 2017), stance time (Rucco et al. 2017), stride time (Ijmker & Lamoth, 2012; Muir et al. 2012b), stride length asymmetry (Maquet et al. 2010), stride length variability (Rucco et al. 2017), stride time variability (Sheridan et al. 2003; Ijmker & Lamoth, 2012; Muir et al. 2012b), stance time variability, swing time variability, and stride width variability (Rucco et al. 2017). Some of the previous studies demonstrate dual-tasking affecting pace, both spatially and temporally, as well as the consistency of those measures to a greater extent in those with AD compared to healthy older adults.

To help understand some of the mechanisms of dual-tasking, lab-based research has been done to help isolate cognitive domains impaired while dual-tasking. Preliminary research of dual-task paradigms and

dementia has found that dementia impairs the ability of participants to dual-task in lab-based tasks, showing significant reductions in computer based motor tracking ability when asked to perform a digit recall task simultaneously (Baddeley et al., 1986). In that experiment, a visuo-spatial motor task was impaired with a concurrent memory task. In a later experiment by Grober and Sliwinski (2008), digit recall acted as the primary task, and a simple choice was provided to the participants after the memorization phase, acting as a method to divide attention. As previously mentioned, divided attention is one of the executive functions most impaired in AD (Baudic et al., 2006; Grober & Sliwinski, 1991). The demented participants had more difficulty than the age matched controls at remembering the numbers that appeared during the memorization phase, even when it wasn't required correctly remember the order of the numbers. In that experiment, the presentation of a simple choice was enough to impair a demented participant's ability to recall numbers. Tracking tasks and digit recall, tests two of the working memory subdomains identified in Baddeley (1992), visuospatial processing, and the phonological loop, respectively. AD patients are more sensitive to dual-task detriments caused by dual-tasking than healthy controls, and this detriment appears to be due to working memory impairments, including both subdomains, and not AD patients showing increased sensitivity to task difficulty (Baddeley et al., 1991). Dual-tasking divides attention and requires actively using working memory, making it an ideal test for use in AD research. There is also evidence suggesting that behavioural problems commonly found in AD might be due to an impairment in the patient's ability to simultaneously balance his or her desires with that of the person they are interacting with (Della Salla et al., 1995). Behavioural problems like disinhibition or disorder may again relate back to AD affecting the attentional subcomponent of divided attention (Baddeley 2017). As previously mentioned, response inhibition may also be an executive function component affected by AD (Yogev-Seligmann et al., 2008). Behavioural changes, specifically disinhibition, can be therefore viewed as an outcome of changes to both attention and executive function or, most likely, an interaction between the two. The aforementioned reasons provide justification for testing dual-task performance as a means to understanding both cognitive and behavioural problems associated with AD. While there is still value in using many of the lab based motor tasks used in many of these early experiments due to their high levels of control and sensitivity, behavioural and clinical research focuses more highly on the more ecologically valid motor tasks like walking and balance.

1.6 Dual-task Costs

To offset any individual variability in gait due to unaccounted variables, the dual-task costs can be calculated. Dual-task costs can be viewed as the difference between normal gait (NG) and dual-task gait (DTG), and can be calculated using the formula: ((DTG - NG) / NG) *100%. Because dual-task costs use an individual's percentage change, each individual acts as their own control. Dual-task costs to gait are higher when both the

verbal task is made more difficult, and when the level of cognitive impairment is higher in the participant (Montero-Odasso et al., 2012a; Muir et al., 2012). It is therefore important that the verbal task is as controlled, and consistent, as possible when making comparisons between participants or studies.

1.7 Falls

Falls are the leading cause of hospitalisation in older adults accounting for 85% of injury related hospitalisations (Public Health Agency of Canada, 2021). Measuring gait in older adults is highly valuable as many gait parameters affected by balance and stability are associated with fall risks in even cognitively unimpaired older adults (Ganz et al., 2007), and the risk of falls is further increased in patients with dementia (Montero-Odasso et al., 2012b; Shaw, 2007). The odds of falls occurring in those with poor dual-task performance are 5.3 times that of those who are not as affected (Beauchet et al., 2009). In those with cognitive impairment, single task and dual-task gait can predict the likelihood of multiple falls (Taylor et al., 2013). More specifically, this remains true when examining AD patients, as fallers in this group also showed a similar decrease in common gait characteristics when compared to non-fallers (Camicioli , 2015). Global tests of cognition may not sufficiently assess fall risk, while monitoring executive function in particular, may provide more valuable information (Muir et al., 2012a). The previously discussed link between gait and executive function further enforces the value of gait as a tool for assessing fall risk. Both poor gait and difficulty dual-tasking are associated with an increased risk of falling, making those valuable tools (Ambrose et al., 2013; Beauchet et al., 2009). Freezing of gait while dual-tasking is also associated with a higher risk of falls (Lundin-Olsson et al., 1997). Even simple measures like variability of gait speed in normal walking may help differentiate prospective fallers from non-fallers (Svoboda, et al., 2017). Increases in gait variability while dual-tasking was identified as another marker of fall risk (Springer et al., 2006). This is further supported by the link between frontal lobe dysfunction and an increase in stride time variability (Allali et al., 2007). Therefore, gait variability is highly valuable to clinicians and rehabilitation specialists as higher levels of gait variability are associated with an increased fall risk (Hausdorff, 2005).

Purpose

Many of the previously mentioned studies have addressed inherent flaws in monitoring cognition over shorter periods of time (Clark et al., 1999). When assessing short term changes to cognition through treatments or therapies it is important to have tools for noticing small changes to cognition or behaviour. This study aims to explore whether noticeable changes to cognition, gait, or dual-task costs to gait occur over a 6 month time period, using our selected cognitive tests, and gait testing protocol. Based on previous research, it is not expected that cognitive scores will change drastically, or significantly, over such a short time period. In the

absence of noticeable changes to cognitive scores, it was important to examine if there were noticeable changes to dual-task costs to gait. This study wanted to further examine the use of dual-task costs as a means to assess changes due to dual-tasking, so individual gait characteristics are accounted for. In the absence of longitudinal changes to dual-task costs to gait or cognition, data can be pooled and viewed as a cross-sectional analysis with three assessments. This study aims to examine how these dual-task costs are correlated with participants' performance on a series of cognitive assessments. We also wanted to measure a wider range of gait parameters than previous studies to examine if any one parameter is more sensitive to dual-task costs to gait in such a diverse group of patients.

Hypotheses

Our first hypothesis was that cognition and normal gait would not change a significant amount over the course of the study, due to the relatively short duration. It was theorised that due to the complexity involved in dual-task walking, dual-tasking may continue to decline over testing sessions despite no changes to cognitive scores or usual gait.

Our second main hypothesis is that cognitive scores, in at least some of the tests, should be correlated with dual-task costs. As the level of cognitive impairment increases, it is assumed an associated decline will occur to both cognitive scores and dual-task gait costs concordantly.

2. Methods

2.1 Participants

Eighteen patients diagnosed with AD by either a geriatrician or neurologist participated in this study. Patients were recruited at the University of Alberta Hospital in Edmonton, Alberta, Canada. All participants were community-dwelling during the course of this study. Participants were required to be fluent in English, and mobile enough to walk 6 metres without major assistance; one participant used a cane while walking. All participants were receiving some form of treatment to help alleviate symptoms. Treatments remained constant and consistent over the course of the study. Treatments were not expected to alter gait performance based on previous meta-analysis findings, although data on this matter remains inconclusive (Beauchet et al., 2014). Average age of the participants was 73 (min: 54; max 84). MMSE at the start of the study showed an average indicative of cognitive impairment; average score of 21/30 with a minimum of 5 and a maximum of 30. Although MMSE did not show impairment in all participants, no participants performed normally on the MoCA (mean: 15;

min: 1; max: 25). Participants' cognition and gait were tested on 3 separate occasions: baseline, and approximately 3 and 6 months.

2.2 Cognition

Cognition was assessed by a registered nurse familiar with the testing protocol. MMSE, MoCA, and Cogstate Brief Battery were completed by each participant when possible; on some occasions participants were unable or unavailable to complete specific tests. Cognitive tests were performed in a quiet room with no outside distractions. MMSE and MoCA contained a mix of verbal and written tasks and were administered by a registered nurse. Cogstate Brief Battery was performed on a computer with two large buttons, with the right one representing “yes”, and the left one “no”. These were placed on the desk in front of the participant. All instructions were verbally explained to the participants.

Missing cognitive data was predicted based on previous research findings regarding longitudinal changes to cognitive scores, conversion tables between cognitive assessments, and the assumption of linearity in cognitive decline.

All participants completed the MMSE during at least one visit during the course of this study. For participants unable to complete the MMSE during a specific visit, a predictive longitudinal change based on the work of Mendiondo et al. (2000) was used. The authors of the previously mentioned study found a relative yearly change associated with differing MMSE scores; this number was converted into a three month change, and used to predict missing scores. The predicted value based on the authors table typically resulted in a ±1 change in the participants' MMSE scores over three months. This amount of change in MMSE is corroborated by Clark et al. (1999). This rate of decline was used in four scenarios involving missing data.

The vast majority of participants completed the MoCA. Two participants (MMSE scores of 8, and 5) were unable/unwilling to complete the MoCA. To not exclude them from data analysis, their scores were predicted using the conversion table created by Roalf et al. (2013). For nine total scenarios in which participants missed specific visit dates, a predicted 3 month change of 0.13 was used based on previous longitudinal studies examining changes to MoCA scores (Carlew et al., 2020; Krishnan et al., 2017).

In three scenarios when cognitive data was unavailable for MMSE and MoCA for the second visit, an average was taken between the first and third visits scores. Although the rate of cognitive decline in AD may not always be linear (Clark et al., 1999; Mendiondo et al., 200), due to the relatively short time interval between visits an assumption was made on the linearity of decline in these rare occasions with unavailable data.

2.3 Gait Measures

Gait measures were assessed using a GAITRite electronic walkway at the University of Alberta Hospital. The GAITRite walkway is a 6 m long walkway utilising pressure sensors to obtain temporal and spatial data for individual footfalls, and maps the centre of pressure throughout the stance phase. To negate the effect of acceleration and deceleration on gait data, one metre before and after the GAITRite walkway were marked with tape, acting as the starting and finishing point respectively. The GAITRite walkway is a validated tool for gait assessment, and has been shown to be an accurate, and simple, tool for assessing temporal and spatial gait parameters (Bilney et al., 2003). Protokinetics Movement Analysis Software calculated, and reported, specific gait data in conjunction with pressure data obtained from the GAITRite walkway.

A member of the research team went through each pass of the gait mat and removed any partial footsteps, or incorrectly labelled footfalls. Data obtained included both means and standard deviations for both individual feet (i.e. left or right), or all footfalls combined, for all gait parameters. Data used in this study used the combined left and right footfalls.

Coefficient of variation (CV) was calculated as SD / mean for each gait parameter when applicable; some measures do not have a SD, so CV cannot be obtained. Gait variables were gathered under single-task and dual-task conditions (see Appendix D. for full gait assessment protocol). The difference between normal gait (NG) and dual-task gait (DTG) was calculated using the formula: ((DTG - NG) / NG) *100%.

This study used the protocol outlined by Cullen et al. (2018). Gait measures were selected based on previous protocols that also examined dual-task gait (Cedervall et al., 2014). These measures included: mean values of stride length (cm), stride time (s), velocity (cm/s), cadence (steps/min), stance time (s), stance centre of pressure path efficiency (%); coefficient of variation for stride length (%), stride time (%), stride velocity (%) stance time (%), and stance centre of pressure path efficiency (%). CV values for cadence and velocity cannot be obtained since those measures do not have an associated SD. To not exclude velocity as a measure of CV, Stride velocity was used instead as a replacement for this parameter.

Measures of stride were calculated using the time and distance from the edge of the first contact of one heel to the edge of the next on the same foot (i.e. right to right, and left to left). From this, the time taken to complete a stride, and the distance of one stride provides values of stride time, and stride length respectively. Velocity was calculated by dividing the distance travelled by the total ambulation time. The stance phase was the time between a heel contact and toe off on the same foot. Stance centre of pressure path efficiency measures the pressure deviation during stance phase from heel plant to toe off. This is calculated as the path length of the centre of pressure divided by the distance from heel plant to toe off. We chose to include this measure as an indicator of dynamic balance during gait.

2.4 Dual-task

Multiple dual-tasks were used at each assessment time. The three different dual-tasks while walking were: counting backwards by 1's from 100; naming random animals aloud; counting backwards by 7's from 100. The protocol used in this study followed the guidelines established by the Canadian Consortium on Neurodegeneration in Aging by Cullen et al. (2018)(see Appendix D). Only data from the animal fluency dual-task were used in this study due to many participants being unable to complete the counting backwards by 7's task. Initial examination of the data showed that the animal fluency task was more demanding than the counting backwards by 1's, shown through larger dual-task costs. This is supported by Muir et al. (2012b) who used the same three dual-tasks and found similar findings with serial subtractions by 7's leading to highest dual-task costs, and animal fluency being the next most demanding verbal task. Animal fluency has already been shown to be an effective dual-task in AD (Cedervall et al., 2014).

2.5 Statistical analysis

Statistical analysis was performed using JASP software.
Shapiro-Wilk tests were performed on all dependent variables to test for normality.
Change in cognition and dual-task costs between visits was assessed using the Friedman test, a non-parametric variant of the repeated measures one-way analysis of variance (ANOVA). Since no statistically significant changes were found, no post hoc analyses were performed. Due to the absence of longitudinal changes to both gait and cognition, data from the three separate visits were pooled (n=52) and treated as cross sectional data with three measures per participant for future statistics. Unfortunately, two participants were unable to complete assessments at the 3 month time period.
Wilcoxon-signed ranks test was used to test the null hypothesis that there was no change in gait due to dual-tasking. This was done to test which gait parameters were impaired through the addition of a dual-task.
Kendall's tau was used for correlation analysis due to its ability to assess concordance and discordance of two variables. This was chosen so that correlations may be more applicable to a more diverse group of patients by limiting the effect of outliers. This is in contrast to a Spearman's rho which is more heavily affected by outliers in the data. It has been suggested that when doing non-parametric statistics that Kendall's tau is the preferred method (Puth et al., 2015). Statistical software used in this study returned Kendall's tau-B, a modification which better handles any ties that may exist in the data. Kendall's tau also provides information on the strength of a relationship without the assumption of linearity. Once again, the Pearson correlation was not used in our case because of its assumption of normality. Due to the observational nature of this study, a p-value of 0.05 was used to highlight any potential areas on interest. Since this study explored the use of multiple gait parameters,

with the purpose of identifying parameters of potential interest, p-values were not adjusted so that areas of future research would not downplayed due to statistical insignificance. It should therefore be noted that statistical significance found may potentially reflect a type-1 error due to multiple statistical analyses.

3. Results

3.1 Baseline Characteristics, Cognition, and Gait

Descriptive statistics of baseline cognitive performance, and general participant information can be found in Table 1. The age of participants in this study was consistent with some previous studies in AD (Cedervall et al., 2014; Gillain et al., 2009). However, it appears as though participants in our study had a higher percentage of post-secondary education compared to these studies. Baseline performance on all four cognitive measures was consistent with some level of cognitive impairment. Based on the MMSE cutoff proposed by Spering et al. (2012) of <27/30 for best balance between sensitivity and specificity, participants in this study, as a group, exhibited signs of cognitive impairment. Average performance on the MoCA was much below <25/30; the proposed indicator of cognitive impairment (Nasreddine et al., 2005). The higher standard deviations found in both the MMSE and the MoCA are the result of extreme diversity of cognitive impairment found in our group of AD participants. For example, three participants scored <10/30 on the MMSE. When cognition is impaired to such an extent, it is likely the participants will be unable to complete/follow many testing protocols if the tasks are too complex. On average, the participants performed just above the borderline cutoffs (>80-85) for the CBB. Borderline performance is not too surprising, as the relative simplicity of the CBB tasks may not have been sufficient in detecting cognitive impairment in a relatively independent group of participants. Baseline single-task and dual-task gait characteristics are presented in Table 2. Data on absolute values of normal-gait, and dual-task gait provides additional information to the pool of data on AD participants' gait performance.

Table 1.

Baseline characteristics of participants	Value
Age (years), mean ±SD	73 ± 9.6
Female, *n* (%)	8 (44.4)
Post-Secondary Education, *n* (%)	14 (77.8)
Mini-Mental State Examination (MMSE) mean score /30 ± SD	20.8 ± 7.7
Montreal Cognitive Assessment (MoCA) mean score /30 ± SD	15.1 ± 7.3
CBB1 mean score /200 ± SD	85.9 ± 17.8
CBB2 mean score /200 ± SD	85.7 ± 14.9

CBB1, Cogstate Brief Battery part 1 psychomotor function and attention; CBB2, Cogstate Brief Battery part 2 learning and working memory

Table 2.
Baseline gait performance during single and dual-task (mean ± S.D).

Gait parameters ±SD	Single-task	Dual-task
Mean		
Stride Length (cm.)	118.5 ± 26.7	107.2 ± 33.8
Stride Time (sec.)	1.1 ± 0.2	1.8 ± 2.1
Velocity (cm./sec.)	107.4 ± 25.6	79.2 ± 32.6
Cadence (steps/min.)	108.4 ± 13.8	87.2 ± 26.9
Stance Time (sec.)	0.8 ± 0.1	1.4 ± 1.8
Stance COP Path Efficiency (%)	96.0 ± 1.3	88.2 ± 14.2
Coefficient of Variation		
Stride Length (%)	5.3 ± 2.5	8.6 ± 7.7
Stride Time (%)	3.8 ± 1.7	12.3 ± 15.2
Stride Velocity (%)	7.2 ± 2.6	14.7 ± 16.0
Stance Time (%)	5.8 ± 1.7	16.0 ± 18.5
Stance COP Path Efficiency (%)	3.1 ± 2.9	10.7 ± 12.8

COP, centre of pressure

3.2 Tests of Normality

Shapiro-Wilk test for normality found significant p-values for all dual-task costs gait measures with the exception of stride length (0.177), indicating the majority of measures are not normally distributed. The same test was run again for the cognitive assessments and found significant p-values (<0.05) for MMSE, and Cog-1; this was not true for MoCA (0.083), and Cog-2 (0.902). Since the assumption of normality is broken for the majority of measures, non-parametric statistics were used. Due to the multifaceted nature of assessing cognition and dual-task gait, it would be improper to assume responses would be normally distributed in a diverse group of participants. It is therefore important to note that the following non-parametric statistics use a rank ordering system, where the absolute values are less significant than the ranking in the whole group. Comparisons are then made from those ranks.

3.3 Longitudinal Changes

Performance on the cognitive tests, and dual-task costs to gait were assessed longitudinally at three visit times approximately three months apart. Between visits, change in cognitive scores assessed using the Friedman Test found no statistically significant differences between visits (p-values: MMSE: 0.895; MoCA: 0.320; Cog-1: 0.513; Cog-2: 0.368) (Figure 1.). Dual-task cost changes between visits, also assessed with the Friedman Test, showed no statistically significant changes over time (all p-values >0.05). As previously mentioned, due to the lack of longitudinal changes, data between visits was pooled for the following statistical analyses. Wilcoxon-signed rank test found that all gait parameters were statistically different under dual-task conditions (p-values all <0.001). This indicates that the animal fluency dual-task is sufficient in eliciting a detrimental effect on gait.

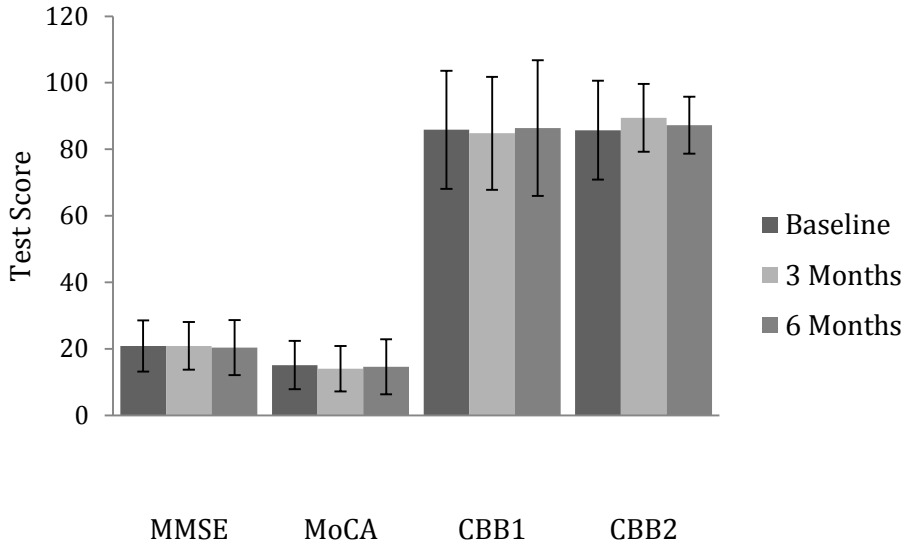

Figure 1. Test scores on the various cognitive assessments at baseline, 3 months, and 6 months (mean±SD). MMSE, Mini-Mental State Examination (/20); MoCA, Montreal Cognitive Assessment (/20); CBB1, Cogstate Brief Battery part 1 psychomotor function and attention (/200); CBB2, Cogstate Brief Battery part 2 learning and working memory (/200).

3.4 Pooled Dual-task Gait Costs

Descriptive statistics for the pooled dual-task costs to gait are provided for the examination of the group response to dual-tasking (Table 3.). Dual-task costs were calculated using the following formula for computing differences between normal gait (NG), and dual-task gait (DTG) for each participant, and each visit: ((DTG - NG) / NG) *100%. Modifications were made to the Cullen et al. (2018) equation so that directionality of

changes are represented through the sign of the dual-task costs; a negative represents a decrease in that gait parameter, while a positive represents an increase. Dual-task gait costs were not normally distributed with the exception of stride length. Minimum and maximum values provide the range of scores, exhibiting the variability of potential responses to dual-tasking; mean values and standard deviation are both influenced by these extremes. The range from 25th to 75th percentile shows the values in which half the participants lie between. Interquartile range, the difference between these numbers, provides an alternative method for examining distribution of the group's response to dual-tasking. Clinically, it may provide values for comparison to assess whether the gait dual-task costs are abnormal for a patient with AD.

Table 3.
Descriptive Statistics of Dual-task Costs to Gait

	Median	Mean	Std. Deviation	Minimum	Maximum	25th Percentile	75th Percentile
Stride Length	-9.5	-11.8	13.9	-53.6	11.4	-19.5	-3.3
Stride Time	14.6	47.9	121.0	2.4	802.1	7.0	36.9
Velocity	-24.9	-28.2	21.7	-95.4	5.6	-39.4	-13.2
Cadence	-12.8	-20.1	19.3	-88.7	-1.7	-27.0	-6.9
Stance Time	17.0	56.5	156.0	1.9	1056.6	9.7	37.8
Stance COP Path Efficiency	-2.0	-6.8	11.2	-59.9	2.3	-8.5	-0.5
CV Stride Length	36.1	104.1	257.5	-73.6	1163.6	-24.9	89.7
CV Stride Time	78.6	315.7	525.6	-79.6	1864.1	-5.9	314.2
CV Stride Velocity	39.9	145.5	287.1	-72.4	1376.4	-9.7	127.8
CV Stance Time	38.3	226.9	401.0	-76.2	1601.6	-7.7	249.7
CV Stance COP Path Efficiency	79.8	490.9	921.4	-89.0	4353.0	12.5	542.9

COP, centre of pressure; CV, coefficient of variation

3.5 Correlations between Cognitive Scores

Kendall's tau B was obtained for comparisons between cognitive scores, and is presented in Table 4. Mini-mental State Examination and MoCA scores were highly correlated (p-value <0.001). Both tests are global measures of cognition, and have been correlated previously (Nasreddine et al., 2005). Scores on the MMSE and MoCA were significantly correlated with scores on the CBB1, while only the MoCA was significantly correlated with the CBB2 scores; the MMSE did not quite reach significance in regards to the CBB2.

Unsurprisingly, both components of the CBB were significantly correlated with each other (p-value <0.001), likely due to the shared testing modality.

Table 4.
Cognitive Assessment Correlations

	MMSE		MoCA		CBB1		CBB2	
	Kendall		Kendall		Kendall		Kendall	
	Tau B	p	Tau B	p	Tau B	p	Tau B	p
MMSE	-	-						
MoCA	**0.740*** **	**< .001**	-	-				
CBB1	**0.218***	**0.042**	**0.217***	**0.043**	-	-		
CBB2	0.198	0.066	**0.241***	**0.025**	**0.405*** **	**< .001**	-	-

MMSE, Mini Mental State Examination; MoCA, Montreal Cognitive Assessment; CBB1, Cogstate Brief Battery Psychomotor Function and Attention; CBB2, Cogstate Brief Battery Learning and Working Memory

3.6 Correlations between Dual-task Gait Costs and Cognitive Scores

Kendall's tau-b were obtained to examine the relationship between cognitive scores and dual-task costs to gait, and are presented in Table 5, with bolded values representing significance at a p-value of <0.05. Dual-task costs to velocity were the only mean gait parameter that was concordant with scores on all the cognitive tasks. Other mean values were inconsistent. The MoCA was most highly correlated with mean gait measures of dual-task costs, almost reaching significance on stride length and stride time (p-values: 0.068, 0.053; respectively). Interestingly, the dual-task costs to CV gait measures were not concordant with any of the cognitive scores. Changes to stance centre of pressure path efficiency were also not significantly correlated with any cognitive scores.

Table 5. Correlations Between Cognitive Scores and Dual-task Costs to Gait

	MMSE		MoCA		CBB1		CBB2	
	Kendall		Kendall		Kendall		Kendall	
	Tau B	p	Tau B	p	Tau B	p	Tau B	p
Mean								
Stride Length	0.160	0.101	0.178	0.068	0.153	0.148	**0.230***	**0.029**
Stride Time	-0.129	0.186	-0.189	0.053	-0.069	0.510	-0.134	0.205
Velocity	**0.199***	**0.042**	**0.274****	**0.005**	**0.210***	**0.046**	**0.260***	**0.014**
Cadence	0.148	0.130	**0.195***	**0.046**	0.086	0.412	0.136	0.198
Stance Time	-0.154	0.115	**-0.234***	**0.017**	-0.131	0.213	-0.177	0.095
Stance COP Path Efficiency	0.159	0.104	0.121	0.217	0.108	0.306	0.102	0.336
Coefficient of Variation								
Stride Length	-0.084	0.388	-0.132	0.178	-0.001	0.992	-0.168	0.112
Stride Time	0.005	0.956	-0.026	0.788	-0.037	0.723	-0.08	0.447
Stride Velocity	-0.116	0.238	-0.121	0.217	-0.067	0.524	-0.196	0.064
Stance Time	0.010	0.918	-0.019	0.849	-0.044	0.678	-0.063	0.550
Stance COP Path Efficiency	-0.049	0.618	-0.039	0.692	0.071	0.498	0.031	0.769

COP, centre of pressure; MMSE, Mini Mental State Examination; MoCA, Montreal Cognitive Assessmer
CBB1, Cogstate Brief Battery Psychomotor Function and Attention; CBB2, Cogstate Brief Battery Learni
and Working Memory. * p-value <0.05; ** p-value < 0.01

4. Discussion

4.1 Cognition Results

At baseline, MMSE scores of the participants are diverse with a minimum score of 5/30, and a maximum score of 30/30. Based on cognitive scores alone, some participants would not be classified as cognitively impaired. Even in those who performed adequately on the cognitive assessments, neurological changes due to AD were supported by all participants showing large performance deficits while dual-tasking, and dual-task performance was consistent with what is expected in a group of participants with dementia (see section 4.2). The value of more stringent criteria for assessing dementia was supported by Shiroky et al. (2007), where they showed that normal scores on the MMSE may not guarantee an absence of dementia. A possible explanation for the high MMSE scores is the compensatory effect of cognitive reserve counteracting the noticeability of cognitive decline associated with AD. As previously discussed, cognitive reserve is highly related to years of education, and the vast majority of participants (14/18) had a post-secondary education. The magnitude in which cognitive reserve compensated for neurocognitive decline is challenging since it is dependent on both lifestyle factors that improve reserve, balanced against the extent of neuropathological degradation.

Our baseline cognition results further support the use of MoCA over MMSE as a diagnostic tool, as none of the participants performed within normal ranges on that test. The higher sensitivity of the MoCA is likely due to the increased difficulty of the MoCA in comparison to the MMSE (Nasreddine et al., 2005). The CBB was used as another tool for the assessment of cognitive function, and incorporated psychomotor function, attention, learning, and working memory. The results for the CBB (both components) showed mixed results as the average performance on both assessments bordered on the ‘borderline’ to ‘normal’ categories. Therefore, like the MMSE, The CBB may be useful for the assessment of cognitive impairment associated with AD only when paired with other tools, as both may have sensitivity issues detecting cognitive impairment as standalone tools in the milder/earlier stages of the disease in some participants.

4.2 Gait Measures

Results for the gait parameters associated with pace, were similar with those of previous studies for: stride length (Gillain et al., 2009), velocity (Gillain et al., 2009; Muir et al., 2012), and stride time (Muir et al., 2012). Although our participants performed similarly to those of Muir et al. (2012) in regards to pace, our participants were less consistent with their single and dual-task stride time, shown through larger CVs. Contradictory findings of Ijmker et al. (2012), found their group of dementia participants were much slower overall, and inconsistent in their single-task gait, compared with our findings. Compared to a review by Moon et al., (2016), participants in our study were more variable in their CV of stride length and stride time. These past findings highlight some of the consistencies/inconsistencies that appear to be largely dependent on the individual gait

characteristics of the participants recruited. Even amongst participants with the same underlying neuropathological diagnosis, participants perform differently between studies making group comparisons between studies inconsistent.

When examining the effect of a dual-task paradigm, it may then be beneficial to consider the purpose of the assessment to help determine the measures of value. For example, studies assessing the impact of a dual-task on an individual's gait and comparing this to others, then dual-task costs may provide comparable data that is wholly dependent on how the secondary verbal task influences gait, independent of the participants initial gait parameters. However, if the purpose is to determine if, while dual-tasking, an individual's gait is impaired to a level in which their gait parameters indicate a higher risk of falls, or comparison of gait between diseases, then absolute values for each gait parameter should be used. Since the primary purpose of this study is comparing the effect of dual-tasking between participants at varying cognitive states, dual-task costs are most applicable.

The pooled comparisons of dual-task costs on varying gait measures are reported in Table 3. Examination of the data shows that extreme levels of poor dual-task performance relative to normal walking are reflected more through temporal measures of pace, rather than spatial. Examining the temporal measures of stride time and stance time, both showed much higher standard deviations than the spatial measures of pace, stride time (121.0% and 156.0% for stride time and stance time respectively; 13.9% for stride length). The interquartile ranges do not reflect this larger deviation. What can be inferred from this relationship is that there is a large effect of outliers skewing the sample standard deviation higher. The effect of extreme temporal dual-task costs is also shown through the large discrepancy between mean and median values (shown in Figure 2.). This discrepancy is due to mean values being affected by outliers, while median values are not. The maximum values provided in Table 3. Highlight the extent to which temporal measures of gait may be influenced by a dual-task. While the median dual-task increase for a parameter like stride time may be approximately 14.6%, values can reach as high as 802.1% (an over 8x increase in stride time). The spatial measure of pace, stride length, is relatively consistent, represented through a comparably lower standard deviation (this can be seen in Figure 3.). In addition, relative consistency between interquartile range and standard deviations supports the idea that participants that fall outside the interquartile range do not differ hugely spatially. Practically speaking, spatial measures of gait would have been insufficient in showing the magnitude of the negative effect of dual-tasking on gait in some participants. Measures that incorporate both spatial and temporal components like velocity provide a more general picture of dual-task costs to gait, but fail to isolate individual components that constitute that global change. The idea that dual-task gait costs for parameters like velocity may not be specific enough to discriminate subtle changes to neurological impairment are not a new finding (Cadore et al., 2015; Cedervall et al., 2014). Due to the heterogeneity of participants in this study it would be expected that dual-task costs would reflect that diversity.

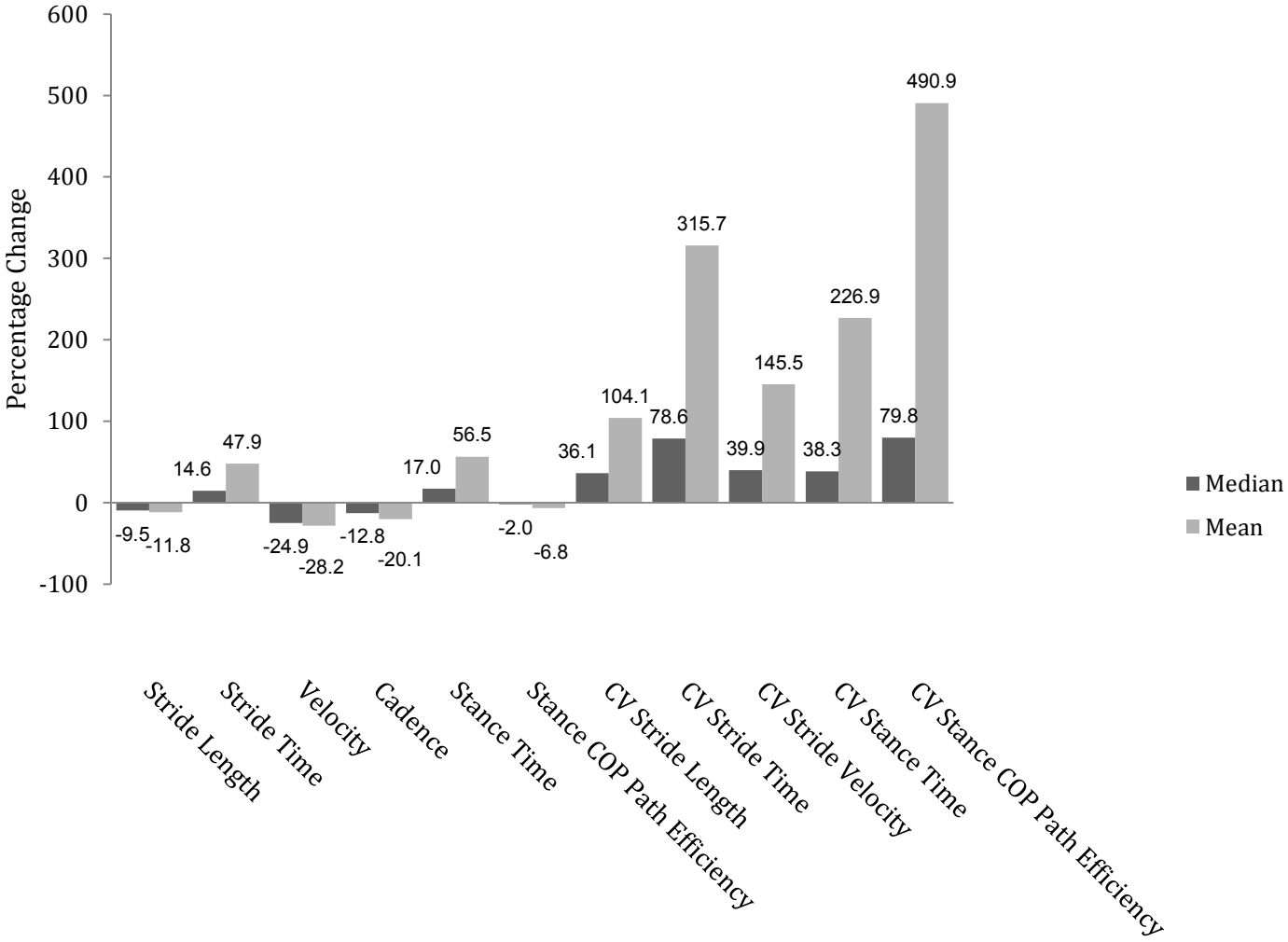

Figure 2. Mean and median pooled dual-task costs to gait (%), due to animal fluency dual-tasking. CV, coefficient of variation; COP, centre of pressure.

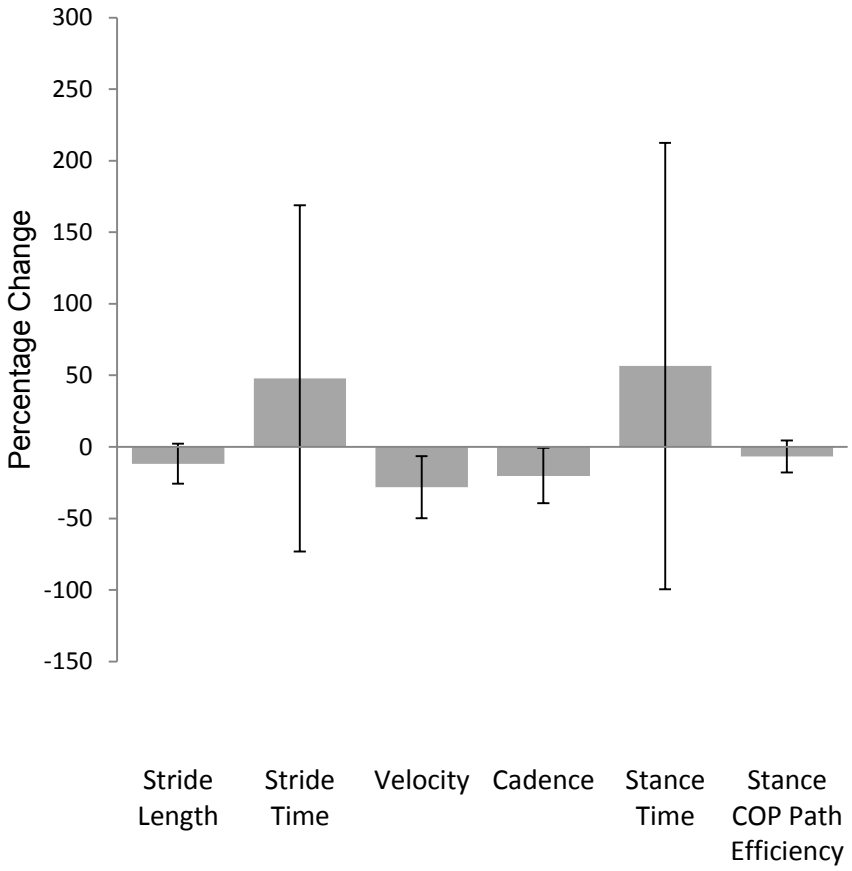

Figure 3. Pooled dual-task costs to gait (%), due to animal fluency dual-tasking (mean±SD). COP, centre of pressure.

Stance centre of pressure path efficiency as a dynamic measure of posture seems to provide information that may not be easily observable, but potentially clinically relevant in the prediction of falls. The majority of participants became less efficient, and therefore, more unsteady during the stance phase of gait while dual-tasking. The extent to which dynamic balance can be affected is shown through the 59.9% decrease in the COP path efficiency of one participant. Further research is needed to draw any conclusions to what magnitude of decrease may be clinically relevant for determining fall risk.

A diverse response to changes to CV gait parameters under dual-task demands is supported by findings showing varying levels of impairment to gait consistency with different neurological diseases (Montero-Odasso et al., 2012). Gait variability is associated with neuromotor diseases that affect the basal ganglia like Parkinson's disease (PD), and Huntington's disease (HD) (Hausdorff et al., 1998; Moon et al., 2016). Comparing data from our study with that of Hausdorff et al. (1998) we found that our group of AD participants had more stride time variability than their healthy controls, but performed slightly better than the PD and HD patients during single-task gait. However, the addition of a dual-task led to performance similar to those

patients with HD. This is important in showing how, although AD is not commonly characterised as a motor disorder, the neurological impairment associated with the disease results in gait variability characteristic of neuromotor disorders like HD while completing a concurrent verbal dual-task. Findings from these studies support the idea that variability of gait provides a measure of the detrimental effect of dual-tasking that is independent of mean values, which could imply consistency of gait requiring more cognitive or attentional resources. In this study changes to gait consistency are presented behaviourally as participants slowing down, or stopping, while trying to complete the dual-task only to suddenly speed up once they remember, and say, a random animal. These unique behaviours may be lost by mean gait parameter values. The link between gait consistency and cognition is further supported through previous research by Hausdorff et al. (2005) where the authors found that stride time variability is more highly correlated with catching (the authors' choice of executive function task) than tapping (a simple motor task with little cognitive involvement). Measures like step variability even in a group of participants with mild cognitive impairment may reflect the heterogeneity of that group (König et al., 2017). The authors reported that the AD participants in their study had much higher variability in step variance, although this was not elaborated on. Our study found a similar result to previous research finding that dual-tasking impairs not all gait parameters equally with the effect on stride-to-stride variability being higher than that on gait speed (Sheridan et al., 2003). Therefore, consistency of gait appears more influenced by dual-tasking than pace, and may therefore provide a better measure of the link between cognition and gait. Figure 4. Highlights mean dual-task costs to gait variability, while also visually depicting between participant variability.

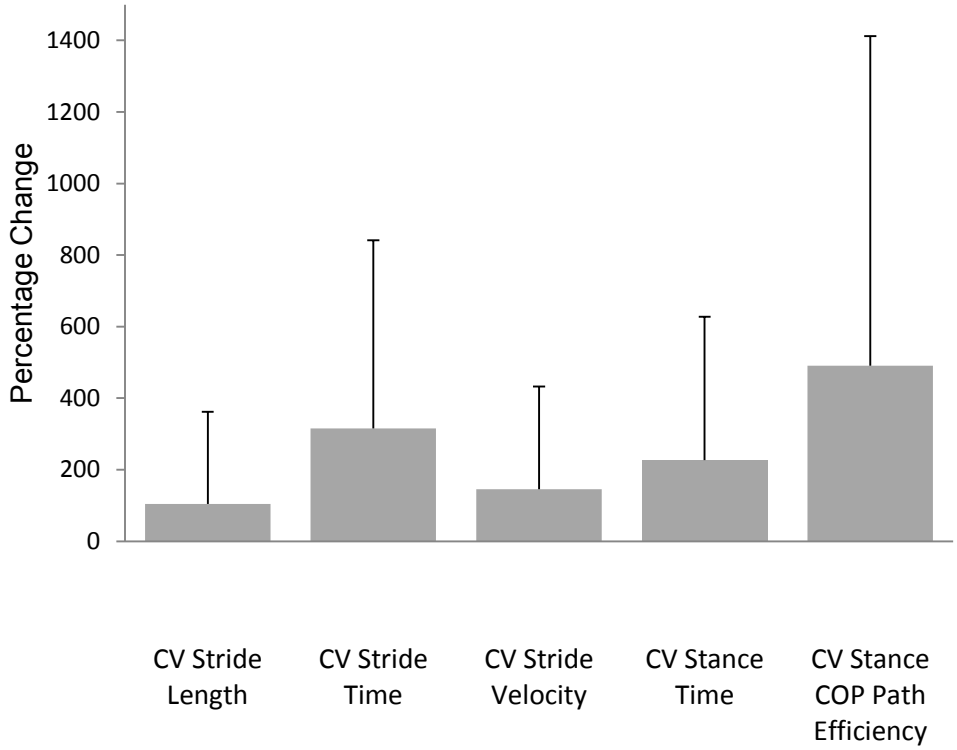

Figure 4. Pooled dual-task costs to gait (%) for coefficient of variation (CV) parameters, due to animal fluency dual-tasking (mean±SD). COP, centre of pressure.

4.3 Changes to gait and cognition

Findings from this study showed that both dual-task gait costs and cognition did not change a statistically significant amount over the course of 6 months. The two most probable explanations are either: the participants remained cognitively stable over the timeframe, or the assessment tools were insufficient in detecting changes over time. The latter explanation would not necessarily be surprising for tools like the MMSE as they may only detect meaningful declines to test scores after at least 3 to 4 years (Clark et al., 1999). MMSE appears to be an unreliable tool for monitoring changes to cognition over time, as even while other cognitive measures detect meaningful changes, the MMSE may not be sensitive enough to detect these changes (Carlew, et al., 2020). Since the MoCA and CBB scores were relatively consistent across the 6 month time period, it can be presumed that within that timeframe cognition did not change significantly.

One purpose of this study was to determine if any dual-task gait measures may be more sensitive to small longitudinal changes associated with disease progression. Unfortunately, none of the dual-task cost gait measures used in this study found a significant change over time. Similarly to the cognitive tests, dual-task costs may not be sensitive enough to notice small changes, or participants did not change a significant amount throughout the study duration.

4.4 Correlations between Cognitive Tests

Correlations between the various cognitive tests show correlations between all the tests with the exception of MMSE and CBB2 (see table 4.). Although this did not reach significance, the p-value was still low at 0.066. As expected, the MMSE and MoCA were incredibly highly correlated. Since both test global cognitive function in a similar method, it would be surprising to see insignificant correlations. The strength of the correlation was nearly identical for the MMSE and MoCA with the CBB1, showing that both global cognitive tests have a significant relationship with a basic test of psychomotor function and attention. The insignificant correlation between the MMSE and CBB2 likely relates back to task difficulty. The MMSE is the easier of the global cognitive tests while the CBB2 is the more difficult of the CBB tests. Task difficulty discrepancy could explain the weaker correlation. Participants may have performed better on the MMSE due to cognitive reserve compensation, while the CBB2 may have been too taxing for cognitive reserve to compensate. This would also explain why the MoCA and CBB2 reached significance, due to them both being the more challenging tasks. The high correlation between CBB1 and CBB2 is not surprising as both are subcomponents of the CBB, and therefore are tested using the same modality.

4.5 Correlations between DTC and cognition

An important area of discussion regarding correlations is the choice of statistical analysis used. The relationship between dual-task costs and cognition has been done using Spearman correlation coefficients to test for the relationship between the two measures (Sheridan et al., 2003). It is important to note that Spearman and Kendall's correlations do not assume linearity of a relationship, unlike Pearson's correlation. It has already been discussed that cognition, as assessed with a cognitive assessment, does not necessarily decline in a linear way, and assumptions should not be made that dual-task costs to gait will line up linearly with cognitive results. Statistical significance is assessed using parametric statistics when normality in gait parameter and cognitive score distributions is observed as has been the case in some previous studies (Cedervall, et al., 2014), or nonparametric statistics in the absence of normality (Ijmker & Lamoth, 2012). Initial examination of the data in our study did not support normality in distributions. Comparing our study with others, our group of patients was much more cognitively diverse as shown through the diversity and range in MMSE scores. It's important to note that studies involving AD limit recruitment to those diagnosed with probable AD, while still being able to complete all the testing procedures, which can be difficult if the tasks are complex. Likely this leads to those with more severe AD being excluded from studies with high task demands, or difficult to understand instructions. Those with milder AD may be excluded from studies that use more stringent criteria

on the diagnosis of probable AD, leading them to being excluded in the earlier stages of their disease. Future studies should aim to be as inclusive as possible and use nonparametric statistics when necessary.

A primary purpose of this study was to explore the relationship between cognitive scores on 4 different tests and dual-task gait costs. Dual-task costs to stride length, the spatial measure of pace, was only correlated with the CBB2. The CBB2 tests working memory and learning so would be expected to correlate with dual-task performance. The rationale for why stride length in particular only correlated with the CBB2 remains unclear, but as previously discussed, spatial measures of pace seem less sensitive to dual-task impairments than the temporal measures.

Temporal measures of pace like stride time, stance time, and cadence were not significantly correlated with any of the cognitive measures with the exception of the MoCA correlating with stance time, and cadence. The MoCA nearly reached statistical significance with stride time (p-value: 0.053). Temporal measures seem most susceptible to dual-task demands, but this relationship is not reflected by comparing with cognitive scores. Based on the results, a more challenging test of global cognition, like the MoCA, may provide better information on temporal specific changes due to dual-tasking. It can be hypothesised that temporal changes to pace reflect a more global decline in cognition not adequately tested with the MMSE or CBB.

Velocity was the only gait parameter significantly correlated with all the cognitive tests. Since velocity incorporates spatial and temporal components it gives a general measure of gait. Dual-task costs to gait speed appear related to performance on all the cognitive assessments used in this study, showing that impairment to gaiy velocity can be inferred by performance on a cognitive assessment. Velocity as a measure does not elucidate the specific subcomponents of the gait cycle that are impaired, making it insufficient in explaining how dual-tasking impairs gait in AD. The MoCA reached a higher level of significance for mean velocity than the other cognitive assessments, further reinforcing its value.

Dual-task costs to dynamic posture were not significantly correlated with any of the cognitive assessments used in this study. Unsteadiness during the stance phase of gait represents a potential risk factor for falls, which appears independent of how participants perform on cognitive assessments. Likely, this is due to stance centre of pressure path efficiency being affected by stance time, and stance consistency. Since changes to measures of consistency and stance time are not highly correlated with cognitive tests, it follows that stance centre of pressure path efficiency would share that pattern. Due to its potential value, when possible, a measure of dynamic balance should be included as it may provide valuable insight into neurocognitive changes to motor control that are not easily predictable with cognitive assessments.

Gait consistency was assessed using coefficients of variation. None of the measures of coefficient of variation correlated significantly with the cognitive assessments. Consistency of gait provides insight into slowing down or freezing during the gait cycle. As previously discussed, these measures, are important in determining fall risk, one of the leading causes of hospitalisation in Canada (Hausdorff, 2005; Lundin-Olsson et al., 1997;

Springer et al., 2006; Svoboda, et al., 2017).The lack of correlations for consistency implies little to no relationship between the two variables. Logically those who perform worse on a cognitive test would be more variable in their dual-task gait. The discordance between the two variables implies an unreliable relationship, practically, that cognitive assessments provide little to no information on how much variability in gait increases while dual-tasking.

Although some gait parameters were correlated with cognition, these findings were not consistent across all gait parameters, especially variability. There is a high likelihood that cognitive reserve compensated for cognitive deficits in a large majority of study participants resulting in higher scores on those assessments. As previously mentioned, cognitive reserve is largely impacted by the level of education, and the majority of participants (14/18) had a post-secondary education. When dual-tasking, cognitive and attentional demands may exceed any compensation provided by cognitive reserve, resulting in large performance deficits despite acceptable performance on a cognitive assessment. The higher correlations found with the MoCA compared to the MMSE may be indicative of how task difficulty may negate benefits of cognitive reserve. Interestingly, the CBB2 was more correlated with dual-task costs to gait than CBB1 for most measures. Since the CBB2 focused on working memory and learning, this provides support to the previously discussed link between working memory, learning, and dual-tasking, more so than psychomotor function, and attention. Overall, dual-tasking appears to be a highly complex task requiring global cognitive function. Tests like the MoCA that more strenuously task global cognition may be the most appropriate tools for predicting dual-task detriments. Even still, these tests are insufficient in explaining gait variability.

5. Conclusions

5.1 Cognition

Cognition as assessed with our tools did not change significantly over the 6 month course of this study. Performance on the selected cognitive assessments showed mixed results, with MoCA being the most sensitive to cognitive impairment. Cognitive assessments may be highly influenced by cognitive reserve, so may not accurately represent the extent of neuropathological impairment, if the task is too easy.

5.2 Gait

Gait can be highly variable even amongst those diagnosed with the same underlying neuropathologies. When examining the effect that dual-tasking has on motor performance, it may be beneficial to exclusively use dual-task costs, a measure of percentage change to gait, for comparisons. By examining percentage change,

individual baseline gait characteristics are accounted for, resulting in a more isolated examination of how secondary task demands alter the primary motor task, providing a clearer picture of the extent to which cognitive impairment and neuropathologies alter dual-tasking along the progression spectrum.

When possible, measures of gait should include subcomponents of pace, consistency, and posture. Pace should incorporate both spatial and temporal components. Temporal measures of pace were much more sensitive in identifying extremely poor dual-task performance than the spatial measures. Gait consistency may provide the most valuable information on the extent to which dual-tasking interferes with the motor control of gait.

5.3 Correlations

Correlations between dual-task costs and cognitive scores are inconsistent. The MoCA is most highly correlated with dual-task costs making it a useful tool to predict dual-task gait performance in the absence of proper tools to assess gait. However, dual-task costs to gait variability are not adequately explained by cognitive scores, suggesting that dual-task walking tests an area not covered by the cognitive tests used in this study.

5.4 Recommendations for future research

Future research using a dual-task with a verbal component where performance is variable (i.e. number of successful subtractions, or number of animals listed), should describe performance on the verbal component should be discussed as a rate of correct subtractions, or number of animals, per second. This allows data to be compared between studies with variable walking distances. When absolute values are used to quantify performance on the verbal task, performance may be inflated by those with slow gait, allowing them more time to complete the verbal component making it appear as though they performed better where in fact it is just a result of their slow gait. This can also be counteracted by using a dual-task where the verbal component is controlled for rate; in the field of motor learning this has been done by using a metronome set at 60bpm and having participants say random letters of the alphabet in time to metronome clicks. In this scenario attention is still divided, but performance on the verbal component is controlled, making gait outcomes the only dependent variable.

Further research should explore more thoroughly some of the gait parameters used in this study. The underlying reason why measures of consistency and dynamic balance are incongruent with cognitive scores needs to be further investigated as these measures are associated with fall risk. These measures should be used as they provide more objective measures

One of the potential limitations of studies using dual-task paradigms is the variability in the secondary cognitive task. It has been suggested that the cognitive dual-task should challenge the underlying neuropathological process; in the case of AD, using a dual-task that targets frontal inhibitory control (Belghali et al., 2017b). At the time of data collection three different dual-tasks were used: serial subtractions from 100 by 1's; animal fluency; and serial subtractions by 7's. The more cognitively impaired study participants were unable to do the serial subtraction dual-tasks, but all were able to complete the animal fluency dual-task. Unfortunately, due to the heterogeneity of this population some participants will be unable to perform certain tasks.

5.5 Summary

Alzheimer 's disease is a neurological disease that affects cognitive function including executive functions. Executive functions are required in goal-oriented actions like walking, and become even more important when attention becomes divided, or working memory is utilised. Many activities of daily living require the dividing of attention between two tasks. Examining dual-tasking performance may therefore provide insight into how people may perform while performing two concurrent tasks in everyday life. Measures of dual-task costs to gait provide insight into the extent to which patients with AD gait may be impaired while distracted, which may be valuable for predicting fall risk, or disorientation, two negative behavioural outcomes associated with AD. The established link between executive function and negative behaviours like disinhibition provide another potential avenue of exploration, as dual-tasking might be a valuable tool to test for this behaviour. The cognitive tests used in this study provide some insight into how gait may be impaired while dual-tasking (most so with the MoCA), but many of the changes to gait are not correlated with cognitive scores. The most noticeable difference is through the discordance between cognitive scores and coefficient of variation. Coefficient of variation is a measure of gait variability/consistency, which are the primary predictors of falling. Discordance between these measures supports the idea that one may not necessarily predict the other. Clinically, dual-task assessments may provide insight into fall risk independent of cognitive scores. This study supports the more frequent use of dual-tasking as an additional measure on top of typical cognitive assessments for a more holistic understanding of cognitive state and fall risk.

Tables.

Table 1.

Baseline characteristics of participants	Value
Age (years), mean ±SD	73 ± 9.6
Female, *n* (%)	8 (44.4)
Post-Secondary Education, *n* (%)	14 (77.8)
Mini-Mental State Examination (MMSE) mean score /30 ± SD	20.8 ± 7.7
Montreal Cognitive Assessment (MoCA) mean score /30 ± SD	15.1 ± 7.3
CBB1 mean score /200 ± SD	85.9 ± 17.8
CBB2 mean score /200 ± SD	85.7 ± 14.9

CBB1, Cogstate Brief Battery part 1 psychomotor function and attention; CBB2, Cogstate Brief Battery part 2 learning and working memory

Table 2.
Baseline gait performance during single and dual-task (mean ± S.D).

Gait parameters ±SD	Single-task	Dual-task
Mean		
Stride Length (cm.)	118.5 ± 26.7	107.2 ± 33.8
Stride Time (sec.)	1.1 ± 0.2	1.8 ± 2.1
Velocity (cm./sec.)	107.4 ± 25.6	79.2 ± 32.6
Cadence (steps/min.)	108.4 ± 13.8	87.2 ± 26.9
Stance Time (sec.)	0.8 ± 0.1	1.4 ± 1.8
Stance COP Path Efficiency (%)	96.0 ± 1.3	88.2 ± 14.2
Coefficient of Variation		
Stride Length (%)	5.3 ± 2.5	8.6 ± 7.7
Stride Time (%)	3.8 ± 1.7	12.3 ± 15.2
Stride Velocity (%)	7.2 ± 2.6	14.7 ± 16.0
Stance Time (%)	5.8 ± 1.7	16.0 ± 18.5
Stance COP Path Efficiency (%)	3.1 ± 2.9	10.7 ± 12.8

COP, centre of pressure

Table 3.
Descriptive Statistics of Dual-task Costs to Gait

	Median	Mean	Std. Deviation	Minimum	Maximum	25th Percentile	75th Percentile
Stride Length	-9.5	-11.8	13.9	-53.6	11.4	-19.5	-3.3
Stride Time	14.6	47.9	121.0	2.4	802.1	7.0	36.9
Velocity	-24.9	-28.2	21.7	-95.4	5.6	-39.4	-13.2
Cadence	-12.8	-20.1	19.3	-88.7	-1.7	-27.0	-6.9
Stance Time	17.0	56.5	156.0	1.9	1056.6	9.7	37.8
Stance COP Path Efficiency	-2.0	-6.8	11.2	-59.9	2.3	-8.5	-0.5
CV Stride Length	36.1	104.1	257.5	-73.6	1163.6	-24.9	89.7
CV Stride Time	78.6	315.7	525.6	-79.6	1864.1	-5.9	314.2
CV Stride Velocity	39.9	145.5	287.1	-72.4	1376.4	-9.7	127.8
CV Stance Time	38.3	226.9	401.0	-76.2	1601.6	-7.7	249.7
CV Stance COP Path Efficiency	79.8	490.9	921.4	-89.0	4353.0	12.5	542.9

COP, centre of pressure; CV, coefficient of variation

Table 4.
Cognitive Assessment Correlations

	MMSE		MoCA		CBB1		CBB2	
	Kendall		Kendall		Kendall		Kendall	
	Tau B	p	Tau B	p	Tau B	p	Tau B	p
MMSE	-	-						
MoCA	**0.740*** **	**< .001**	-	-				
CBB1	**0.218***	**0.042**	**0.217***	**0.043**	-	-		
CBB2	0.198	0.066	**0.241***	**0.025**	**0.405*** **	**< .001**	-	-

MMSE, Mini Mental State Examination; MoCA, Montreal Cognitive Assessment; CBB1, Cogstate Brief Battery Psychomotor Function and Attention; CBB2, Cogstate Brief Battery Learning and Working Memory

Table 5. Correlations Between Cognitive Scores and Dual-task Costs to Gait

	MMSE		MoCA		CBB1		CBB2	
	Kendall		Kendall		Kendall		Kendall	
	Tau B	p	Tau B	p	Tau B	p	Tau B	p
Mean								
Stride Length	0.160	0.101	0.178	0.068	0.153	0.148	**0.230***	**0.029**
Stride Time	-0.129	0.186	-0.189	0.053	-0.069	0.510	-0.134	0.205
Velocity	**0.199***	**0.042**	**0.274****	**0.005**	**0.210***	**0.046**	**0.260***	**0.014**
Cadence	0.148	0.130	**0.195***	**0.046**	0.086	0.412	0.136	0.198
Stance Time	-0.154	0.115	**-0.234***	**0.017**	-0.131	0.213	-0.177	0.095
Stance COP Path Efficiency	0.159	0.104	0.121	0.217	0.108	0.306	0.102	0.336
Coefficient of Variation								
Stride Length	-0.084	0.388	-0.132	0.178	-0.001	0.992	-0.168	0.112
Stride Time	0.005	0.956	-0.026	0.788	-0.037	0.723	-0.08	0.447
Stride Velocity	-0.116	0.238	-0.121	0.217	-0.067	0.524	-0.196	0.064
Stance Time	0.010	0.918	-0.019	0.849	-0.044	0.678	-0.063	0.550
Stance COP Path Efficiency	-0.049	0.618	-0.039	0.692	0.071	0.498	0.031	0.769

COP, centre of pressure; MMSE, Mini Mental State Examination; MoCA, Montreal Cognitive Assessmer
CBB1, Cogstate Brief Battery Psychomotor Function and Attention; CBB2, Cogstate Brief Battery Learni
and Working Memory. * p-value <0.05; ** p-value < 0.01

Figures.

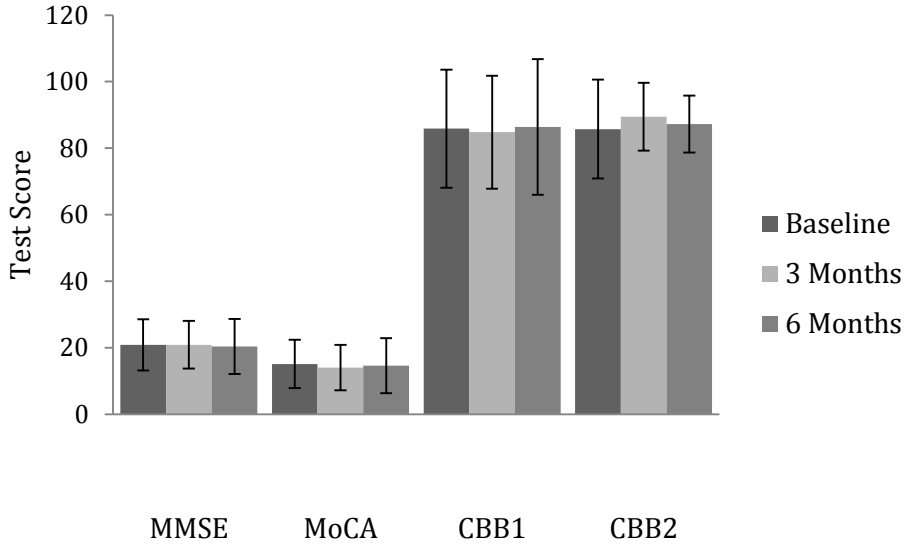

Figure 1. Test scores on the various cognitive assessments at baseline, 3 months, and 6 months (mean±SD). MMSE, Mini-Mental State Examination (/20); MoCA, Montreal Cognitive Assessment (/20); CBB1, Cogstate Brief Battery part 1 psychomotor function and attention (/200); CBB2, Cogstate Brief Battery part 2 learning and working memory (/200).

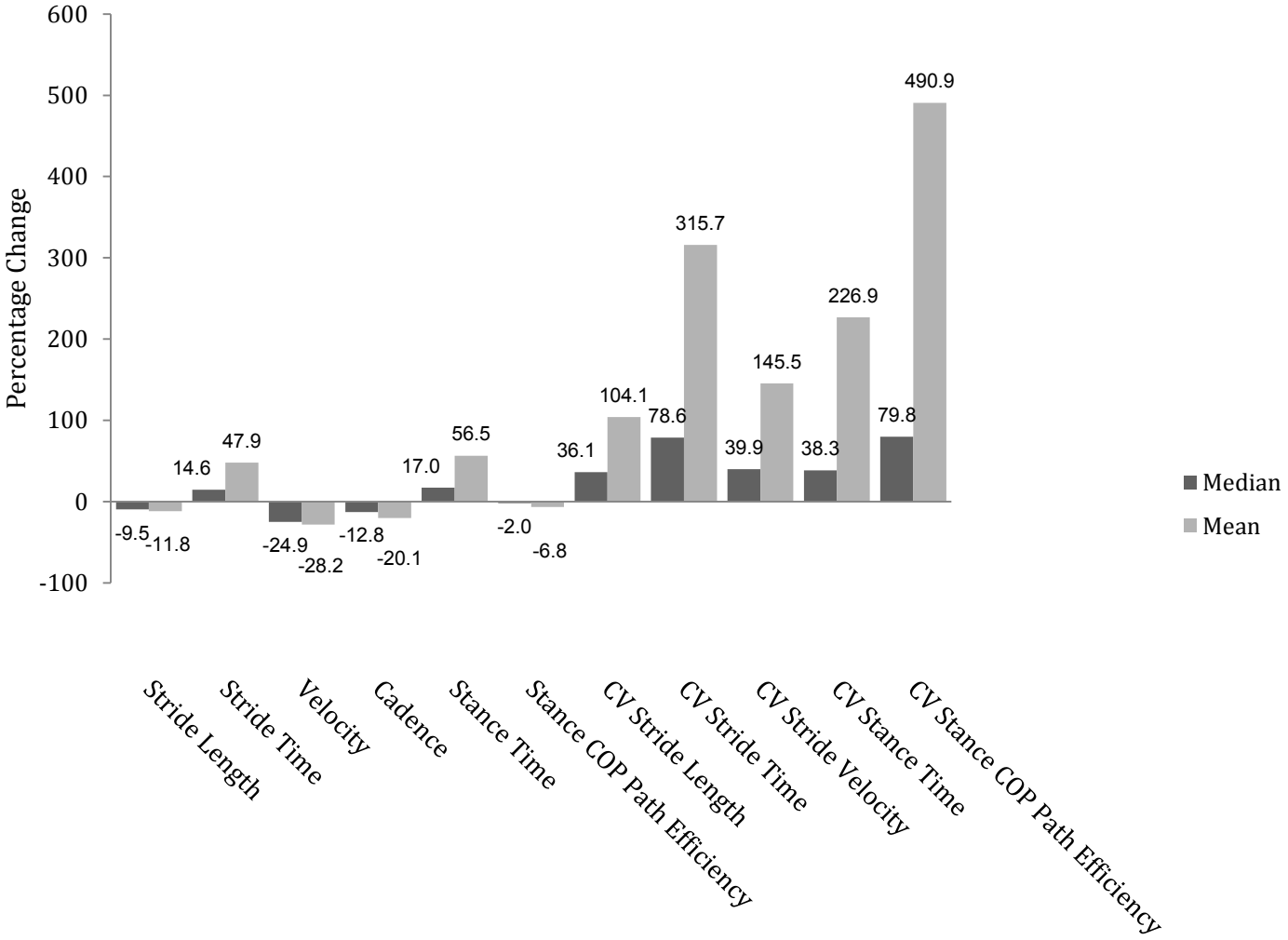

Figure 2. Mean and median pooled dual-task costs to gait (%), due to animal fluency dual-tasking. CV, coefficient of variation; COP, centre of pressure.

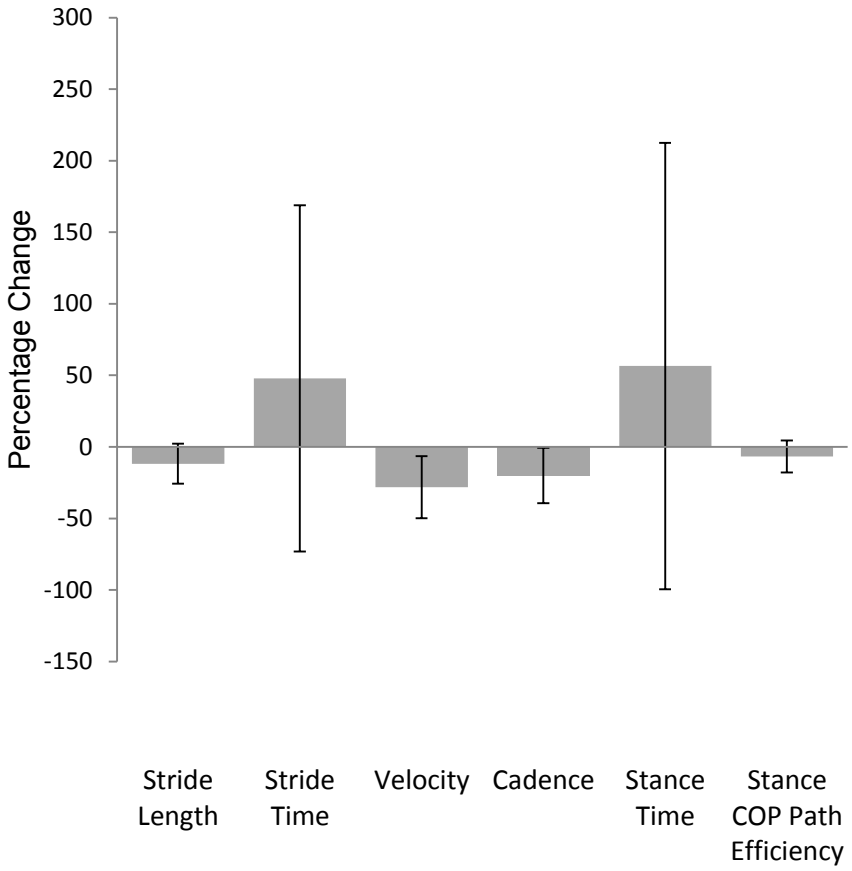

Figure 3. Pooled dual-task costs to gait (%), due to animal fluency dual-tasking (mean±SD). COP, centre of pressure.

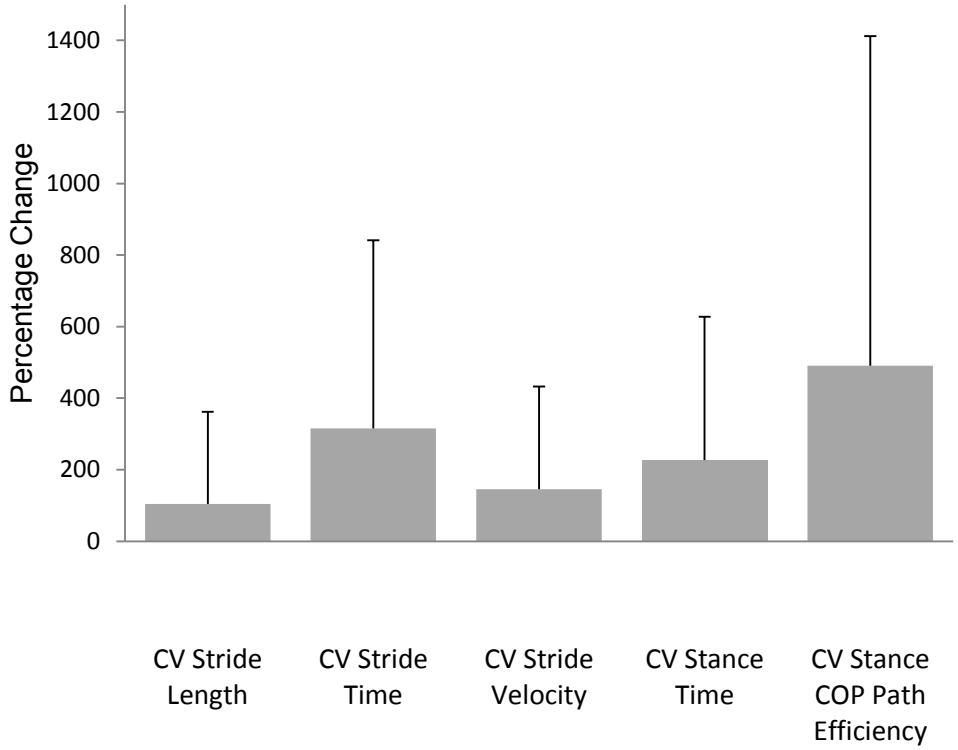

Figure 4. Pooled dual-task costs to gait (%) for coefficient of variation (CV) parameters, due to animal fluency dual-tasking (mean±SD). COP, centre of pressure.

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Appendix A: Mini-Mental State Examination (MMSE)

Mini-Mental State Examination (MMSE)

Patient's Name: Date: ***Instructions: Score one point for each correct response within each question or activity.***

Maximum Score	Patient's Score	ons
5		s the year? Season? Date? Day? Month?"
5		are we now? State? County? Town/city? Hospital? Floor?"
3		aminer names three unrelated objects clearly and slowly, then the instructor a ent to name all three of them. The patient's response is used for scoring. The er repeats them until patient learns all of them, if possible.
5		l like you to count backward from 100 by sevens." (93, 86, 79, 72, 65, …) tive: "Spell WORLD backwards." (D-L-R-O-W)
3		I told you the names of three things. Can you tell me what those were?"
2		ne patient two simple objects, such as a wristwatch and a pencil, and ask the to name them.
1		t the phrase: 'No ifs, ands, or buts.'"
3		ne paper in your right hand, fold it in half, and put it on the floor." (The exami ne patient a piece of blank paper.)
1		read this and do what it says." (Written instruction is "Close your eyes.")
1		up and write a sentence about anything." (This sentence must contain a noun

1		copy this picture." (The examiner gives the patient a blank piece of paper ar to draw the symbol below. All 10 angles must be present and two must inter
30		

Interpretation of the MMSE:

Method	Score	retation
Single Cutoff	<24	mal
Range	<21 >25	sed odds of dementia ased odds of dementia
Education	21 <23 <24	nal for 8th grade education nal for high school education nal for college education
Severity	24-30 18-23 0-17	gnitive impairment gnitive impairment cognitive impairment

Interpretation of MMSE Scores:

Score	Degree of Impairment	l Psychometric sment	-Day Functioning
25-30	Questionably significant	l signs of cognitive impairment are pre assessment of cognition may be valua	ve clinically significant but mild deficits o affect only most demanding activities ing.
20-25	Mild	assessment may be helpful to ne pattern and extent of deficits.	ant effect. May require some supervisi and assistance.

10-20	Moderate	assessment may be helpful if there ar clinical indications.	pairment. May require 24-hour super
0-10	Severe	not likely to be testable.	impairment. Likely to require 24-hour sion and assistance with ADL.

Source:

• Folstein MF, Folstein SE, McHugh PR: “Mini-mental state: A practical method for grading the cognitive state of patients for the clinician.” *J Psychiatr Res* 1975;12:189-198.

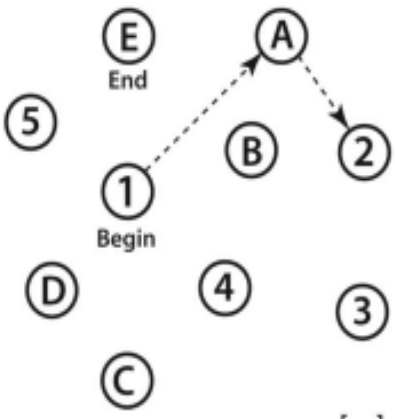
Appendix B: Montreal Cognitive Assessment (MoCA)

MONTREAL COGNITIVE ASSESSMENT (MOCA)

Version 7.1 Original Version

NAME :
Education : Date of birth :
Sex : DATE :

VISUOSPATIAL / EXECUTIVE



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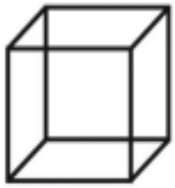

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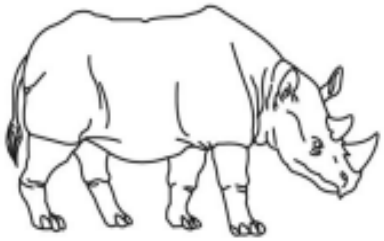
Draw CLOCK (Ten past eleven)
(3 points)

[ ] Contour [ ] Numbers [ ] Hands

POINTS __/5

NAMING

[ ]



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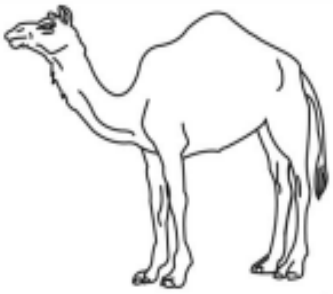

[ ]

__/3

MEMORY

Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful. Do a recall after 5 minutes.

	FACE	VELVET	CHURCH	DAISY	RED
1st trial					
2nd trial					

No points

ATTENTION

Read list of digits (1 digit/ sec.).

Subject has to repeat them in the forward order [ ] 2 1 8 5 4

Subject has to repeat them in the backward order [ ] 7 4 2

__/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors

[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B

__/1

Serial 7 subtraction starting at 100 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65

4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt**

__/3

LANGUAGE

Repeat : I only know that John is the one to help today. [ ]

The cat always hid under the couch when dogs were in the room. [ ]

__/2

Fluency / Name maximum number of words in one minute that begin with the letter F [ ] _____ (N ≥ 11 words)

__/1

ABSTRACTION

Similarity between e.g. banana - orange = fruit [ ] train – bicycle [ ] watch - ruler

__/2

DELAYED RECALL

	Has to recall words WITH NO CUE	FACE [ ]	VELVET [ ]	CHURCH [ ]	DAISY [ ]	RED [ ]	Points for UNCUED recall only
Optional	Category cue						
	Multiple choice cue						

__/5

ORIENTATION

[ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City

__/6

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Normal ≥ 26 / 30

TOTAL __/30

Add 1 point if ≤ 12 yr edu

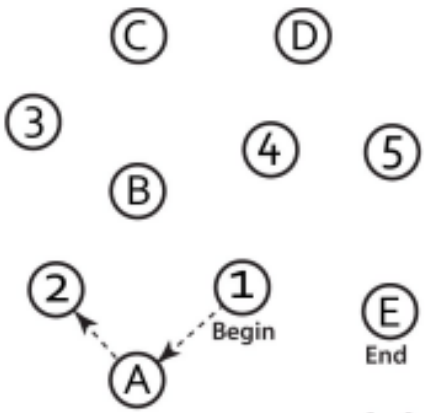
Administered by: _____

MONTREAL COGNITIVE ASSESSMENT (MOCA)

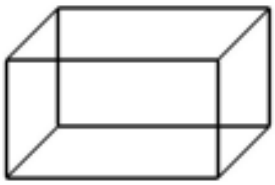
Version 7.2 Alternative Version

NAME :
Education : Date of birth :
Sex : DATE :

VISUOSPATIAL / EXECUTIVE



Copy rectangle



[ ] [ ]

Draw CLOCK (Five past four)
(3 points)

[ ] Contour [ ] Numbers [ ] Hands

POINTS ___/5

NAMING

[ ]

[ ]

[ ]

___/3

MEMORY

Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful. Do a recall after 5 minutes.

	TRUCK	BANANA	VIOLIN	DESK	GREEN
1st trial					
2nd trial					

No points

ATTENTION

Read list of digits (1 digit/ sec.).

Subject has to repeat them in the forward order [ ] 3 2 9 6 5

Subject has to repeat them in the backward order [ ] 8 5 2

___/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors

[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B

___/1

Serial 7 subtraction starting at 90 [ ] 83 [ ] 76 [ ] 69 [ ] 62 [ ] 55

4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt**

___/3

LANGUAGE

Repeat : A bird can fly into closed windows when it's dark and windy. [ ]
The caring grandmother sent groceries over a week ago. [ ]

___/2

Fluency / Name maximum number of words in one minute that begin with the letter S [ ] _____ (N ≥ 11 words)

___/1

ABSTRACTION

Similarity between e.g. carrot - potato = vegetable. [ ] diamond - ruby [ ] cannon - rifle

___/2

DELAYED RECALL

	Has to recall words WITH NO CUE	TRUCK [ ]	BANANA [ ]	VIOLIN [ ]	DESK [ ]	GREEN [ ]	Points for UNCUED recall only
Optional	Category cue						
	Multiple choice cue						

___/5

ORIENTATION

[ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City

___/6

Adapted by : Z. Nasreddine MD, N. Phillips PhD, H. Chertkow MD

www.mocatest.org

Normal ≥ 26 / 30

TOTAL ___/30

Add 1 point if ≤ 12 yr edu

Administered by: _____

Appendix D: CCNA Testing Protocol

Gait Assessment

(Requires a stopwatch/chronometer)

Participants will perform walks along a 6m path, with markings placed one meter before the start point, at the 4m mark, and one meter after the end point. When available, electronic walkways such as GaitRite™ or the Zeno Walkway System will be used. Below are abbreviated instructions for the three gait assessment tasks–please consult the instructions manual for more comprehensive instructions, set-up details, and scoring guidelines.

The evaluator will perform a demonstration of the walking, and one practice trial will be allowed to the participants. Please indicate the walking times to the tenth of a second, e.g., 4.3 s.

1. **Preferred Walking** (4m & 6m times)

   [Say]: "In this task, we are interested in measuring your usual walking pattern. When I say GO, please walk to this line [INDICATE END LINE]**."**

   Note: Be sure not to mention that he/she will be asked to do the dual task walk next. We want to avoid the individual "practicing" the dual task subtractions and animal naming while completing the preferred walking speed trial. (3 TRIALS)

   Trial 1: 4 m time: _____ s 6 m time: _____ s

   Trial 2: 4 m time: _____ s 6 m time: _____ s

   Trial 3: 4 m time: _____ s 6 m time: _____ s

   Please indicate if: ☐ test not administered ☐ test not completed If either, code reason: ____

2. **Dual-Task Walking** (6m time)

   a) Serial 1s

   [Say]: "This time, I am going to ask you to walk to the line [INDICATE END LINE]**, but I am going to make it a bit more difficult by asking you to count backwards from 100 by 1s, out loud as you're walking. Try to maintain your normal, comfortable walking pace while you are doing the calculations. When I say GO, please walk to the line** [INDICATE END LINE]**. Remember that it is important that you do not stop your walking or counting."**

   Note: Evaluators are allowed to clarify by providing a verbal example: "For example: 100, 99, 98, and so on". Evaluators are allowed to prompt the task if participants tend to stop during the task. (1 TRIAL)

   Counting trial (6m): _____ s

   Counted: ☐100 ☐99 ☐98 ☐97 ☐96 ☐95 ☐94 ☐93 Errors:
   ☐92 ☐91 ☐90 ☐89 ☐88 ☐87 ☐86 ☐85 ☐☐☐☐☐☐

   (Total # subtractions (1s): _____ Total correct: _____ Total errors: _____)

   Please indicate if: ☐ test not administered ☐ test not completed If either, code reason: ____

Gait Assessment

b) Animal fluency

[Say]: "Next, you are going to walk to the line [INDICATE END LINE] **at your usual pace and try to name as many animals (fluency test) as you can think of without repetition. Please do this out loud. Remember that it is important that you do not stop your walking or talking."**

Note: Evaluators are allowed to prompt the task if the participants tend to stop during the task. (1 TRIAL)

Fluency trial (6m): _____ s Total # of animals named: _____

Please indicate if: ☐ test not administered ☐ test not completed If either, code reason: _____

c) Serial 7s

[Say]: "For this next walk I am going to ask that you walk to the line [INDICATE END LINE] **at your usual pace and to count backwards from 100 subtracting 7s out loud. Remember that it is important that you do not stop your walking even if you can't think of the numbers."**

Note: Evaluators are allowed to clarify by providing a verbal example: "For example: 100, 93, and so on. Evaluators are allowed to prompt the task if participants tend to stop during the task. (1 TRIAL)

Counting trial (6m): _____ s

Counted: ☐100 ☐93 ☐86 ☐79 ☐72 ☐65 ☐58 ☐51 ☐44 ☐37 Errors: ☐☐☐☐☐☐☐

(Total # subtractions (7s): _____ Total correct: _____ Total errors: _____)

Please indicate if: ☐ test not administered ☐ test not completed If either, code reason: _____

3. **Fast Walking** (6m time)

[Say]: "Finally, I am going to ask you to walk to this line [INDICATE END LINE] **at a pace that is a little faster than your usual pace. Please go at a pace you feel comfortable at. No running please. When I say GO, please walk to this line** [INDICATE END LINE]." (1 TRIAL)

Fast walking (6m): _____ s

Please indicate if: ☐ test not administered ☐ test not completed If either, code reason: _____

Completed by: _____; _____ / _____ / _____ ☐ Check if form sent to LORIS
Initials DD MM YYYY