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An fNIRS Investigation of the Prefrontal Cortical Processing Demands Associated with a Communication Based Assessment for Mild Cognitive Impairment

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Abstract

When working with people who have communication impairments, there are few cognitive assessment tools to discern between baseline function, mild cognitive impairment (MCI), and Alzheimer's Disease (AD). While there are some available behavioral measures, this repertoire needs to be expanded. Because these diseases are progressive, these tasks must hold up against test/re-test principles, including accurate tracking over time. This study proposes to expand these tools used to assess MCI, exploring tasks linguistically and with functional near-infrared spectroscopy (fNIRS) to monitor neural activation during naturalistic communication, or discourse. This study observed fifteen total participants, all from the University of Vermont, as they talked through nine various discourse tasks. These tasks included three complex procedural, two simple procedural, two baseline rest tasks, and two additional tests. The baseline rest tasks and additional tests were not analyzed. The hypotheses were that the complex procedural tasks would elicit higher activation than the simple tasks and that the novel tasks would be equivalent to the previously-established tasks. The results show general increased PFC activation over all discourse tasks, indicating involvement of the PFC in connected discourse communication. Results also show increased prefrontal cortex (PFC) activation while performing complex procedural discourse tasks compared to simple procedural discourse tasks. The novel complex procedural discourse tasks were found to be linguistically and cognitively equivalent to the established measure. The novel simple discourse task was also found to be equivalent to its previously-established counterpart. These tasks may have implications in clinical assessment tools in the future. More research must be conducted investigating other brain regions to gain a better insight into the functional brain mechanisms of mild cognitive impairment and Alzheimer's Disease to determine more useful assessment tools.

Literature Review

Overview

Mild cognitive impairment (MCI) and related dementias are prevalent. However, distinguishing between MCI, Alzheimer's Disease (AD), and normal cognitive aging can be challenging, since similar symptoms are common in all circumstances. It is important that clinicians can correctly differentiate between these disorders because in some cases MCI progresses to Alzheimer's Disease, but in other cases, the brain reverts back to baseline cognitive function (Mayo Clinic, 2018). Currently, there are no definitive assessments for the clinical diagnosis of MCI; neuropathology reports show signs of Tau tangles and plaques, but this is post-mortem (Weintraub et al., 2012). Changes and impairments in communication, particularly in complex discourse tasks, have been reported in many types of MCI and may hold promise in potential assessment tools for early symptoms. Discourse is naturalistic communication, so discourse tasks are designed to emulate conversation that is representative of how a patient would speak in their daily life. This pilot study aims to determine the relationship between discourse tasks and neural output of the prefrontal cortex in order to find more conclusive communication-based assessments to distinguish baseline function from other progressive diseases like MCI. Though this study observed only healthy participants, the implications of this research can be applied to further clinical treatment for those with diseases like mild cognitive impairment and dementia. Since MCI and dementia are progressive processes, studying neurotypical brains is one way to find baselines that can be applied to clinical longitudinal treatment and management plans.

What is Mild Cognitive Impairment (MCI)?

Mild cognitive impairment (MCI) is characterized as "cognitive impairment that is greater than would be expected for an individual's age and educational background" (Fleming & Harris, 2008). It affects between 3% and 19% of individuals over the age of 65. The main risk factor of acquiring mild cognitive impairment is age. However, there is a small genetic risk if one has a specific form of the APOE-e4 gene, which is also linked to the likelihood of developing Alzheimer's Disease (Mayo Clinic, 2018). Some other risk factors for developing MCI include having diabetes, being male, smoking, high blood pressure, elevated cholesterol, obesity, depression, lack of physical exercise, low education level, and infrequently participating in socially stimulating activities (Mayo Clinic, 2018). One recent study that focused on multi-morbidity and development of MCI found that people with four or more chronic conditions, particularly two of the following – hypertension, hyperlipidemia, coronary artery disease, and osteoarthritis – had the highest risk of MCI (Sanford, 2017). Those who are "cognitively or physically sedentary" are also at greater risk of developing MCI (Sanford, 2017).

Unfortunately, distinguishing between MCI and normal cognitive aging can be challenging, since similar signs are common in both circumstances, such as "expected declines in sensory acuity, decreased speed of processing, and decrements in executive function" (Fleming & Harris, 2008). However, there is a 5% to 10% annual rate of progression to dementia in those with MCI, which is considerably higher than the 1% to 2% rate of incidence among the general population (Mayo Clinic, 2018). These conversion and regression rates suggest that there may be modifiable factors in play, indicating that early screening and diagnosis may greatly benefit efforts aimed at preventing progression to dementia. An early diagnosis means earlier

interventions, whether this means implementing new diet or exercise regimens or simply being able to better plan for future outcomes.

Early diagnoses could be helpful because although people with MCI can often return to typical cognitive function, approximately 50% of people with MCI will progress to a diagnosis of Alzheimer's dementia within five years (Fleming & Harris, 2008). Returning to typical cognitive function is thought to be related to factors such as having a single-domain impairment, no co-occurring depression, using anticholinergic medications, greater hippocampal volume upon neuroimaging, and higher scores on cognitive testing (Sanford, 2017). There are likely also genetic components at work here as well. People either have zero, one, or two apolipoprotein e4 alleles – the more alleles present, the higher the risk there is of developing further dementia.

Demographics and Societal Burden

Cognitive impairment comes at a great cost. Alzheimer's disease and related dementias are estimated to be the third most expensive diseases to treat in the United States (CDC, 2011). With the Baby Boomer generation getting older, this cost is only expected to increase in the coming decade and will place greater demands on systems of care (CDC, 2011). In fact, the average Medicaid payment for a person aged 65 or older with Alzheimer's or other dementias is nine times higher than that for other people in the same age group (CDC, 2011). The average Medicaid nursing facility spends about $647 million per state in 2010 on individuals with Alzheimer's Disease (CDC, 2011).

In addition to these costs, there are currently more than 10 million family members providing unpaid care to people with cognitive impairments. In 2009, it was estimated that 12.5 billion hours of unpaid care were provided, which translates to an estimated value of $144 billion

(CDC, 2011). These costs are only going to grow as the proportion of the older population increases, thus increasing the importance of early identification and treatment interventions aimed at promoting recovery rather than further illness and decline.

There is currently no known cure for mild cognitive impairment. A study of almost 900 people published in the September 2015 *Alzheimer's and Dementia* found that the Mediterranean-DASH Intervention for Neurodegenerative Delay (MIND) diet was associated with slower mental decline in adults (Harvard Health Publishing, 2017). This diet emphasizes high amounts of plant-based foods like berries, vegetables, whole grains, and a minimal amount of animal products (Harvard Health Publishing, 2017). As with many forms of cognitive impairment and general age-related decline, exercising for 30 minutes a day 3-5 times a week is also strongly recommended (Harvard Health Publishing, 2017).

These methods are helpful, but it would be more beneficial to be able to definitively tell when the onset of mild cognitive impairment is occurring so that one can better make interventions to suit patient needs and make beneficial lifestyle changes as early as possible. Currently, there are not enough diagnostic or clinical tests to make reliable distinctions between levels of impairment related to early markers of MCI and general cognitive decline. This pilot study could provide a way to make better and earlier distinctions.

Neurophysiological Changes In MCI

Neuroimaging results have shown abnormal clumps of beta-amyloid protein plaques and tau proteins in MCI similar to those seen in Alzheimer's. Beta-amyloid plaques are protein deposit biomarkers seen as early as the prodromal period of Alzheimer's Disease (AD) – that is, the asymptomatic period that comes years before onset of cognitive decline (Weintraub et al.,

2012). These plaques are typically found within functionally interconnected cortical areas that project to medial temporal lobe structures, which can be involved in memory (Weintraub et al., 2012). Tau proteins are proteins which typically stabilize microtubules; however, in Alzheimer's pathology, they are found to tangle into insoluble clumps that impede neuronal functioning and cellular health (Weintraub et al., 2012). Tau proteins and amyloid plaques can also be detected in cerebrospinal fluid years before Alzheimer's symptoms appear. Both proteins are observed in relation to MCI pathology as well (Weintraub et al., 2012).

Neurofibrillary tangles, or tau protein clumps, are implicated in reducing executive functioning in the early course of AD, including the "MCI stage" (Weintraub et al., 2012). These deficits in executive functioning involve the manipulation of information, concept formation, verbal problem solving, and cue-directed behavior (Weintraub et al., 2012). It is hypothesized that these problems arise pathologically due to the neurofibrillary tangle burden in the prefrontal cortex specifically (Weintraub et al., 2012).

Other potential neurophysiological changes include the presence of Lewy body proteins, which are seen in Parkinson's Disease and in some cases of Alzheimer's (Weintraub et al., 2012). These Lewy body proteins are alpha-synuclein positive intracytoplasmic neuronal inclusion bodies, which essentially means that the protein alpha-synuclein aggregates together in clumps. These clumps form Lewy bodies and impede neuronal functioning (Weintraub et al., 2012). Additionally, pathological signs of small strokes or reduced blood flow through brain blood vessels have also been observed. Structural brain imaging shows notable shrinkage of the hippocampus, the part of the brain involved in memory, enlargement of the fluid-filled ventricles, and reduced use of glucose (Mayo Clinic, 2019).

Even with the neuropathological evidence of the disease processes in MCI, there are still no definitive assessments for clinical diagnosis using these techniques. According to Weintraub et al., discerning between diagnoses like MCI, AD, and Dementia with Lewy Bodies is primarily symptom-based and can often be faulty because there are so many symptoms that occur on a spectrum or overlap (Weintraub et al., 2012). The other primary route of diagnosis is autopsy-based, which is certainly not helpful for patients seeking treatment (Weintraub et al., 2012). Therefore, it is clinically significant to determine better ways to measure differences in cognitive impairment. If one of the best diagnostic tools right now is autopsy, there is a clear lack of interventional tools.

How is MCI Diagnosed?

Currently, there is a lack of consistency in screening for MCI. Universal screening and reversible cause prevention would be ideal, but there is no gold-standard for diagnosis (Sanford, 2017). In fact, it has been shown that cognitive decline is not recognized or documented by primary care physicians in more than one-half of patients who later go on to receive a diagnosis of MCI or related dementias (Sanford, 2017). This occurs for many reasons; it takes a lot of time to delve into patient history, seek out information from family members, administer evidence-based assessments, and do a work-up for causes.

Another aspect that may influence consistency is that MCI is does not appear to be a unitary construct; various subtypes have been characterized. Amnestic MCI refers to problems with memory such as misplacing personal items, whereas Nonamnestic MCI involves changes in other cognitive domains, such as attention, concentration, executive function, language and visual skills. Furthermore, there is single-domain versus multi-domain MCI; single-domain

refers to having a deficit in only one area and multi-domain involves mild deficits in several areas. One interesting thing to note is that men are more likely to have MCI-related problems with executive function skills like concentration, decision-making, and creativity than are women, adding increased variation to the symptom presentation picture (Mayo Clinic, 2019).

A small number of screening tools have gained popularity for general cognitive assessment in MCI; the Saint Louis University Mental Status Examination (SLUMS), Rapid Cognitive Screen, and the Montreal Cognitive Assessment (Sanford, 2017). The SLUMS assessment is a 30-point questionnaire that takes less than 10 minutes to administer. It is a highly-validated tool for diagnosing both MCI and dementia and adjusts for educational level, which is an important component because people with limited education naturally do not perform as well as their more educated peers (Sanford, 2017). It generally tests for orientation, memory, attention, and executive functions (Tariq et al., 2006).

In the past, a Mini Mental Status Examination (MMSE) has been used clinically, but the SLUMS exam has been found to be more specific and more sensitive, meaning that it can detect smaller changes in function (Sanford, 2017). In a study done by the St. Louis University School of Medicine, it was found that the MMSE and SLUMS had "comparable sensitivities, specificities, and areas under the curve in detecting dementia" but the MMSE failed to detect "mild neurocognitive disorder" at all (Tariq et al., 2006). In addition to this detection advantage, the SLUMS test has also been translated into 24 languages and does not cost money to use, unlike the MMSE (Sanford, 2017). This is why the SLUMS has become more popular.

Another screening tool is the Rapid Cognitive Screen (RCS). The RCS is a 10-point questionnaire like the SLUMS but it takes less than three minutes to administer, which can be helpful for clinicians in a rush or in a primary care setting (Sanford, 2017). It involves three

components – recall, clock drawing, and insight. However, it is not as sensitive in detecting MCI as the SLUMS is due to its narrower focus and brief nature (Sanford, 2017). Some may disagree, however; in a recent study, it was found that the "3-item RCS exhibits good sensitivity and specificity for the detection of MCI and dementia, and higher cognitive function on the RCS is protective against nursing home placement and mortality" (Malmstrom et al., 2015). Therefore, this appears to have potential as a screening instrument even though it is administered quite rapidly, making it useful for some settings over others.

Finally, there is the Montreal Cognitive Assessment (MoCA), which is like the SLUMS because it is also a 30-question questionnaire that takes about 10 minutes to administer. It demonstrates high test-retest reliability, good internal consistency, and equivalence when detecting MCI (Nasreddine et al., 2005). Its sensitivity was 90%, which is "considerably more sensitive" than the MMSE (Nasreddine et al., 2005). This could be because the MoCA's memory testing involves more words, fewer learning trials, and a longer delay before recall than the MMSE (Nasreddine et al., 2005). There are also more "numerous and demanding tasks" in the MoCA that test "executive functions, higher-level language abilities, and complex visuospatial processing [that] can also be mildly impaired in MCI" (Nasreddine et al., 2005). This could be why it is seen to be more specific in diagnosing MCI, particularly over the MMSE.

Even with the promise of these tests, however, the DSM-V does not specify a specific screening test that should be used (Sanford, 2017). In general, scores "need to fall one to two standard deviations below age- and education-adjusted normative means on cognitive testing for a diagnosis of MCI to be considered" (Sanford, 2017). This is vague because it does not specify exactly what cognitive testing is recommended.

Therefore, more in-depth neuropsychological testing is often required to determine what the cognitive problem is. Neuropsychological testing is particularly helpful in MCI where deficits could be quite subtle or only found in certain domains. Perhaps if these bedside cognitive assessments were further researched and found to be ecologically valid, they could be used more effectively in clinical diagnosis. Regardless, more assessments, including more ecological and neuropsychological measures, are needed.

Functional Neuroimaging and Symptomatic Changes

Currently, neuroimaging for MCI is primarily used to rule other things out. MRI or computerized tomography (CT) can look for things like brain tumors, hydrocephalus, strokes, and vascular malformations (Sanford, 2017). This could also reveal things like ischemic small vessel changes that are important in distinguishing cognitive impairment from vascular dementia (Sanford, 2017).

Another helpful neuroimaging option is the use of positron emission tomography (PET) scan with F-fluorodeoxyglucose (FDG). This scan is often not clinically available and is more commonly used in research, but it involves observing a radioactive tracer that marks glucose metabolism in the brain. This tracer binds to areas in the brain that readily use glucose. Often, neurodegeneration can be signified by low glucose use in temporal and parietal lobes, and this is related to whether someone may be at a high risk of progressing from MCI to dementia (Sanford, 2017). Single-photon emission computed tomography (SPECT) also uses a radioactive tracer to measure regional cerebral blood flow. This is a more indirect measure of brain activity. However, it is cheaper and more readily available than the FDG-PET scan (Sanford, 2017).

One recent study utilized PET imaging to observe plaques and tangles in MCI patients versus Alzheimer's patients. This PET scan worked by using a marker – in this case, Pittsburgh compound-b ([^{11}C]-PIB) – to bind to beta-amyloid in the brain and show the location and purveyance of these plaques (Weintraub et al., 2012). It was found that the global values for PET marker binding with plaques and tangles was higher in those with mild cognitive impairment than in the control group, but the levels of plaques and tangles in MCI were less than that seen in Alzheimer's disease (Weintraub et al., 2012). This shows that PET scanning can potentially differentiate people along this spectrum of decline from control group to MCI to AD. However, this technique is not very advanced and most of the participants with MCI in this study had memory impairment as a symptom, which is not always the case (Weintraub et al., 2012). More studies will have to be done to determine how PET scanning can fit into diagnostics.

There are some notable drawbacks of using clinical PET procedures, however. For one, PET imaging can cost more than $3000 per visit (Mitka, 2013), which is often not fully covered by patient insurance (Bateman, 2012). It is also an expensive machine with high ongoing costs that may deter its availability and clinical utility (Bateman, 2012). These more negative aspects should also be accounted for when considering PET as a diagnostic tool.

Diffusion tensor imaging (DTI) is useful because it can detect microstructural integrity of white matter tracts (Medina et al., 2006). This device detects small alterations in white matter by measuring the direction of molecular diffusion; this is known as fractional anisotropy (FA). Highly organized white matter tracts have high FA because diffusion is constrained by the tract's cellular organization. When white matter is damaged, as in MCI and AD, FA will decrease due to less diffusion (Medina et al., 2006).

One study using DTI showed that there were substantial regional reductions of fractional anisotropy in posterior brain regions in individuals with MCI and Alzheimer's disease compared to control groups. There was overlap in the regions in which white matter loss was experienced, including the internal capsule, the superior longitudinal fasciculus, and the posterior cingulum bundle (Medina et al., 2006). This could be due to vascular risk factors that often with come with age. Another possibility is that oligodendrocytes fall prey to free-radical and other metabolic damage, thus supporting less axons and leading to less white matter integrity. Because these white matter changes are seen in both MCI and Alzheimer's, this data suggests that white matter changes occur in MCI prior to developing dementia (Medina et al., 2006). This could be one way to screen for the disease; however, there is still no clear criteria for when MCI becomes Alzheimer's.

Again, there are some drawbacks of using DTI in a clinical setting. One is that it is impossible to tell the directionality of axons; rather, one is only able to observe the motion of water molecules (Mori & Zhang, 2006). There is also a fair amount of information reduction because the DTI calculation assumes that fiber structures are all the same within a pixel, which is not necessarily true (Mori & Zhang, 2006). This could be combated with increased image resolution in the future. Furthermore, DTI detects the motion of water, which takes a relatively long scanning time. Any physiological motions during this time could interfere with the accuracy of DTI results (Mori & Zhang, 2006). Ultimately, DTI is not always the most clinical utilizable tool and this should be a consideration as well.

Functional Near-Infrared Spectroscopy (fNIRS) Imaging and MCI

Functional near-infrared spectroscopy, or fNIRS, "capitalizes on the changing optical properties of… tissues by using light in the near-infrared range to measure physiological changes" (Farzin et al., 2006). Essentially, this headband-like device uses infrared light to measure changes in oxygen levels in the bloodstream, which is an indirect measurement of cortical neuronal activation. This works because neuronal activity is fueled by glucose and oxygen consumption. Blood filled with glucose and oxygen (via oxygenated hemoglobin) rushes to the site of the brain that is activated. fNIRS then tracks these oxygenation changes quickly because "both oxygenated and deoxygenated hemoglobin have characteristic optical properties in the… near-infrared light range" (Farzin et al., 2006). fNIRS measures the changes in this emitted near-infrared light. It is possible to do this because the absorption spectrum of a tissue depends on the amount and proportion of its constituents, which include hemoglobin (Wallois et al., 2012). Tissues will emit different wavelengths of infrared light depending on whether they have hemoglobin or deoxyhemoglobin constituents within them, which then indirectly reflects neuronal activation (Wallois et al., 2012).

Since fNIRS uses the optical properties of the tissues to deduce brain activation, it is flexible and fast, making it a popular neuroimaging technique. It is notably cheaper than many of the other options mentioned such as fMRI or PET (Wallois et al., 2012). It also has very good temporal resolution, meaning that it is time-sensitive (in the millisecond range); it picks up on cortical activation almost instantly due to the use of infrared light and the optical properties of tissues (Wallois et al., 2012). It is clinically useful because it is very resistant to motion artifacts, unlike other popular techniques, so it can be used during cognitive testing and speaking tasks. Additionally, fNIRS is mobile, noninvasive, silent, and does not require confinement, so it is also

easy to use during natural settings or in an office visit (Wallois et al., 2012). Unlike fMRI, it can be used on people with cochlear implants (Wallois et al., 2012).

There are some downsides - it has limited spatial resolution; it can only project millimeters below cortical surface and maxes out at five centimeters below. There is also risk of attenuation of the light signal by outer layers of the skin, skin pigmentation can hinder signal detection, and there can be difficulties obtaining baselines of types of hemoglobin (Farzin et al., 2006). However, these can be overcome with proper data collection procedures. Therefore, it is ultimately a relevant and reliable tool to study prefrontal cortex activation during naturalistic tasks.

Recent fNIRS studies have attempted to discern between MCI and AD-linked atrophy. This is possible because these diseases change the metabolic activity of cortical neurons, which in turn can alter the optical properties of the neurovascular supply to cortical brain tissues. Functional near-infrared spectroscopy (fNIRS) can pick up on these optical property changes.

Studies have shown abnormal activity in the prefrontal cortices of MCI and AD patients during various cognitive tasks (Li et al., 2018). During a verbal short-term memory task, Li's research shows that there is a "uniform response pattern in [the] frontal area, where increasingly significant reductions in oxygenated hemoglobin (HbO) were observed as the disease severity developed from MCI to moderate/severe AD" (Li et al., 2018). This reduction in oxygenated hemoglobin could be because people with MCI or AD require more oxygen than a healthy control person would to complete the same tasks due to functional impairments (Li et al., 2018). This reduction in HbO could also occur because cortical neurodegeneration caused by MCI or AD could induce functional reorganization, meaning that other brain areas would be recruited to support the prefrontal cortex. This recruitment would increase overall oxygen consumption (Li et

al., 2018). This uniform response pattern seen in the frontal area supports Weintraub et al.'s study (2012), which found that the prefrontal cortex was negatively impacted in MCI.

Li et al.'s study also used the MMSE clinical assessment to see if this test correlated to neural data. It did show a significant difference between the healthy control group and AD groups; however, there was no significant difference between healthy controls and MCI groups seen from the MMSE scores (Li et al., 2018), indicating the challenges in diagnosing MCI from a simple clinical assessment. However, this study only used a verbal short-term memory task. It is yet to be found if there are ecologically valid communication tasks that could show both neural and behavioral correlations in determining MCI from healthy control groups. This study is still important, however, because it is one of the first forays into using fNIRS as a clinical tool in determining normal neural function from MCI and AD. fNIRS is clearly showing clinical promise in the Li study and could be a useful diagnostic tool in the future. The added advantages of being flexible, fast, noninvasive, and mobile make fNIRS something that could be utilized in natural settings, such as during the natural communication tasks given in this pilot study. Its ease of use and utility make it a viable possible future option for clinical office visits as well.

Discourse and MCI

Due to a great lack in clinical options, it has been suggested that more ecologically valid tasks such as discourse-related assessment tools should be created. Discourse, or naturalistic communication, would be particularly useful for this reason because it emulates typical conversation. Therefore, these tasks would tap into everyday cognitive-communicative functions as an additional tool for MCI detection. Of course, these tools should be standardized and

repeatable to work in conjunction with cognitive screens and neuroimaging techniques discussed above.

In general, procedural discourse presents a series of steps leading to a goal and can have different levels of complexity. Procedural discourse can be assessed using both simple and complex tasks. Complex tasks are open-ended and provide more room for unique responses. These responses are often longer with more complex themes and syntax. Simple procedural tasks often have less room for variability and elicit less complex syntax, usually involving only one main theme or focus. An example of this is the ATM task, which asks participants to describe how they would withdraw money from an ATM (Snow, Douglas & Ponsford, 1997).

One such task that has been shown to detect subtle differences is an experimental discourse task called "Trip to New York" (Fleming & Harris, 2008). This task involves asking people to plan a trip to New York City. This complex procedural discourse task involves planning, problem solving, and communicative skills and is considered a valid and ecologically valid form of measuring executive function found in everyday activities (Cannizzaro, 2013).

Fleming and Harris's study (2008) showed that those with cognitive deficits provided less thematic information and had more irrelevant comments and words than others without cognitive impairment during the task. The sparseness in description by the MCI group reflected the inability of the MCI patients to retrieve words and provide detailed discourse (Fleming & Harris, 2008). However, "Trip to New York" is just one assessment tool and more equivalent tasks should be normalized to increase options for testing patients repeatedly to track progression, improvement, or stable functioning in this domain. Identifying these discourse deficits following brain damage and determining patterns in brain activation can result in early intervention and expanded therapeutic options.

While the exploration of complex discourse seems to be a promising way to assess executive frontal skills in adults with possible MCI, there are many conflicting conclusions regarding language impairments of MCI patients. One recent study intended to delineate language-specific impairments using participants with amnestic MCI (aMCI), non-amnestic MCI (naMCI), and healthy controls (HCs) (Kim, 2019). Through three discourse tasks (an episodic narrative, planning, and a picture description), it was found that the discourse of aMCI participants was less efficient and less cohesive than those of naMCI participants because amnestic MCI involves a loss of semantic memory and execution (Kim, 2019). However, naMCI patients were less cohesive and demonstrated longer pauses during discourse production due to reduced attentional and executive functions (Kim, 2019). This emerging data suggests that clinicians may be able to use various discourse impairments to assess MCI and its subtypes. The richness of information that can be drawn from these types of language samples also suggests that similar methods may be possible to measure signs of early dementia. Thus, measurement of discourse performance can then be considered part of a clinical diagnostic criterion in the future (Kim, 2019). This is one of the first times this has been demonstrated and this may have a large clinical impact. Combining discourse assessment tools with clinically accessible neuroimaging techniques such as fNIRS could have great implications for biomarker development and the future of MCI detection and research.

Discourse, fNIRS, and MCI

Overall, there are a very limited number of tools available for specific diagnosis and sub-categorization of mild cognitive impairment. Clinically, this is important because definitive and standardized testing tools with alternate equitable forms would not only provide more clarity in

MCI diagnosis but also be beneficial in identifying MCI diagnoses early. If MCI could be diagnosed in its early stages, doctors could put interventions in place before further damage occurs, preventing or postponing dementia. Even if the MCI did progress, there would be more time to make future arrangements, appoint durable power of attorney for health care and financial matters, communicate between patient and family, educate family members, engage in community support groups, and participate in research studies.

Recent research has been pivotal in finding correlations between fNIRS neural data and clinical diagnoses of MCI and AD (Li et al., 2018). Simultaneously, there have been studies showing that discourse assessments can be helpful in determining MCI from other neurodegenerative diseases, including different MCI subtypes (Kim, 2019). In combination, perhaps these discourse and prefrontal cortex fNIRS approaches *together* could be useful for clinical diagnosis. Testing discourse is often helpful because it is so naturalistic – basic communication is something that can parallel behavior in real-world settings and make this applicable and ecologically valid for a diagnostic tool. One could also use simple and complex discourse tasks to determine if the prefrontal cortical demand is greater for complex tasks, particularly for those with neurodegenerative diseases.

Not only could this partnership of discourse and fNIRS help diagnose MCI earlier, research suggests that fNIRS shows promise in identifying disease progression as well (and perhaps, regression). Alternate equitable discourse tasks should be able to test accurately over time without practice effects, thus being able to follow the course of a disease. These approaches used in combination could be the missing link between clinical assessment tools and neuronal function in the diagnosis of MCI and other dementias; therefore, this research is clinically pertinent and could make a huge impact on patients' lives.

The purpose of the present study is to determine whether linguistically equivalent discourse tasks (three complex and two simple) are also equivalent in terms of prefrontal cortical activation as measured by fNIRS. The hypothesis is that based on the behavioral data, these tasks are equivalent and therefore the demand on the prefrontal cortex to temporally organize and integrate content is equivalent as well. It is expected that complex demands will be more challenging than simple tests, showing a statistically significant increase in cortical activation between complex and simple tasks. This is a pilot work and will be the first step toward determining whether using discourse and fNIRS can be used as a reliable clinical tool which can help diagnose MCI earlier, thus making a huge clinical impact on patient lives.

Methods

Recruitment of Sample

Participants in this study were recruited as a convenience sample and consisted of fifteen UVM undergraduate students, including five males and ten females. All the subjects were students at the University of Vermont. Participants were screened to exclude anyone with a speech or language disorder that could affect their discourse. This research also excluded anyone who had sustained a traumatic brain injury in the past, which was defined as a loss of consciousness following head injury for more than five minutes. The subjects were native English speakers who communicated with no known language or communication impairments. These participants were recruited through friends and acquaintances of the research team and through neuroscience class announcements.

Data Collection

Data was collected during individual participant research sessions, lasting approximately 30 minutes each. These sessions consisted of two parts, starting with the informed consent process. After reviewing this form, data collection began with demographics, which included age, marital status, occupation, education, screening for traumatic brain injury history, and screening for language disorders. This was recorded via a self-report. After this, the Montreal Cognitive Assessment (MoCA) was given to each participant to assess functions including short-term memory, executive function, attention, concentration, working memory, language comprehension, and language production (Sanford 2017). All participants scored in the range of normal cognitive functioning. Typically, normal cognitive functioning means a final MoCA score of 26 and above. In recent normative studies, however, it has been found that total scores of neurotypical patients often fall below 26. In fact, a study of 2,653 people showed that total scores had a mean of 23.4, with 66% falling below the suggested cutoff for impairment (Rossetti et al, 2011). However, the participants in this pilot study scored an average of 28.88, thus satisfying the previously-determined neurotypical set-point.

fNIRS Instrumentation

The functional near-infrared spectroscopy (fNIRS) device was a 16-channel continuous wave system used to monitor changes in the concentration of oxygenated blood flow in the PFC. The fNIRS headband was fastened on participants' foreheads after wiping their skin with an alcohol wipe. It was adjusted according to optimal positioning guidelines following the manufacturer's instructions. The detectors on the PFC cover Brodmann's Areas 44, 45, 9, and 10 (Optical & Imaging, 2018). Pre-wrap tape was used to cover the outer surface of the device to prevent light intrusion.

One examiner recorded and monitored fNIRS data from a different computer while the other examiner sat next to the participant to guide them through the tasks. The recording of data consisted of a simple "start" and "stop" computer cue; the fNIRS machine ran without stopping for the duration of the tasks. The examiner monitoring fNIRS data would press the keyboard when each separate task started and stopped to mark the beginning and end of each task and make it easier for later data extraction.

Discourse Tasks

During the data collection session, discourse prompts were displayed on the computer through a PowerPoint presentation and were read aloud to the participant by one examiner. The first slide was a general overview of the protocol and tasks, including things like "speak naturally" and "minimize forehead movements" so as not to interfere with the fNIRS signal. Next, a baseline task was performed to ensure that the fNIRS machine was working and that the data was going to be compared to a passive baseline task. This baseline task was a recitation of months beginning with January until the measure was complete. After this, the discourse tasks commenced. Participants were shown and read the prompt and cued by the participant to start responding. There was no time limit for these tasks and they were moved to the next task when they were done the previous one. In between prompts, a ten-second slide containing "+" was presented to denote that there was a passive rest period in which the participants' cortical blood flow could revert to normal levels before starting the subsequent task. In between Procedural Discourse tasks and Narrative Discourse tasks, counting to 20 was used to help blood flow reach normal levels as well.

Procedure

Participants all received the same series of prompts organized by genre of discourse. This included Procedural Discourse, which had three complex and two simple procedural tasks, Narrative Discourse, and Conversational Discourse. There were two forms of the PowerPoint – Form A and Form B – which swapped task order to reduce order and practice effects.

Procedural Discourse

Five procedural discourse tasks prompts were given during data collection – three complex followed by two simple. One of the complex tasks was called *Trip To New York City*, which is a previously normed discourse task (Fleming & Harris, 2008). The instructions were, "*Imagine that you are going on a vacation a week from now. You are traveling to New York City for a two-week stay. Think about all you will have to do to get ready to go, such as how you will get there, what you will bring, and what you will do. When the slide changes, describe in detail all the activities associated with the trip. There are no right or wrong answers."*

The other two complex procedural tasks were unique to this study, though semantically and syntactically like *Trip to New York City*. The *Dinner Party* task instructions were: *"Imagine that you are planning a dinner party for 50 people a week from now. You are throwing this party for a good friend who has recently had an important birthday. Think about all you will have to do to get ready for the party, such as identifying a place, planning a menu, and what activities will take place during the party. When the slide changes, please describe in detail all of the activities associated with planning the dinner party. There are no right or wrong answers."*

The *Moving* task was: *"Imagine that you are moving to a new town a month from now. You are moving for a fresh start and a change of scenery. Think about all you will have to do to get ready for the move, such as finding a place to live, moving your belongings, and all of the*

other things you will need to get set up in a new town. When the slide changes, please describe in detail all of the activities associated with moving. There are no right or wrong answers." These new tasks were designed to be similar to the previously normed complex procedural task in order to elicit the same types of responses.

The two simple procedural discourse tasks included one that was normed and one that was new. The normed task was called the *ATM Task*, which used the prompt: *"Imagine you are going to withdraw money from an ATM. When the slide changes, please describe all of the steps involved in withdrawing money from an ATM."* This is considered a simple discourse task because it relies on drawing from expected prior knowledge that participants have about withdrawing money from an ATM.

The other simple procedural discourse task followed this pattern – it was called *Pumping Gas*. The examiner prompted: "*Imagine you are going to fill the gas tank of a car. When the slide changes, please describe in detail all of the steps involved in pumping gas."* Again, it was expected that the participants would have prior knowledge about how to pump gas.

Analysis

Preprocessing of fNIRS Data

Oxygenation data was analyzed using the program fNIRSoft, which comes with the BioPac fNIRS data acquisition hardware. All data was preprocessed and visually inspected, checking for any abnormal data segments. If a signal indicated motion artifacts, it was deleted on a segment by segment basis for each participant to ensure signal integrity. Optical density data was then filtered, de-trended, and corrected with fNIRSoft preprocessing tools before analysis of oxygenation changes relative to baseline. Filtering accounted for biological noise (such as

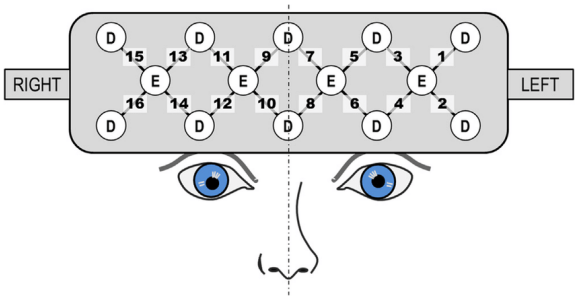
respiration), de-trending countered the effects of blood accumulation accompany prolonged mental activity resulting in global signal drift, and corrections removed large spikes due to head motion (Cui, Bray, & Reiss, 2010).

Blocking

The examiner used fNIRSoft to put in markers that delineated when participants were starting and stopping tasks. Using these markers, it was possible to discern when peak activation for each task occurred by looking at the upward and downward trajectories of the hemodynamic response associated with answering each prompt. The total "activation time" for each task was determined by subtracting the beginning activation time from end activation time, representing the time 50% around the peak of each task-related hemodynamic response.

Data Extraction and Reduction

The fNIRS data was first processed by finding the temporal average deviation from baseline for each optode for each task (AppendTemporalMeans). This tool gives an average score for each optode within the denoted blocks for a total of sixteen scores per participant, per task. To further reduce the data and the number of comparisons in the analysis, the 16 optodes were grouped into 4 regions. Data for Quadrant 1 represented an average of the data from optodes 1-4, covering the left lateral region of the fNIRS headband (see image below). Data for Quadrant 2 represented an average of the data from optodes 5-8 covering the left medial region of the fNIRS headband. Data for Quadrant 3 represented an average of the data from optodes 9-12 covering the right medial region of the fNIRS headband. Data for Quadrant 4 represented an average of the data from optodes 13-16 covering the right lateral region of the fNIRS headband.



fNIRS Headband. Mandrick et al., 2016.

Statistical Analysis

Temporal averages of the cortical activation were used for all analyses. Pearson correlation coefficients were calculated to evaluate within-task and between-task cortical activation levels. A paired-samples t-test was used to compare differences in activation for the simple discourse tasks and repeated-measures ANOVA were used to compare activation levels between the complex procedural discourse tasks and also between the complex (e.g., NYC), simple (e.g., ATM), and conversational discourse tasks. A significance level of $p<0.05$ was used to determine statistical significance and all data were analyzed using SPSS (Version 26).

Results

Subjects

Eighteen individuals ultimately participated in the study; however, Participant 001, Participant 002, and Participant 15 were excluded from analysis. This is because 001 was a test run and 002 and 015 did not have properly-recorded fNIRS data. Therefore, fifteen participants' data was analyzed. Participant demographic information is displayed below (Table 1). Ages ranged from 18 to 21 (average = 20.07; SD = 0.96). Ten of the fifteen participants were women. Descriptive statistics for all baseline questionnaires can be seen in Table 1 as well. MoCA scores

ranged from 27 to 30 (average = 28.87; SD = 1.06). The average MoCA score was above the 26-point cutoff for typical cognitive function (Nasreddine et al., 2005).

Table 1
Demographics of Sample

Subject Code	Ages (years)	Gender	MoCA Total	MoCA Language	MoCA Fluency
003	21	F	29	12	24
004	20	M	28	11	10
005	20	F	30	13	18
006	21	M	28	12	17
007	20	F	29	12	16
008	20	M	27	11	21
009	21	M	30	13	14
010	20	F	30	13	12
011	18	F	30	13	18
012	21	F	29	13	13
013	19	F	29	12	9
014	19	F	27	10	9
016	19	F	29	12	9
017	21	M	28	11	13
018	21	F	30	13	16

Statistical Results

All discourse tasks were found to show an increase in PFC activation across all quadrants compared to the baseline condition of naming the months of the year in order (i.e., an automatic rote language task).

To compare PFC activation patterns for the two simple procedural discourse tasks, a paired sample t-test was used to determine if the mean activation values of the quadrants were significantly different between the ATM task and the Pumping Gas task. Results from the paired samples t-tests revealed no statistically significant differences for any quadrant comparisons between tasks (Table 2).

Table 2
Paired Samples t-test ATM vs. Gas Task

	T	Df	Sig (two-tailed)

	Mean Difference	Std. Deviation	Std. Error Mean			
Quadrant 1	-.543	1.231	.318	-1.708	14	.110
Quadrant 2	-.372	1.362	.352	-1.058	14	.308
Quadrant 3	-.460	1.576	.407	-1.131	14	.277
Quadrant 4	-.340	1.699	.439	-.776	14	.451

To compare PFC activation patterns for the three complex discourse tasks (i.e. NYC, Moving and Dinner Party), a repeated-measures ANOVA was conducted to determine if the mean activation values of each quadrant were significantly different between these discourse tasks. No statistically significant differences were observed (Table 3).

Table 3
Complex Procedural Discourse Task Repeated Measures Comparisons by Quadrant

Quadrant	(I) Task	(J) Task	Mean Difference (I-J)	Std. Error	Sig.[a]
Q1	1	2	.014	.462	.976
		3	.282	.651	.671
	2	3	.268	.483	.588
Q2	1	2	.059	.563	.918
		3	.696	.651	.303
	2	3	.637	.445	.174
Q3	1	2	-.083	.606	.893
		3	.645	.726	.389
	2	3	.728	.482	.153
Q4	1	2	.188	.596	.757
		3	.638	.771	.422
	2	3	.449	.508	.391

Notes: Task 1=NYC, Task 2=Moving & Task 3=Dinner Party

After comparing complex procedural discourse task differences, Pearson's R-values of correlation were performed to determine if there were similarities in activation across tasks by

quadrant. Significant positive correlations were found between complex procedural discourse tasks in Quadrant 3 ($p < 0.05$), seen in Table 4.

Table 4
Complex Procedural Discourse Correlations in Quadrant 3 (Q3)

		NYC Q 3	Moving Q 3	Dinner Party Q3
NYC Q3	Pearson Correlation	1	.633*	.406
	Sig. (2-tailed)		.011	.133
Moving Q3	Pearson Correlation		1	.688**
	Sig. (2-tailed)			.005

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

To compare PFC activation patterns between the previously normed simple and complex procedural discourse tasks, a paired sample t-test was used to determine if the mean activation values of the quadrants were significantly different between the ATM task and the NYC task. Results from the paired-samples t-tests revealed no statistically significant differences for any quadrant comparisons between tasks (Table 5).

Table 5
Paired Samples t-test ATM vs. NYC Task for Quadrants

Quadrant	Task Comparison	Mean Difference	Standard Deviation	Significance (two-tailed)
Q1	NYC - ATM	.9160	1.750	.062
Q2	NYC - ATM	1.279	2.399	.058
Q3	NYC - ATM	1.078	2.965	.181
Q4	NYC - ATM	1.102	2.540	.115

Since probability values for the quadrant results were approaching significance, a follow-up paired sample t-test was conducted to determine if there were significant differences by optode between the simple and complex discourse tasks. Because of the small sample size and potential variability within quadrant values, individual optodes may reveal significant differences between these tasks. This is due to perceived difficulty of the complex tasks that may not have

been apparent in the average values of the quadrants. Results from the paired sample t-test revealed statistically significant differences between four optodes in the left hemisphere (Table 6).

Table 6
Paired Samples t-test ATM vs. NYC Task for Optodes

Optode	Task Comparison	Mean	Standard Deviation	Significance (two-tailed)
Opt. 1	NYC - ATM	.866	1.478	.040*
Opt. 2	NYC - ATM	1.112	1.877	.038*
Opt. 3	NYC - ATM	.955	1.824	.062
Opt. 4	NYC - ATM	.730	2.071	.193
Opt. 5	NYC - ATM	1.176	2.046	.043*
Opt. 6	NYC - ATM	1.072	2.347	.099
Opt. 7	NYC - ATM	1.377	2.441	.046*
Opt. 8	NYC - ATM	1.492	2.955	.071
Opt. 9	NYC - ATM	1.296	2.646	.079
Opt. 10	NYC - ATM	1.422	3.022	.090
Opt. 11	NYC - ATM	1.278	2.536	.071
Opt. 12	NYC - ATM	.3142	4.614	.796
Opt. 13	NYC - ATM	.853	2.124	.142
Opt. 14	NYC - ATM	.937	2.428	.157
Opt. 15	NYC - ATM	1.357	2.988	.100
Opt. 16	NYC - ATM	1.258	2.924	.118

Note: *p<.05 Significance Level

Summary of the Results

The results found from these correlations, paired t-tests, and repeated-measure ANOVAs support the initial hypotheses and answer questions about discourse task equivalence. Results show that there is a general prefrontal cortical activation seen across all discourse tasks, as expected.

The ATM and Pumping Gas tasks (simple discourse) were found to be equivalent in terms of cortical activation. The New York City task, Moving task, and Dinner Party task (complex discourse) are equivalent in this way as well. Results also show that there is a specific

area of the PFC, Brodmann's Area 10, that showed correlated activation across each of the complex procedural discourse tasks.

When looking at data by quadrant, the ATM and NYC tasks were not significantly different, though they approached significance. When observing by optode, there was seen to be a left-lateralized significant difference. The initial results from this pilot study support the original hypotheses and provide evidence to encourage further study of these tasks and potential utilization of novel tasks as equivalent communication-based assessment tools.

Discussion

The purpose of this study was to measure PFC activation during novel tasks to be used for the assessment of discourse in individuals with mild cognitive impairment (MCI) or Alzheimer's Disease (AD). These new tasks were designed to be like the previously-normed and widely-used New York City and ATM discourse tasks. If equivalent, these tasks could become part of a larger cognitive assessment toolkit to discern MCI and AD from baseline neural function and could be utilized as alternate forms for testing over time. These initial results indicate that the newly-created tasks are similar to the previous tasks in terms of the neural output (activation) data and provide evidence that further study of these tasks could lead to valid, new clinical and research tools. These tools could not only test for different impairments but could also track progress over time, which is particularly important for these conditions.

Simple Procedural Discourse Tasks

It was predicted that simple procedural discourse tasks would show non-statistically significant cortical activation patterns between tasks. This was proven true in these results; the ATM and Pumping Gas tasks were found to be equivalent as far as neural output by quadrant.

The negative mean difference seen in Table 2 suggests that, though statistically equivalent measures, the Pumping Gas task requires slightly more neural output than the ATM task. One reason for this could be the fact that many people struggle to find the words to describe the rather vague components that are involved in pumping gas (i.e. “lever”, “nozzle”, “button”), whereas using an ATM is more straightforward to describe. Searching or struggling to find appropriate words would increase prefrontal cortical output because this would involve executive function. This aligns with prior linguistic data which showed that the Pumping Gas task produced more CIUs (correct information units) per minute than the ATM task did (Harlan, 2019). This means that people used more words to describe the Pumping Gas task, which in turn requires more prefrontal exertion.

In the future, it may be useful to consider a task that will elicit a more similar linguistic response to the ATM task. Nevertheless, the prefrontal cortical data was found to be significantly correlated between the two tasks.

Complex Procedural Discourse Tasks

The complex procedural discourse tasks were predicted to show activation that was not statistically significantly different by cortical region to demonstrate equivalency. Based on previous research, it was known that these complex tasks held up under behavioral linguistic measures of equivalence (comparing correct information units (CIUs), CIUs/minute, and time taken to complete the tasks) (Harlan, 2019). The New York City task, which had been previously

normed and used in other studies, was used to create the Moving and Dinner Party tasks. The three tasks did not show a statistically significant difference in cortical activation by region, showing that the tasks were similar. They also had a statistically significant strong positive correlation, showing a high level of predictability between these tasks on this measure of neural PFC activation. Since these tasks all show similar responses, they could potentially be used for the same purpose in clinical and research settings.

Quadrant 3: Right Medial Prefrontal Activation Patterns

Between-tasks comparisons were made to look at correlations between the procedural discourse tasks. According to Table 4, there is a positive correlation between the procedural discourse tasks in Quadrant 3, specifically between the Moving task and NYC task and the Moving task and Dinner Party. This is the most indicative of specific predictive activation changes related to complex procedural discourse planning. Quadrant 3 is located on the right medial polar surface of the prefrontal cortex, which is the area most associated with Brodmann's Area 10, also known as the anterior or rostral prefrontal cortex (Stuss, 2011).

Brodmann's Area 10 is typically involved in the metacognitive aspects of human nature (Stuss & Alexander, 2009). Metacognition, or thinking about thinking, is involved in "orchestrating the energization, motivation, emotional perspective, and executive capacities that are necessary to accomplish complex, novel tasks" (Stuss, 2011). This higher-order processing function is both integrative and coordinating. During the complex procedural discourse tasks, each participant was required to respond to a prompt that was new to them, discussing a detailed plan that involved coordination and executive functions like working memory – a perfect example of metacognition. It makes sense that the prefrontal cortex activation patterns in

Quadrant 3 were correlated across these tasks because they all require integrating the high-level executive cognitive functions mentioned above.

Area 10 is also associated with decision making, working memory, personality, social cognition, theory of mind, humor appreciation, and self-awareness (Peng et al, 2018). Perhaps participants were also thinking about how their answers could be perceived, using humor, or using personal examples, thus involving theory of mind as well. This perfectly describes the set of skills required to respond to complex procedural discourse questions like the NYC, Moving, or Dinner Party tasks.

In contrast, there was no correlation in this quadrant for the simple procedural discourse tasks. This could be because pumping gas or describing how to use an ATM is more mundane – one could assume that most people know how to do both tasks without having to really consider what they were saying. Therefore, these tasks may not require as much self-reflection, judgement, or working memory, thus resulting in a lower cognitive demand. If there is a lower cognitive demand, these tests may not be as sensitive in detecting subtle changes between MCI, AD, and other dementias in comparison with baseline neural function.

Complex vs. Simple Procedural Tasks

It was hypothesized that complex procedural discourse tasks would be more demanding than simple tasks and that there would be a statistically significant increase in cortical activation between complex and simple tasks. However, there was no statistically significant difference between the NYC and ATM tasks by quadrant when compared using a t-test. This is likely due to the issue of power in this pilot study since there is a small sample size with tasks that require similar cognitive demands.

Since these quadrant values were approaching significance, optode activation data was analyzed as well. It was found that four left frontal optodes were significantly different in activation values between the simple and complex tasks. It was also found that the mean difference was positive, meaning that the NYC task produced higher levels of activation than the ATM task. This left-lateralization and increased activation is likely due to the fact that the complex language tasks required more activation to answer. This is supported by the fact that activation in the left inferior prefrontal cortex occurs during language tasks involving semantic working memory (Gabrieli et al., 1998). It makes sense that planning a trip to New York City would require more language skill, decision-making power, and working memory than describing how to withdraw money from an ATM, thus increasing activation. Knowing this shows great promise for providing a more diverse array of communication-based assessment tools in the future. With further study of these tasks, specifically complex procedural discourse, on a larger and more variable population, these could be proven equivalent measures for use in future treatment and diagnoses.

Limitations

The sample size and population are this study's main limitations. All participants were college students at the same university and most were female. Because there are shared cultural experiences at play, their responses to discourse questions could be influenced in similar ways. For instance, someone living in a different state may not be familiar with pumping gas, which could make the Pumping Gas task more cognitively strenuous for them. Another example would be if someone had moved or hosted dinner parties frequently; they may be more familiar with these tasks and therefore experience less cognitive demand while talking about planning such

things. These tasks must be further normed with populations that include more diversity than this pilot study did.

It is also important to consider that the population sampled was made up of exclusively college students. This participant group could have garnered different cortical responses for the Dinner Party planning task than an older (or younger) group of people. Since the main risk factor of experiencing mild cognitive impairment is age, it is especially important to consider this distinction (Mayo Clinic, 2018). It is important to create tasks that are stable across many populations because patient populations can vary so widely. All the tasks studied, though found to be significantly correlated in this population, will need to be reviewed in other populations to verify that they are still applicable.

There were also some cases of statistical tests that approached significance but were not yet statistically significant. This was likely due to a power issue – if there had been more participants, it is likely that there would have been significantly different results. Due to this low power (only 15 participants), the effect size of these results is relatively low. More participants coming from a more diverse background must be analyzed to reinforce these findings.

Finally, there are variations in methodologies and processing steps when using fNIRS technology, which can create inconsistencies in outcome (Vitorio et. al, 2017). There was also no replication in fNIRS blocking decisions, which means that blocking problems could have been overlooked.

Future Directions of Research

These results are extremely promising to encourage further study of these tasks as measures of equivalent procedural discourse communication. The next step would be to recruit a

more diverse and larger population to create more representative results. With this new population, it is hypothesized that the equivalency between the complex procedural discourse tasks would be reinforced on a larger scale. Similarly, the simple procedural discourse task equivalencies that were found would strengthen as well. With greater power, it is also likely that the NYC and ATM tasks would be found to be significantly different by quadrant rather than only by optode.

These results are further bolstered by Li et al's recent study (2018), which used fNIRS to find that patients with MCI and AD displayed abnormal prefrontal cortical activity during verbal short-term memory tasks. Reductions in oxygenated hemoglobin were found to increase as the disease severity developed from MCI to AD. Similarly, the novel tasks from this pilot study involve verbal short-term memory tasks. They could be an additional tool used to track performance; seeing a decline could be a useful way to indicate disease progression.

Furthermore, studies should look at multiple brain areas, not just the prefrontal cortex. Cortical neurodegeneration caused by MCI or AD could induce neural reorganization, meaning that other language areas could be recruited to support the prefrontal cortex during tasks. There are also many areas of the brain implicated in discourse production that were not involved in this pilot study that could be of note.

Because this study successfully determined equivalent procedural discourse tasks which was further supported by behavioral data, these tasks will hopefully be used in many future studies involving discourse communication. They could be useful in discerning between baseline cognitive function compared to mild cognitive impairment (MCI) or Alzheimer's Disease (AD) and could track disease progression. Studies examining the effect of specific therapy on procedural discourse could use these equivalent tasks on participants to avoid practice effects.

They could also be used to measure improvement (or decline) over time. This is a very promising start in creating discourse tasks that are both linguistically and cognitively equivalent.

Conclusion

The purpose of this study was to look at the similarities between previously normed procedural discourse tasks and novel tasks to find more equivalent measures. These measures could then be used in future studies, but importantly also in clinical settings to assess cognition and communication. This pilot study found that both the complex procedural discourse tasks and simple procedural discourse tasks were equivalent to the New York City and ATM tasks, respectively. The procedural discourse tasks were also found to show significantly higher activation outputs than the simple discourse tasks by optode, thus differentiating the two on a neural level. Further research must be done to fortify these results, using a larger and more diverse population to increase power. It is important for future studies to norm these tasks so that they can eventually be used on a population with MCI or AD to measure improvement, track changes over time, or perhaps even diagnose these conditions. There are currently very few cognitive assessment tools that measure discourse, thus providing further impetus to continue working toward creating new sensitive measures. This pilot study is hopefully a step forward in increasing the resources available to researchers and clinicians to improve communication and quality of life for people with MCI or AD.

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